Pedalling Towards Sustainable Mobility

An investigation into factors that influence a modal shift towards e-bikes in an urban environment

Kevin Leonard
November 20, 2023

Abstract

This paper examines the characteristics of urban environments that contribute to modal shifts away from cars and towards active modes of transportation, specifically e-bikes. Given the push towards sustainable transportation, much of the roadmap in the United States is still focused on electric vehicles. However, e-bikes offer an alternate solution as a healthier and more environmentally friendly mode of active transport.

Incorporating best practices from successful bicycle-friendly cities, and insights about San Francisco as a case study of a city, this study demonstrates that San Francisco is making appreciable strides towards sustainable transportation, but progress in limited primarily by political will. The research was carried out by performing literature review around e-bikes in cities and San Francisco, as well as through semi-structured interviews with stakeholders local to the San Francisco Bay Area. The data then was mapped to the Functions of Innovation Systems framework (FIS) in order to characterize the inner workings of the mobility ecosystem in San Francisco.

This study purports that political will, the natural and built environment, and human characteristics are the core pillars that influence a modal shift within a mobility ecosystem. Of these pillars, and in San Francisco specifically, it is shown that political will ultimately influences policies directing infrastructure, public outreach, and equity for all residents within a city. Without the political will to influence projects, funding, and accessibility, continued adoption of e-bikes and other modes of sustainable mobility is unlikely to reach an appreciable scale.

This approach and research could be replicated for other cities, in order to assess the proclivity for a modal shift towards more sustainable transportation. Additionally, future results can compare the pros and cons of various mobility ecosystems in order to assess the characteristics most favorable for a modal shift towards e-bikes and other forms of active transportation.

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1 Introduction

The International Energy Agency (IEA), a leading intergovernmental organization focused on analyzing the global energy sector, states that over 50% of the world's population currently lives in cities, with this percentage projected to increase to nearly 70% by the year 2050 (International Energy Agency, 2021). The same report, titled "Empowering Cities for a Net Zero Future", also asserts that cities generate around 70% of the world's carbon dioxide (CO_2) emissions. When looking at emissions by sector, transportation accounts for nearly 25% of all global carbon emissions (Mason, Fulton, & McDonald, 2015) and urban transport specifically accounts for 40% or 4 billion tonnes of CO_2-eq of all transportation emissions (International Energy Agency, 2021). Thus, there exists a large opportunity for decarbonizing cities in the realm of transportation.

It is often quipped that Americans love their cars, and there is some truth in that. Thus, it is not surprising that the United States has one of the longest urban trip distances in the world and many American cities were accordingly built around the car as the primary mode of transport (Mason, Fulton, & McDonald, 2015). On a global scale, the United States has the highest modal share of commuters traveling to work via a private car (*Infographic*, 2022).

When looking towards a sustainable future, the U.S. also appears to be doubling down on cars being the predominant mode of transportation, even in a decarbonized world. For example, the U.S. Department of Transportation (DOT)'s strategic plan for fiscal years 2022-2026 aims to install 500,000 EV chargers by 2030 in order to stimulate adoption of electric vehicles (U.S. Department of Transportation, 2022). Additionally, the recently passed Inflation Reduction Act (IRA) includes tax credits of up to $7500 for the purchase of an EV in the United States (Internal Revenue Service, 2022).

However, what appears to be lacking from these strategic roadmaps to decarbonizing transportation and urban environments is the seemingly lack of focus on alternatives to personal car usage. Specifically, alternatives such as cycling/e-cycling and the accompanying urban planning, political will, and incentives to support such a modal shift appear to be underrepresented in these roadmaps and subsidies, especially in the United States.

Overall, it seems these transportation decarbonization roadmaps do not consider potential solutions that could reduce the dependency on cars altogether, thereby potentially reducing emissions associated with production of electric vehicles, as well as congestion and safety incidents. While there are many variables that influence a life cycle analysis (LCA) of CO_2 emissions, one study in China estimated the lifecycle CO_2 emissions per person-kilometer (g CO_2/person-km) associated with various modes of transportation in as follows: bicycles = 4.7 g, e-bikes = 22 g, buses = 48.4 g, and cars = 306 g (Cherry, 2007). Another calculation shows that e-bikes emit around 2 g CO2 per person kilometer, as opposed to 152 g for a private vehicle (Bosch eBike Systems, n.d.).

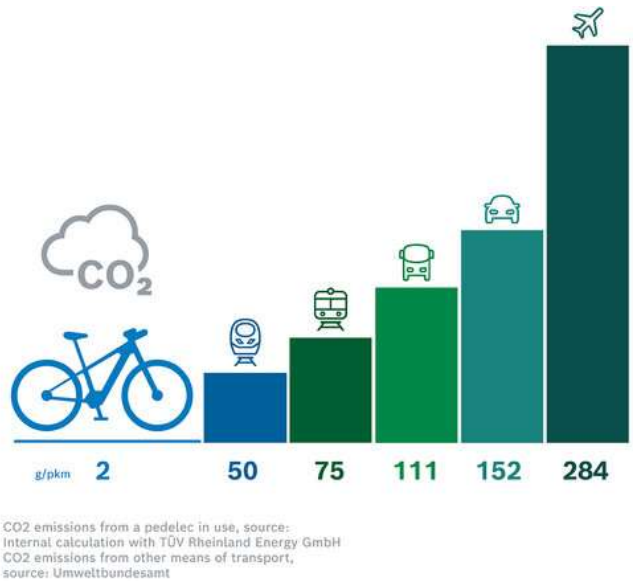

FIGURE 1 - CO2 EMISSIONS PER PERSON KILOMETER OF VARIOUS MODES (BOSCH EBIKE SYSTEMS, N.D.)

Thus, for a country that has historically been heavily car-dependent, a modal shift towards e-biking may yield more environmental and socioeconomic benefits in the transition towards electric mobility and sustainable city development. Given that in the U.S., 50% of all car trips are less than 5 miles (~ 8 km) in distance, there presents an opportunity for a modal shift away from the private automobile (Mason et al., 2015). This short distance for car trips seems to be a good match with studies identifying average distances suitable for traveling by conventional cycling and e-cycling, which were estimated at 5.3 km and 8 km, respectively (Bourne et al., 2020). Additionally, e-bikes may help apprehensive riders overcome barriers associated with conventional cycling, such as distances travelled and arriving to work/school sweaty and dishevelled (Mayer, 2020).

Generally speaking, studies have shown that e-bikes substitute the previous primary mode of transit in the local environment (Bourne et al., 2020). That is to say, if the primary modal share in a city was previously dominated by cars, e-cycling will likely replace more car trips, as opposed to a city where conventional cycling was the primary mode of transport. In addition to reducing emissions associated with each passenger-km travelled and increasing traffic safety and overall health, there are other quality of life benefits associated with a more cyclable city, such as those outlined in the 15-minute city concept, which include easier and more convenient access from homes to public areas, education centers, and health facilities that make a city more liveable for its residents (Moreno et al., 2021).

1.1 Knowledge gap

Given the confluence of factors such as the reduced environmental footprint and the potential match between car trip distances and e-bike distances, it would behoove transportation planners and government officials to investigate how feasible it might be to facilitate a modal shift away from private automobiles and towards e-bikes. Indeed, some cities, such as San Francisco, have signaled strategic objectives that aim to "Eliminate pollution and greenhouse gas emissions by increasing the use of transit, walking, and bicycling" (San Francisco Municipal Transit Agency, 2021). However, it is unclear whether cities like San Francisco are actually following through on policy and infrastructure proposals that will effectively enable this modal shift to e-bikes. From a scientific context, there is limited research that combines human-centric perspectives (from residents, public officials, and companies) with the natural and built environment factors to assess and understand barriers and opportunities to facilitating modal shifts in American cities. This research is key to understanding what would ultimately influence behaviour to switching modes of transport, and how all these elements have to work in conjunction to influence change in people's mobility patterns.

1.2 Research questions

Thus, this report aims to investigate the city of San Francisco as a case study to get a better idea of whether the city is enabling or inhibiting the proliferation of e-bikes as a primary mode of transport, and highlight the interaction of various factors that contribute to or hinder a modal shift away from car-centric transport in an urban environment. The research is guided by the following research questions:

1. What are the various elements in an urban mobility ecosystem that influence a modal shift towards e-cycling?
2. To what degree is the city of San Francisco enabling or inhibiting the proliferation of e-bikes through recent policy and urban planning actions?
3. What are the outstanding barriers and opportunities to facilitating a modal shift away from private cars and towards e-bikes in San Francisco?

This research is important because there is a possibility that EVs are disproportionately being considered as the primary solution to decarbonizing personal urban transport, particularly in the U.S. The focus on EVs for decarbonizing transport could overshadow the potential environmental and quality-of-life benefits of adopting e-bikes instead. This research would be relevant to urban planners working towards decarbonizing and decongesting personal urban transportation in their respective cities, as well as political figures looking to support cities in this transition to a more environmentally and socially sustainable future. It is also relevant in the academic space, as influencing modal shifts is ultimately a behavioural modification which is not an exact science, and it is key to understand all factors in this mobility ecosystem that affect the behaviour of people in an urban environment. Additionally, a holistic framework for analyzing a mobility ecosystem has not been well established for American cities.

1.3 Structure

The structure of this report is as follows: First, the methodology for the analysis is outlined in Section 2. Then in Section 3, some background information and findings from the literature review is presented to understand what is known about existing factors impact the decision to bike/e-bike. Section 4 presents the theoretical framework used to analyze the mobility ecosystem in San Francisco. Section 5 presents the findings from the research, and Section 6 elaborates on these findings as part of a larger discussion. Section 7 presents the conclusion of this project, in addition to recommendations for further research, and reflection on the project as a whole.

2 Methodology

The research methodology for this study comprised several interconnected phases, underpinned by the Functions of Innovation Systems framework (Hekkert et al., 2007). This framework was integral in guiding the research process, providing a systematic approach to assessing the overall urban mobility ecosystem of San Francisco and its inclination towards e-bike adoption. The motivation for choosing this framework and an overview of the theory behind it is explained in Section **Error! Reference source not found.**.

The initial phase of the research involved an extensive literature review, aimed at identifying key factors influencing e-bike adoption. This process entailed systematic keyword searches through Google Scholar, primarily using terms such as 'e-bike', 'infrastructure', 'policy', 'behavior', 'incentives', and 'health'. The selection of scholarly articles and grey literature was based on their relevance to e-bike adoption, with some articles and literature containing information related to cycling in general. The literature was then analyzed thematically, extracting salient themes that were subsequently categorized according to the Functions of Innovation Systems framework.

Subsequently, an investigation into San Francisco's current e-cycling initiatives was conducted through a review of grey literature. Search terms including 'San Francisco', 'E-biking', 'Roadmap', 'Vision', and 'Projects' were used to gain a nuanced understanding of the city's current posture towards e-cycling and the alignment of its initiatives and projects with this vision.

In the final phase, in an effort to gain insight into the local dynamics of San Francisco's urban ecosystem, semi-structured interviews were conducted with a targeted sample of stakeholders, selected based on their academic or professional involvement in mobility and transportation in the San Francisco Bay Area. These stakeholders included residents, a municipal official, and an academic local to the area, as summarized in Table 1 below. The academic interviewee was selected based on relevant research that was specific to the region. The civil servants were selected by reaching out via a mutual contact, and through further conversations identifying these individuals as working on projects related to this thesis topic. The residents were selected for interview as personal connections whom live in San Francisco. All interviewees gave consent to being recorded and transcribed via Microsoft Teams, and agreed to be cited as references as part of this project. In this case, the transcripts were automatically transcribed via software, and were not sent for further review to the interviewees.

Name	Reference	Role/Description
Marcel Moran	Academic 1	PhD City and Regional Planning - UC Berkeley
Matt Lasky	Civil Servant 1	Project Manager - SFMTA
Christopher Kidd	Civil Servant 2	Transportation Planner - SFMTA
Anna Sciaruto	Civil Servant 3	Clean Transportation Specialist – SF Environment
Joey Rohrer	Resident 1	Personal contact – Resident of SF
Renee Hamilton	Resident 2	Personal contact – Resident of SF

TABLE 1 - LIST OF INTERVIEWEES

The interviews were designed to explore factors in the mobility ecosystem that either foster or hinder e-bike adoption. The interview data was processed by reviewing the transcripts, and extracting common themes amongst interview participants. These insights, alongside other data from literature review and event analysis in San Francisco, was used to form conclusions for this paper. The Functions of Innovation Systems framework was applied to the data obtained from literature and interviews, facilitating a holistic assessment of San Francisco's urban mobility ecosystem.

The application of the FIS framework and the interviews with local stakeholders constituted a systematic review of the city's role in facilitating a modal shift, determining whether it appears to be a driver or an inhibitor in the shift away from cars towards e-bikes.

3 Elements Impacting the E-Cycling Ecosystem

This chapter provides an overview of various factors in the urban environment that either help foster or inhibit an ecosystem conducive to e-cycling. Literature is reviewed via aforementioned methods in pursuit of distilling the core elements that comprise the e-cycling ecosystem, and what is currently known about barriers and drivers of each element. It is expected that through the course of the literature review, these factors will overlap between conventional and e-cycling and thus, notable differences between factors affecting the two modes of cycling is explicitly called out. The research is presented based on themes discovered in various studies and grey literature, first with policy related elements, then infrastructure, and finally individual consumer behavior. Additionally, this chapter is not meant to be an in-depth analysis of each theme and underlying elements, as each theme alone could likely be its own project. Rather, this section is meant to present a conceptual model of common elements in a mobility system that affect cycling/e-cycling.

3.1 Policy

As with many other technological innovations and efforts to shape the public realm, change arguably starts with policy. In a way, policy reflects the attitudes of community leaders, whose attitudes (ideally) reflect the attitudes of their constituents. Thus, when assessing whether how conducive a city is to e-cycling, it can be helpful to start by investigating various policies in place that encourage or discourage e-cycling. Examples of policies that are discussed in this section include general traffic safety and design guidelines as well as modal-specific policies used to disincentivize car travel or promote cycling.

3.1.1 Traffic safety and design guidelines

Many countries, states, and cities have a version of a stated traffic policy, which orients the local mobility system around guiding principles in designing a safe, effective traffic system. One traffic safety strategy and paradigm often recognized on the global stage is the Vision Zero project, which began in Sweden and aims to improve road safety through the following principles(Vision Zero, n.d.):

1. Human error is inevitable so the mobility system should be designed to minimize the risk of severe injury or death
2. Creating a safe mobility system requires a multi-disciplinary approach involving the collaboration of policymakers, technologists, traffic planners/engineers, and many other stakeholders

Immediately, these two principles acknowledge that humans are fallible, and that everyone in a mobility system should be protected equally, including the vulnerable road users like pedestrians and cyclists. Additionally, the acknowledgement of a multi-disciplinary approach also indicates the reality that mobility systems are inherently complex, and involve consulting multiple stakeholders when designing them. A policy such as this Vision Zero policy provide guiding principles to how traffic safety is approached, and since pedestrians and cyclists are more vulnerable, this principle prioritizes design guidelines with these users in mind.

Another example of road safety guidelines is the Sustainable Safety plan, which is effectively the Dutch equivalent of Vision Zero which was implemented around a similar time (SWOV, n.d.). Similarly, two core principles found in this guideline are:

2. Road networks can be represented in a hierarchy based on function: through roads, distributor roads, and access roads. Efforts should be made to minimize multi-functionality.
3. Differences in speed, direction, and mass of users should be minimized through physical or temporal separation, and vulnerable road users (i.e. pedestrians, cyclists, elderly) should be allocated appropriate protection.

Once again, this plan highlights some of the various road users encountered in a mobility ecosystem, as well as alludes to design principles for maximizing safety for all users, such as separating roadways by functionality.

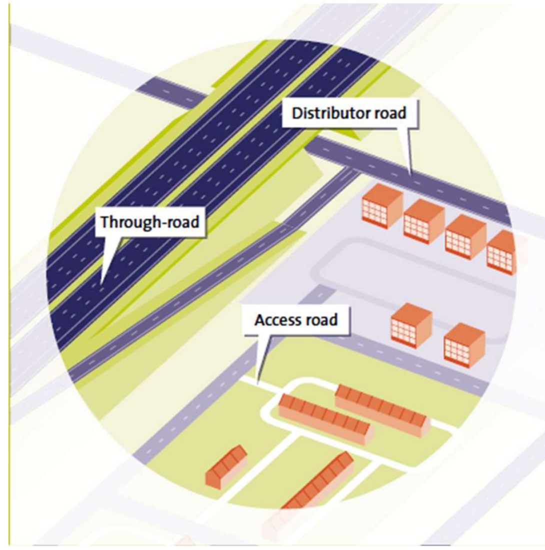

FIGURE 2 - FUNCTIONS OF ROADS ACCORDING TO DUTCH SUSTAINABLE SAFETY PLAN (SWOV)

Ultimately, these are just two summarized examples of traffic plans, but what these plans reflect is the attitude of the local leaders regarding traffic, safety, and prioritization of road users with an emphasis on those more vulnerable users, which is paramount to designing infrastructure that is conducive to cycling and e-cycling.

3.1.2 Modal specific policies

Aside from general traffic safety paradigms, many cities around the world have implemented city-specific policies that incentivize or disincentivize various modes of transport. When implemented, these types of policies have a direct impact on consumer behavior and are also effective tools in facilitating a modal shift in an urban environment.

One high profile policy roadmap is the Plan Velo (Bike Plan) released by the city of Paris and supported by the pro-cycling mayor Anne Hidalgo (O'Sullivan, 2021). The plan involves adding 180 km of protected cycle tracks throughout the city, as well as tripling the number of bike parking spots to 180,000 by the year 2026. Paris, which sees nearly 1 million daily bike journeys is responding to increased cycling demand that was exacerbated during the COVID-19 pandemic. Overall, one of the goals referenced in the plan is to enable more cycle journeys on protected cycle tracks, as well as create safer traffic conditions on the distributor roads of this global city. However this transition is not without its challenges as Parisians still report conflicts managing pedestrian space with new cycling infrastructure and the behavior of drivers throughout the city.

While Paris's Plan Velo entails a high level strategic roadmap to promoting cyclability, other cities are implementing incentives in the form of financial rebates to promote e-cycling. The city of Denver, Colorado launched a program to provide rebates to purchasers of e-bikes, offering more money for cargo bike models as well as to lower income residents (Toll, 2022). So far, this program has provided funding for nearly 5000 e-bikes, with half of them being purchased by low-income riders, and the program is praised as helping solve the chicken and egg problem of cyclists/e-cyclists and cycling infrastructure. Similarly, California is set to allocate $10 million in funding for providing their own rebates, of which eligibility for the voucher is determined by income level, as the program targets low-income residents as well (Toll, 2023).

In addition to the 'carrot' type policies such as rebates that are used to pull riders into a modal shift, there also exist 'stick' type policies to push users away from an existing modal. One popular policy implemented in several cities around the world is congestion pricing, which is effectively a fee designed to disincentivize driving private automobiles in congested areas of cities and shift users to other modes of transport. In London, for example, the amount of private automobiles entering Central London decreased by 39% between 2002 and 2014 (Badstuber, 2018) due to the implementation of congestion pricing. Additionally, these fees collected from drivers can be used to fund alternative modes of transport. However, as the author admits, the policy still needs continual work to ensure that people are shifting their modes of transport to more sustainable modes, and not simply replacing private vehicle trips to trips made via Uber and other car-share services. In addition to congestion pricing, other car-reducing policies include the withholding of additional parking permits and gradual reduction of parking spaces, as seen in Amsterdam (O'Sullivan, 2019), as well as the elimination of parking minimums required in new buildings, as seen in San Jose, California (Abonour, 2022).

Finally, an example of policy that is not directly related to cycling, but represents the counter-productive attitudes towards solving congestion in U.S. cities, is the continual expansion and widening of various highways (Weingart, 2023). Many cities, having received funding to address infrastructure spending, focus on widening freeways as a solution to congestion, despite studies showing that this simply leads to more induced demand in the long run (Hymel, 2019). This concept basically describes how increasing the capacity of freeways will alleviate congestion at first, but over the course of a few years, congestion will return and there will be an increase in vehicle kilometres travelled (VKT) (Duranton & Turner, 2009). Thus, while this policy does not explicitly incentivize e-cycling, it does serve as an example of policy that could further incentivize car usage and counter e-bike adoption.

In summary, policies of countries, states, and cities can reflect the general attitude towards the respective mobility ecosystem, and all the users that are part of it. Policies which focus on vulnerable road users (i.e. pedestrians/cyclists) aim to implement these design principles in infrastructure design, so that the safety of everyone involved can be maximized. Additionally, technology specific policies such as rebates for e-bikes is not a new concept, but still represent valuable tools to incentivizing cycling/e-cycling adoption and disincentivizing private car transport. Overall, as is shown in the next section, these policies serve as the blueprint for actually implementing infrastructure that aligns with a community's transportation vision.

3.2 Natural and Built Environment

Directly in the periphery of e-cyclists and cyclists alike is the environment that the rider is exposed to. This includes both the natural environment encompassing landscape and climate, as well as the built environment which includes infrastructure and connectivity. This section will outline various factors in the environment that influence the decision to e-cycle/cycle.

3.2.1 Topography and Climate

Regarding the natural environment, the regional climate and terrain can heavily impact the rates of cycling and e-cycling. Henry Cutler, an American who moved to the Netherlands and started a Dutch bike company, admitted that outside the Netherlands, the Dutch style bike may not be suitable for other geographic conditions because the majority of people will not cycle up hills (Bruntlett & Bruntlett, 2018). Indeed, several other studies indicated that barriers to active modes of travel include hilly terrain, which can exacerbate being out of breath or arriving at the destination sweaty (Bourne et al., 2020). Thus, when considering the natural landscape of a city, an e-bike can be used to overcome physical barriers (i.e. flatten hills) associated with excess physical exertion that is inherent to conventional cycling.

Aside from hills, the weather patterns have a direct impact on the rate of e-cycling as well. In a study conducted in the Noord-Brabant region of the Netherlands, it was found that snow and ice on a cycle path was the biggest weather-related barrier to e-cycling, followed by total precipitation and high winds (de Kruijf et al., 2021). This indicates that cities with a high frequency of inclement weather, especially during winter, may not be suitable for e-cycling/cycling. However, it was noted that the e-bike may help mitigate some barriers related to high winds for example, as there would be less physical exertion associated with riding into the wind.

Ultimately, it is rather intuitive that most e-cyclists/cyclists would not want to be exposed to harsh elements or overexertion as part of their daily commute. While there is not too much to be done regarding the weather and terrain, there exist other ways to mitigate the impact of poor weather and unfavorable terrain when cycling, including using an e-bike to lower physical exertion, and utilizing weatherproof clothing for inclement conditions.

3.2.2 Cycle lanes/tracks

Moving on to the built environment, one study, which aimed to understand the motivations and barriers to e-cycling in the U.S. found that the major reported barrier to e-cycling was the lack of cycling infrastructure (Mayer, 2020). Additionally, other respondents in the same study mentioned the cycling infrastructure that was present in the U.S. did not connect to anywhere useful, such as economic centers, schools, or places of employment. Additionally, the presence of built cycling infrastructure has a direct effect on the safety of riders. For example, one study used naturalistic data and measured critical events of riders, which were defined as events that made the riders uncomfortable (Dozza & Werneke, 2014). These authors found that cycling near an intersection increased the risk of a critical event by four-fold, and this risk increased twelve-fold when there was some visual obstruction present in the intersection. Additionally, the same study concluded that poor road conditions (associated with infrastructure) such as gravel paths, increased the risk of a critical event by tenfold.

Thus, a key component of cycling infrastructure are cycle tracks and cycling lanes that are provisioned for cycling traffic only. The difference between the two is that cycle tracks are dedicated, separate pathways designed for bicycle traffic while cycle lanes are simply lanes on the road that are carved out with paint to indicate a lane for bicycle traffic. The difference is illustrated in the below images.

FIGURE 3 – DIFFERENCE BETWEEN AN ON-ROAD CYCLE LANE (LEFT) (WAGENBUUR, 2020) AND A PROTECTED CYCLE TRACK (RIGHT) (ROBERTS, 2018)

Studies routinely show that a protected cycle track provides far more safety benefits to cyclists compared to an on-road cycle lane. One study suggests that separated cycle tracks can reduce crashes by 50 – 60 % when compared to on-road cycle lanes (Petegem et al., 2021). Additionally, the authors perhaps surprisingly concluded that there was no difference in crash likelihood between on-road cycle lanes and mixed traffic, where cyclists shared the same roadway with car traffic. This interesting conclusion seems to raise questions around the efficacy of on-road cycling lanes in preventing accidents.

What becomes clear from these studies and design of infrastructure is that the physical separation from motorized traffic is paramount to the perceived and actual safety of cycling/e-cycling, as envisioned in the aforementioned Dutch Sustainable Safety plan. Some cities have even taken these principles to the next level by building cycling highways exclusively for cyclists. For example, Beijing opened a 6.5km cycling highway with signalized lanes that allows commuters to travel to their workplace in 25 minutes, which previously would take 1.5 hours for cyclists (Hanley, 2019). These types of highways could be more conducive to e-cycling as they enable safe cycling with higher speeds, and allow for longer uninterrupted distances to be covered. Thus, dedicating more protected lanes which are isolated from motorized traffic seems to be a strong driver towards increased cycling rates, especially when this infrastructure is built for primarily utilitarian purposes such as commuting to work or school.

3.2.3 Secure Parking/Storage

While cycling paths and intersections are undoubtedly crucial components of cycling infrastructure for getting riders from point A to B, parking is another component that deserves as much, if not more attention. After all, most bikes are parked most of the time, mainly at home but also at work and school, with some estimates over 23 hours per day (Heinen & Buehler, 2019).

A lack of bike parking can be aesthetically displeasing as the streets and sidewalks can become lined with disorganized bikes, but more importantly, a lack of parking can discourage further bike/e-bike use. For example, bike sales in NYC rose by 50% in 2020 but was accompanied by an increase in bike thefts by 27%, and the city did not install any new secure bike corrals (Austin & Est, n.d.) despite these upticks in crime. Subsequently, most e-bike owners in NYC resort to locking up their bike on the street, which is especially an issue for e-bikes as they tend to be more expensive than conventional bikes, and thus riders are more nervous about damage and theft.

Parking infrastructure appears to affect both conventional cycling and e-cycling similarly, with the notable exceptions being associated with the increased costs and weight of an e-bike. These two factors combined with a lack of adequate parking infrastructure may discourage e-cycling adoption, as users would be more nervous about leaving an e-bike on the street, and it may be less feasible to carry it in and out of homes and apartments (Heinen & Buehler, 2019). Thus, creating space for parking at home, work, school, and other public facilities is important to facilitating a modal shift to cycling/e-cycling.

Another principle of bicycle infrastructure and specifically parking is the use of cycling/e-cycling to feed transit, which is especially popular in the Netherlands (Bruntlett & Bruntlett, 2018). Indeed, by providing parking near public transit stations, it is found that this can increase both public transit ridership as well as cycling rates, due to the wider catchment area (aka last-mile) that is accessible by bike (Heinen & Buehler, 2019).

An example of a successful implementation of bike parking and public transit pairing is in Utrecht, a city in the Netherlands, which currently holds the record for the largest bike parking facility in the world. This facility, which happens to be built under the busiest train station in the Netherlands, opened in 2019. It was bult to accommodate the projected increase in train traffic through the station, and the fact that 40% of travellers to the station arrive by bike. (Wagenbuur, 2014).

More recently, a similar bike parking facility is finally being opened in Amsterdam at the end of January, 2023. Similarly, this facility which houses 7000 bikes is being installed to organize the large amounts of bicycles used to arrive at the station, to make the last-mile cycling experience smoother for commuters, and to make the busy area around the station more pedestrian friendly (Boztas, 2023).

FIGURE 4 - AMSTERDAM (LEFT) (BOZTAS, 2023) AND UTRECHT (RIGHT) BIKE PARKING (WAGENBUUR, 2014)

Ultimately, parking is yet another part of infrastructure that can help facilitate a modal shift, and in the same way riders view cycle tracks, it is a critical component that should be present at the important destinations in a mobility system if a city desires to facilitate a modal shift away from cars. Additionally, where possible, bike parking can be used to complement public transit infrastructure as well, so that the relatively shorter distances covered on bikes/e-bikes can be paired with longer commutes on public transit.

3.2.4 Intersections

Another important component of cycling infrastructure from a safety standpoint is the intersection, where the cyclist is exposed to mixed traffic, and a higher volume of vehicles changing directions. In the U.S. for example, it was found that the majority of bicycle motor-vehicle crashes (51%) occur at intersections (NHTSA, n.d.). At these intersections the NHTSA further found that the main causes of these collisions were due to cyclists riding out in front of a motorist, a motorist failing to yield, or a motorist hitting a parallel moving cyclist (i.e. turning lane). The National Association of City Transportation Officials (NACTO), which represents a coalition of various departments of transportation (DOT) of North American cities, states that 43% of urban cyclist fatalities were at intersections as well. (NACTO, n.d.).

Thus, given this statistic, it comes as no surprise that the design of intersections is a highlight of many urban cycling design guidelines. In the NACTO guide for designing bicycle crossings, there are several designs presented to increase the safety of cyclists at intersections. The most effective design has been to build signalized, protected intersections, analogous to protected/separated cycle tracks, as this design has been shown to increase the probability that motorists and pedestrians will yield appropriately (NACTO, n.d.). A simplified diagram showing a protected intersection is shown in the image below.

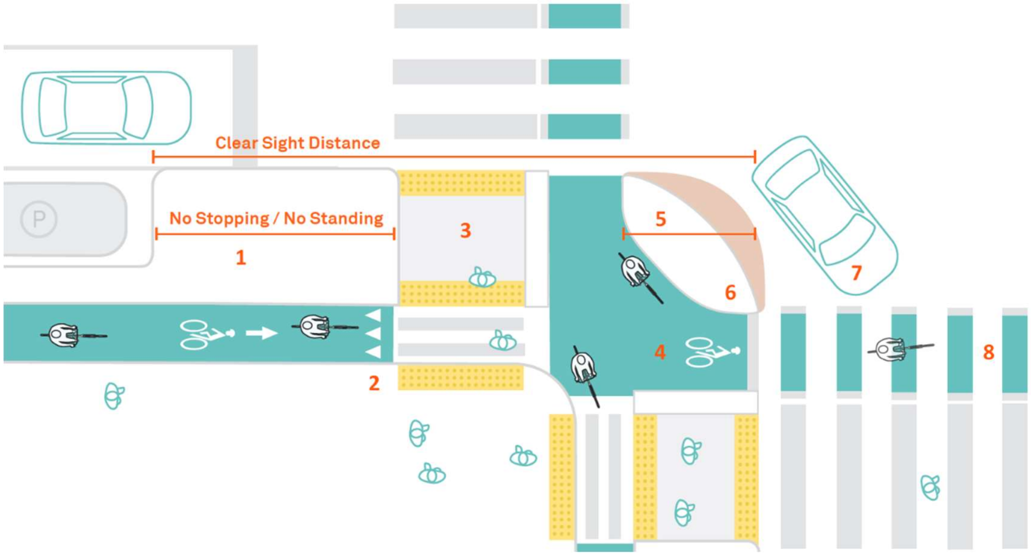

FIGURE 5 - DIAGRAM OF PROTECTED INTERSECTIONS (NACTO, N.D.)

In short, the strengths of this design can be attributed to the physical separation of bicycle traffic from motorist and pedestrian traffic, once again reaffirming similar principles in the Dutch Sustainable Safety plan. This allows for better visibility for all users, reduces the possibility of high-speed turns, and more space for pedestrian crossing as well. A more detailed description of the design can be found in NACTO's design report.

In addition to signalized protected intersections, a design commonly found in some Dutch cities is the cycling roundabout, as shown in the Google Maps image below.

FIGURE 6 - ROUNADABOUT INTERSECTION WITH PROTECTED BIKE LANES (DEN HAAG, NETHERLANDS - GOOGLE MAPS)

This intersection is popular in lower traffic areas in the Netherlands, where the motorized traffic is forced into a single lane, thus minimizing car accidents to rear-end type accidents. (Wagenbuur, 2020). Additionally, the lack of right angle crossings and yield markings for motorists increases visibility for the motorists crossing over the cycle tracks. However, Wagenbuur mentions that these roundabout type intersections are typically used in areas with lower traffic and more space, and a signalized protected intersection as shown in Figure 5 might be the best solution for areas with higher traffic.

Thus, the design for intersections follows similar principles to that of cycle lanes, in that physically separated lanes and crossings at intersections yield the safest and friendliest options for cyclists. As most cycling accidents with motorized traffic occurs at intersections, the design of intersections for cycling is of paramount importance. Regarding the difference between e-cycling and cycling, there does not appear any nuances associated specifically with e-bikes at intersections, other than the inherent risks associated with higher speeds.

3.2.5 Bike sharing/subscription schemes

While likely not considered infrastructure in the traditional sense, various bike sharing/subscription models around various cities contribute to the overall mobility ecosystem and modal shifts away from traditional transit modes. For some e-bike riders, these business models can be a gateway for riders to purchase their own e-bike, or potentially outsource some of the challenges with private ownership to companies.

For example, Swapfiets, which a Dutch bike subscription business, has 280,000 active users across several European cities, and charges a monthly subscription fee for various models of bikes they rent out (Bearne, 2023). Currently, they also rent out e-bikes which account for 15% of their subscriptions. According to their co-founder Richard Burger, Swapfiets originally wanted to address the challenges with private bike ownership, such as maintenance.

Other models, such as bike-share systems, are also popular and also apply to other mobility modes such as scooters. For example, OV-Fiets, which is a national bike rental scheme in the Netherlands, helps solve last-mile issues associated with getting to and from public transit (Bruntlett & Bruntlett, 2018). As mentioned in the previous section on parking, services like this allow commuters to couple cycling with public transit.

New York City, home to the Citi Bike docked sharing system, is another great example of a successful bike share scheme as it is the second largest bikeshare system in the world outside of China (Surico, 2022). According to the same Bloomberg article, the system boasts nearly 7 million rides a year, and despite their e-bikes only representing 20% of their total fleet, 32% of all riders were taken on e-bike.

One challenge with these types of models is the actual business viability of it, as all these mobility sharing/subscription schemes require a lot of capital upfront to purchase the fleet, and then the additional costs associated with maintenance and movement of the fleet (Bearne, 2023). Nonetheless, these ridership and subscription volumes does indicate some type of consumer interest, and these schemes may still present a viable way to influence e-bike adoption without the private ownership of an e-bike.

3.3 Human factors and characteristics

Aside from policy and infrastructure, there exists other human-related factors that influence adoption of electric bikes as a viable mode of transit. This includes elements such as economic status, social stigma, health and hygiene, environmentalism, and individual tolerance related to risk and safety. In this section, various individual factors are presented that affect an individual's decision to decide to adopt an e-bike as a viable mode of transport.

3.3.1 Income status and financial situation

As with many other goods, the cost of a product or service often informs the decision of a consumer to purchase said product or service. According to a scoping review, many studies found that the costs associated with the purchase of an e-bike and replacement of batteries was a primary barrier to buying one (Mayer, 2020).

In the case of electric bikes, the range of prices varies greatly from less than $500 to over $6000 (Preston, 2022). In the same Consumer Reports article, it is mentioned that a good price point for a decent quality e-bike is around $1500, although the average price of a commuter e-bike is between $2000 - $3000, compared to the average price of a conventional commuter bike of $1000. Additionally, it was estimated that maintenance costs are drastically higher with e-bikes as these were estimated at costing $100/yr compared to conventional bikes at $30/yr (Mason et al., 2015).

Thus, the price tag associated with several models of e-bikes may be prohibitive for certain parts of the population, particularly those with lower incomes. This further reaffirms the utility of having financial incentives implemented to help offset the high upfront cost, especially targeted towards those who are less socioeconomically fortunate. Additionally, as mentioned in the previous section on infrastructure, other alternatives to private e-bike ownership exist in the form of bike-sharing or bike subscription schemes.

However, when comparing to the upfront cost associated with a new electric car for example, the cost of a new e-bike is much lower than that of a Tesla Model 3 for example, which is priced at $43,900 in the US at the time of this writing (Tesla, 2023). Thus, even with the federal incentives currently available in the U.S. for EV purchases, the cost of an e-bike is a fraction of this cost. Finally, many e-bike riders have touted the cost savings of commuting via e-bikes versus cars, citing savings on fuel, insurance, and maintenance costs (Mayer, 2020).

3.3.2 Accessibility

Another factor influencing the personal decision to utilize an e-bike is the accessibility associated with the hardware itself. On one hand, the increased accessibility due to electrically assisted pedalling helps overcome barriers related to distances and hills, as mentioned in the prior section on the natural environment. Additionally, it has been found that e-bikes allow elderly and disabled individuals to bike further and longer than they would have been able to on a conventional bike (Mayer, 2020). The same individuals have also cited an increase in quality life related to a rediscovered 'fun factor' associated with e-bike.

Conversely, some challenges associated with e-bike usage are the increased weight due to the battery has been found to be problematic amongst women and the elderly (Bourne et al., 2020). In some studies, more elderly people were found to have reported the increased weight as a contributing factor to an accident (Haustein & Møller, 2016). Thus, it's possible that e-bikes present another safety risk for those uncomfortable with the additional weight of the bike itself.

3.3.3 Social Stigma

Regarding social stigma, studies have shown that the perception of riding an e-bike may influence a consumer's decision as well. For example, some riders mentioned they received negative attention from motorists and conventional cyclists, as others felt like riding an e-bike was 'cheating' (MacArthur et al., 2014).

Additionally, the perception that e-bikes may only be for overweight or lazy individuals also deterred people from adopting an e-bike (Bourne et al., 2020). This perception may change with increased adoption and normalization of a mode of transport, however it can still present a barrier to some prospective riders transitioning to an e-bike.

3.3.4 Perceived safety

From a personal standpoint, one of the most frequently reported barriers to e-cycling was the perceived lack of safety when riding next to motorized traffic, or even next to pedestrians and conventional bicycles. (Bourne et al., 2020). The scoping review by Bourne et al mentions conflicting studies related to perceived safety on e-bikes, with some studies indicating users feel more comfortable being able to keep up with traffic, and others reporting the opposite effect.

Another study concluded that because e-bikes allow for higher accelerations and speeds, the riders can often be more cavalier when riding, which can also decrease perceived safety (Haustein & Møller, 2016) In any case, these observations of perceived safety appear to echo the Sustainable Safety design principles mentioned previously, which ideally separates road users by speed and mass (SWOV, n.d.).

Finally, another aspect related to perceived safety relates to the availability of secure parking infrastructure, whereby riders are more concerned in protecting their e-bikes while not in use, due to the increased value of the e-bike (Heinen & Buehler, 2019).

3.3.5 Health

While e-bikes do offer pedalling assistance and decrease the amount of physical exertion needed to cycle, in some cases there can actually be a positive health benefit associated with e-cycling. Specifically, if users who previously commuted in car or by public transit now adopt an e-bike, they can benefit from a form of active transportation (Bourne et al., 2020). Additionally, as mentioned before, e-bikes can provide accessibility benefits to elderly and disabled people in a way that provides them a means of exercising where they couldn't before.

In a study that monitored the physical activity of both conventional and electric bike riders, the authors found that the amount of physical exercise is comparable between the two modes (Stenner et al., 2020). They found that although heart rate and exertion were observed to be lower on e-bikes, this was compensated for by an increase of volume of trips. Thus, it would appear that e-bike users tend to ride more frequently, which compensates the decrease in exertion, but still allows the riders to maintain an actively healthy lifestyle.

3.3.6 Environmentalism

From a user standpoint, concerns for the environment are not found to be a popular motivation for most riders of e-bikes (Mayer, 2020). However, there seems to be some variation in this attitude as younger generations disproportionately expressed concern for the environment when choosing to ride an e-bike, particularly millennials (Ling et al., 2017).

It should be noted that reducing environmental impact through a modal shift would only occur if the amount of kilometers driven in a car decrease as well. It has been found that the degree to which an e-bike could substitute alternative modes of transit depend on the existing predominant mode of transit in that region (Bourne et al., 2020).

One study conducted in Portland, Oregon found that if residents of the region increased their modal share of trips to just 15% by e-bike, an individual could reduce their carbon footprint by 225 kg CO_2 per year (McQueen et al., 2020). Thus, transitioning to an e-bike might be a good compromise between the various barriers associated with conventional cycling and the higher environmental impact of driving a car.

3.4 Summary of factors influencing the mobility ecosystem

In summary, it can be observed that all the aforementioned themes of a mobility infrastructure are highly interconnected with one another. That is, the mobility policies put forth in a city reflect the attitude of the leaders and communities towards transport, which in turns influences the types of city projects that benefit or hurt cycling and e-cycling adoption. This is then reflected in the personal preferences and attitudes of the individuals that inhabit this mobility ecosystem, as they respond to various factors that influence their safety, well-being, and health. The interrelatedness of all these factors can be summarized in the diagram below:

FIGURE 7 - INTERRELATED DOMAINS OF THE MOBILITY ECOSYSTEM

Overall, it appears that facilitating a modal shift away from cars requires tradeoffs with various alternative modes. Specifically, provisioning the ideal safest cycling infrastructure requires creating space away from motorized traffic and pedestrians (for cycle tracks and parking as an example), so that all participants of a mobility ecosystem can function safely and efficiently. In order to achieve this, this inevitably leads to a combination of carrot and stick policies that can make it more inconvenient to drive and more lucrative to cycle/e-cycle and take public transport.

Through a modal shift like this, it is important to ensure that the new, envisioned mobility system is still equitable to the majority of the population, particularly those who may live further from work, school, and other necessary amenities. Ultimately, the potential financial, quality of life, and health benefits associated with shifting away from car-dependency should be accessible to everyone, and ensure the safety of the most vulnerable road users.

Regarding the similarities and differences in how factors of a mobility ecosystem impact both conventional and e-bikes, there were many similarities as expected. For example, adequate infrastructure is found to be a common, necessary feature to stimulating adoption of either mode. However, some differences arise when looking at safety, costs, and accessibility.

In these cases, different policies or infrastructure designs can help both modes thrive harmoniously. For example, since e-bikes travel faster than conventional bikes, it likely makes sense to further investigate how infrastructure can be designed to safely accommodate both, while adhering to Sustainable Safety principles of separating users of different speeds and sizes. Additionally, the financial incentives towards e-bikes can make them more feasible to purchase, especially to those individuals where the price tag may be prohibitively expensive.

Ultimately, as indicated in the Vision Zero principles, facilitating a modal shift towards cycling and e-cycling requires mobilizing the political and social space across many different stakeholders, so that way every individual's needs are addressed. Together, communities in cities can work to tune these elements of their local environment and aim towards the vision of creating a safer, more efficient, more equitable, and more sustainable mobility ecosystem.

4 Theory of the Functions of Innovation Systems

This section will elaborate on the underlying theory behind the Functions of Innovation Systems, which is the foundational framework used to guide the analysis of the mobility ecosystem of San Francisco.

4.1 Background

Firstly, an innovation system is a term used to describe and analyze various stakeholders and mechanisms that influence the emergence or production of an innovation (Hekkert et al., 2007). In some ways, this system is analogous to performing a certain level of market research for a new product or service. Namely, a system in the context of a product or service is comprised of companies, individuals, consumers, government entities, educational institutions, and many other stakeholders. The relationship and activities between these stakeholders illustrate the degree to which a new innovation might be successfully developed, deployed or implemented.

Thus, the Functions of Innovation Systems focuses on the activities between these various stakeholders, by proposing a set of functions that are used to map these activities between stakeholders, and to describe how these activities influence the development and proliferation of a new innovation (Hekkert et al., 2007). Thus this framework is akin to a process or history event analysis.

These proposed set of functions according to Hekkert are as follows:

- Entrepreneurial activities
- Knowledge development
- Knowledge diffusion through networks
- Guidance of the search
- Market formation
- Resources mobilization
- Creation of legitimacy/counteract resistance to change

The motivation on selecting this framework to underpin the analysis of San Francisco's e-bike ecosystem is due to the fact that this framework is comprised of several functions which help connect several different stakeholders and interactions within a larger system. By its nature, the topic of an e-bike ecosystem is one that is multi-faceted and covers may elements such as infrastructure in the urban fabric, residents and politicians, and companies that provide various mobility services. Thus, with a complex network of stakeholders, this framework can help portray the relationships and interactions between all parties, and provide the 'systems-level' overview of a complex ecosystem.

The following sections will present each of these functions according to Hekkert et al, and will also provide more concrete examples of stakeholders that are involved in activities related to each of these functions. These functions will then serve as the basis for categorizing the various themes/elements previously identified as being important in an e-bike mobility system, and be used to analyze events specific to San Francisco.

4.2 Entrepreneurial Activities

In any innovation system, entrepreneurs are of paramount importance, as they are the catalysts for aggregating new knowledge, networks, and markets to capitalize on new business opportunities (Hekkert et al., 2007). In effect, these stakeholders identify problems or gaps with an existing

product or service for a set of users, evaluate the potential market landscape and ecosystem, and build or deliver a commercially viable solution that meets these needs.
Regardless of whether the entrepreneurial entity is an individual, a startup, or a corporation, the endeavors and experiments they stimulate are necessary to move an innovation system in a direction other than the status quo. A clear example of this might be the company Uber, which was able to provide a ride-hailing service combined with technology to provide a customer experience better than conventional taxis. This type of innovation is disruptive, as most entrepreneurial activity tends to be, and is crucial for stimulating the movement of other functions in an innovation system.

4.3 Knowledge Development

Knowledge development is the heart of any innovation process and are therefore prerequisites to the development of any innovation, usually by learning by searching, or learning by doing. (Hekkert et al., 2007).

Learning by searching consists of doing research and development (R&D), typically at an educational or government institution, or even within an R&D department within a company. An example of this could be running a research experiment within a laboratory in order to develop a more efficient solar cell, by testing out various materials.

Learning by doing is facilitated by change agents who aim to gather feedback and knowledge by putting into practice new methods and ideas. As an example, in software development, there is a method of working known as 'agile', which aims to develop and release new software often, in small increments. Contrast this with a 'waterfall' style of working, which aims to gather all requirements upfront first before delivering a full solution. The former allows for more immediate, iterative feedback, thus developing knowledge early and often through implementation of frequent changes.

4.4 Knowledge Diffusion

Knowledge diffusion, otherwise known as learning by interacting and sometimes learning by using, is the mechanism by which knowledge is exchanged between various actors in an innovation system (Hekkert et al., 2007). The diffusion of knowledge is important to keeping all actors in an innovation system informed of the latest developments, as this level of communication can influence appropriate policymaking and further research.

This meeting of the minds in a particular innovation system can be observed in the form of conferences, seminars, and workshops. An example of these types of meetings in the software world could be annual conferences hosted by big platforms such as AWS, Salesforce, SAP, etc. At these types of summits, customers, partners, and vendors, and users interact with each other to learn how other stakeholders in the same space are interacting in a particular innovation system.

To allude to the previously mentioned agile development methodology, knowledge diffusion is an example of a feedback loop (as shown below) between the technology producer and consumer, ultimately validating and aligning new product/service ideas as quickly as possible (Neisler, 2018).

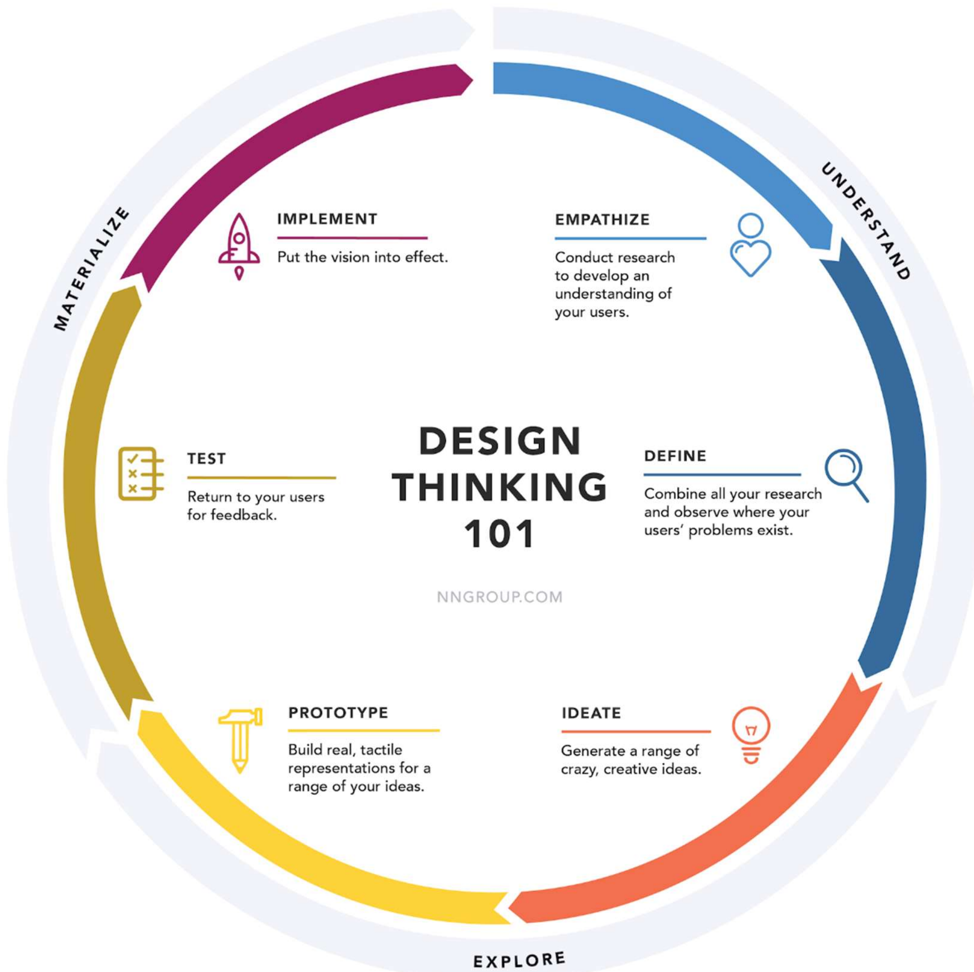

FIGURE 8 - DESIGN THINKING FEEDBACK LOOP (NEISLER, 2018)

4.5 Guidance of the Search

Guidance of the search refers to the narrowing of scope of technology development based on other indicators in the system that ultimately influence the visibility and clarity of the desired goals amongst technology users (Hekkert et al., 2007). Effectively, this is a form of focused roadmapping, giving actors in a system a more concrete goal to aim at, and to narrow the total amount of explorable trajectories.

Signals that can contribute to guidance of the search could be set by a multitude of stakeholders, such as the government, or every day consumers. For example, if a regulatory agency sets a goal related to electric car adoption for a given country or region and provides financial incentives, this provides a signal to companies that they should focus their developments and innovations on electric cars, in order to meet this target and capture some of the resources that are being deployment by agencies to achieve this goal. Regardless of where these signals originate from, they serve to be trail markers for stakeholders in an innovation system, so that efforts towards innovation are not too dispersed, and therefore resources can be spent intentionally and efficiently on innovation.

4.6 Market Formation

Because new innovations often face an uphill battle against incumbent technologies, it's often necessary to stimulate an early market for a new innovation before in order to eventually allow the market to mature. The market formation function can be quantified by the number of niche markets that have been introduced, through the forms of favorable tax incentives, or new regulatory standards (Hekkert et al., 2007).

For example, many renewable energy technologies have seen benefits in the form of tax credits or subsidies when it comes to installing rooftop solar panels or the purchase of electric vehicles. These types of policies help stimulate demand for these new, innovative technologies which allows the additional funds to be used for additional resources, thereby decreasing the cost of the technology over time. These types of incentives eventually get phased out, once a market has been developed enough to function on its own.

4.7 Mobilization of Resources

In order to further advance the development of new technology, resources will need to be mobilized in the form of human and financial capital (Hekkert et al., 2007). Examples of financial capital could be the amount of venture capital money being invested into a particular technology sector, or perhaps government programs that earmark funds for a technology. Relating to the previous function, financial resources could be allocated towards providing subsidies, rebates, or tax credits to stimulate a new market.

Regarding human capital, this could refer to the skilled labor that might be needed to produce the new technology, or new knowledge. This type of knowledge required for human capital could be obtained from a variety of sources including online courses, higher education institutions, or perhaps even vocational school.

4.8 Creation of Legitimacy/Counteract Resistance to Change

As mentioned before, a new technology must be able to overcome the inertia in place from incumbent technologies in order to thrive. Thus, advocacy groups can serve to evangelize a new innovation by lobbying for resources or promoting the new innovation can be a strong force in overcoming incumbent stakeholders and technologies (Hekkert et al., 2007).

These advocacy groups could be formed by actors with aligned industry interests (i.e. California Fuel Cell Partnership), or could even be reference customers of new technology who share positive testimonials of a product or service. These groups, and more generally outspoken advocates of a new innovation, are crucial for the ‘marketing’ of a new innovation, in the sense that they can have an outsized impacts on other areas of an innovation system, such as public opinion or resources allocated to the development of the innovation.

4.9 Summarizing the Synergy of FIS Functions

Overall, the successful functioning of each of these individual innovation functions contribute to the success of the innovation system as a whole. As outlined above, these functions must work in synergy with each other to create an ecosystem where new innovation can thrive. None of them are independent from the rest.

These functions ultimately embody big feedback loops between actors from government, industry, research, and consumers, all of whom influence each other and the overall innovation system, as shown in the figure below. These loops thrive on communication, sharing of knowledge, trying new ideas, and listening to feedback from the public and all stakeholders involved. If the overall innovation system functions as a well-oiled machine, this is likely a positive indicator that a new innovation can successfully grow from being a niche technology to one that may one day become part of the new regime.

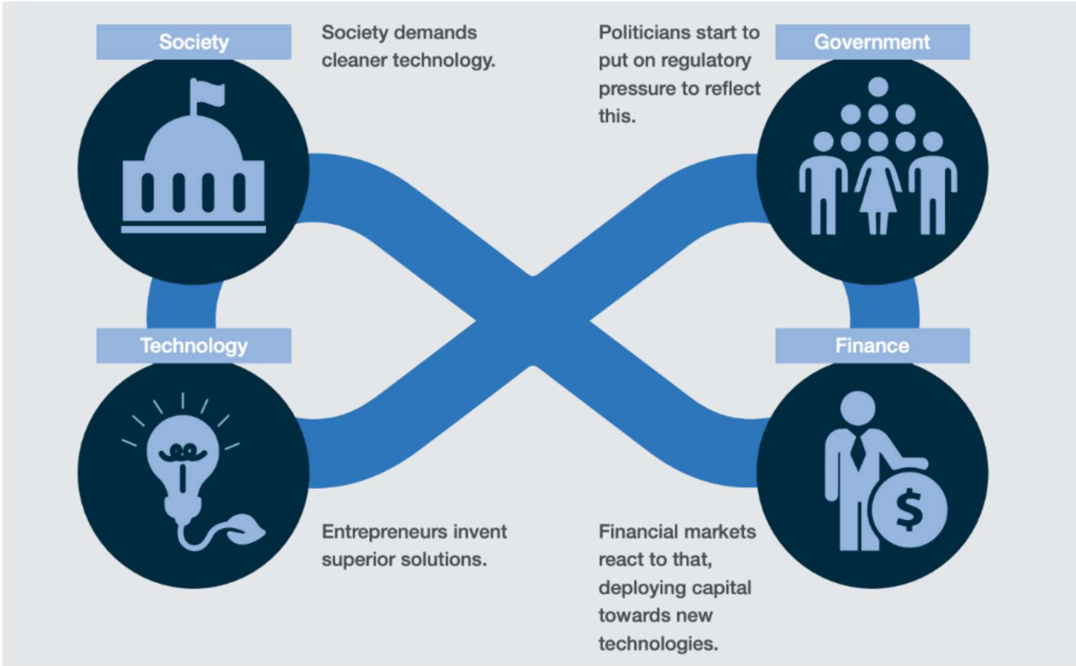

FIGURE 9 -VISUALIZATION OF FIS FUNCTIONS FEEDBACK LOOP (SAULT, 2021)

5 Results – Attitudes and Actions Influencing San Francisco's Mobility Ecosystem

This section comprises the results of comprehensive research and investigation into attitudes and actions that influence San Francisco's mobility ecosystem. The findings are categorized into four sections: Political Will and Governance, Infrastructure and Safety, Community Engagement and Equity, and Innovative Programs. The findings are comprised of both concrete policies, infrastructure projects, partnerships, and programs, as well as more abstract assessments as to the attitudes or mechanisms by which decisions get made in any of the aforementioned domains. The combination of both sets of findings helps paint a dynamic overview of the overall mobility system in San Francisco. Each of the findings are associated with one or more impacted functions from the FIS framework, and these results are summarized in a table at the end of the section.

5.1 Political Will and Governance

This section will outline the overall political landscape in San Francisco, with regards to how decisions get made, as well as specific policies that the city has drafted that impact the mobility ecosystem.

5.1.1 Overarching Political Landscape

In an interview with Academic 1, an academic in urban and regional planning at UC Berkeley, Academic 1 identifies a pervasive "status quo bias" within American municipal governance that prioritizes car throughput and storage over the safe movement of bicycles (M. Moran, personal communication, April 17, 2023). According to Academic 1, this bias manifests itself in the reluctance of city councils, mayors, and planning departments to make transformative changes to the urban landscape, even when such changes could significantly benefit active mobility options like cycling and e-biking. Academic 1 argues that the key challenge in this field is not empirical but political as the strong case for cycling and active mobility has already been made, but converting this into political power and policy action remains a significant hurdle.

Academic 1 suggests that the way forward lies in building coalitions among various advocacy groups, including those focused on cycling, transit, pedestrian rights, disability rights, and climate change. He observes that cities that have successfully shifted towards more sustainable transportation options have done so through a concerted effort involving policymakers, advocates, academics, and activists.

Academic 1's insights were also reinforced by Civil Servant 1, a project manager at the SFMTA, as he stated that the lack of a unified vision among political leaders often results in fragmented policies and initiatives, which in turn affects the effectiveness and reach of mobility solutions (M. Lasky, personal communication, April 21, 2023). He criticizes the existing governance structures for being reactive rather than proactive, suggesting that a more visionary approach is needed to drive systemic change. Civil Servant 1 also points out that the structure of having district supervisors can lead to political interests which are not always aligned or cohesive across other districts, and rather focus only on district planning, which is not conducive to infrastructure planning for a whole city.

Civil Servant 1's observations indicate that governance and political will are not just administrative elements but are deeply intertwined with the city's mobility culture and infrastructure. He argues that for a meaningful modal shift to occur, political leaders must be willing to make bold decisions that may initially be unpopular but are essential for long-term sustainability. This includes not only the allocation of resources but also the creation of policies that incentivize active mobility options over traditional car-centric models.

Civil Servant 2, a transportation planner at the SFMTA, also echoed similar sentiments pointing out that political will is essential in directing city planning towards accommodating sustainable transit, particularly e-bikes and other forms of active mobility (C. Kidd, personal communication, October 20, 2023). He criticized the general lack of coherence and coordination among different government bodies, which he argues often results in sluggish or fragmented policy implementation. While Civil Servant 2 acknowledged that political support can catalyze essential projects, he also emphasized that the absence of unified political backing could hinder promising initiatives. In particular, he stressed the role of city planners and elected officials in shaping policy and asserted that their decisions can either facilitate or hinder advancements in sustainable mobility, such as the adoption of e-bikes or the development of bike lanes.

The observations from Academic 1, Civil Servant 1, and Civil Servant 2 showcase all functions **"Creation of Legitimacy/Counteract Resistance to Change**", **"Resources Mobilization",** "**Knowledge Development", "Knowledge Diffusion", "Guidance of the Search", "Market Formation"** within the FIS framework. The insights highlight the need for legitimizing active mobility options through political will, thereby counteracting resistance to change. The coalition building needed to stimulate political will also allows for the development and sharing of knowledge, which simultaneously helps alignment in which direction to enact policy. Moreover, the call for coalition-building speaks to the mobilization of social, political, and financial resources necessary to enact meaningful changes in the mobility ecosystem. These mobilized resources can then be used for new projects/businesses, thereby stimulating entrepreneurial activity.

5.1.2 San Francisco Climate Action Plan (CAP)

The city of San Francisco has several plans that have been written and released that aim to illustrate the future vision of transportation in the city. One of these plans is San Francisco's Climate Action Plan (CAP), which outlines the city's progress towards existing climate goals, as well as future goals towards decarbonization (City & County of San Francisco, 2021). Specifically, this plan indicates the desire to reach net zero emissions by 2040, through decarbonization efforts related to housing, transportation and land use, and buildings.

Regarding transportation, the plan states that transportation currently accounts for almost 50% of total city emissions, and must be transformed to reduce reliance on cars and promote low-carbon modes of transportation such as transit, walking, and biking (City & County of San Francisco, 2021). San Francisco has set a goal for 80% of trips to be made by low-carbon modes by 2030, and all remaining vehicles must transition to zero emissions. Additionally, the city had completed 42 total miles of protected bike lanes in 2019, and targeted to complete a total 49 miles in 2022. However, it should be noted that the definition of a protected/segregated bike lane in San Francisco is inconsistent with the Dutch definition, as shown in the below figure.

FIGURE 10 - SAN FRANCISCO 'PROTECTED/SEPARATED' BIKE LANE (GOOGLE MAPS)

Overall though, the CAP appears to strike a supportive tone and emphasizes the need to expand bicycle lanes and safe places for people to walk to reduce reliance on cars, ultimately making cycling safer, more convenient, and even fun. The strategy towards creating a connected and complete active transport network include expanding the cycling network by 25 miles by 2025, expanding parking facilities, and funding e-bike subsidies for low-income residents. (City & County of San Francisco, 2021)

As this plan sets goals for the city regarding climate objectives, it is a great example of a policy that impacts the **Guidance of the Search, Knowledge Diffusion, and Mobilization of Resources** functions, as it provides a north star of goals to aim for and allows resources to be allocated accordingly.

5.1.3 San Francisco Transportation Plan (SFTP)

While the CAP outlines a vision of San Francisco from the environmental perspective, the San Francisco Transportation Plan (SFTP) outlines transportation investment priorities for the allocation of $80 billion in existing and projected revenues through 2050 (Chang et al., 2022). When looking at the plan in greater detail, the plan signals interest in expanding pedestrian and bicycle network connectivity, as well as the replacement of short car trips with more sustainable modes of transport.

The report quantifies that improvements will be made to over 200 miles of the pedestrian and bike network. Additionally, when assessing past objectives from the previous transportation plan, San Francisco was able to expand the bike network by 34 miles since 2013. While no cost figures or projects were explicitly called out, it was mentioned that San Francisco is also preparing for e-bike adoption by installing secure bike parking facilities.

According to the San Francisco Transportation Plan (SFTP), which aims to outline transportation spending through 2050, $5.38 billion is designated for pedestrian and bicycle safety and traffic calming, maintenance, rehabilitation, and replacement of road infrastructure, streetscape improvements, and freeway safety and operational improvements (Chang et al., 2022). The plan proposes investment into over 200 miles of safer streets for pedestrians and bicyclists.

Additionally, the plan also mentions the intention to rollout a downtown congestion pricing scheme, which would charge drivers for driving into congested areas of the city. This scheme would be similar to the aforementioned congestion pricing scheme introduced in London. The revenues from this scheme would then be used to increase bicycle and pedestrian connectivity as well as public transit services in these areas (Chang et al., 2022).

Similar to the CAP, this plan sets goals for the city regarding transportation objectives, and is also a great example of a policy that impacts the **Guidance of the Search, Knowledge Diffusion, and Mobilization of Resources** functions for the same reason.

5.1.4 California E-bike Incentive Project

While there does not exist a state level rebate at the time of writing, California is in the process of rolling out a rebate program. Specifically, this will be a $10 million program that will be released in the second quarter of 2023, and targets Californians living at 300% below the federal poverty level (FPL) (McCamy, 2023). Specifically, Calbike states the voucher amount will likely be $1,000, with an extra $750 for a cargo or adaptive bike, and $250 additional for people below 225% FPL or living in a disadvantaged census tract. Additionally, E-bikes are grouped into three classes, and all three classes of e-bikes will be eligible for the program, provided the e-bikes are on a list of approved models. The introduction of the rebate program for electric bicycles is part of the wider push towards cleaner transportation in California.

Additionally, according to Civil Servant 3, who is the program lead for the E-Bike Delivery Pilot Program in San Francisco, she mentioned that a city-wide rebate is in the works as well. Specifically, the city is collaborating with the SF Environmental Group and the MTA on drafting a rebate that could supplement the state rebate as well. (A. Sciaruto, personal communication, October 17, 2023). Civil Servant 3 had mentioned that their pilot program is being used to influence the rebate model, based on the class and model of bike being used. According to Civil Servant 2, a transportation planner at the SFMTA, the development of a city-wide rebate is necessary because e-bikes are still quite expensive and the state credit is not enough to offset the cost for low-income earners (C. Kidd, personal communication, October 20, 2023).

The California rebate model as well as the ongoing development of a city-wide rebate represent impacts to both the **Mobilization of Resources**, **Guidance of the Search, and Knowledge Development** functions, as money is being allocated to stimulate adoption, and learnings from the pilot program are being used to inform further development of more financial incentives.

5.1.5 Federal E-BIKE Act

More recently at the federal level, the Electric Bicycle Incentive Kickstart for the Environment (E-BIKE) Act was reintroduced in the US Congress, providing consumers with a tax break for buying an e-bike (Deliso, 2023). The E-BIKE Act was initially introduced in the US House of Representatives in 2021, but was left out of the Inflation Reduction Act and was ultimately eliminated from the Build Back Better Act. According to Deliso, the bill aims to encourage e-bike ownership and reduce carbon emissions by offering a refundable tax credit amounting to 30% of the e-bike's price, capped at $1,500, for new e-bikes costing less than $8,000. Additionally, income limits for maximum credit have also doubled, up to $150,000 for a single filer and $300,000 for joint filers. The proposed bill would also help address battery hazards by defining eligible e-bikes as ones that meet battery safety standards set by Underwriters Laboratory or that "may be recognized by the United States Consumer Product Safety Commission."

As stated in the previous section, e-bikes provide an alternative to cars but the high cost of e-bikes can be a barrier to adoption for many consumers, particularly low-income earners. The E-BIKE Act aims to address this issue by providing a tax credit that will make e-bikes more affordable for a wider range of consumers. If the bill becomes law, it could help to accelerate the shift towards more sustainable modes of transportation and reduce carbon emissions from the transportation sector.

As such, this is another example of policy that is directly related to the **Mobilization of Resources**, as money is being funnelled into a program to stimulate adoption of e-bikes.

5.1.6 Post-COVID Impacts and Priorities

While the previous investments and incentives point to positive signals regarding additional investments into e-bike infrastructure and financial tools, there are other developments about San Francisco that paint another side of the struggle to amass resources generally.

Specifically, in the post-COVID era, San Francisco was recently rated as the city with the worst downtown recovery rate of any major US city, citing only 32% of activity of pre-pandemic times (Symon, 2023). Additionally, where office vacancy used to be 4% pre-pandemic, it is now sitting at nearly 30% after Q1 2023, which will also prove difficult in terms of relying on a tax base that used to come from these businesses which have downsized their workforces or office footprints (Darrow, 2023). Finally, to compound some of the post-pandemic recovery challenges, many of the cities' public transit services such as BART and MUNI have warned of facing fiscal cliffs in the next few years without further assistance, thereby prompting a bailout of $1.1 billion that would delay these operational challenges for these agencies (Cano, 2023). It should be noted however, that this bailout is stated only to help in the short-term and more long term aid would be needed to help public transit as well in the future.

Looking at these challenges surfacing in San Francisco in a post-pandemic world bring into question the ability to fund services and projects related to e-biking, especially with many other high-priority initiatives that may be more critical to the functioning of the city. Thus, it is reasonable to expect that facilitating e-bike adoption may not be a high priority, relative to other challenges the city is facing regarding transit, office space, and homelessness.

With these challenges in mind, a barrier like this directly impacts the **Mobilization of Resources** and **Guidance of the Search** as other competing priorities within a city like San Francisco will funnel money and attention away from an effort like increased e-bike adoption.

5.2 Infrastructure and Safety

This section will highlight the results and findings related to infrastructure and safety, ranging from general attitudes towards infrastructure, to specific projects and processes that contribute to biking infrastructure in San Francisco.

5.2.1 Approach to Infrastructure

Academic 1 underscores the critical importance of infrastructure in promoting e-bikes and active mobility in San Francisco (M. Moran, personal communication, April 17, 2023). He advocates for an "infrastructure-centric approach," emphasizing that safe, protected bike lanes are essential for diversifying the urban cycling demographic. He cites the success of European cities like Copenhagen, Amsterdam, and Hamburg, where robust cycling infrastructure has led to a more inclusive and widespread adoption of cycling and e-biking. According to Academic 1, while other elements such as subsidies, parking, and educational classes are important, they are secondary and complementary to the foundational role of infrastructure as he claims there won't be any significant increase in adoption without foundational infrastructure changes. This insight aligns with previous findings of safety arguably being the largest barrier to cycling and e-cycling.

Another interesting insight gleaned from the interview Civil Servant 2, is that the city thinks about infrastructure that is not only specific to bikes, but also other forms of active mobility such as scooters, electric skateboards, and other devices (C. Kidd, personal communication, October 20, 2023). He mentioned that many service workers working multiple jobs drive into the city and commute between jobs via scooter, so that is a crucial detail that's included in planning infrastructure. Additionally, while the modal share of bikes is somewhere around 3.4%, he mentioned other surveys indicated that 10% of San Franciscans ride some form of active mobility, which encompasses more than just bikes.

Regarding project planning and execution, Civil Servant 2 also commented on challenges regarding how projects get put together. Firstly, he felt that often times they have trouble staffing all the projects and getting resources and funding especially with the costs increasing due to inflation. Secondly, he identified challenges in streamlining project development with all the stakeholders involved. He mentioned that each project is treated as a unique endeavor, and one of the MTA's goals is to put together a project toolkit for all stakeholders so to better streamline the planning process. Additionally, he mentioned that the city often has to deal with several environmental regulations, which he generally thought were good, but were too excessive, causing delays in projects. These insights seem to align before with previous observations regarding political alignment and difficulty facilitating change with multiple stakeholders.

To address some of the challenges with long timelines on projects, the city has engaged in some quick build projects, according to Civil Servant 1 (M. Lasky, personal communication, April 21, 2023). These projects, simply set up bike lanes with plastic posts and paint, which can be quickly achieved as opposed to doing concrete work which can take a while to execute. Many of these projects have been implemented on the High Injury Network (HIN), in order to reduce accidents related to cycling.

Overall, these insights highlight several functions in the FIS Framework, namely **Mobilization of Resources, Guidance of the Search, Creation of Legitimacy, and Knowledge Development.** Infrastructure changes requires funding, and the project planning process helps refine better processes for all stakeholders, and overall directly contributes to increased adoption of e-bikes and other active mobility options.

5.2.2 Bay Wheels Bike Share

One of the most significant entities enabling the modal shift to e-bikes in San Francisco is the Bay Wheels Bike Share system. The first Bay Area Bike Share pilot program was introduced in August 2013 (Metropolitan Transportation Commission, 2013). According to the MTC, the initial idea for introducing such a program stemmed from the agency's Climate Initiative Programs, which aimed to reduce the greenhouse gas emissions from transportation. These initiatives that inspired this pilot project shows an example of how the Guidance of the Search function has a direct impact on the types of programs/actions that an entity in the innovation system will take.

In 2015, Motivate, which was the operator at the time, agreed to a contact for an expansion of the initial pilot program with MTC (Boone, 2015). Together, Motivate and the MTC planned to increase their fleet size from 700 bikes to more than 7000 bikes and to become the first regional bikeshare operator in the US by serving San Francisco and the other surrounding cities in the Bay Area. However, it was not until about a year later that Motivate actually secured private funding from Ford to fund this expansion worth $50 million at the time (Goebel, 2016). This resulted in the Bay Area service being rebranded as Ford GoBike.

In 2018, under the Ford GoBike network, Motivate announced it would introduce 250 pedal-assisted electric bikes to its fleet as part of a one year pilot (Dickey, 2018). Later in the same year, Lyft acquired Motivate and the several bike-share systems it operated across the United States, including the Ford GoBike network in the Bay Area, California (Bevilacqua, 2018). Since then, a partnership between Lyft, the California Metropolitan Transportation Comission (MTC), and local government was established to operate the bike-sharing service under the name Bay Wheels (MTC, 2021).

Figure 11 - Bay Wheels E-Bike Model in the San Francisco Bay Area (*Meet Our Bikes | Bay Wheels | Lyft*, n.d.)

One of the key partnerships established in recent years has been with Lyft and the San Francisco Municipal Transportation Agency. As part of this partnership, SFMTA and Bay Wheels, also known as Lyft Bikes, reached a 4-year agreement earlier to provide 4,000 stationless shared e-bikes throughout San Francisco (SFMTA, 2019). According to the press release, Lyft began deploying 4,000 new e-bikes in December 2019 with full rollout by April 2020. These new e-bikes functioned as "hybrids", meaning that they can be docked at stations but also locked to bike racks around the city, thus expanding the reach of the system and providing citywide access to bikeshare.

SFMTA mentioned the hybrid e-bikes were in addition to the 4,500 traditional pedal bikes already provided for by SFMTA's contract with Lyft, ultimately allowing Lyft to operate up to 8,500 total bikes in San Francisco. In addition to the rollout of a larger fleet, the same article stated that Lyft also provided $300,000 in fees to fund SFMTA bike rack installation citywide, thus increasing the footprint for bicycle parking. The agreement ensured that shared e-bikes were a reliable, accessible and affordable transportation choice for San Francisco riders by introducing new, more stringent performance standards and requirements to ensure that Lyft provided reliable and redundant service throughout the city.

Towards the end of 2021, Lyft and Mastercard expanded their nationwide partnership to include bikeshare in the Bay Area, California, ultimately aiming to sustain bike sharing in the area and support future growth (Bay Wheels, 2021). According to the announcement, an additional 35 stations were planned for 2022, and the Bike Share for All equitable access program was expanded, with more than 2,000 free memberships distributed through community partners. Additionally, Lyft joined the Priceless Planet Coalition, created by Mastercard, which promotes the reduction of carbon emissions and reforestation through the contribution from businesses, consumers, and governments. Ultimately, this partnership allowed Lyft to expand their service in the local area, and also promote the idea of Bay Wheels being a fast, clean, and affordable way to get around San Francisco.

Today, Bay Wheels operates not only in San Francisco, but also other Bay Area cities such as Oakland, Berkeley, Emeryville, and San Jose (MTC, 2021). Their combined fleet consists of over 7000 bikes (both conventional and electric) across 500 docking stations. Since the pandemic, however, membership and ridership has suffered as memberships decreased by 64% between February 2020 and May 2020 (Schneider, 2021). As reported by Schneider in November 2021, membership was still down 62% percent compared to the peak in February 2020. However, according to more recent data published by the SFTMA, ridership has since increased to levels higher than average pre-pandemic levels, as shown in the figure below. When looking at the data, the total ridership of the bike share system saw a record high of around 250,000 rides in September of 2022, leaving aside a brief pre-pandemic spike observed in February of 2020 (*Bike Share System Wide Activity*, n.d.). Additionally, of this 250,000 rides, over half (176,000) were taken on e-bikes. This indicates that not only are the number of shared bike rides increasing, but riders also seem to prefer e-bikes over the conventional bikes.

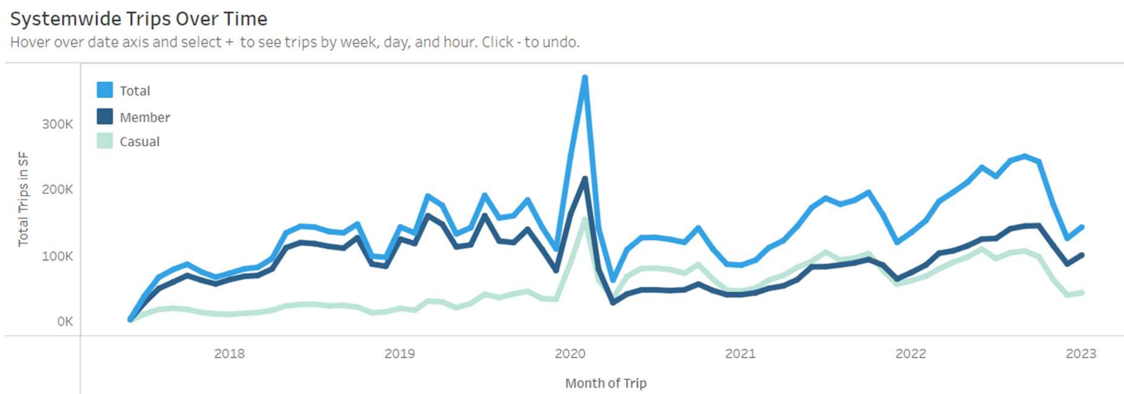

FIGURE 12 - BAY WHEELS BIKE SHARE SYSTEM RIDESHIP (*BIKE SHARE SYSTEM WIDE ACTIVITY*, N.D.)

The same article states that the company has faced issues with growth and financials, referencing challenges related to theft, vandalism, and difficulties cooperating with local authorities.

In the interview with Academic 1, a significant focus was placed on the role of Bay Wheels' publicly available data in shaping the mobility ecosystem in San Francisco. Academic 1 emphasized that this data serves as a crucial resource for academic research, particularly in spatial analysis to identify gaps in the existing bicycle infrastructure. The data, which includes start and end coordinates for rides, has been used to map popular routes and could potentially guide infrastructure development. Furthermore, Academic 1 noted that privacy concerns have not significantly constrained the use of this data, allowing for a more comprehensive understanding of ridership patterns.

In the interview conducted with Civil Servant 2, he elucidates that Bay Wheels, owned by Lyft, is one of many stakeholders that support the city's efforts to enhance active transportation. The system is particularly aligned with the city's objectives to expand a safer, more comfortable bike network, as this would invariably boost ridership for Bay Wheels. However, the relationship between the city and Bay Wheels is not merely transactional; it is shaped by a complex permitting process that aims to serve broader city goals, including equity and accessibility. For instance, the city has enacted policies through its permit with Bay Wheels to incentivize the parking of e-bikes in priority neighborhoods like Bayview - Hunter's Point, which is a heavily minority and equity priority community. This nuanced partnership highlights the role of Bay Wheels not just as a service provider, but as an integral part of the city's strategy to achieve diverse mobility goals.

In the interview with Civil Servant 1, he highlighted the significance of the Bay Wheels bike share system as a key component of San Francisco's mobility ecosystem. He mentioned that the bike share agreement in the region is expected to last until 2027, indicating a long-term commitment to this form of active transportation. Lasky also touched upon the uncertainty surrounding the future of Bay Wheels, particularly given that its current operator, Lyft, is facing challenges. Despite this, he expressed optimism about the potential for bike share systems to evolve, possibly transitioning to a public system with a private operator, akin to models seen in other cities like Washington, D.C.

From the resident’s perspective, the interview with Resident 1 seems to indicate that the cost of using the Bay Wheels service might be a barrier to increased adoption of the system. Another interview with another resident, Resident 2, yielded valuable insights into the role of the Bay Wheels bike share system in the city's mobility ecosystem. She highlighted the system's convenience, particularly in her centrally-located neighborhood of Hayes Valley, but noted that the availability of charging stations diminishes in more residential areas like the Sunset or Richmond districts. Resident 2 also emphasized the importance of cost-competitiveness, suggesting that more affordable e-bike options could significantly drive user adoption. While she appreciates the city's efforts in creating "slow streets" for safer cycling, she expressed concerns about theft and cleanliness as barriers to using public e-bikes.

These insights primarily impact five FIS functions**: "Market Formation,"** as the bike share system establishes a market for e-bikes and pedal bikes within the city, **"Knowledge Development** and **Knowledge Diffusion"** by enhancing the understanding of Bay Wheels' impact on San Francisco's mobility, equity, and accessibility, **"Guidance of the Search,"** as the long-term agreement and potential evolution of the bike share system help to direct future efforts and investments in active mobility solutions, and ultimately **"Resource Mobilization"** in regards to expanding the system. Also the widespread usage and business idea around the bike sharing system also contribute to **“Entrepreneurial Activities”** and **“Creation of Legitimacy”.**

5.2.3 Valencia Street Bike Lane

As mentioned in the prior section on policies in San Francisco, the city has plans to increase the cycling network in the coming years. Additionally, Civil Servant 2 identified current challenges associated with design and implementation. Namely, the number of stakeholders involved in any given project makes it difficult to coordinate, and the lanes must be designed for all types of users, not just bikers, in order to be accessible to everyone.

The Valencia St bike project epitomizes the process that’s involved in planning an infrastructure project in San Francisco, and all the challenges with it. According to Civil Servant 2, the Valencia Street bike lane project in San Francisco took about eight years from conception to completion (C. Kidd, personal communication, October 20, 2023). The process was riddled with challenges, particularly the negotiation with multiple stakeholders, including local merchants and advocacy groups, and other municipal services like the fire department. He highlighted the fact that the Valencia Street bike lane served as a template for many subsequent projects, but its development was not without its complications. One issue he cited was parking changes, specifically the need to create new metered spaces and loading zones, which was a highly contentious point and required a lot of time for approval.

Additionally, despite these new parking and loading spaces, people still often double park in the lane, leading to backups in traffic. Another piece of feedback that was received from Civil Servant 3 was that the e-bike delivery riders as part of the city’s pilot program have mixed experiences using the bike lane, since it runs down the center of the street making it difficult for the delivery riders to stop in front of the restaurants. The center lane design has proved unpopular for some as well, with users citing safety concerns regarding accidents and turning in and out of the lane, as well as some drivers who drive on the lane over the plastic barriers as well (Thorud, 2023).

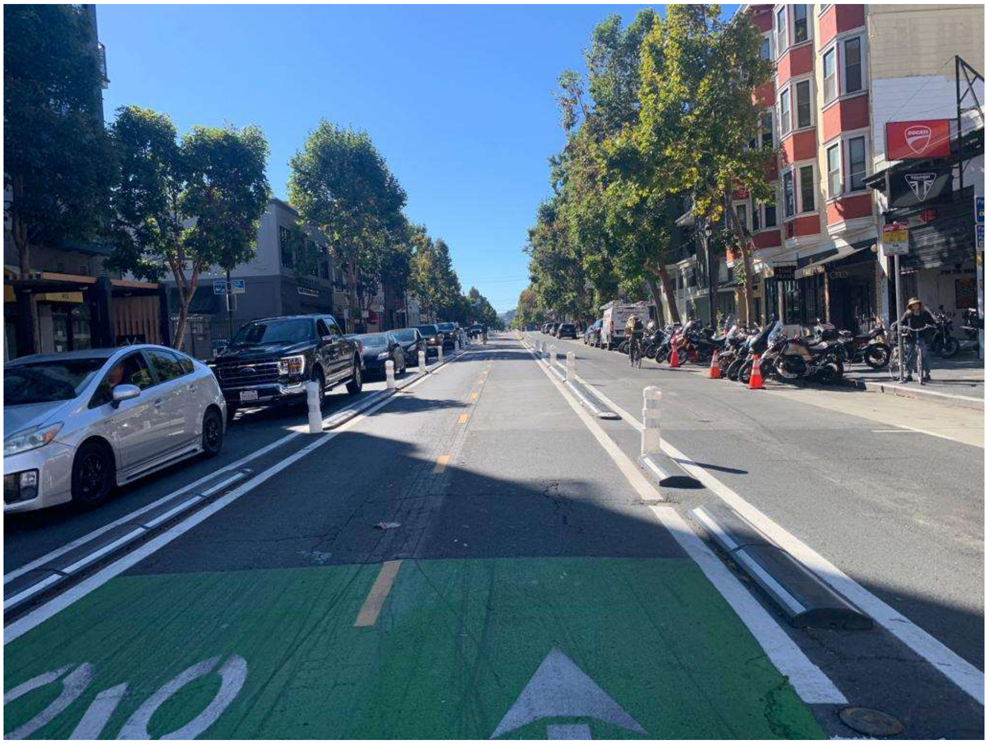

FIGURE 13 - VALENCIA ST BIKE LANE - RUNS DOWN CENTER OF THE STREET

Overall, the multiple steps involved in planning, community consultations, and stakeholder negotiations prolonged the process and made it a laborious undertaking. Civil Servant 2 expressed that these complexities and lengthy timelines exacerbate the city's existing mobility issues and slow down the transition to more sustainable modes of transportation. Nonetheless, the fact that infrastructure projects like these do happen show positive movement in influencing the functions of **Mobilization of Resources, Knowledge Development, and Guidance of the Search** through feedback provided about the project.

5.2.4 Secure parking and theft

One of the biggest barriers to owning an e-bike is also the risk of theft, which is understandable given their high price tag. In an interview with Resident 2, she mentioned that this is the largest barrier for her owning one, citing high rates of petty crime, and that she has actually had a nice bike stolen (R. Hamilton, personal communication, June 4, 2023). Similarly, Resident 1 expressed similar concerns around theft, citing that his neighbour had bought a brand new bike and stored it in his garage, which was broken into and stolen as well (J. Rohrer, personal communication, May 25, 2023).

This is also confirmed by city officials as well with Civil Servant 2 mentioning that a survey revealed that one third of respondents had had a bicycle stolen in San Francisco (C. Kidd, personal communication, October 20, 2023). He also mentioned that while the city is continuing to work on installing bike racks, many people who live in public houses or single-room occupancy housing do not have space to store bicycles indoors either.

Additionally, Civil Servant 3 mentioned that bikes were stolen as part of the e-bike delivery pilot, even though they were properly parked (A. Sciaruto, personal communication, October 17, 2023). She also mentioned the same observation that Civil Servant 2 mentioned, that some people don’t have the luxury of storing their bike indoors. In the short term, the program is thinking about other ways to prevent theft, via more trainings. However, the program is also relaying feedback to the city about the need to expand secure bike parking to prevent such theft.

According to Academic 1, he also agrees about the need to expand secure bike parking, and suggests the docked bike share system Bay Wheels partially resolves this problem, although not for private ownership (M. Moran, personal communication, April 17, 2023). He even suggested using the containerized bike parking systems that can be found in places like London. However, he generally feels that the city is not making great strides towards expanding secure parking.

While no details were researched about specific bike parking projects, Civil Servant 2 did mentioned that the city installs roughly 600 – 800 bike racks a year. He mentioned there can be a few staffed bike stations found throughout the city, notably at the Caltrain and BART stations which are two public transit systems in the area. Overall, this aligns with Civil Servant 2's vision of a mobility hub where these secure stations are at locations for first and last mile transit.

Similar to bike lanes, the addition of bike parking represents both **Mobilization of Resources** and **Guidance of the Search** as feedback from individuals owning and using bikes drives needed infrastructure improvements for more, secure bike storage.

5.3 Community Engagement and Equity

This section will present results related to community engagement and equity, highlighting the focus on how stakeholders engage the community, ensure equity, and stimulate networking opportunities for e-biking.

5.3.1 Attitudes towards Community Engagement and Equity

In his interview, Civil Servant 2 stressed the significance of community engagement and equity in the shaping of San Francisco's active mobility landscape (C. Kidd, personal communication, October 20, 2023). He noted the e-bike food delivery pilot as a noteworthy example where community needs were recognized and integrated into mobility solutions. However, he was critical of the Bay Wheels bike-sharing program's limited reach and high costs, arguing that such initiatives often fail to serve marginalized communities adequately. However, he did acknowledge that the city has enacted policies to ensure some of the e-bike are parked in lower income neighbourhoods, and there are programs specifically tailored for low income individuals.

Civil Servant 1 indicated that as part of the Active Communities Plan, there is a focus on equity priority communities (M. Lasky, personal communication, April 21, 2023). As part of this, the city is doing outreach to several communities, and working with them through community organizations to discuss ideas and projects that have historically not had much investment regarding transportation.

In another interview, Academic 1 (M. Moran, personal communication, April 17, 2023) highlighted the importance of community engagement and equity in the development and implementation of active mobility solutions in San Francisco. He notes that research has played a significant role in understanding the gaps in bicycle infrastructure provision and in conducting equity analyses that are anthropological in nature. Academic 1 emphasizes the value of understanding the social interpretations of bikes in different ethnic communities, stating that academic surveys can help cities understand who is biking, who is not, and where they are biking. He also mentions the role of third-party operations like bike share companies in providing valuable ridership data. These insights point to the need for a multi-stakeholder approach that includes academics, policymakers, and community members to ensure that mobility solutions are equitable and inclusive.

Within the Functions of Innovation Systems (FIS) framework, these insights on community engagement and equity relate closely to **'Knowledge Development and Diffusion through Networks,'** by emphasizing the importance of community input for effective policy, **and 'Creation of Legitimacy/Counteract Resistance to Change,'** by underscoring the need for equity in gaining broad acceptance of new mobility solutions for every demographic.

5.3.2 Ridership Reports

Another way to learn about the community is to assess whether a market is forming around e-bikes in San Francisco by looking at the sales of e-bikes or ridership data.

For example, the SFMTA estimated 82,000 bike trips per day in 2015 as part of their 2017 – 2021 report on biking in the city (SFMTA, 2018). They estimated that this amount of bike trips represented a 4.3 % modal share of all commuting trips in the city. However, the more recent transportation plan (SFTP) indicates a lower modal share of 2% of all intra-city trips, as shown in Figure 14. Perhaps the difference in reported modal shares is due to the definition of a commuting trip vs a non-commuting trip.

In addition to this reported modal share, the previously mentioned bike share system Bay Wheels, has been seeing increased ridership, with the majority of the ridership being comprised of e-bike rides. This can be seen in the previous section in Figure 12.

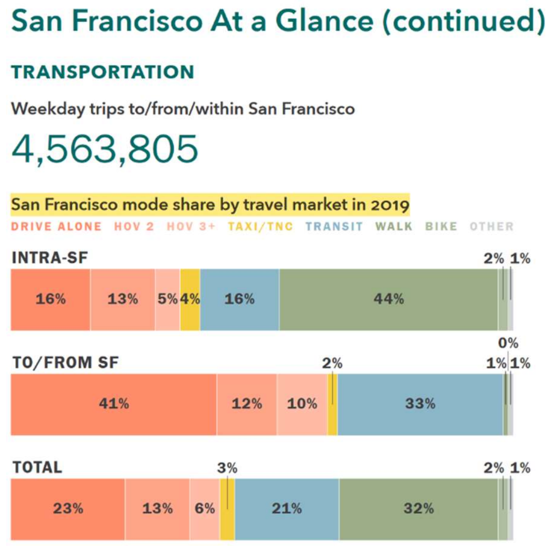

Figure 14 - Modal share of San Francisco Trips - (Chang et al., 2022)

Finally, when looking at a national scale, the Bay Area metro (which includes SF) has the highest modal share of bicycle trips of major U.S. metros, as observed as part of a transportation study carried out in 2018 - 2019. The modal share can be seen in the figure below, however it should be noted that this data is from before the pandemic, which greatly affected people's working and commuting habits.

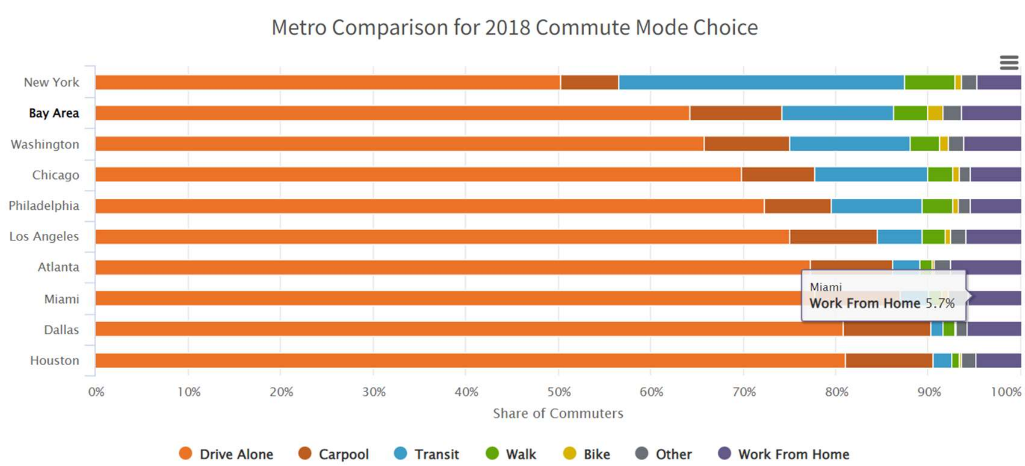

FIGURE 15 - 2018 MODAL SHARE IN MAJOR U.S. METROS (*COMMUTE MODE CHOICE | VITAL SIGNS*, N.D.)

This type of ridership report represents an impact on the **Knowledge Development** and **Guidance of the Search** function, as it allows those who gathered these reports to understand how to quantify their goals for a modal shift, and which modes could be reduced further through policy and infrastructure.

5.3.3 California Bike Summit and Micromobility America

Aside from partnerships that have been observed between public and private agents, San Francisco has had exposure to various networking events and conferences to discuss ideas around bicycling and micromobility in general. One of these summits is the California Bicycle Summit, which is a biennial conference of bicycling advocates, city planners, enthusiasts, and industry members who meet to discuss a range of topics from policies to quick-build methodologies for how to further evangelize cycling culture in the state (*The California*

Bicycle Summit, n.d.). In 2022, the event took place in neighboring Oakland, where several workshops were held discussing topics ranging from open streets programs, to upcoming rebates, and also a workshop on e-bikes (California Bicycle Coalition, n.d.).

Additionally, another more global organization, Micromobility America, hosted their conference in San Francisco in 2022. This conference is focused on small electric vehicles, including e-bikes, and their potential to change urban mobility (Micromobility, n.d.). According to the website, the conference is aimed at bringing together builders, thinkers, and leaders in the field of micromobility, including founders, journalists, investors, technologists, and policymakers. Here, attendants can browse the latest products as well as participate in a series of discussions related to mobility. Ultimately, the conference aims to showcase various products and discussions, and also help facilitate networking opportunities for those interested in the field of micromobility. In 2023, the Micromobility Europe conference will take place in Amsterdam.

Both of these events represent networking opportunities that contribute to the functions of **Knowledge Development** and **Knowledge Diffusion**, as it allows industry experts to share ideas with each other and broaden the overall knowledge base.

5.3.4 SF Bicycle Coalition

The Sunday Streets program was also initially introduced with the support of another advocacy group, the San Francisco Bicycle Coalition (*About Us – Sunday Streets SF*, 2023). The San Francisco Bicycle Coalition is a prominent bicycle advocacy group that promotes the use of bicycles for everyday transportation, creating safer streets and more livable communities for all San Franciscans (*About - San Francisco Bicycle Coalition*, n.d.). According to the group's website, the organization was founded in 1971 by a coalition of activists representing environmental and neighborhood groups, and has since evolved into a powerful alliance of individuals working towards a more bicycle-friendly city.

Their most recent 2018 – 2022 strategic plan outlines four key goals with some associated objectives highlighted below (*Strategic Plan 2018 – 2022*, n.d.):

1. Demand high-quality infrastructure and push for visionary improvements to connect the city.
    a. Establish physically-protected bike lanes as the standard for bike improvements
    b. Expand car-free spaces within parks and on city streets
2. Build public support and political power to win affordable and sustainable transportation for all San Franciscans.
    a. Secure significant, new funding sources for bicycle infrastructure
    b. Ensure new and emerging mobility technologies and services, especially transportation network companies (TNCs) and delivery services, are safe and complement bicycling
3. Grow, engage, and empower our membership to strengthen our organization and deepen community support for bicycling.
    a. Increase the number of members through grassroots organizing and strategic coalition building
    b. Engage members and individuals to power our advocacy and increase our effectiveness
4. Introduce San Franciscans of all ages, identities, and backgrounds to the joy of bicycling and encourage more San Franciscans to bicycle more often.
    a. Reach thousands of people through bicycle education and school safety programming
    b. Support bicycling for everyday transportation among communities that experience barriers to riding

This type of advocacy group plays multiple roles in helping the community adopt e-bikes as an active form of transport, and also as a lobbying group to push for new policies, as Academic 1 previously stated when describing how to drive political will (M. Moran, personal communication, April 17, 2023). Additionally, as is discussed in the next section, the SF Bicycle Coalition is a key partner in the city's current e-bike delivery pilot program.

Overall, similar to the previously described conferences and summits, the SF Bicycle Coalition also serves the functions of **Knowledge Development** and **Knowledge Diffusion**, but also the **Guidance of the Search** and **Creation of Legitimacy ,**and **Mobilization of Resources** functions as it is a group that represents the voices of cyclists in the city, who can further push for change at the political level, and normalize cycling as a popular mode of transport.

5.4 Innovative Programs

This section will describe results and insights gained from specific programs the city is trying out to further align with goals of a modal shift and a more livable city.

5.4.1 San Francisco E-Bike Delivery Pilot Program

An e-bike delivery pilot program was announced in the summer of 2022, with the plan to give a subset of delivery drivers for various food/grocery delivery companies (i.e. Uber Eats, DoorDash, Instacart) e-bikes (Schneider, 2022). The program was commissioned by San Francisco's Department of the Environment, and aims to reduce carbon footprint, improve street safety, and lessen the financial burden on low-paid workers who work for these companies. The program was based on a previous study that polled delivery workers and found that 70% were willing to deliver by e-bike, citing vehicle expenses as a major cost of being a delivery driver (Schneider, 2022).

More recently, the pilot program started accepting applications in March 2023, and plans to carry out the program from 2023 to 2024 (Wong, 2023). According to Wong, the study will consist of two cohorts of e-bike delivery drivers, as well as a control group of drivers using cars. Both groups of participants will be studied for six months each in order to collect data to better understand impacts towards the workers, the delivery service, and the climate. If deemed successful, the hope is that this pilot will signal a change in the delivery industry to align a more sustainable form of delivering food to residents of the city.

An interview with Civil Servant 3, from the San Francisco Environment Department and the program manager for this pilot program, provided additional valuable insights into the city's e-bike food delivery pilot program, which is seen as something of an experiment to prove the usefulness of e-bikes in the commercial sector. She mentioned that the program was funded by a $2.4 million grant from the California Energy Commission (CEC), and employs a data-driven approach to assess various metrics such as working conditions, income, safety, and emission reductions. The program also places a strong emphasis on equity, aiming to serve participants with demonstrated financial need, and employs feedback mechanisms like surveys and mid-cohort meetups for continuous improvement.

At the end of the program, Civil Servant 3 hopes the program can show that e-bikes are faster, cleaner, and more cost effective method for food deliveries. After the first three phases, the riders get to keep to the e-bikes assuming they participate for the full six months. In the future, the program may be able to receive more funding from the Department of Energy to expand its reach and goals. One of the discussed end goals of that expanded program would be to develop some time of e-bike cost savings calculator that delivery riders could use to determine if it was worth it to switch from a car to an e-bike.

According to Civil Servant 3, the pilot program has the potential to influence future urban planning and transportation policies in San Francisco, as it aims to share its findings with city partners. Additionally, it was mentioned that the e-bike food delivery pilot program has partnered with the San Francisco Bicycle Coalition to offer training for riders. This training aims to educate riders on safe and efficient e-bike usage, thereby enhancing the overall safety and effectiveness of the program. The partnership with a well-established advocacy group like the SF Bicycle Coalition also lends credibility and expertise to the initiative.

This initiative primarily impacts all Functions of Innovation Systems (FIS**): Entrepreneurial Activities, Guidance of the Search, Market Formation, Resource Mobilization, Knowledge Diffusion, and Creation of Legitimacy**. The program embodies these functions by introducing a novel venture into the delivery sector, leveraging external funding, forming partnerships with private companies, and setting a direction for the future of sustainable urban mobility through data collection. Additionally, the partnership with the San Francisco Bicycle Coalition facilitates the sharing of expertise and best practices between organizations, thereby contributing to the diffusion of knowledge within the mobility ecosystem. Finally, the involvement of a reputable organization like the SF Bicycle Coalition helps in legitimizing the e-bike program and potentially counteracting any resistance to this new form of mobility.

5.4.2 Sunday Streets

One program present in San Francisco that indirectly promotes active transportation in the name of reclaiming streets from cars is the Sunday Streets program, which started in 2008 (*About Us – Sunday Streets SF*, 2023). As state on the program's webpage, the program is inspired by the Ciclovia in Bogota, Colombia, and aims to create open space, encourage physical activity, foster community building, and inspires people to view the streets as a public space for community activity.

Historically, the program was started originally to address public health crises related to chronic disease and climate change (City, 2019a). The success of the first event led to Sunday Streets becoming a permanent program that has expanded to include multiple routes dedicated to various neighborhoods throughout the city. Additionally the focus on addressing these issues resulted in pushing a modal shift towards cycling, walking, and public transit being the only option for participating in these events. This modal shift has also been shown to permeate to other parts of people's lives outside of these events as well (City, 2019b).

Furthermore, Sunday Streets also provides an opportunity for local businesses and organizations to showcase their products and services to a wider audience. The event "is made possible by the entire Sunday Streets community, including 400+ volunteers, hundreds of local nonprofits and small businesses, dozens of sponsors and City agencies, and the residents of our host neighborhoods."(*About Us – Sunday Streets SF*, 2023).

Overall, by creating a safe and inclusive environment for people to engage in physical activity, Sunday Streets legitimizes the importance of public health and wellness as key components of urban planning. This demonstration of a different way of using public space helps to build support for more permanent changes to the urban landscape, such as the creation of bike lanes and pedestrian walkways. Additionally, this program serves as an innovative approach to legitimize the importance of creating public spaces that prioritize people over cars, promoting community engagement, public health, and economic development.

This program impacts several functions: namely **Knowledge Development, Knowledge Diffusion, Guidance of the Search, and Creation of Legitimacy** as it provides a confluence for multiple stakeholders to gather, share their experiences and knowledge, and further legitimize the idea of a livable city, in which pedestrianized streets and cycling play a part in.

5.4.3 Slow Streets

Another program, similar to Sunday Streets, was introduced to San Francisco and is called Slow Streets, which "aims to expand the city's growing Active Transportation network and encourage more people of all ages and abilities to travel by low-carbon modes." (SFMTA, 2020). According to the program's website, these streets were identified as low-traffic/low-speed streets that could be opened up to all modes of transit, but where the care shares the street with pedestrians, cyclists, and other people.

The program found that after designating streets as slow streets specifically, collisions decreased by 48%, compared with 14% in the rest of the city. Additionally, it found that the average speed traveling on these streets decreased to 16mph from 20mph before the pandemic, and average volume on the streets also decreased from 2000 cars per day to around 800 cars per day. Thus, this program has been a successful way to implement traffic calming measures that can make more streets cyclable and friendly for e-bikers and c-bikers alike.

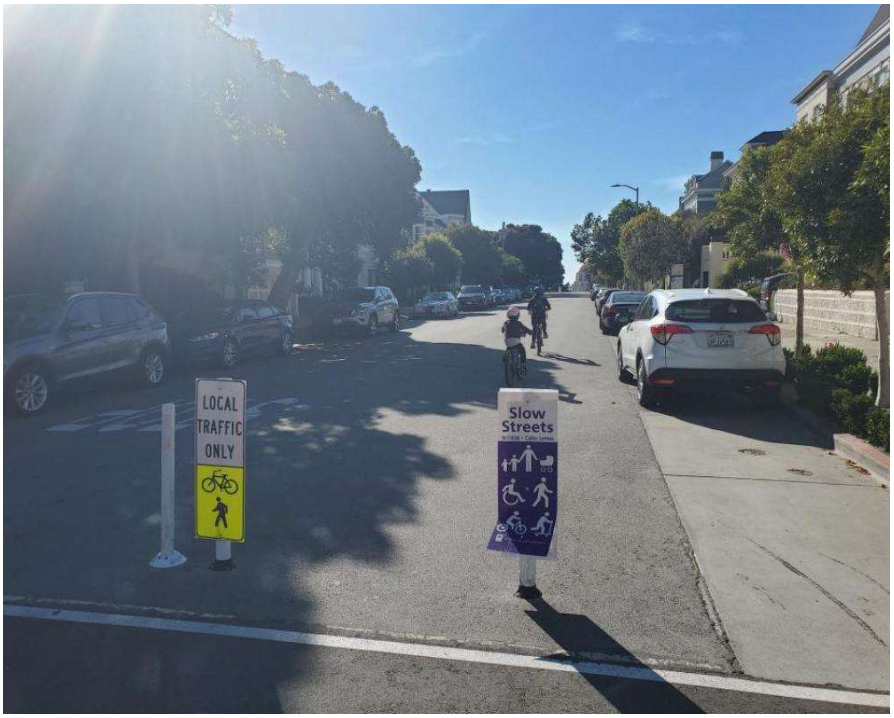

FIGURE 16 - PHOTO OF SLOW STREET IN SF, ALLOWING ONLY LOCAL TRAFFIC (SFMTA, 2020)

For the same reasons as the Sunday Streets program, this program also impacts the following functions **Knowledge Development, Knowledge Diffusion, Guidance of the Search, and Creation of Legitimacy** as it provides people with an opportunity to experience car-free streets and see how walkable, bikeable, and liveable their streets are. Both programs work towards creating safer streets, expanding car-free spaces, increasing bicycle and pedestrian safety infrastructure, and ultimately encouraging more people to participate in a more liveable community.

5.5 Summary of Results

In summary, these are just several of many ideas, events, programs, policies, and projects that contribute to San Francisco's mobility system. The mix of both abstract ideas and concrete examples helps paint a holistic view of the city and its attitude towards facilitating a modal shift towards e-bikes. To summarize, the full list of topics covered and the impacted functions are outlined in the below table.

Functions	**Topics**
Entrepreneurial Activities	Overarching Political Landscape Bay Wheels Bike Share San Francisco E-Bike Delivery Pilot Program
Knowledge Development	Overarching Political Landscape California E-Bike Incentive Approach to Infrastructure Bay Wheels Bike Share Valencia Street Bike Lane Attitudes towards Community Engagement and Equity Ridership Reports California Bike Summit and Micromobility America SF Bicycle Coalition San Francisco E-Bike Delivery Pilot Program

	Sunday Streets Slow Streets
Knowledge Diffusion	Overarching Political Landscape Climate Action Plan Transportation Plan Bay Wheels Bike Share Attitudes towards Community Engagement and Equity California Bike Summit and Micromobility America San Francisco E-Bike Delivery Pilot Program Sunday Streets Slow Streets
Guidance of the Search	Overarching Political Landscape Climate Action Plan Transportation Plan California E-Bike Incentive Approach to Infrastructure Bay Wheels Bike Share Valencia Street Bike Lane San Francisco E-Bike Delivery Pilot Program Secure Bike Parking and Theft Ridership Reports SF Bicycle Coalition San Francisco E-Bike Delivery Pilot Program Sunday Streets Slow Streets
Market Formation	Overarching Political Landscape Bay Wheels Bike Share San Francisco E-Bike Delivery Pilot Program
Mobilization of Resources	Overarching Political Landscape Climate Action Plan Transportation Plan California E-Bike Incentive Federal E-BIKE Act Approach to Infrastructure Bay Wheels Bike Share Valencia Street Bike Lane Secure Bike Parking and Theft SF Bicycle Coalition San Francisco E-Bike Delivery Pilot Program
Creation of Legitimacy/Counteract Change	Overarching Political Landscape Approach to Infrastructure Bay Wheels Bike Share Attitudes towards Community Engagement and Equity SF Bicycle Coalition Sunday Streets Slow Streets San Francisco E-Bike Delivery Pilot Program

TABLE 2 - SUMMARY OF IMPACTED FUNCTIONS BY TOPIC

As can be seen in Table 2 above, many of the functions within the FIS framework seem to function well, with several examples of events, programs, and projects that contribute to each respective function. The exception to this are the functions around entrepreneurial activities and market formation. Additionally, many of the results specific to San Francisco in this section can map to the factors from Section 3, indicating an alignment between the model of the mobility ecosystem presented in Figure 7 and actual events in practice. In the following section, a deeper discussion on the results in the context of the research questions is presented.

6 Discussion

When reconciling the initial research of what drives e-bike adoption in a mobility ecosystem with specific ideas, events, and projects related unfolding in San Francisco, there appears to be an alignment with the purported mobility ecosystem model established in Section 3 and the results gathered in Section 4. Specifically, the model presented in Section 3 established policy, the natural and built environment, and human characteristics as three pillars that drive a modal shift towards e-bikes. Both of these sections help answer the research questions related to the elements that are required to facilitate a modal shift towards e-bikes, as well as the specific questions that concern how San Francisco is doing in this space, and what outstanding barriers and opportunities exist to improve their roadmap to sustainable transportation.

As it relates to the natural and built environment, physical infrastructure appears to be the main actionable barrier to increased adoption of e-bikes. This includes safe intersections, adequate cycle lanes, and secure parking. Overall, this infrastructure contributes to the user's sense of safety, both while riding, and also when securing their bike unattended. Without satisfying the human need for safety while riding or protecting personal property, it seems unlikely that an appreciable increase in e-bike adoption would be observed. Additionally, the ability to form cohesive networks with cycling infrastructure that connect to public transit (in the form of mobility hubs) also seems to be a successful method to mutually stimulate public transit usage and active transportation. Finally, various operating models ranging from bike sharing, to long-term rentals/leasing, to private ownership seem to open up more options for users to choose from, and can positively influence adoption of e-bikes as well.

Regarding the human factors and characteristics that impact e-bike adoption, equity and accessibility seem to be the guiding values in this domain. E-bikes help lower the barrier to entry for a mode of active transportation, as they allow users to flatten hills, and ride longer distances with less effort and less impact on their physical appearance after arriving at their destination. However, it is crucial that e-bikes are affordable for the majority of the population, as the cost can be prohibitive for low income earners. Similarly, low income neighborhoods also need access to the same level of infrastructure, for the reasons cited in the previous paragraph. For this reason, it's crucial that the city servants ensure they are gathering feedback from a broad demographic sample of the region.

Underpinning all change in a mobility ecosystem is ultimately a direct result of policy. Whether its infrastructure projects to build additional bike lanes, or new rebates and incentives to stimulate e-bike sales, all of these changes are downstream of the attitudes and policies enacted by the civil servants in charge of a region. These attitudes can be reflected in published traffic safety or climate roadmaps, but ultimately, politicians and civil servants need to mobilize resources to actually enact change. Whether that's setting up streamlined processes, allocating more funding, or facilitating more public outreach, it all starts with political will.

Focusing on San Francisco, the city appears conducive to transitioning towards e-bikes due to its topography and compact size. The city's history of promoting cycling, both through projects targeting cycling lanes and "slow streets" initiatives during COVID, shows a proactive approach. Additionally, the city has several ongoing projects intended to encourage cycling, such as bike-sharing schemes, dock expansions, new infrastructure, and trials involving e-bike grocery/food delivery services.

One area the city seems to excel in is in the attitude towards community engagement, accessibility, and equity. This is evidenced in the collaborations with advocacy groups and disadvantaged neighborhoods, which in turn lead to an increased focus on this demographic when planning projects or programs. Examples include the Bay Wheels bike share system, where the city structured contracts to offer service in low income neighborhoods, or during infrastructure planning, when the lives of those who live in historically underfunded neighborhoods are considered for project planning purposes. Finally, the fact that the city is working on a supplemental city-wide e-bike subsidy shows that it is committed to making active transportation options available for everyone, regardless of financial status.

Nevertheless, obstacles persist. San Francisco's recovery from COVID has lagged behind other U.S. cities, casting doubt on the city's capacity to allocate funds towards further cycling initiatives. Other concerns include the dwindling downtown area due to businesses leaving and rising crime rates. The risk of theft is a ubiquitous barrier to the adoption of e-bikes in any capacity, whether for personal or commercial use. Additionally, because of the diverse alternative modes of transport such as scooters and electric skateboards, the planning of infrastructure can be a much more cumbersome process. The planning of new infrastructure seems like it could benefit from a more streamlined process with all stakeholders involved, in order to realize a quicker rate of infrastructure expansion. Additionally, gathering more feedback earlier from local communities appears like it could assist with better e-bike friendly designs that benefit not only the locals, but also those visiting neighborhoods from elsewhere.

Other structural barriers include facilitating public consensus and the city's political structure. District supervisors can find it challenging to agree on specific projects or a common vision, impacting the prioritization of projects like secure parking and connected bike networks, affecting residents' perceptions and their reluctance to own private bikes due to theft or vandalism risks. Moving forward, San Francisco must address these resident concerns and clearly outline its vision for a modal shift, akin to the strong political will seen in cities like Paris, to encourage a shift from car to e-bike commuting. This political alignment underpins infrastructure projects, which is ultimately the foundation by which a modal shift occurs. Without sufficient infrastructure, other policies like rebates may not be as effective as people will simply not feel safe riding an e-bike in the city.

From the FIS analysis, San Francisco seems to be doing fairly well in regards to all functions with the exception of two. Specifically, it would appear the city could benefit from additional activities that spur Entrepreneurial Activities and Market Formation in the space of e-bikes. Bay Wheels is a great example of a public-private partnership that has continually grown since its inception, helping provide a city-wide service for residents to take advantage of active forms of transportation. Additionally, this partnership and the sources of public and private funding seem to help allay the operating concerns and costs associated with operating such a system at an affordable price point. More recently the e-bike food delivery pilot program is another promising example of a publicly funded program, that aims to expand the footprint of active transportation in conjunction with a private company that provides the e-bikes. While the Bay Wheels system and the e-bike food delivery pilot are good examples of programs that span all FIS functions, the overall mobility space could stand to benefit from more companies entering the space as well. If the city can prove the versatility of e-bikes for an increasing amount of personal and commercial uses, the legitimacy of e-bikes as a primary mode of transportation can feed a positive feedback loop for increasing e-bike adoption in the future.

7 Conclusion

In summary, a city's readiness to embrace e-bikes as a main form of transport is a significant, albeit small, facet of the larger urban planning ecosystem. At a high level, mobility is a crucial part of city infrastructure, alongside other key utilities such as electricity, water, gas, and sewage, all of which are critical to its functioning. This core infrastructure forms the foundation for fostering growth in communities, public services, and entertainment within a city. All these elements are interconnected, with mobility serving as a crucial link enabling individuals to commute from home to work, schools, and essential services. Therefore, mobility acts as a connective tissue that fosters cohesiveness in an urban environment.

First and foremost, it appears e-bike adoption largely hinges on the policies implemented by policymakers. That is, the political will by politicians and the resulting policies drive downstream changes in infrastructure, incentives, attitudes, and form the overall mobility vision for a city. These policies, which might incentivize e-biking or discourage driving, often require years to formulate and implement, and the infrastructure projects necessitated by such policies could take even longer. This prolonged timeline regarding policy and infrastructure complicates efforts to evaluate a city's readiness to adopt e-bikes as a main mode of transportation, as a transformation of a city could take decades to be realized, and even then it is always an evolving work in progress.

Nonetheless, such efforts are integral to transforming the urban mobility landscape. Policies providing financial incentives to less affluent potential e-bike owners, and those encouraging infrastructural modifications to add biking lanes or secure parking are positively associated with e-bike adoption. These policies and infrastructural shifts directly influence residents' attitudes towards e-bike usage by creating a safer, secure, and accessible environment.

Broadly, the shift towards e-bikes necessitates cooperation between public and private sectors. This is evident in the services offered by cities such as bike-sharing schemes or private companies providing e-bikes to employees, making this form of transport more accessible and ubiquitous. Such collaborations establish feedback loops, helping to resolve the conundrum of whether to build cycling infrastructure in the absence of users.

As an individual city, San Francisco has made significant progress in facilitating alternative transportation modes, though immediate challenges may supersede e-bike adoption and the required infrastructural or policy changes. If the city can recover in a post-pandemic world, attract businesses, sustain public transit ridership, and revitalize commercial and entertainment sectors, e-bike adoption might once again gain momentum. However, because of the long timescales needed to realize such changes in a city, these types of transformations could take several years or even decades to realize.

The biggest challenge for San Francisco, and likely other cities looking to facilitate a modal shift away from cars to active modes of transportation, is a lack of political will. When looking at the value chain for how this modal shift happens, political will sits at the front of the chain, and infrastructure projects, financial incentives, and community engagement efforts all are a result of strong determination by civic leaders to realize this vision. As one interviewee eloquently put it, the challenge of sustainable active transportation is not so much empirical, as the case for biking/e-biking as a sustainable mode of transportation has already been made, but is rather how to convert these insights into political willpower. With this in mind, the leaders of San Francisco should look to nurture this political will through continued engagement from civic leaders, community members, private entities, academics, and activists in order to realize a future without the need for car dependency, and one more oriented around sustainable transportation and liveable cities.

8 Reflections and Recommendations

For the purpose of this project, the theoretical framework of the Functions of Innovation Systems proved to be a sufficient framework for analyzing a city's mobility ecosystem. The seven functions in this framework all encompass various characteristics of an innovation system (in this case e-bikes), which is helpful to apply in this analysis given the complexity of the topic at hand. It serves as a holistic framework which can capture the social, economical, and political dimensions of an innovation system. Thus, the approach seems generalizable to investigate how other cities are doing in regards to facilitating modal shifts towards more sustainable modes of transportation.

For further research the following recommendations can be made:

1. Perform the same analyses on other U.S. and international cities to compare how mobility ecosystems vary from city to city. By comparing different political structures or infrastructural footprints for example, one could draw conclusions on if there is a more effective way of facilitating modal shifts. There are countries like the Netherlands which has quite successfully facilitated a modal shift, so there exist blueprints that could be copied.
2. Extend the study for a more longitudinal timeframe. Change, especially in the realm of urban planning, takes years to realize, so a more longitudinal study could show a broader view over time of how specific policies, projects, and advocacy efforts led to long lasting impacts. Similar with the Netherlands, much of the change observed today unfolded over decades of work.
3. Delve into more research around the political decision making process. Given that this was identified as the primary barrier, it would be interesting to learn how decisions get made in San Francisco compared to other cities and the pros and cons of various political structures.
4. Interview stakeholders from the private sector. To understand better the role that the private sector plays in the mobility space, interviews with representatives from mobility companies could be performed. This may yield insights into the challenges associated with running a viable business in the mobility sector.
5. Interview more residents to understand their transportation needs. This could be a more in depth analysis on what modes of transportation residents currently use, and commute patterns like how far they live away from their place of employment and other critical services.
6. Expand the scope of research to the topic of urbanism. Transportation is one element of urbanism, and there are many other factors at play that are needed to realize the liveable city. For example, perhaps there are some insights into how certain development patterns compliment active mobility.
7. Explore the role of activism in facilitating change. As seen from several activist movements in the Netherlands, these can often result in substantial paradigm shifts which can influence the direction and transportation policies of the future

Regarding practical recommendations for the city of San Francisco, there are some suggestions further lowering the barrier to adopting e-bikes as a larger modal share:

1. Streamline the political process regarding infrastructure projects. Political will is what drives projects forwards, including infrastructure projects. Infrastructure is paramount to e-bike adoption and good infrastructure requires cohesive networks, that are accessible to all demographics in every part of the city.
2. Explore opportunities to solve multiple overlapping problems with the adoption of e-bikes. For example, could the e-bike delivery program somehow help the city with getting the homeless population back on their feet?
3. Install additional secure parking facilities at hub locations. Because theft is a primary deterrent to buying an e-bike, being able to securely lock an e-bike on the street is crucial to private ownership.
4. Assist in theft recovery or provide theft insurance. For e-bikes that are GPS-enabled, partner with the city to allocate resources to recovering bikes. Additionally, perhaps explore models for insuring against theft.

5. Increase the number of pooled/shared bikes at transit hubs and hotspots. Because there are often popular stations for the shared bikes, it is important for residents to have a bike available when they need it. Therefore, the number of bikes at these locations could be increased, using ridership data to influence where.
6. Subsidize the cost of bike sharing and further integrate it into public transport. If residents still feel the price is too high, they won't use the service. This could be alleviated through further subsidies so it is more cost comparative with other modes of car-dependent transit. Also, the renting of bikes could be integrated with the transit card for a more seamless experience to enable more trip chaining.
7. Continue to focus on mobility equity and accessibility. Since e-bikes are pricey, it is crucial to focus policies and rebates on those who need them the most, and ensure transit projects serve the majority of the population.

9 References

Abonour, R. (2022, December 7). *San Jose Says No to Minimum Parking Requirements*. NRDC. https://www.nrdc.org/experts/rabi-abonour/san-jose-says-no-minimum-parking-requirements

About Us – Sunday Streets SF. (2023). https://www.sundaystreetssf.com/about/

About—San Francisco Bicycle Coalition. (n.d.). Retrieved March 22, 2023, from https://sfbike.org/about/

Austin, P. L., & Est, P. (n.d.). *E-Bikes Are Taking Off—But We Need to Make Space for Them*. Time. Retrieved January 18, 2023, from https://time.com/5925286/e-bikes-parking-lanes/

Badstuber, N. (2018, April 11). London's Congestion Charge Is Showing Its Age. *Bloomberg.Com*. https://www.bloomberg.com/news/articles/2018-04-11/london-s-congestion-charge-is-showing-its-age

Bay Wheels. (2021, November 17). *Mastercard and Lyft Come Together to Advance Sustainability Goals with Support of Bay Wheels Bikeshare Program*. Lyft. https://www.lyft.com/blog/posts/mastercard-and-lyft-come-together

Bearne, S. (2023, January 26). Subscription-based bike hire schemes on a roll. *BBC News*. https://www.bbc.com/news/business-64371657

Bevilacqua, M. (2018, June 1). *Lyft to Buy Bike-Share Company for at Least $250 Million*. Bicycling. https://www.bicycling.com/news/a21052742/lyft-buys-motivate-bike-share/

Bike Share System Wide Activity. (n.d.). Retrieved March 22, 2023, from https://stats.sfmta.com/t/public/views/FordGoBike/BikeShareSystemwideActivity?iframeSizedToWindow=true&%3Aembed=y&%3AshowAppBanner=false&%3Adisplay_count=no&%3AshowVizHome=no#3'

Boone, A. (2015, May 28). It's Coming: MTC Approves 10-Fold Expansion of Bay Area Bike Share. *Streetsblog San Francisco*. https://sf.streetsblog.org/2015/05/28/bay-area-bike-share-expansion-approved-with-4-5-million-public-grant-program/

Bosch eBike Systems. (n.d.). *Sustainable mobility with the eBike*. Bosch eBike Systems. Retrieved February 14, 2023, from https://www.bosch-ebike.com/us/service/sustainability

Bourne, J. E., Cooper, A. R., Kelly, P., Paul Kelly, Kinnear, F. J., England, C., Leary, S. D., & Page, A. S. (2020). The impact of e-cycling on travel behaviour: A scoping review. *Journal of Transport and Health*, *19*, 100910. https://doi.org/10.1016/j.jth.2020.100910

Boztas, S. (2023). Underwater bike garage solves Amsterdam station's storage headache. *The Guardian*. https://www.theguardian.com/world/2023/jan/18/underwater-bike-garage-solves-amsterdam-stations-storage-headache

Bruntlett, M., & Bruntlett, C. (2018). *Building the Cycling City*. Island Press.

California Bicycle Coalition. (n.d.). *Workshops & Presenters*. CalBike. Retrieved March 23, 2023, from https://www.calbike.org/events/california_bicycle_summit/workshop-highlights-2022/

Cano, R. (2023, June 12). *Budget proposal by California Legislature includes a $1.1 billion bailout for BART, state transit*. San Francisco Chronicle. https://www.sfchronicle.com/bayarea/article/california-1-1-billion-bailout-bart-bay-area-18147147.php

Chang, T., Hiatt, R., Young, E., Paz, A., Long, D., Tischler, D., Bingham, A., Beaulieu, M., Hillis, R., Rodgers, A., Tran, T., Tumlin, J., McGuire, T., Uchida, K., Tanner, K., Yip, D., & Heard, E. (2022). *San Francisco County Transportation Plan 2050*.

Cherry, C. (2007). *Electric Bike Use in China and Their Impacts on the Environment, Safety, Mobility and Accessibility*. https://escholarship.org/uc/item/8bn7v9jm

City & County of San Francisco. (2021). *SAN FRANCISCO'S CLIMATE ACTION PLAN 2021*. San Francisco Environment Department. https://sfenvironment.org/sites/default/files/events/cap_fulldocument_wappendix_web_220124.pdf

City, L. (2019a, February 28). *MODE SHIFT IN ACTION: The Story of Sunday Streets San Francisco*. Livable City. https://www.livablecity.org/sunday-streets-san-francisco-history/

City, L. (2019b, April 4). *Why Open Streets are an Important Tool in the Fight Against Climate Change*. Livable City. https://www.livablecity.org/open-streets-against-climate-change/

Commute Mode Choice | Vital Signs. (n.d.). Retrieved March 22, 2023, from https://www.vitalsigns.mtc.ca.gov/commute-mode-choice

Darrow, M. (2023, June 1). *Office space vacancies soar in post-pandemic San Francisco; 'It's not a good look'—CBS San Francisco*. https://www.cbsnews.com/sanfrancisco/news/downtown-san-francisco-post-pandemic-economy-vacant-office-space-real-estate/

de Kruijf, J., van der Waerden, P., Feng, T., Böcker, L., van Lierop, D., Ettema, D., & Dijst, M. (2021). Integrated weather effects on e-cycling in daily commuting: A longitudinal evaluation of weather effects on e-cycling in the Netherlands. *Transportation Research Part A: Policy and Practice*, *148*, 305–315. https://doi.org/10.1016/j.tra.2021.04.003

Deliso, M. (2023, March 21). *US lawmakers reintroduce e-bike tax credit bill offering up to a $1,500 refund*. ABC News. https://abcnews.go.com/Politics/us-lawmakers-reintroduce-bike-tax-credit-bill-offering/story?id=98020617

Dickey, M. R. (2018, January 8). Ford GoBikes are going electric in San Francisco. *TechCrunch*. https://techcrunch.com/2018/01/08/ford-gobikes-by-motivate-are-going-electric-in-san-francisco/

Dozza, M., & Werneke, J. (2014). Introducing naturalistic cycling data: What factors influence bicyclists' safety in the real world? *Transportation Research Part F: Traffic Psychology and Behaviour*, *24*, 83–91. https://doi.org/10.1016/j.trf.2014.04.001

Duranton, G., & Turner, M. A. (2009). *The Fundamental Law of Road Congestion: Evidence from US cities* (Working Paper 15376). National Bureau of Economic Research. https://doi.org/10.3386/w15376

Goebel, B. (2016, September 9). *The Bay Area's Expanded Bike-Share System—Brought to You by Ford*. KQED. https://www.kqed.org/news/11079980/the-bay-areas-expanded-bike-share-system-brought-to-you-by-ford

Hamilton, R. (2023, June 4). *Assessing San Francisco's E-bike Ecosystem* [Personal communication].

Hanley, S. (2019, June 17). *Beijing Opens New Bicycle Expressway*. https://cleantechnica.com/2019/06/17/beijing-opens-new-bicycle-expressway/

Haustein, S., & Møller, M. (2016). E-bike safety: Individual-level factors and incident characteristics. *Journal of Transport & Health*, *3*(3), 386–394. https://doi.org/10.1016/j.jth.2016.07.001

Heinen, E., & Buehler, R. (2019). Bicycle parking: A systematic review of scientific literature on parking behaviour, parking preferences, and their influence on cycling and travel behaviour. *Transport Reviews*, *39*(5), 630–656. https://doi.org/10.1080/01441647.2019.1590477

Hekkert, M. P., Suurs, R. a. A., Negro, S., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of Innovation Systems: A new approach for analysing technological change. *Technological Forecasting and Social Change*, *74*(4), 413–432. https://doi.org/10.1016/j.techfore.2006.03.002

Hymel, K. (2019). If you build it, they will drive: Measuring induced demand for vehicle travel in urban areas. *Transport Policy*, *76*, 57–66. https://doi.org/10.1016/j.tranpol.2018.12.006

Infographic: How the World Commutes. (2022, September 19). Statista Infographics. https://www.statista.com/chart/25129/gcs-how-the-world-commutes/

Kidd, C. (2023, October 20). *Assessing San Francisco's E-bike Ecosystem* [Personal communication].

Lasky, M. (2023, April 21). *Assessing San Francisco's E-bike Ecosystem* [Personal communication].

Ling, Z., Cherry, C. R., John MacArthur, MacArthur, J., & Weinert, J. X. (2017). Differences of Cycling Experiences and Perceptions between E-Bike and Bicycle Users in the United States. *Sustainability*, *9*(9), 1662. https://doi.org/10.3390/su9091662

MacArthur, J., Dill, J., & Person, M. (2014). Electric Bikes in North America: Results of an Online Survey. *Transportation Research Record*, *2468*(1), 123–130. https://doi.org/10.3141/2468-14

Mason, J., Lew Fulton, Lew Fulton, Lew Fulton, Lew Fulton, Lew Fulton, Fulton, L., & McDonald, Z. (2015). *A Global High Shift Cycling Scenario: The Potential for Dramatically Increasing Bicycle and E-bike Use in Cities around the World, with Estimated Energy, CO2, and Cost Impacts*.

Mayer, A. (2020). Motivations and barriers to electric bike use in the U.S.: Views from online forum participants. *International Journal of Urban Sustainable Development*, *12*(2), 160–168. https://doi.org/10.1080/19463138.2019.1672696

McCamy, L. (2023, February 2). *E-Bike Purchase Incentives FAQs*. CalBike. https://www.calbike.org/e-bike-purchase-incentives-faqs/

McQueen, M., MacArthur, J., & Cherry, C. R. (2020). The E-Bike Potential: Estimating regional e-bike impacts on greenhouse gas emissions. *Transportation Research Part D-Transport and Environment*, *87*, 102482. https://doi.org/10.1016/j.trd.2020.102482

Meet Our Bikes | Bay Wheels | Lyft. (n.d.). Retrieved March 20, 2023, from https://lyft.com/bikes/bay-wheels/meet-our-bikes

Metropolitan Transportation Commission. (2013, August 12). *Bay Area Bike Share pilot program to launch on August 29, 2013*. Metropolitan Transportation Commission. https://mtc.ca.gov/news/bay-area-bike-share-pilot-program-launch-august-29-2013

Micromobility. (n.d.). *Micromobility America*. Micromobility. Retrieved March 23, 2023, from https://micromobility.io/events/micromobility-america

Moran, M. (2023, April 17). *Assessing San Francisco's E-bike Ecosystem* [Personal communication].

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. *Smart Cities*, *4*(1), Article 1. https://doi.org/10.3390/smartcities4010006

MTC. (2021, March 17). *Bay Wheels Bike Share Program | Metropolitan Transportation Commission*. Bay Wheels Bike Share Program. https://mtc.ca.gov/operations/traveler-services/bay-wheels-bike-share-program

NACTO. (n.d.). *NACTO_Dont-Give-Up-at-the-Intersection.pdf*. National Association of City Transportation Officials. Retrieved January 17, 2023, from https://nacto.org/wp-content/uploads/2019/05/NACTO_Dont-Give-Up-at-the-Intersection.pdf

Neisler, B. (2018, January 24). *How to apply design thinking to lean startup software development*. http://serverless.com//blog/appy-design-thinking-lean-startup-software-development

NHTSA. (n.d.). *Bicycle Safety _ NHTSA.pdf*. U.S. Department of Transportation. https://www.nhtsa.gov/book/countermeasures/countermeasures-work/bicycle-safety

O'Sullivan, F. (2019, March 29). *A Modest Proposal to Eliminate 11,000 Urban Parking Spots*. Bloomberg.Com. https://www.bloomberg.com/news/articles/2019-03-29/amsterdam-s-plan-to-eliminate-11-000-parking-spots

O'Sullivan, F. (2021, October 22). *Inside the New Plan to Make Paris '100% Cyclable'*. Bloomberg. https://www.bloomberg.com/news/articles/2021-10-22/how-paris-will-become-100-cyclable

Petegem, J. H. van, Schepers, P., & Wijlhuizen, G. J. (2021). The safety of physically separated cycle tracks compared to marked cycle lanes and mixed traffic conditions in Amsterdam. *European Journal of Transport and Infrastructure Research*, *21*(3), Article 3. https://doi.org/10.18757/ejtir.2021.21.3.5283

Preston, B. (2022, November 4). *Is an Electric Bike Right for You?* Consumer Reports. https://www.consumerreports.org/electric-bikes/is-an-e-bike-right-for-you-electric-bike-buying-guide-a2136838953/

Roberts, D. (2018, August 28). *No helmets, no problem: How the Dutch created a casual biking culture*. Vox. https://www.vox.com/science-and-health/2018/8/28/17789510/bike-cycling-netherlands-dutch-infrastructure

Rohrer, J. (2023, May 25). *Assessing San Francisco's E-bike Ecosystem* [Personal communication].

San Francisco Municipal Transit Agency. (2021). *SFMTA Strategic Plan*. https://www.sfmta.com/sites/default/files/reports-and-documents/2021/11/sfmta_strategic_plan.pdf

Sault, S. (2021, January 24). *Davos Agenda: What to know about how to save the planet | World Economic Forum*. https://www.weforum.org/agenda/2021/01/davos-agenda-2021-how-to-save-the-planet-climate-change-action-net-zero-circular-economy-energy-transition/

Schneider, B. (2021, November 18). *San Francisco's bike sharing program reckons with an uncertain future*. San Francisco Examiner. https://www.sfexaminer.com/archives/san-francisco-s-bike-sharing-program-reckons-with-an-uncertain-future/article_7e1e6028-e21e-5078-afda-975924932701.html

Schneider, B. (2022, June 6). *City to give free e-bikes to delivery workers*. San Francisco Examiner. https://www.sfexaminer.com/news/city-to-give-free-e-bikes-to-delivery-workers/article_56faac5c-e37e-11ec-abda-37baee9b75b7.html

Sciaruto, A. (2023, October 17). *Assessing San Francisco's E-bike Ecosystem* [Personal communication].

SFMTA. (2018). *PEDALING FORWARD A Glance at the SFMTA's Bike Program for 2017—2021*. https://www.sfmta.com/sites/default/files/reports-and-documents/2018/04/pedaling_forward_booklet_final_web_version.pdf

SFMTA. (2019, November 6). *SFMTA and Bay Wheels Reach Agreement* [Text]. SFMTA; San Francisco Municipal Transportation Agency. https://www.sfmta.com/blog/sfmta-and-bay-wheels-reach-agreement

SFMTA. (2020, April 22). *Slow Streets Program* [Text]. SFMTA; San Francisco Municipal Transportation Agency. https://www.sfmta.com/projects/slow-streets-program

Stenner, H. T., Boyen, J., Hein, M., Protte, G., Kück, M., Finkel, A., Hanke, A. A., & Tegtbur, U. (2020). Everyday Pedelec Use and Its Effect on Meeting Physical Activity Guidelines. *International Journal of Environmental Research and Public Health*, *17*(13), 4807. https://doi.org/10.3390/ijerph17134807

Strategic Plan 2018 – 2022. (n.d.). Retrieved March 22, 2023, from https://sfbike.org/about/strategic-plan-2018-2022/

Surico, J. (2022, May 5). The E-Bike Effect Is Transforming New York City. *Bloomberg.Com*. https://www.bloomberg.com/news/features/2022-05-05/as-e-bikes-surge-new-york-city-tries-to-keep-up

SWOV. (n.d.). *Sustainable Safety*. Retrieved January 23, 2023, from https://sustainablesafety.nl/

Symon, E. (2023, May 6). New Report Shows San Francisco Has Worst Downtown Recovery Rate Of Any Major US, Canadian City. *California Globe*. https://californiaglobe.com/articles/new-report-shows-san-francisco-has-worst-downtown-recovery-rate-of-any-major-us-canadian-city/

Tesla. (2023). *Design Your Model 3 | Tesla*. Design Your Model 3 | Tesla. https://www.tesla.com/model3/design

The California Bicycle Summit. (n.d.). CalBike. Retrieved March 23, 2023, from https://www.calbike.org/events/california_bicycle_summit/

Thorud, K. (2023, August 15). *Unusual Valencia Street center bike lane in San Francisco's Mission causes confusion—CBS San Francisco*. https://www.cbsnews.com/sanfrancisco/news/san-francisco-mission-district-valencia-street-bike-lane-controversy/

Toll, M. (2022, December 28). *Denver gave out huge rebates on electric bikes. Now it's making the bike lanes they need*. Electrek. https://electrek.co/2022/12/28/denver-e-bike-rebates-bike-lanes/

Toll, M. (2023, January 21). *California's $10M electric bike rebates are coming. Here are the latest updates*. Electrek. https://electrek.co/2023/01/21/californias-electric-bike-rebates-updates/

U.S. Department of Transportation. (2022). *U.S. Department of Transportation Strategic Plan FY 2022—2026*. https://www.transportation.gov/sites/dot.gov/files/2022-04/US_DOT_FY2022-26_Strategic_Plan.pdf

Vision Zero. (n.d.). Vision Zero Network. Retrieved January 23, 2023, from https://visionzeronetwork.org/about/what-is-vision-zero/

Wagenbuur, M. (2014, July 3). *Utrecht's Indoor Bicycle Parking Facility*. https://bicycledutch.wordpress.com/2014/07/03/utrechts-indoor-bicycle-parking-facility/

Wagenbuur, M. (2020, August 10). Cycle lanes in the Netherlands. *Junction Design in the Netherlands*. https://bicycledutch.wordpress.com/2020/08/12/cycle-lanes-in-the-netherlands/

Weingart, E. (2023, January 6). Widening Highways Doesn't Fix Traffic. So Why Do We Keep Doing It? *The New York Times*. https://www.nytimes.com/2023/01/06/us/widen-highways-traffic.html

Wong, G. (2023, March 22). *Want a job and an e-bike? Apply to this new SF delivery program*. San Francisco Examiner. https://www.sfexaminer.com/news/the-city/san-fransisco-accepting-apps-for-e-bike-delivery-program/article_c829eb0a-c824-11ed-b5ee-b70d1c78ab46.html