The E-Bike City

Designing sustainable streets

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The E-Bike City

1. Urban mobility reimagined: The E-Bike City vision

Kay W. Axhausen and Catherine Elliot

The now obvious climate change and the damages caused by them ever more frequently force policy makers and their supporting infrastructure in think tanks, consultancies and academic departments to think the previously unthinkable. With the 1.5 degree increase already surpassed, the dilemma of transport policy is becoming even more acute (World Meteorological Organization, 2025). The dilemma of having to trade the positive effects of new capacity accommodating population growth and increasing productivity against their negative ones of increasing greenhouse gas emissions and sprawl. The climate is now the decisive factor in shaping transport policy. The longstanding argument that "no cars equals no economic prosperity" can no longer justify delaying the necessary transition in urban mobility. The window for prioritizing economic concerns over environmental imperatives has closed. Climate change impacts are forcing policymakers to consider transformative adaptation and mitigation policies, beyond incremental changes (European Environment Agency, 2024). Our E-Bike City (EBC) project offers a transformative adaptation to urban networks and transportation.

The existing set of policy ideas are well known and well known to have limitations and counterproductive effects. “Business as usual” of continuing building new capacity is known to have only time-limited effects, as its induced demand will negate its impact in due course. In addition, in the Swiss context the voters were recently unwilling to pay for new motorway capacity projects and the highest reported factor were the concerns for the climate. The people are well-aware of the impacts that their personal driving has on the climate, and they are ready to make the shift, but the policy-makers continue to procrastinate. The shift to electric and later automated vehicles is slowing as the local authorities are dithering with the installation of charging points, especially in older denser built-up areas. Relying solely on a transition from fossil fuels to electric cars is insufficient: while electric vehicles address fuel-related emissions, they do not solve the broader challenges of sustainable material supply, space allocation, congestion, and society’s continued dependence on private car ownership. In addition, that shift will lower the variable costs/perceived generalized costs of vehicle use and with it will lead to unwanted induced demand effects. The shift to shared vehicles from pooled taxis to buses to trains is self-limited in its effect due to their system-inherent higher generalised costs. Its upfront capacity cost is high, as well, which slows it down as an effective policy instrument. The fourth policy idea of pricing the negative externalities of traffic from congestion, emissions to parking search, while known to be effective, is also known to be unpopular with the voting public, which in the OECD countries is in its majority vehicle-owning.

In this situation there is a clear need to develop new ideas, unusual ideas, dramatic ideas to explore the solution space for the policy discussion and the public. The arrival of market ready, reasonably cheap, but fast electric bikes (pedelecs, s-pedelecs) makes the idea to reallocate road space to them an obvious idea. Their urban speed is equal to the speed of urban traffic. So, the accessibility they could produce at scale should be comparable to the existing levels of accessibility. We know from many studies that the adoption of cycling is limited by its lack of space on the road, which produces a feeling of insecurity for many potential users. We are late for incremental or unproven solutions; what is needed are quick, easy-to-implement measures that can be deployed immediately. The EBC project explores such a realistic and scalable solution in an integrated and interdisciplinary approach, tested specifically in the Swiss context and widely applicable anywhere that bicycles can be ridden.

The EBC project is therefore assessing the impact of allocating 50% of road space to the active modes, while a) maintaining the existing public transport infrastructures b) maintaining existing sidewalks for pedestrians, and c) maintaining the motorised vehicle access to each street address for deliveries, emergency vehicles, craftsmen, etc. and to any private parking on the property. A further aspect of the project was to determine if it can maintain the levels of accessibility for the urban residents. EBC proposes a fundamental reallocation of urban space towards micromobility. By dedicating substantial road space to active modes such as bikes, e-bikes, cargo bikes and scooters, the project introduces a modest but essential inconvenience for private car use (namely a reduction of on-street parking) which is an indirect intervention needed to drive meaningful change away from the conveniences offered by the car. Importantly, emergency vehicles and those with specific mobility needs will retain full access to all locations, ensuring that critical services are not compromised.

The project's design is anchored in shifting away from private car use, particularly for daily commuting. It does so by ensuring access to shared vehicle hubs within 200 meters (or another designated distance) of every residence, promoting convenience and accessibility. EBC also inherently supports an intermodal transportation system, encouraging seamless integration between public transport and shared vehicles – both cars and micromobility options. Transitioning away from the convenience and perceived luxury of private automobiles presents financial challenges for the automotive industry and disrupts the routines of individuals accustomed to car ownership. In exchange, it gives rise to financial benefits for the households and fully supports offers by public transportation providers. Next to this shift in industry supply and demand, we must critically assess the human and environmental costs we are willing to bear to maintain the status quo. Equally all social costs in terms of infrastructure and accessibility need to be considered. "Business as usual" is simply no longer sustainable. Business as usual is damaging our climate and potentially making some environments unliveable. As extreme weather events intensify, driven by climate change, even the use of cars will become impractical or impossible in many cases.

A group of chairs at the Department of Civil, Environmental and Geomatic Engineering (ETH Zurich) coalesced around this idea in 2021, when the department was searching for lighthouse projects highlighting its abilities. Later, one chair at ENAC (EPFL) joined them. The chairs contributed their own resources, which were supplemented with departmental funds and contributions by the Federal Office of Energy and Energy Switzerland. The chairs are:

Prof. Dr. Bryan Adey Institute of Construction & Infrastructure Management
Prof. Dr. Kay Axhausen Institute for Transport Planning and Systems
Prof. Dr. Michel Bierlaire Transportation and Mobility Laboratory, EPFL
Prof. Dr. Francesco Corman Institute for Transport Planning and Systems
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Dr. Anastasios Kouvelas Institute for Transport Planning and Systems
Prof. Dr. Stephan Pfister Institute of Environmental Engineering
Prof. Dr. Martin Raubal Institute of Cartography and Geoinformation

This brochure highlights key results of our work that are especially policy relevant, but all elements are present.

The city of Zurich was our case study, as we had previous work on which we could build. Here, the simulation models implemented and calibrated in the MATSim and Sumo frameworks were important given the three-year timeframe of our project. Access to the existing Swiss Mobility Panel[1] was also important for the work on the public acceptance of the idea. The earlier EBIS (E-Bikes in Switzerland) and MOBIS (Mobility in Switzerland) GPS tracking and survey studies provided further insights and data.

We are looking forward to the discussion of this promising idea. We are aware that our project was not able to explore all issues such a dramatic shift would raise. The lack of integration of suburbia is the most obvious one. The possible longer-term disinvestment in cars and suburban real estate is the other one. Equally, the shifts in retail and other customer services needs further attention. We also would need to study the resorting of workers and their households by their home and work locations. Inside the transport modelling frameworks more attention is needed on the rescheduling of the days and weeks of the agents. Equally the acquisition of cycles and the other mobility tools in the medium term and of their use over the course of the year will be important to understand the possible acceptance of the EBC.

We hope that our work will become an important starting point in the achievement of the climate goals to which Switzerland has committed itself.

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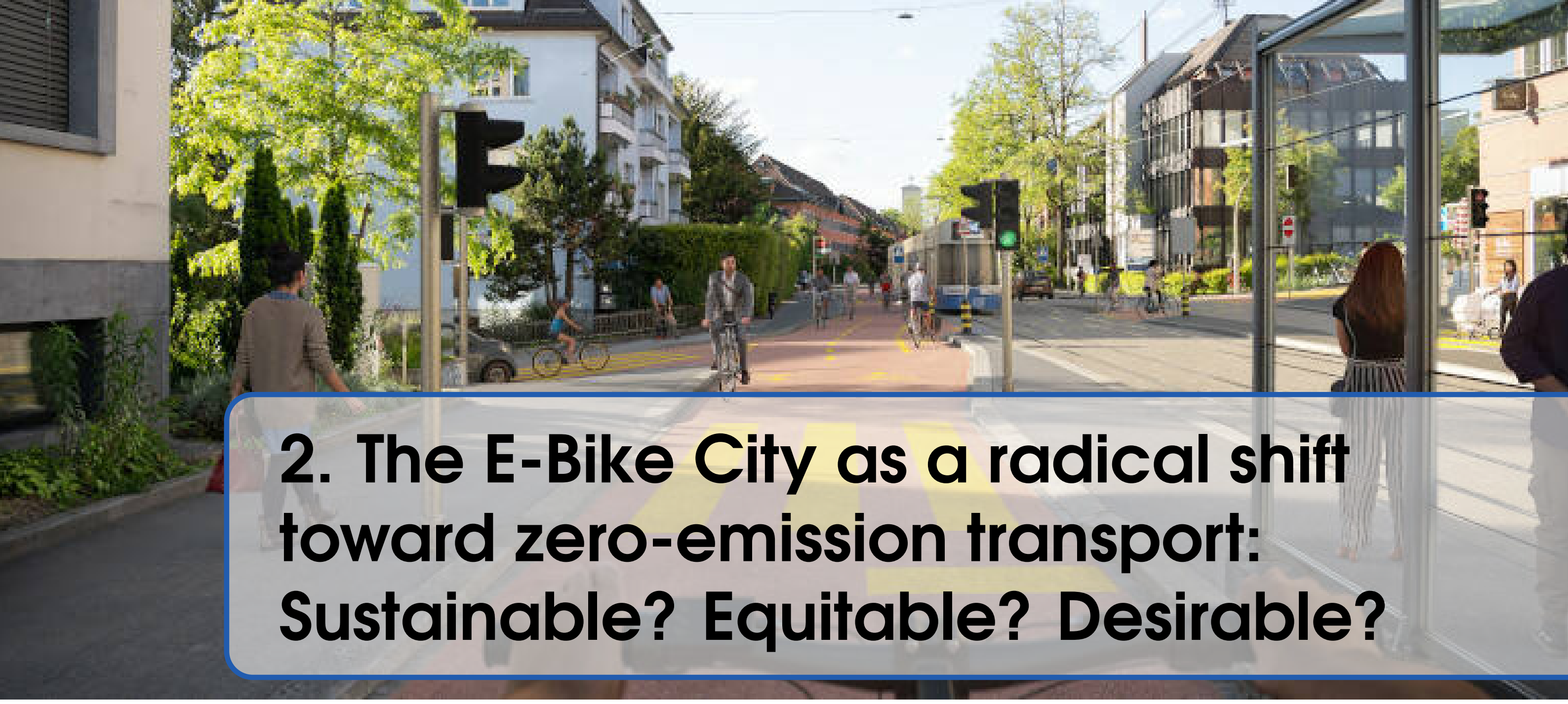
[1] https://istp.ethz.ch/research/swiss-mobility-panel.html



2. The E-Bike City as a radical shift toward zero-emission transport: Sustainable? Equitable? Desirable?

Lukas Ballo, Lucas Meyer de Freitas, Adrian Meister and Kay W. Axhausen

Abstract This think piece discusses current barriers to the rapid decarbonization of transport and ways to overcome them. Policymakers face a set of contradictory goals, leading them to ponder only incremental measures: The need to reduce carbon emissions conflicts with accessibility improvements and the resulting induced traffic. At the same time, the prevention of urban sprawl as a means of promoting sustainable mobility is fundamentally thwarted by technical advances in electric cars and autonomous driving. Unable to attract public acceptance for measures that would effectively reduce travel demand, transport policy is failing to provide convincing transition pathways toward sustainable and equitable mobility for growing urban populations.

As a possible way forward, we propose a new starting point for transport policy discussions, exploring the feasibility of urban transport systems based on sustainable, flexible, and relatively cheap modes of active mobility – the E-Bike City. This paper[1] aims to outline a research agenda for testing the effects of such a policy direction. In contrast to the literature on "cycling cities", this effort should include possibilities newly opened by the recent availability of electric micro-mobility vehicles. Also, it should aim for a balanced and realistic transition rather than a unimodal utopia. Inspired by friendly conversations around recent urban visions like 15-Minute Cities or Superblocks, this paper is meant to begin a new discussion about alternative future directions for transport policy beyond mere optimization and technical incrementalism.

2.1 Introduction

The transport sector must reduce its carbon footprint by at least 59% by 2050 (IPCC, 2022). It is also under pressure to reduce its other negative externalities, such as accidents, noise, and extensive usage of public space (Moreno *et al.*, 2021). At the same time, investments in better road infrastructure generate economic value through accessibility improvements but

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also lead to induced traffic (Hymel *et al.*, 2010; Hymel, 2019; Great Britain Department of Transport, 1994; Duranton and Turner, 2011). This trend is further amplified by population growth (UN, 2019) and increasing wealth (Steffen *et al.*, 2015).

The global population in cities is expected to grow by 58% from 2018 to 2050. Most of this growth will happen in less developed regions (UN, 2019), often with weak institutional practices of spatial and transport planning. The vast majority of surface-bound passenger travel is using private cars, most often occupied by solo drivers (BFS and ARE, 2023), resulting in high energy consumption, substantial negative externalities, and carbon emissions (ITF, 2020). Globally, the mode share of private cars is estimated at 71% of passenger kilometers (PKM) in urban areas (Aguiléra and Grébert, 2014). Even in Switzerland and the Netherlands, despite a relatively robust supply of alternatives, the mode share of private cars accounts for roughly 69% and 71% of PKM, respectively (BFS and ARE, 2023; KiM, 2022). Car driving is further perpetuated by building codes requiring a generous provision of (uncharged) parking, making all tenants and homeowners involuntarily pay for the car-centric transport system (Shoup, 2005). At the same time, this reduces the supply of commercial and residential space, particularly in North America, where parking typically consumes around 5% of total urban land to provide 2.5 to 3 parking spaces per vehicle (Davis *et al.*, 2010).

Since the COVID-19 pandemic, the “new normal” has further exacerbated already existing challenges. A study in Switzerland has shown that road traffic volumes have quickly returned to their pre-pandemic levels (Molloy *et al.*, 2021). At the same time, falling transit ridership, partially paralleled by growing car ownership, poses fiscal challenges to transit agencies (Basu and Ferreira, 2021). Recent studies suggest an increased preference for solo driving over more sustainable collective modes (Abdullah *et al.*, 2021; Basu and Ferreira, 2021; Das *et al.*, 2021). Less regular commuting may further reduce revenues from season tickets (Axhausen, 2020). Policymakers need to find new ways of securing transit financing and managing road traffic volumes.

Although much hope has been placed on the technical progress of battery-electric vehicles (BEV) to mitigate climate change, realistic scenarios show that this will not decarbonize transport quickly and strongly enough (de Blas *et al.*, 2020; Gebler *et al.*, 2020). BEVs still produce substantial greenhouse gas (GHG) emissions throughout their lifecycle and do not address many other negative externalities of traffic, including accidents or the excessive use of space. As of 2020, the lifecycle CO_2 emissions of private BEVs were only roughly 25% lower compared to vehicles with internal combustion engines (ICE) (ITF, 2020). Depending on the exact vehicle model and the location where the vehicle is charged, many BEVs in the US currently produce more emissions than equivalent hybrid-electric vehicles (Singh *et al.*, 2024). Cox *et al.* (2018) estimate that future BEVs may generate lifecycle GHG emissions of 45 to 78% of today’s values, although parts of the necessary technologies are still in the prototype stage (IEA, 2021).

Moreover, ongoing technical progress in electric vehicles will likely decrease the generalized cost of driving below the current levels, thus inviting additional demand (Wang *et al.*, 2021). While the lifecycle costs of BEV and ICE vehicles are approximately equal today (Verma *et al.*, 2022), falling battery costs will make BEVs cheaper (Schmidt *et al.*, 2017). The emergence of autonomous vehicles will further accelerate this trend by lowering the generalized cost of car travel (Bösch *et al.*, 2018; Steck *et al.*, 2018), enabling a wider group of potential users and perpetuating urban sprawl (Meyer *et al.*, 2017). As a result, a large part of the BEV sustainability benefits will be counterbalanced by induced demand, in line with Jevon's Paradox – see Alcott (2005) and Sorrell (2009).

The car has been a critical driver of economic growth since the early 1900s, with many jobs dependent on its supply chains. Attempting to retain this model while at the same time addressing the climate crisis, transport policy is caught in a dilemma between maximizing accessibility and making transport sustainable (Axhausen, 2020, 2022). This chapter aims to catalyze a discussion about ways out of this dilemma.

The remainder of this chapter is structured as follows: Section 2.2 presents an overview of behavior changes necessary for effective transition paths to sustainable mobility. Among different ways to achieve such changes, it emphasizes the potential of urban visions that positively frame future travel behaviors. Section 2.3 proposes the E-Bike City as a new starting point for urban transport policy discussions. Section 2.4 elaborates on changes in accessibility patterns that may emerge from such policy direction in existing cities. Section 2.5 outlines potential barriers and emerging avenues of research, followed by a conclusion in Section 2.6.

2.2 Behavior change for sustainability

Necessary and possible

As shown in the introduction, technical progress alone is insufficient for decarbonizing transport within the necessary time frame. A substantial body of literature concludes an inevitable need for large behavior changes alongside technical progress (de Blas *et al.*, 2020; Grubler *et al.*, 2018; Moriarty and Honnery, 2013). Multiple studies have analyzed the potential of such behavior changes (see Creutzig (2019); Santos (2017); Banister (2011); Santos *et al.* (2010); Zhang and Zhang (2021). Experience from the COVID-19 pandemic shows that substantial changes in travel behavior are possible (Molloy *et al.*, 2021). However, the following sections illustrate how difficult it is to induce them under normal conditions.

Supply-side changes

Mobility pricing

A frequently discussed way of changing travel behavior is through comprehensive pricing (Levinson, 2010). Such schemes may focus on internalizing the adverse external effects of carbon emissions, noise, usage of space, accidents, etc., and helping to maintain desirable levels of service in traffic. Successful examples from Stockholm, Milan, London, New York City, and Singapore (Croci, 2016; Schaller, 2010; Anas and Lindsey, 2011) show that such measures are, in principle, possible and effective. However, evidence from democratic countries also shows that implementing such measures is highly unpopular and politically unfeasible on a larger scale (Jakobsson *et al.*, 2000; Gu *et al.*, 2018; Lichtin *et al.*, 2022). Even payment for parking is contested in many places (Shoup, 2005).

Land use and transit

In the long term, mode choices or, more generally, the amount of travel may be influenced by changing land-use patterns or providing attractive transit options. Public transport's lifecycle GHG emissions per PKM are roughly 50-70% lower compared to private cars (ITF, 2020). Its use of road space is about 16 times more efficient in terms of passengers/hour on a single traffic lane (NACTO, 2016). However, the time needed to implement land-use changes and transit is too long, given the urgency of the climate crisis. Also, the benefits of residential areas favoring car-free lifestyles, such as transit-oriented development (Ohland and Dittmar, 2004; Calthorpe, 1993), can vanish over time if high property values attract groups with high car ownership rates (Paul and Taylor, 2021; Steuteville, 2017).

Cycling infrastructure

A different type of behavior change could be induced by encouraging shifts to active modes with light and energy-efficient vehicles. Over the entire lifecycle, cyclists on privately owned e-bikes emit $\sim$5 times less GHG per PKM than car users ($\sim$10 times less in the case of conventional bicycles) (ITF, 2020), and a single traffic lane can carry 5 to 12 times more passengers per hour on bicycles than in private cars (NACTO, 2016). Besides low emissions and high space efficiency, widespread cycling may also increase transit catchment areas, making demand bundling on existing infrastructure easier. Finally, compared to car traffic, cycling produces substantial health benefits (Garrard *et al.*, 2021), resulting in net positive externalities (ARE, 2022). Many individuals would, in principle, be willing to cycle if it were safer (Dill and McNeil, 2016; Geller, 2009). Providing a safe cycling infrastructure is therefore an essential instrument for inducing the shift (Pucher and Buehler, 2008). Since the 1990s, New York, San Francisco, Portland, London, Paris, Berlin, Seville, Bogotá, and many other cities have increased their modal splits of cycling by investing in safer, dedicated infrastructure for cyclists (Pucher *et al.*, 2021). Unprecedented progress happened during the COVID-19 pandemic, with massive networks of pop-up bike lanes deployed in many prominent cities, e.g., Paris, London, Washington DC, and Boston (Buehler *et al.*, 2021; Kraus and Koch, 2021; Becker *et al.*, 2022), many of which have remained until today. Active modes are increasingly seen as a functional solution to multiple challenges of transport policy (Fishman, 2016; Parkin, 2012; Pucher and Buehler, 2017), and the recent developments may be a starting point for discussions about more radical changes in urban transport systems in the post-COVID-19 world. However, despite the growing popularity of cycling policies, it is still unclear to what extent cycling could replace a substantial part of private car trips and what the consequences would be.

Demand-side changes

Pooling

The average car occupancy in Switzerland is 1.53 passengers, resulting in a load factor of 31% (BFS and ARE, 2023). With 69% of car capacity unused, increasing the occupancy could substantially reduce the volume of traffic. Pooling in relatively small paratransit vehicles is popular in emerging countries (Behrens *et al.*, 2016), as there are few alternative modes of transport. However, it remains a marginal phenomenon wherever solo driving is affordable. Evidence from the US shows that pooling is largely limited to low-income communities lacking alternatives (Shaheen, 2018) and mainly draws passengers from public transit (Shaheen *et al.*, 2016). For similar reasons, even the large-scale potential of autonomous pooled taxis is contested (Alonso-González *et al.*, 2021; Becker, 2020).

Working from home

Working from home can reduce the need for commuting (Delventhal *et al.*, 2022). However, rebound effects would likely shrink the resulting benefits (O'Brien and Yazdani Aliabadi, 2020). A GPS tracking study in Switzerland during and after the initial stages of the pandemic shows that road traffic returned to its original levels within five months despite an unprecedented increase in work from home (Molloy *et al.*, 2021). Older studies on “telecommuting” also suggest that working from home bears no substantial potential for reducing car travel, given long-term rebound effects (Choo *et al.*, 2005; Zhu and Mason, 2014).

Urban visions as enablers for transport policy discussions?

Unlike traditional measures for controlling travel demand via pricing and restrictions, positive images such as 15-Minute Cities (Moreno *et al.*, 2021) or Superblocks (Rueda, 2019) enjoy a rather favorable discussion despite aiming for similar goals. Through their positive reception, they open ways of rethinking elements of urban planning that might otherwise not be negotiable. In such cities, sustainable mobility can enjoy a universal preference without the possibility of some groups buying themselves out. The practical complexities may only become apparent later, once the public is enthusiastic about the benefits of living in such cities.

Images of modern urbanism from the beginning of the 20th century also enjoyed great popularity and shaped urban planning throughout the rest of the century. Visions like Le Corbusier’s *Ville Radieuse* (Le Corbusier, 1935), Frank Lloyd Wright’s *Broadacre City* (Wright, 1932), or Hans Bernhard Reichow’s car-oriented city *Autogerechte Stadt* (Reichow, 1959) quickly won the favor of the public, while the resulting traffic and parking challenges only became apparent later.

Observing the normative power of such urban visions, the question arises as to whether the enthusiasm they produce could be used to open a stream of more ambitious transport policy discussions. As a starting point for this discourse, we propose to explore the feasibility of an E-Bike City, building on early ideas in (Axhausen, 2022).

2.3 The E-Bike City

The basic idea

The E-Bike City aims to provide a new starting point for transport policy discussions. It should mobilize research to test the feasibility of an urban transport system based primarily on active mobility and public transit, potentially opening new pathways for future transport policies. Its core idea is allocating road space in favor of transit, walking, and cycling while incorporating e-bikes as an accelerator for longer trips and wider user groups. As an initial assumption, it may dedicate approximately 50% of the existing road space to cycling while leaving the remaining space for motorized traffic, mainly in the form of one-way streets. A generous provision of dedicated infrastructure would make cycling attractive to a wide spectrum of users. Public transit would allow longer trips and complement cycling when it is not feasible. On the other hand, reducing road space for motorized traffic would make driving less attractive, further encouraging a shift to sustainable modes.

The recent mass availability of e-bikes and other micro-mobility vehicles, such as cargo bikes or e-scooters, massively broadens the potential appeal compared to traditional bicycles. They allow longer trips and reduce the impact of elevation differences (Rérat, 2021; Meister *et al.*, 2023; Meyer de Freitas and Axhausen, 2023b; Bourne *et al.*, 2020; MacArthur *et al.*, 2018). Using e-bikes helps increase cycling frequencies (Van Cauwenberg *et al.*, 2022; Edge *et al.*, 2018) and maintain cycling despite changing circumstances

(Marincek and Rérat, 2021) and is being seen as an enabler, strengthening transition pathways (Edge *et al.*, 2020). Giving wider user groups the capability to cover short and medium distances using micromobility improves the cost-effectiveness of transit systems by allowing stronger demand bundling on lower-density networks with longer stop distances.

In contrast to more extreme visions of cycling cities like Velotopia (Fleming, 2017) or Bicycle Utopias (Popan, 2019), the E-Bike City should not be seen as a unimodal utopia but rather as a means of seeking a new balance between existing modes of transport. Its streets would still permit private car travel, although possibly at lower speeds and with some detours. The available road capacity could be priced or otherwise managed to ensure a sufficient level of service for essential trips and commercial and emergency vehicles.

A conscious supply of public and private parking spaces would help manage both the demand for driving and car ownership rates. It would also help provide more space for commercial, residential, and public uses – resulting in more local businesses, affordable housing, and attractive street spaces. Fully internalizing the cost of parking to its users would relieve car-free households from the cost of car traffic and incentivize economically efficient mode choices.

Similar to the pop-up bike lanes implemented in response to the COVID-19 pandemic, the E-Bike City could be started by merely repainting existing road surfaces, at first, perhaps, as a set of temporary pilots. Experimenting at little cost and with immediate results would replace lengthy planning processes. If successful, the first progress toward healthy and sustainable cities would be achievable within a few years.

The E-Bike City vision is a research agenda for a way out of the present transport policy dilemma by exploring to what extent future transport planning could utilize the potential of active mobility. The following section outlines its key challenges, together with areas of research to address them.

Addressing practical challenges

Long trip distances

Decades of car-centric lifestyles have created urban geographies that are difficult to serve by modes other than private cars (Illich, 1974). Long distances and dispersed travel patterns in sprawling cities and agglomerations are a considerable challenge for sustainable mobility transitions. However, the vast majority of trips in Western metropolitan areas are still short, well within the range of e-bikes, possibly in combination with public transit. Assuming an average e-bike speed of 22 km/h for longer trips (Lopez *et al.*, 2017), distances of up to 11 km are attainable within a travel time of 30 minutes. Faster micromobility vehicles such as s-pedelecs with average speeds of 22-25 km/h (Schleinitz *et al.*, 2017) could extend the viable distances even further. In the greater Zurich area (Kanton Zürich), including suburban and some rural areas, 65% of passenger car trips are within 10 km, and 75% are within 16 km (Hofer, 2017). In the major US metropolitan areas of San Francisco, Boston, Chicago, and Atlanta, 72-77% of passenger car trips are within 16 km (Federal Highway Administration, 2020). Despite concerns over range anxiety (Edge *et al.*, 2018), entire chains of such trips are well within the range of standard e-bike batteries, typically lasting for 50-80 km (Robert Bosch GmbH, 2023b). Intercommunal cycling “super-highways” (Rich *et al.*, 2021; Hallberg *et al.*, 2021; Pucher and Buehler, 2017) could help maximize the distances that can be covered using micro-mobility. Longer trips could leverage public transit, mainly using existing networks even if they have low density. However, the real potential, given daily activity chains, personal capabilities, and cargo loads, remains unclear. Future research is needed to show a more accurate estimate of trips that are feasible with active modes under real conditions and constraints.

Weather

In large parts of North America and Northern Europe, cold temperatures and icy streets challenge the safety and comfort of users. Rainfall and heat also reduce the attractiveness of cycling. In an E-Bike City, users would have an alternative offered by public transit services, although the travel times might be longer and the overall cost higher for such occasional trips. Nevertheless, evidence from Germany suggests that high cycling levels are associated with lower sensitivity to weather conditions. In cities with high levels of cycling, the weather-based variation in bicycle counts during morning peak hours is under 5% (Goldmann and Wessel, 2021). To reduce the weather sensitivity further, E-Bike Cities could incorporate existing biodiversity efforts connecting green spaces (Kong *et al.*, 2010; Parker *et al.*, 2008) to create a primary network of cycling streets where greenery protects against rain and heat. Finally, a lasting increase in working from home could imply more flexibility in deciding when to travel, shifting travel demand to times with better weather conditions. To gain a fuller understanding of these effects, future research should explore the demand variations closer and show how they impact the usage of alternatives like public transit. If many cyclists turn to transit on rainy and cold days, research should show possible ways of operating rail and buses under such conditions.

User capabilities

Bicycle usage is limited by personal capabilities, e.g., leading to substantially lower speeds for the elderly (Schleinitz *et al.*, 2017). However, electrification helps even less able-bodied groups to stay mobile (Leger *et al.*, 2019; Meyer de Freitas and Axhausen, 2023b). The wide range of available micro-mobility vehicles and safe infrastructure could help people with disabilities to move independently. On the other hand, electric micro-mobility vehicles of different sizes, weights, and speeds present a challenge for infrastructure design, requiring new approaches and quality measures (Kazemzadeh and Ronchi, 2022). While higher speeds may lead to more dangerous behavior (Vlakveld *et al.*, 2021), users of electric vehicles still seem to violate traffic rules no more often than those with non-electric vehicles (Langford *et al.*, 2015), and the overall safety of e-bike users appears to be similar to those using conventional bicycles (Jenkins *et al.*, 2022). Given the wide variety of electric and human-powered vehicles needed to make active mobility a primary mode of transport, future research should show what infrastructure will be needed, how it can be integrated into existing streets, and how it performs compared to traditional car-based transport systems.

Parking

Large quantities of (electric) micro-mobility vehicles of different sizes would require parking facilities, and the high value of e-bikes and cargo bikes creates a need for weather and theft protection. In cases where micro-mobility replaces car trips, parking can be provided by reallocating existing car parking spaces. However, if cycling replaces short transit trips, additional space for bicycle parking may be needed, particularly at central locations.

Studies of travel behavior in E-Bike Cities should clarify the number and type of bicycle parking spots needed.

Charging

The batteries of private e-bikes will put some additional load on the power grid, but even a massive usage is unlikely to create relevant challenges. Typical e-bike chargers, with a power rating of 0.1-0.3 kW (Robert Bosch GmbH, 2023a), correspond to roughly one to five incandescent light bulbs, which were in wide use until the early 2000s. This is in sharp contrast to standard home chargers for BEV, which have a power rating of up to 11.5 kW (Tesla, 2021) and 250 kW in the case of "superchargers" (Tesla, 2023). A typical e-bike battery has a capacity of 0.5-0.75 kWh (Robert Bosch GmbH, 2023b) – less than 1% of a Tesla Model S battery with up to 100 kWh (EV Database, 2023). The power consumption of a typical e-bike is approximately 0.01 kWh/km, over 90% less compared to the Tesla Model S (EV Database, 2023). Nevertheless, issues of power consumption, potentials of power storage, as well as lifecycle emissions remain a concern. Future research should deepen our understanding of these aspects in an E-Bike City, especially compared to other urban mobility futures.

	City residents		Suburban commuters	
	(1) without car	(2) with car	(3) without car	(4) with car
(H) High-density city with attractive public transit	**H1** + → + + (gain)	**H2** + + + → + + (loss)	**H3** - → o (gain)	**H4** + → o (loss)
(L) Low-density city with unattractive public transit	**L1** - → + (large gain)	**L2** + + → + (loss)	**L3** - - - → - - (gain)	**L4** o → - (loss)

Accessibility scale:

+ + +	Highest
+ +	Excellent
+	Good
o	Fair
-	Poor
- -	Bad
- - -	Lowest

Table 2.1: Eight combinations of urban typology and population groups, together with a conceptual estimate of what accessibility changes they would experience (accessibility before → after)

Vehicle availability

In an E-Bike City, small micro-mobility vehicles are a crucial enabler for an achievable transition to sustainable urban mobility. But despite their growing popularity, their mass adoption faces an uptake barrier of purchase prices that are not affordable for some population groups (Jones *et al.*, 2016; Jenkins *et al.*, 2022). The E-Bike City may need to leverage large-scale sharing schemes to give everyone access to the vehicle they need. Even though shared vehicles are associated with higher lifecycle GHG emissions (Reck *et al.*, 2022), they may be crucial for low-income groups or could enable flexible trip chaining with public transit.

2.4 Accessibility effects

Changes in accessibility geographies

Accessibility refers to the possibility of reaching destinations from a particular place (Hansen, 1959) and is a crucial metric for transport and land use. Literature on equity suggests that transport systems should be designed to follow desired accessibility structures rather than aim for free-flowing traffic (Van Wee, 2011; Martens, 2016). However, accessibility is a complex measure. Depending on the question analyzed, components like travel time, comfort, or time-dependent opening hours of the different activities may be considered. In reality, each person's accessibility is also influenced by individual preferences and capabilities like vehicle and license ownership, bodily fitness, or time constraints. Therefore, accessibility has no single definition but needs to be tailored to each analysis. Here, we focus on the accessibility components of travel time and cyclists' comfort.

The reallocation of road space in the E-Bike City would substantially change the accessibility for cyclists and drivers. While drivers would experience longer travel times and detours due to reduced road capacity, reduced speeds, and one-way streets, cyclists would enjoy increased comfort while using the dedicated infrastructure. The resulting accessibility difference would result in mode shifts.

However, capabilities and preferences for changing modes vary across user groups. Depending on their degree of physical fitness or level of education, some users might be less inclined to switch to cycling, even with competitive travel times and better safety (Hudde, 2022; Meyer de Freitas and Axhausen, 2023b). Also, the actual accessibility gains in cycling and public transit might not compensate for the travel time losses incurred by those currently driving. In particular, longer trips from outside of the city might be less attractive using transit and micro-mobility. On the other hand, some groups benefit from massively improved accessibility and independence once cycling becomes safer.

Table 2.1 shows estimated conceptual relationships of accessibility impacts on different user groups. We distinguish two types of urban settings representing simplified examples from industrialized nations: Cities with high density and strong public transit, and cities with low density and less attractive public transit. Within each city type, we consider city residents and suburban commuters, both with and without a car, all resulting in a 2x4 matrix of cases. The conceptual relationships are strongly simplified, representing the average situation of the exemplary groups, without considering cases under exceptional circumstances, such as cities where driving is already restricted to a minimum while allowing safe cycling. The following paragraph uses terminology from the scale below the table to describe the different levels of accessibility.

In dense cities with attractive public transit, urban residents without cars (H1) currently have "good" accessibility, greater than car-free residents in the suburbs, but less than their urban counterparts with cars. In an E-Bike City, their accessibility would increase through safer and faster cycling alternatives for shorter trips. On the other hand, those owning a car and enjoying the highest accessibility levels would experience longer travel times. Although the attractiveness of cycling would increase for this group as well, switching to cycling and transit would still likely result in slightly less accessibility for this group. Suburban commuters without a car (H3) currently have "poor" accessibility, less than all other groups. The E-Bike City's transit, optimized for fast travel across longer distances and safer last-mile cycling within the city, would increase their accessibility. Those with a car presently have substantially higher accessibility (H4) and would incur losses similar to group H2, reaching accessibility equivalent to their neighbors without a car.

In cities with low density and less attractive public transit, those without a car (L1) currently experience substantially lower levels of accessibility than their counterparts in high-density cities. In an E-Bike City, they would enjoy substantial gains due to attractive cycling and faster transit. On the other hand, those with a car (L2) would experience a loss, resulting in accessibility levels similar to those without a car. Suburban commuters without a car (L3), who currently experience the lowest accessibility among all groups, would experience gains similar to their counterparts in high-density cities, but their accessibility would remain "bad". Those with a car (L4), on the other hand, would incur longer travel times, but driving would likely still provide them better accessibility in comparison to the previous group.

Overall, the groups already using sustainable modes of transport would gain accessibility, while those driving would lose some. Large gains would be experienced by residents living in low-density cities without a car, possibly correlating with low-income communities. However, the exact losses for car owners might vary strongly depending on how the future conception of transit systems provides alternative travel options over longer distances. Also, those switching from driving to cycling might experience additional losses due to discomfort. Further research is needed to better understand the expected changes in accessibility structures and how they correlate with existing lines of division in society.

Distributive justice and equity

The previous section outlined the conceptually expected accessibility changes and introduced a set of questions to be explored in future research. This section focuses on possible implications for distributive justice and social equity.

The Production of Space (Lefebvre, 1991) calls for a definition of space through social relations rather than its physical characteristics. Along these lines, a city is a place of social exchange to which every person should be entitled; see also The Right to the City (Lefebvre, 1972). Theories of transport justice frame this right through the concept of accessibility, combined with theories from political philosophy. According to Spheres of Justice (Walzer, 1983), some goods should be excluded from a free exchange due to their special meaning in society. Applying Lefebvre's point, social interaction is one such good. The Capability Approach (Sen, 2009) identifies the mere possibility of accessing destinations as essential, regardless of whether they are reached. The Difference Principle (Rawls, 1999) marks the importance of redistributing resources to those who are worst off (such as those with low accessibility). And finally, the theory of "auctions and insurance schemes" in (Dworkin, 2000) justifies partial compensations for those incurring unjust accessibility deficits.

Building on these theories, Pereira *et al.* (2017) propose that distributive justice concerns over transport and social exclusion should primarily address accessibility as a human capability. Following this argument, the social equity of transport policies is mainly a question of groups experiencing the lowest accessibility to key locations. Transport Justice (Martens, 2016) introduces an analytical method of evaluating the social equity of real transport-land use systems. In Martens's view, transport planning must aim to provide every population group with at least a basic level of accessibility above a sufficiency threshold. In contrast to these accessibility-centric theories, Gössling *et al.* (2016) adopts a wider view of transport injustices in three dimensions: exposure to traffic risks and pollutants, distribution of space, and the valuation of travel time. He concludes that pedestrians and cyclists are the most sustainable participants in urban contexts, yet are particularly often affected by the negative effects of motorized traffic, which is a clear case of injustice.

Taking the perspective of Gössling *et al.* (2016), the E-Bike City would mitigate the injustices in today's Western cities: It would reduce the pollution faced by cyclists and pedestrians and improve their safety. From the perspective of transport justice, it would reduce the accessibility disadvantage typically experienced by people who don't have access to cars. A notable instance of the E-Bike City improving the lowest accessibility levels would be the effects on car-free residents in low-density cities and suburban areas.

However, while reducing the injustice faced by some groups, the E-Bike City might also exacerbate the disadvantage of other people. Especially where living costs in dense urban areas are not affordable and property ownership is increasingly determined by inheritance (Adkins and Konings, 2020), underprivileged groups could face inequitable car dependency due to their involuntary choice of residential location. Reducing road capacity in favor of cyclists might deepen their inequitable disadvantages unless balanced in other ways.

The anticipated changes in accessibility structures could also challenge the relationship between urban and rural communities. While the former would benefit from fewer negative externalities from motorized traffic, the latter would face higher generalized costs on their trips into the city. Although such changes would correct existing injustices in terms of Gössling *et al.* (2016), their distributive effects might create substantial controversies over different groups' "right to the city".

In summary, the E-Bike City could help weaken existing injustices between different population groups and their modes of transport. It could also benefit those groups experiencing the lowest accessibility because of no car ownership. However, its pure form in existing car-centric cities might increase injustices based on involuntary residential location choice and increase tensions between urban and rural communities unless addressed. To explore the feasibility and effects of an E-Bike City, further research is needed to understand its impacts on transport justice, given the existing spatial structure, social networks, and market conditions in real cities.

2.5 Getting there: Equitable and desirable?

Transitioning to a more sustainable transportation system is crucial for mitigating climate change. However, getting there in existing car-centric cities poses considerable challenges. In addition to improving sustainability, the proposed transition must avoid creating new injustices and be capable of gaining political acceptance. This section discusses a series of further issues that may be crucial to acquiring democratic acceptance of E-Bike Cities and implementing them.

The E-Bike City would favor those already using sustainable modes while producing losses for those presently driving. Designing proposals for real cities must involve tools for a precise understanding of the expected changes in accessibility patterns, how they relate to different population groups, and perhaps even to voting districts. Fine-tuning the exact road space allocation, changing public transit services, or adjusting the boundaries of areas where the transformation should be applied might play a key role in developing a proposal that is desirable for the majority.

The radical character of the proposal might also trigger fears of change. It might spur anxieties about the need for (unwanted) reorganization of everyday behaviors and changes in real-estate values (Liu and Shi, 2017; McDougall and Doucet, 2022). To address these concerns, the E-Bike City must emphasize its core vision and provide a locally embedded taste of it. Also, it must be transparent about the expected effects. Akin to Wright and Le Corbusier, the concept must be presented "not in dry formulas, but through three-dimensional models" (Fishman, 1982), creating strong positive images that will shape the planning process and the public discussion. As put by Banister (2005), sustainability policies must build on high levels of information, empowerment, and consistent policy direction to reach the required acceptance and impact.

2.6 Conclusion

Making urban mobility sustainable will demand a deep rethinking of transport policies, far beyond relying solely on technical progress. Behavior changes toward sustainable mode choices are an inevitable part of realistic pathways for addressing the climate crisis. The E-Bike City proposed in this think piece is intended to provoke a discussion about new directions for policymaking and inspire supporting research. It is meant to provide a taste of a sustainable mobility future, serving as a conceptual anchor for future work. Like Le Corbusier's and Wright's visions from the early 20th century, or the more recent 15-Minute Cities and Superblocks, the E-Bike City is designed to motivate scholars, policymakers, and the public to work toward a sustainable, equitable, and desirable urban future.

3. Effects of an E-Bike City

Lucas Meyer de Freitas, Marco Miotti and David Zani

Abstract An E-Bike City massively shifts demand away from cars, but not only to bicycles, but also mainly towards public transport. This results in a substantial reduction of CO_2 emissions. At the same time, the transport system's external effects for society become positive, instead of negative, mostly due to the use of more sustainable modes and the greater benefits of physical activity.

To understand the effects of an E-Bike City, a two-stage survey was carried out to understand the mode-choices of individuals in such a scenario. This survey was the basis for the calculation of the mode-shifts expected in an E-Bike city and the evaluation of its effects for the environment and society. More details about this survey and the mode-shift potentials of different groups is presented in chapter 12. The survey results were then implemented in an agent-based transport simulation of a study area consisting of the city of Zurich as well as all municipalities where at least 10% of its population commutes to Zurich (Figure 3.1). This large study area ensures that the majority of trips and the full effects of an E-Bike city implementation in the city of Zurich are considered. For the evaluation we assumed that the E-Bike city would be implemented today and considered a 50-year evaluation period.

The reduction in road space for cars resulted in a substantial increase in travel times for car trips with origin or destination in the city of Zurich. During the morning and evening peak hours, car travel times increased by 80%. This increase in travel times by car is a main factor pushing drivers away from their cars towards other modes. Figure 3.2 shows the changes in mode-choice that result from a potential implementation of the E-bike city proposal. Most of the reduced car trips shift towards public transport. At the same time, in percentual terms, bike modes are the ones that increase their shares the most, with conventional Bikes and slow E-Bikes (25 km/h) roughly quadrupling their demand. It is therefore assumed that e-bikes and s-pedelec ownership would increase accordingly. The overall cycling demand of 17.5% is almost double of the share of cycling person-kilometers (pkm) in The Netherlands of 9% (Statistics Netherlands, 2016).

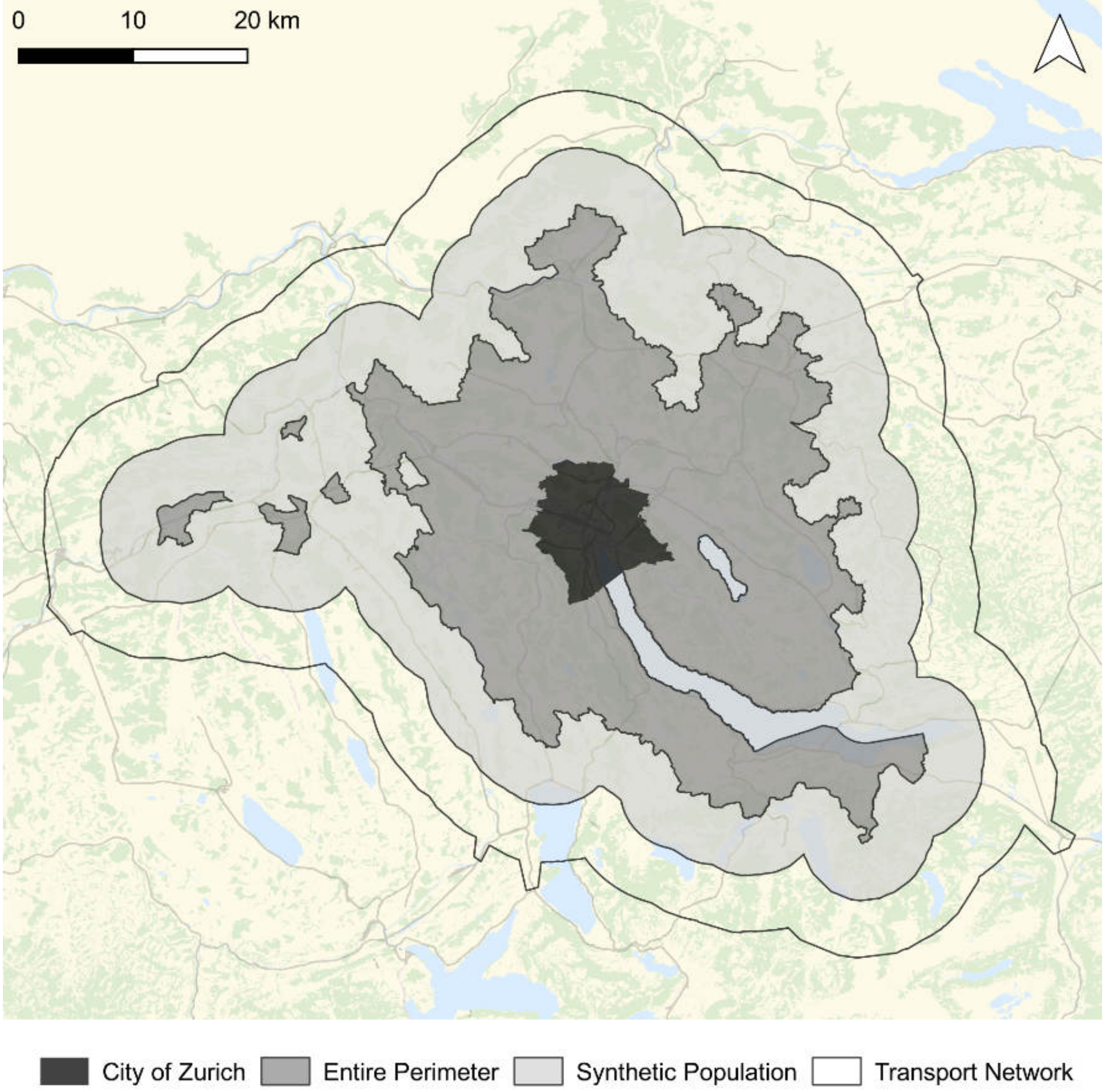

Figure 3.1: Study area: All trips within the perimeter are considered. E-Bike City implementation only within the city of Zurich.

This massive mode-shift has two main effects: A reduction in the emissions of the transport system in the study area of ca. 1’250’000 t CO_2 over 50 years (Figure 3.3), amounting to an emissions reduction of ca. 45% for the passenger transport system. At the same time, the external cost of the transport system, that is, its effects on health, the environment, accidents and noise, shows a major turn: from external costs of ca. -0.5 bn CHF over the 50 years’ study period, up to +1.0 bn CHF (Figure 3.3). Effectively, this means that our mobility would end up having positive instead of negative external effects for society. The positive upturn arises mostly due the increased cycling rates and public transport usage. At a trip level, cycling and e-bikes have positive external costs of 36 and 28 CHF-cents/km, respectively. At the same time walking has a positive effect of 95 CHF-cents/km while public transport’s external cost varies greatly, from -20 CHF-cents/pkm for buses to -3 for trams and -1 CHF-cents/pkm for rail. These low externalities of electric rail based public transport associated with the high positive externalities of walking result in the fact that trips with distances of up to ca. 12km end up having positive net externalities (Figure 3.4). The externality values are all based on the official Swiss external costs of transport (Ecoplan and INFRAS, 2024).

This turn in the sign of the external costs of transport shows that, based on today's monetary values associated to the externalities of the transport system, the health benefits of cycling and walking would outweigh the negative effects of the emissions and externalities caused in the transport system. More details on the externalities are presented in chapter 12.

Besides the external costs of the transport system, the full cost-benefit analysis (CBA), also requires information on the costs of implementing the E-Bike City as well as the consumer surplus, that is, the individual next to the societal (dis-)benefits of transport. While externalities evaluate the costs of travel carried by society as a whole, the consumer surplus shows the cost of travel carried by travelers. We calculated the cost-benefit effects based on two different methodologies: The current Swiss cost-benefit analysis norm (Ecoplan and Metron, 2005) as well as on the Logsum method (de Jong *et al.*, 2007).

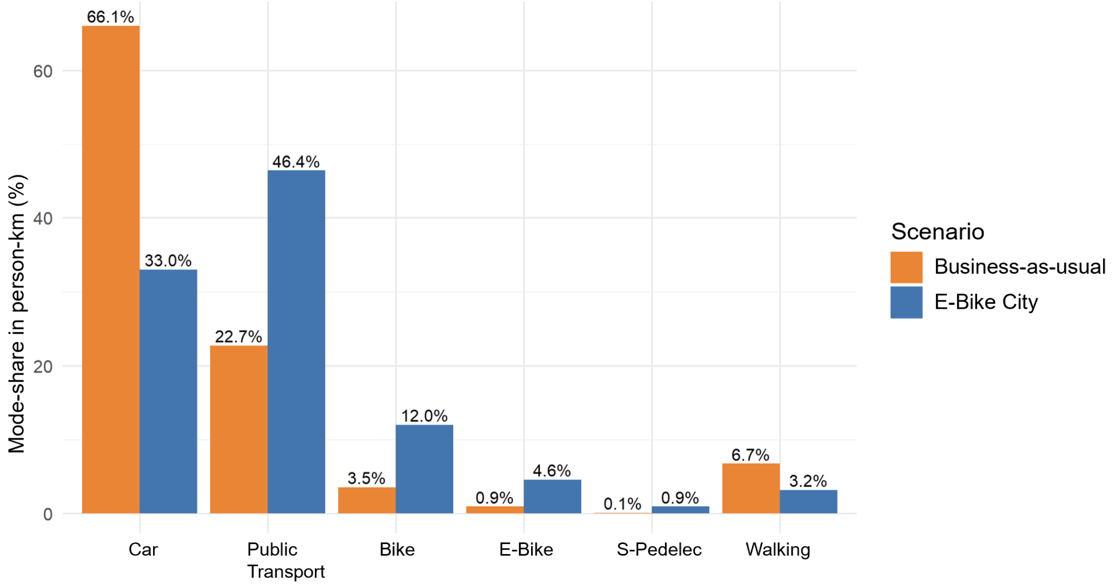

Figure 3.2: Mode-choice in a E-Bike City: Results for all trips within the study area.

The reason for doing so is the fact that the Swiss cost-benefit analysis, as well as the majority of transport cost-benefit norms and practices around the world, bases the consumer surplus solely in terms of travel time savings and direct monetary costs of travel while, most importantly, it only considers benefits resulting from the the use of individual motorized modes (car, motorcycles) and public transport. That such a norm is not well suited to evaluate a project with a cycling focus is evident. Nonetheless, we compare its results to the more integrated and complete method for computing consumer surplus: the Logsum method. The advantage of this method is that it accounts for all transport modes in the one hand, while it also for the full (dis-)benefits associated with each mode.

Table 3.1 shows the results of the CBA for both methods. If the project were to be evaluated using the current VSS norm, the consumer surplus would be ca. 7.5 times lower than when using the Logsum method. This massive difference arises mostly because when applying this norm, the effect of so many car trips switching to other modes has a negative outcome. At the same time, the benefits of travel by public transport has a lower monetary value and cycling is not even accounted for. When all modes are considered (Logsum), the effect is still negative, an outcome of car travel times increasing considerably. Still, the consumer surplus and externality values are substantially higher than the cost of implementing an E-bike city (more details on the cost estimation in chapter 13). The CBA calculation considers the forecasted population increase and demographic change up to 2050 and a discount rate of 2% as in the VSS CBA norm.

	VSS Norm	Logsum
Costs (CHF)	-0.36 bn	-0.36 bn
Consumer surplus (CHF)	-75.19 bn	-10.22 bn
Externalities (CHF)	-10.22 bn	-10.22 bn
Total NPV (CHF)	**-26.87 bn**	**+38.10 bn**

Table 3.1: Cost-benefit analysis results in net present values (NPV). The shown values are differences to the do-nothing scenario.

The results show the massive socioeconomic benefits that can arise from a transport policy aimed at shifting transport demand away from cars in favor of cycling and public transport. While the demand for cycling could increase substantially to levels above those observed in The Netherlands, they also show that public transport would need to cope with a doubling of demand. How public transport can deal with this increased demand is discussed in chapter 6. Nonetheless, the benefits that can potentially arise are nothing less than transformative for society. Less noise, pollution, and healthier lives are the direct results for inhabitants in and around Zurich, while the near halving of CO_2 emissions would be a substantial contribution to respond to the climate crisis. The true benefits are expected to be even larger, as the evaluation methods used solely focus on the transport system itself. More space for greenery and gained urban space for different activities, increasing livability are further positive outcomes of an E-bike City which provide even further benefits for society.

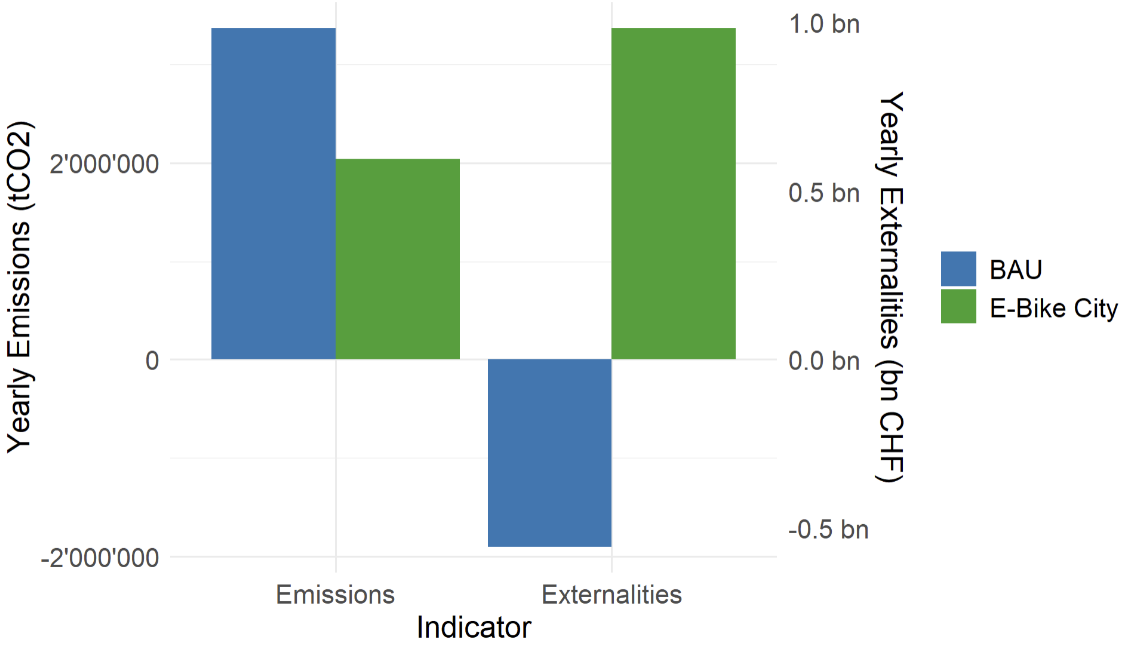

Figure 3.3: Yearly CO_2 emissions and externalities of the (passenger) transport system before and after an E-Bike City.

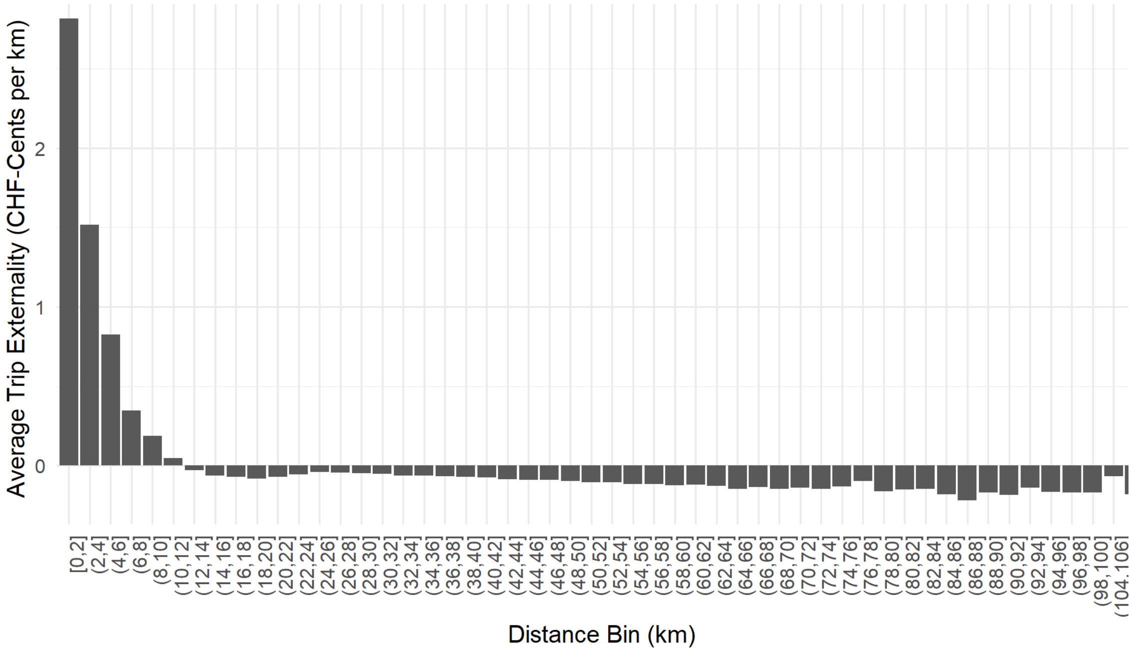

Figure 3.4: Public-transport average trip externalities in the study area by distance.

Guidelines

4. Street network manipulator tool

Lukas Ballo, Martin Raubal and Kay W. Axhausen

Abstract The E-Bike City concept proposes dedicating roughly 50% of road space to small vehicles like e-bikes. In dense cities like Zurich, this requires a complete reorganization of traffic networks rather than incremental changes. We present SNMan (Street Network Manipulator), a tool that automatically redesigns street networks within existing road constraints, ensuring building access, public transport operations, and a minimum supply of on-street parking. Using graph theory and heuristics, the method minimizes detours while maintaining connectivity, offering a scalable approach for sustainable city transformations and future urban master planning.

The E-Bike City idea (Ballo, 2023a; Axhausen, 2022) proposes to dedicate roughly 50% of road space to infrastructure for small vehicles like e-bikes and bicycles. Past studies e.g., Szell *et al.* (2022); Steinacker *et al.* (2022); Paulsen and Rich (2023) have introduced multiple approaches for designing optimal cycling networks in existing cities. However, while mostly focusing on detours and construction costs, they neglect the availability of road space that is necessary for implementing the new cycling infrastructure.

In dense cities with severely limited road space, like Zurich, cycling infrastructure cannot be simply added, nor are such changes possible on a street-by-street basis. Only by changing the organization of traffic across the entire network can we obtain the space needed for the cycling paths. For instance, by converting streets to one-way traffic and by limiting car access to residential streets, a large part of the existing road space becomes available for such new uses.

However, during the design process, it must be ensured that the resulting transportation network remains consistent: The resulting one-way streets must provide access to every building (within a reasonable walking distance), the network if individual travel lanes must remain connected, and the existing public transport services must be able to operate along the same routes and without reductions of dedicated bus and tram lanes. Finally, the access to buildings must be complemented with a minimum supply of on-street parking.

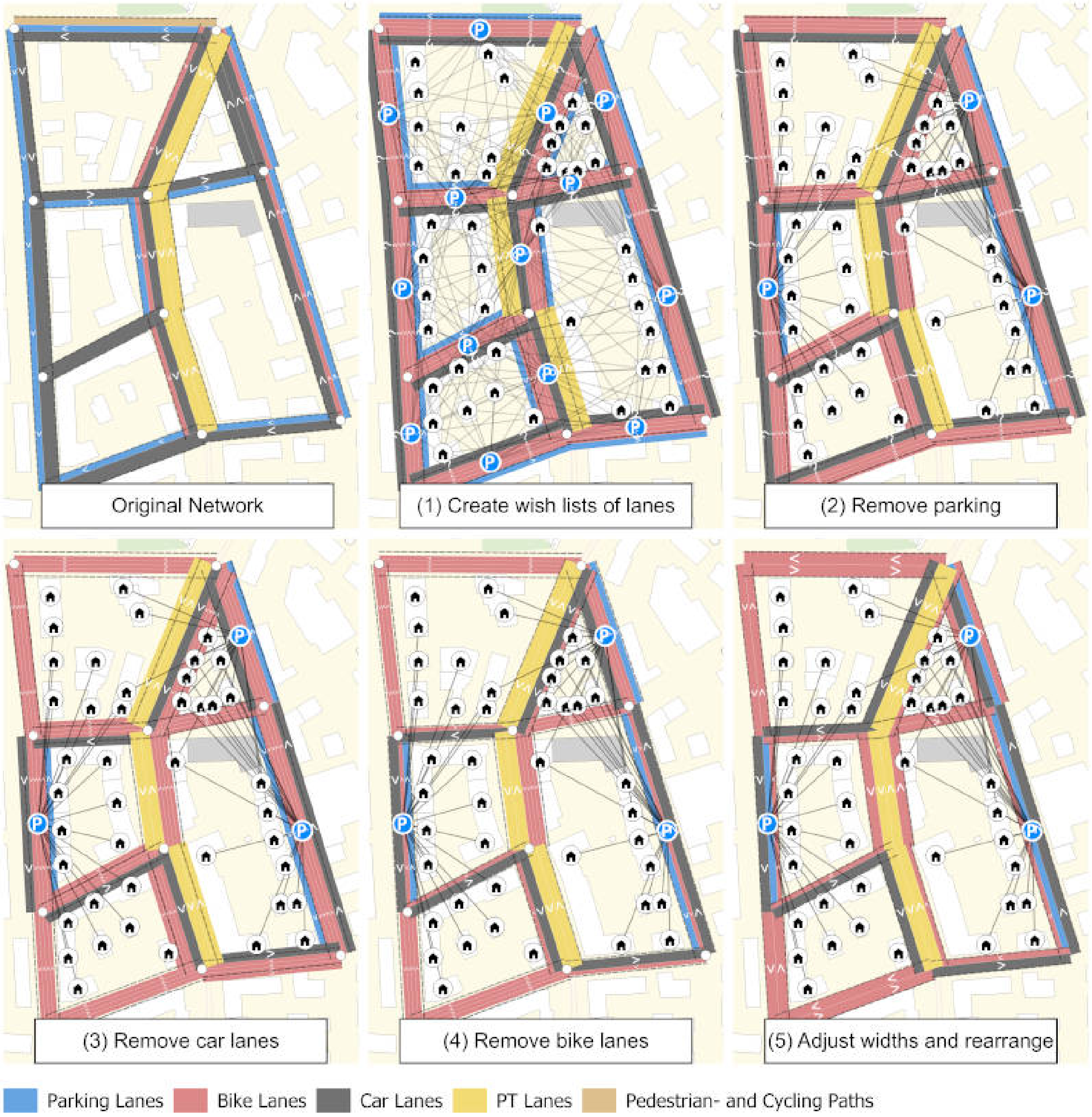

Figure 4.1: Network design steps

To facilitate the design process, we have developed the SNMan (Street Network Manipulator[1]) software, which can automatically generate alternative transportation networks within existing road space. It can consider user-defined constraints such as the ones mentioned above. By using globally available open geodata, it can be applied to almost any city in the world. Locally specific datasets, such as precise information about population, jobs, exact street widths, parking, and public transport, can be applied optionally to enhance the accuracy and level of detail.

The following outlines a simplified representation of the design process (see 4.1 for an illustration):

1. Creating a digital twin of the existing network and road space allocation, including the available road widths

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[1] https://github.com/lukasballo/snman

2. For every street, creating a wish list of lanes typically exceeds the available road width
3. Successively removing on-street parking as long as the minimum provision for every building is met
4. Successively removing travel lanes with the lowest betweenness centrality while maintaining connectivity
5. Removing excessive cycling infrastructure, while maintaining practical constraints, e.g., priority for bike lanes in the upward direction on grades
6. Consolidating and rearranging lanes in cross-sections

The present design process is based on graph theory and heuristics that minimize the resulting detours using betweenness centrality. See the original research paper (Ballo *et al.*, 2024) for more details on the process. A recent extension (Wiedemann *et al.*, 2025) allows the usage of mathematical optimization for distributing cycling infrastructure according to a more comprehensive and flexible objective function.

The process presented in this work can be used for designing schemes of sustainable transformation in existing cities, as well as for creating master plans of future ones. The resulting networks can have a wide range of uses, including bike lanes, greenery, on-street parking, or additional pedestrian infrastructure. The design process can be applied at any scale, ranging from a few blocks to entire cities, including complex hierarchies of roads.

5. Street design guidelines

Lukas Ballo and Matias Cardoso

Abstract Municipal planning authorities seeking to implement the principles of the E-Bike City can refer to this manual for standardized design guidelines. Its structure is aligned with norms issued by the Swiss Association of Road and Transport Officials, *Verband der Strassen- und Verkehrsfachleute* (VSS).

5.1 Purpose

This manual facilitates the transition from existing urban street designs to those in an E-Bike City. The concept was developed as a strategy to address urban mobility challenges by restructuring transport systems around sustainable travel modes (Ballo, 2023a; Ballo *et al.*, 2024).

5.2 Scope

This manual provides complete design specifications for typical streets and intersections in Swiss cities (based on Zurich), following the principles of the E-Bike City concept. It is inspired by elements in the existing design standards and guidelines (ASTRA, 2022; Kanton Zürich, 2023; Stadt Zürich, 2024; NACTO, 2025; CROW, 2016) and demonstrates how they can be integrated to create a cohesive and functional cycling network.

5.3 Usage

This design manual provides guidance for the physical implementations of the network design for an E-Bike City. Tables 5.1 and 5.2 show overviews of the standard design solutions provided for different types of streets and intersections.

5.4 Parking

Under conditions of limited road space, prioritizing cycling and other small-scale modes of transport necessitates a substantial reorganization of on-street motor vehicle parking. However, access to buildings must remain guaranteed through the provision of short-term parking spaces within walking distance from all destinations.

Type	Function	Dir.	Tram	Parking	Status quo	Archetypes Separated one-way cycling paths	 Separated two-way cycling paths	 Cycling street
R1	Res. Str.	→	No	Yes	R1-Base	R1-A2, R1-A3	R1-A4	R1-A1
R2	Res. Str.	↔	No	No	R2-Base	-	-	R2-A1
R3	Res. Str.	→	No	Yes	R3-Base	R3-A2	-	R3-A1
S1	Sec. Str.	↔	No	No	S1-Base	S1-A1	S1-A3	S1-A2
S2	Sec. Str.	↔	Yes	No	S2-Base	S2-A2*	S2-A1	-
P1	Prim. Str.	↔	Yes	No	P1-Base	P1-A1	P1-A2	-
P2	Prim. Str.	↔	No	No	P2-Base	P2-A1, P2-A2, P2-A4	P2-A3	-

* With partially removing the separation of public transport

Table 5.1: Overview of standard design solutions for streets

		Major street R1-Base	 R1-A3	 S2-Base	 S2-A1	 S2-A2	 P1-Base	 P1-A1	 P1-A2
Minor Street	R1-Base	RR-Base	-	-	-	-	PR-Base	-	-
	R1-A1	-	RR-A1	-	-	-	-	-	PR-A1
	R1-A4	-	-	-	-	-	-	PR-A2	-
	R3-Base	-	-	SR-Base	-	-	-	-	-
	R3-A1	-	-	-	SR-A3	SR-A1, SR-A2	-	-	-
	S1-Base	-	-	-	-	-	PS-Base	-	-
	S1-A1	-	-	-	-	-	-	PS-A2	PS-A1

Table 5.2: Overview of standard design solutions for intersections

<table>
<tr><th rowspan="2">Archetype</th><th colspan="2">Minimum</th><th colspan="2">Desirable</th></tr>
<tr><th>Width</th><th>Passing scenario*</th><th>Width</th><th>Passing scenario*</th></tr>
<tr><td>One-way cycling lanes/paths</td><td>1.6m</td><td>C</td><td>4.25m</td><td>CB ¦ C</td></tr>
<tr><td>Two-way cycling paths</td><td>3.2m</td><td>C | C</td><td>7.1m</td><td>CB ¦ C | CB</td></tr>
<tr><td>Cycling streets</td><td>4.6m</td><td>C | M</td><td>5.65-6.5m[†]</td><td>CB | M</td></tr>
</table>

*B: Bicycle (1.25m), C: Cargo bike/trailer (1.6m), M: Motorized vehicle - delivery van (3.0m), ¦: Overtaking, |: Opposite directions

[†] Maximum width to avoid high speeds of motorized traffic

Table 5.3: Minimum and desirable widths

On-street parking for motor vehicles will be typically concentrated on some streets, where a portion of the roadway width will be allocated for parking spots. Other streets will be kept free of on-street parking, allowing an uninterrupted cycling infrastructure.

In contrast, bicycle parking will be distributed in small clusters along all streets to provide easy access. These facilities will be located along building facades or as part of a physical separation between different transportation modes. Large bicycle parking hubs at major activity centers require separate site-specific planning and are not covered in this design guide.

5.5 Dimensions

The recommended widths of cycling infrastructure elements are based on clearance profiles in the VSS 40201 norm VSS (2019), illustrated in Figure 5.1. They consist of three components: (1) Base dimensions, (2) Dynamic movement margin, and (3) Safety margin. In the case of cyclists riding side by side, the safety margin between them is applied only once. For motorized vehicles, a unified width of 3 meters is assumed which is sufficient for cars, delivery vans, and light trucks.

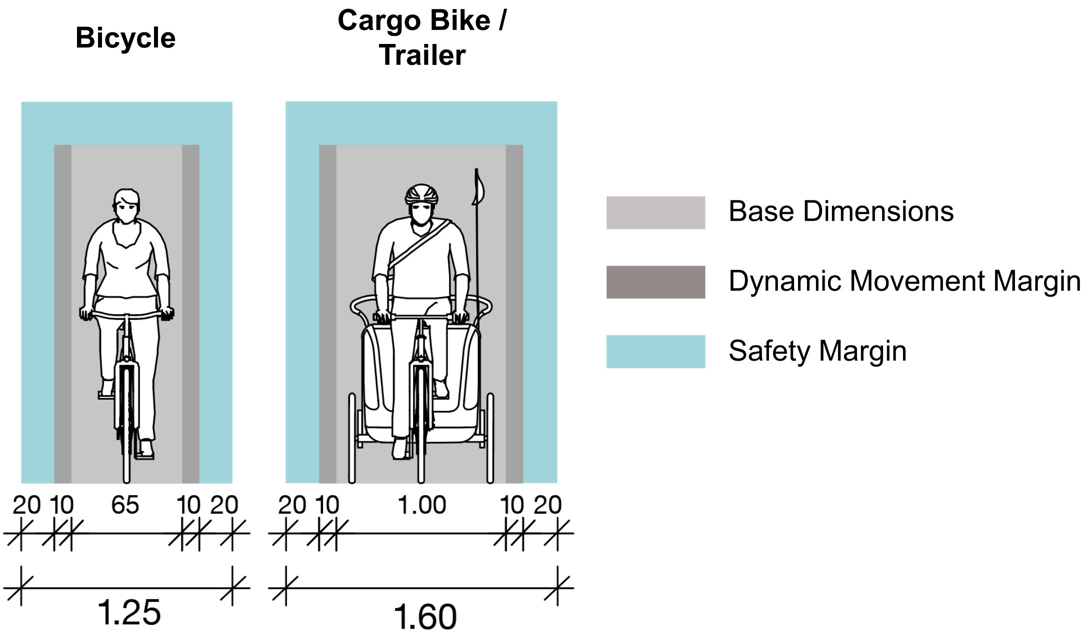


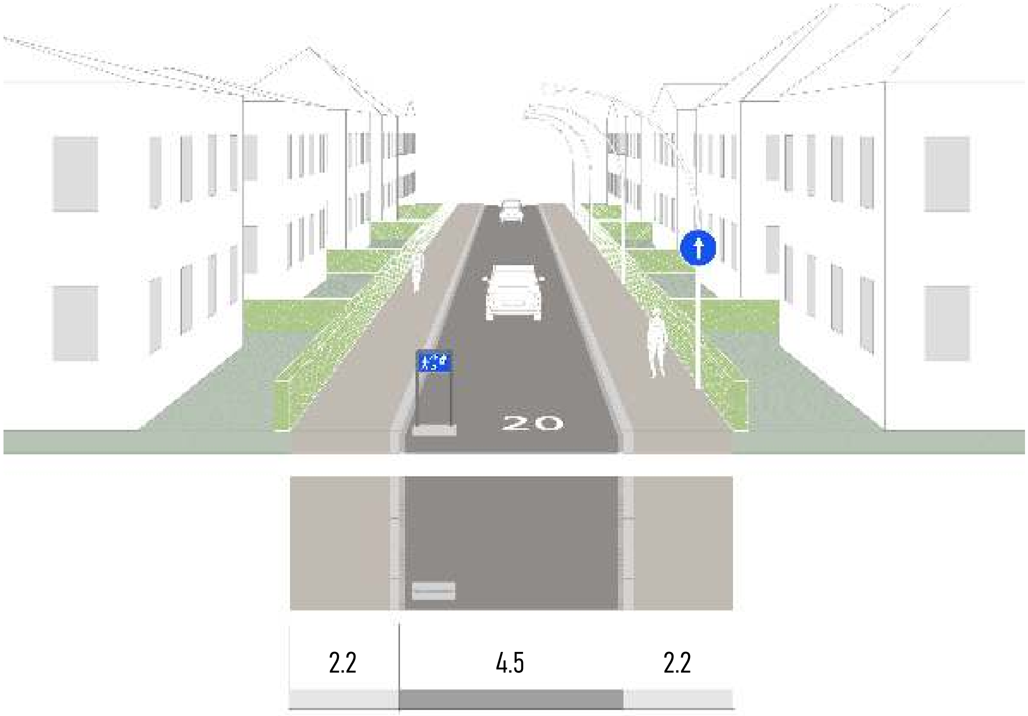
Figure 5.1: Clearance profiles of cyclists. Adapted from Kanton Zürich (2023).

5.6 Standard designs for streets

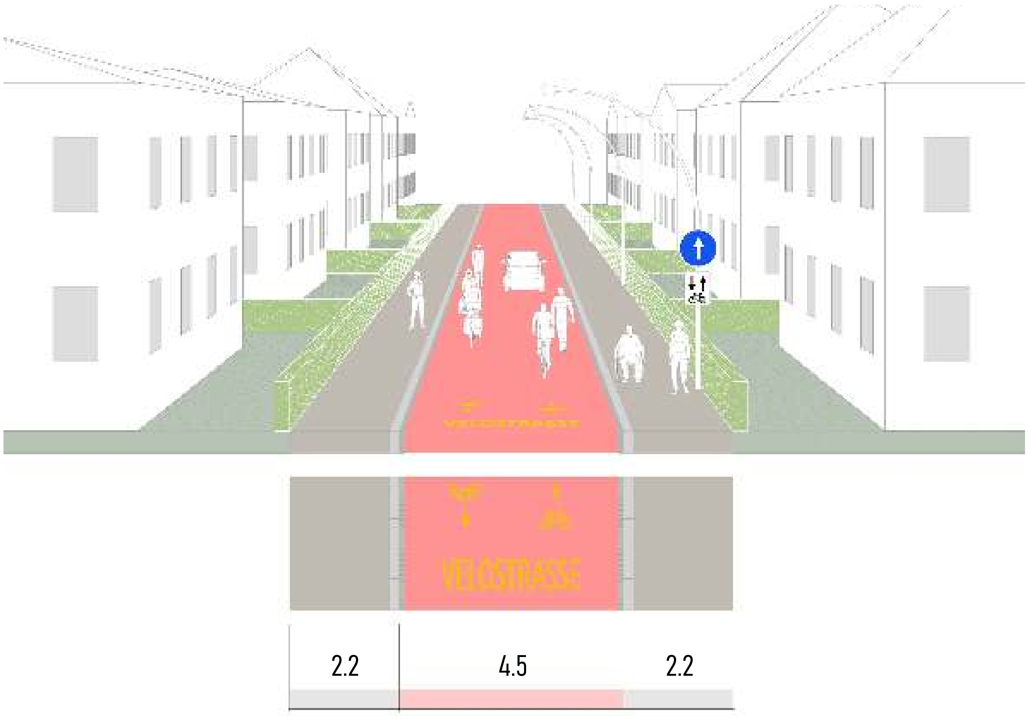
This section shows standard design solutions for combinations of street type and design archetype. The dimensions are based on typical situations in Zurich and are in meters. For general recommendations on minimal and desired dimensions, please refer to table 5.1.

R2: Residential street, two-way, without parking

R2-Base: Mixed traffic (status quo)

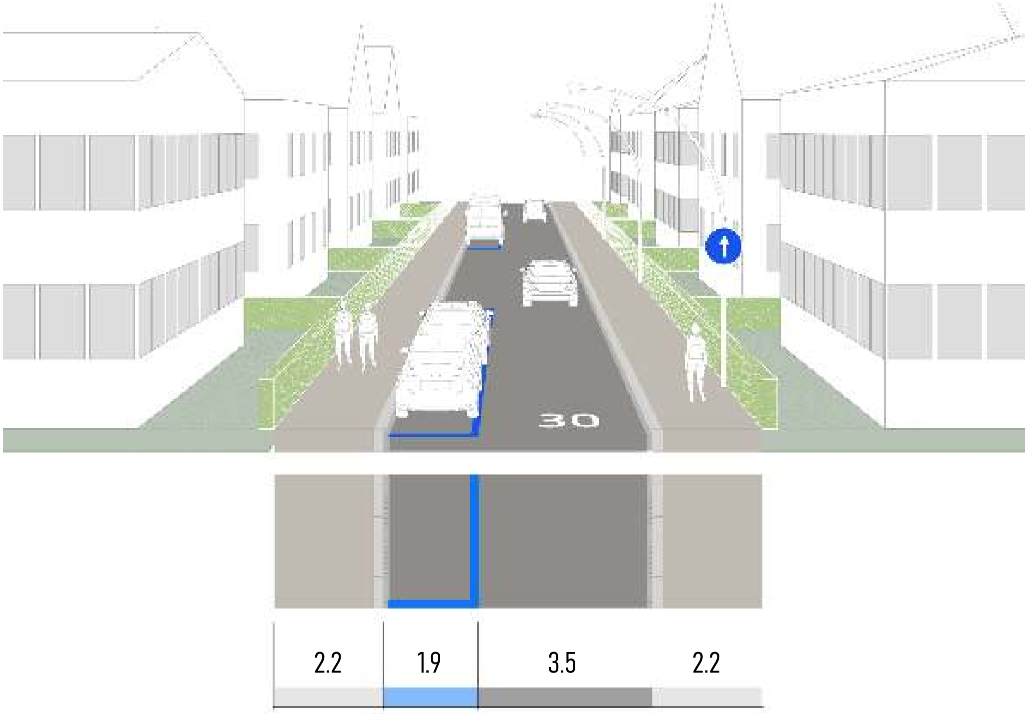


R2-A1: Cycling street

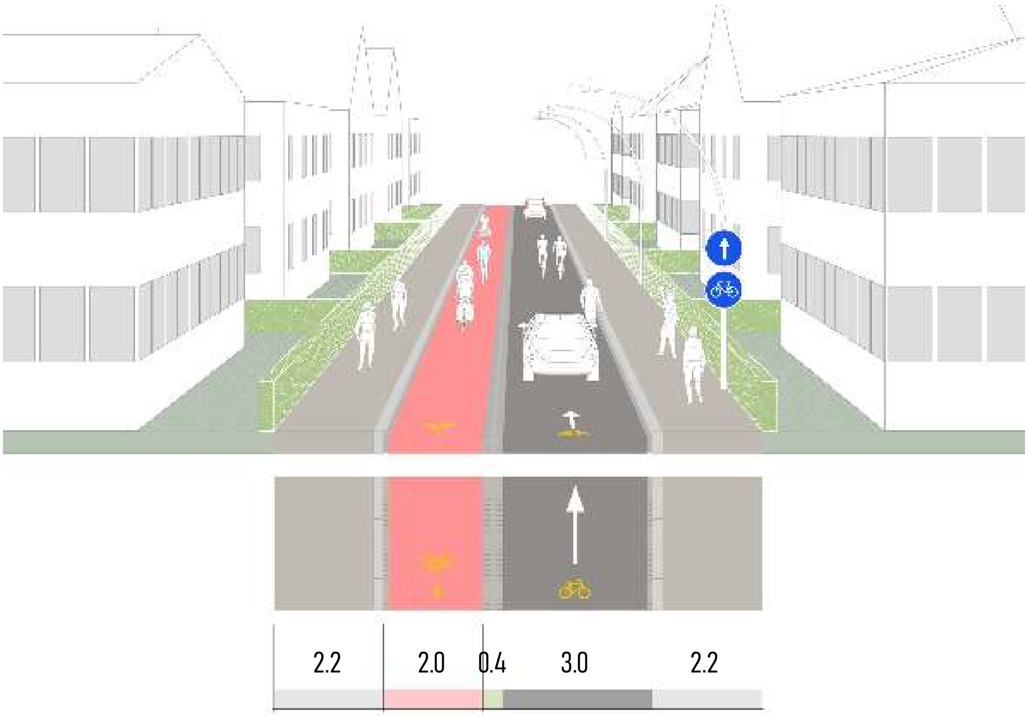


R3: Residential street, one way, with parking

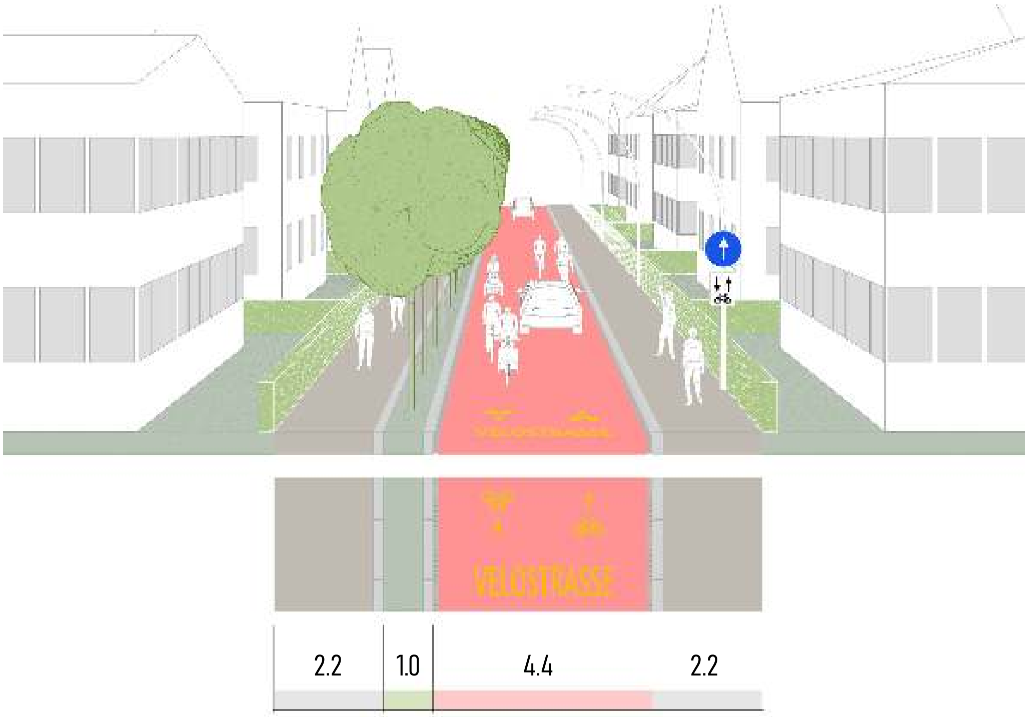
R3-Base: One-way mixed traffic with parking (status quo)



R3-A2: One-way mixed traffic, with separated contraflow cycling path

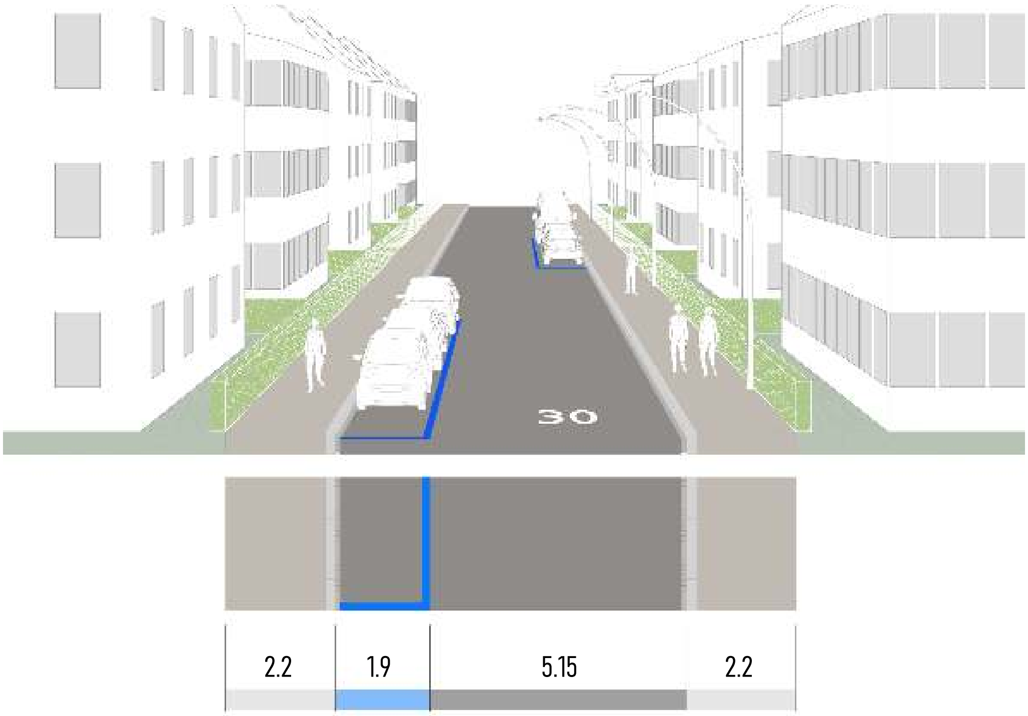


R3-A1: Cycling street

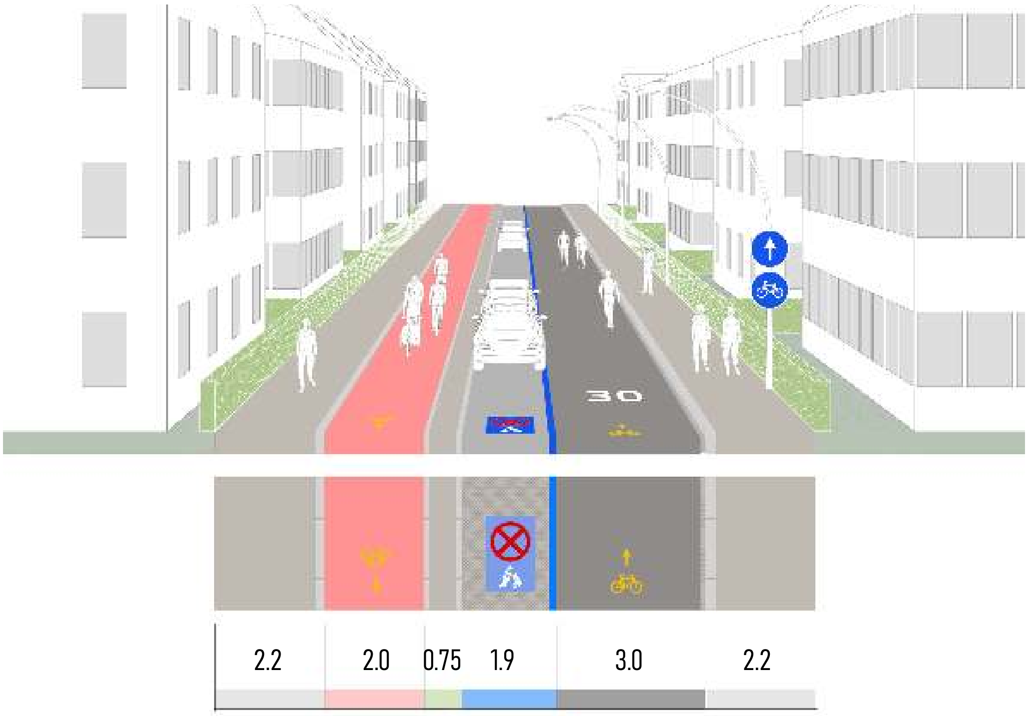


R1: Residential street, two ways, with parking

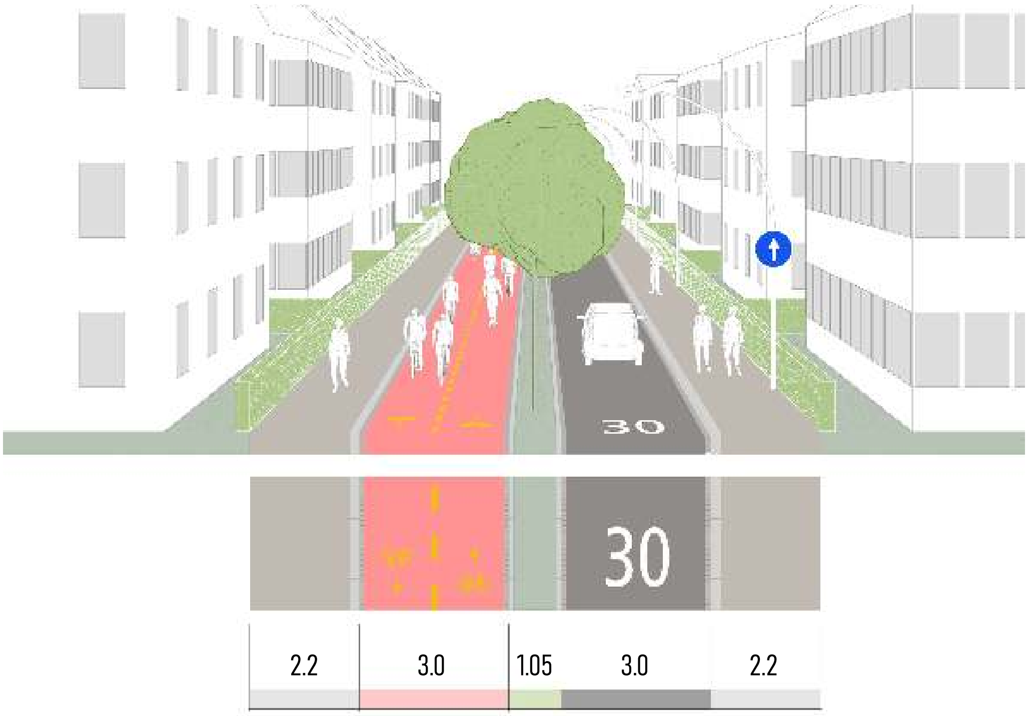
R1-Base: Two-way mixed traffic, with parking (status quo)



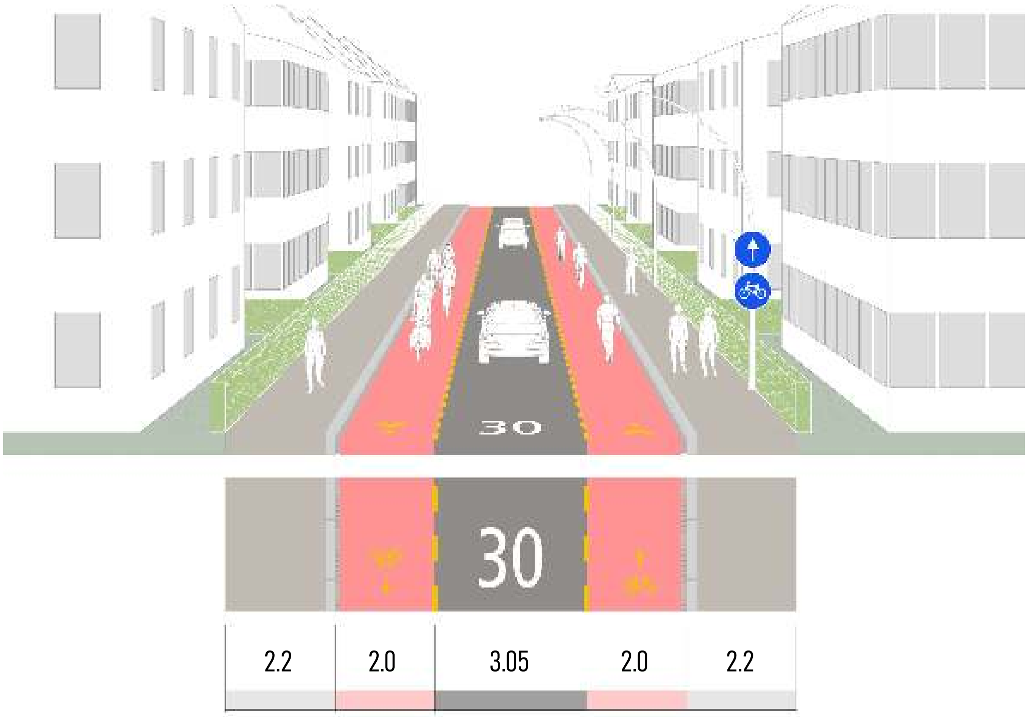
R1-A3: One-way mixed traffic with parking and separated contraflow cycling path



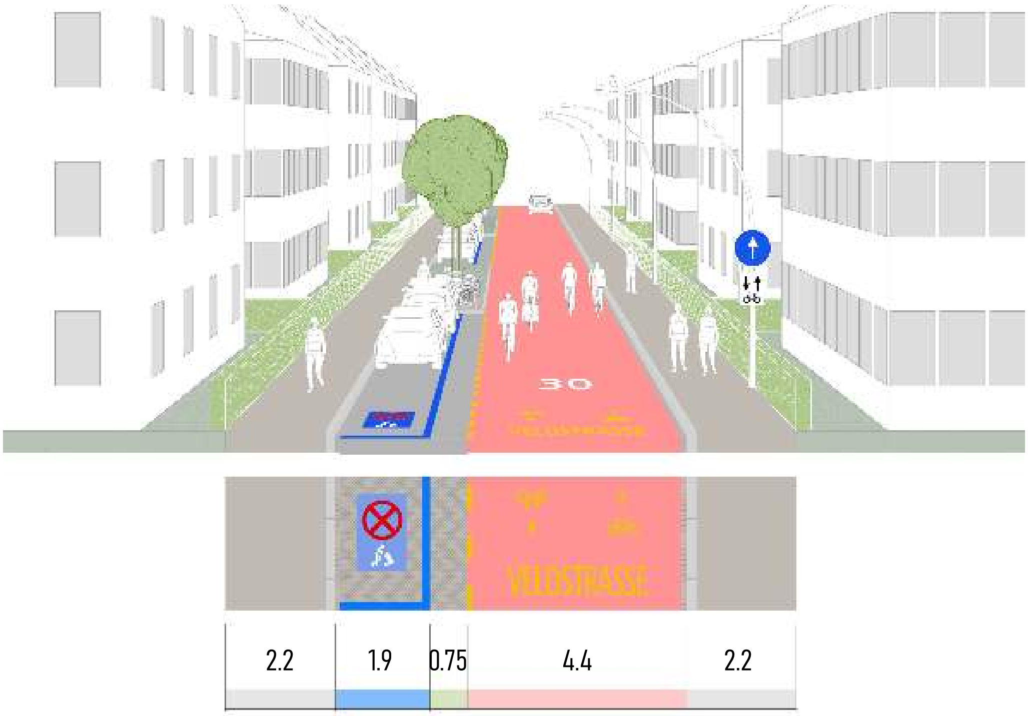
R1-A4: One-way motorized traffic and separated cycling path



R1-A2: One-way motorized traffic, with cycling lanes

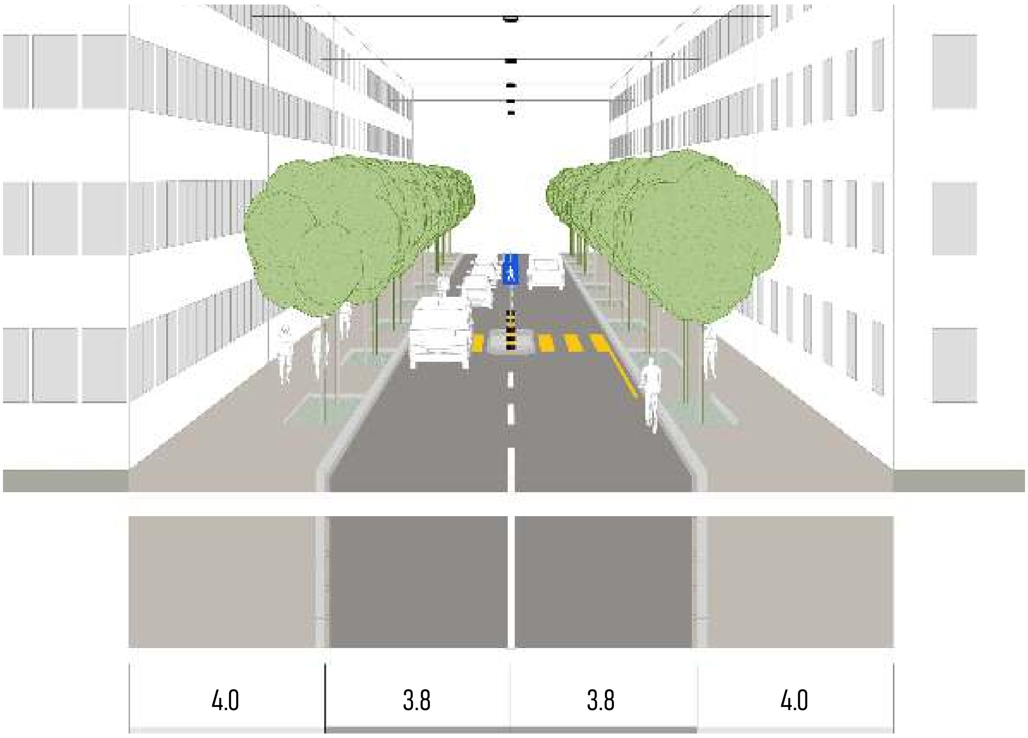


R1-A1: Cycling street

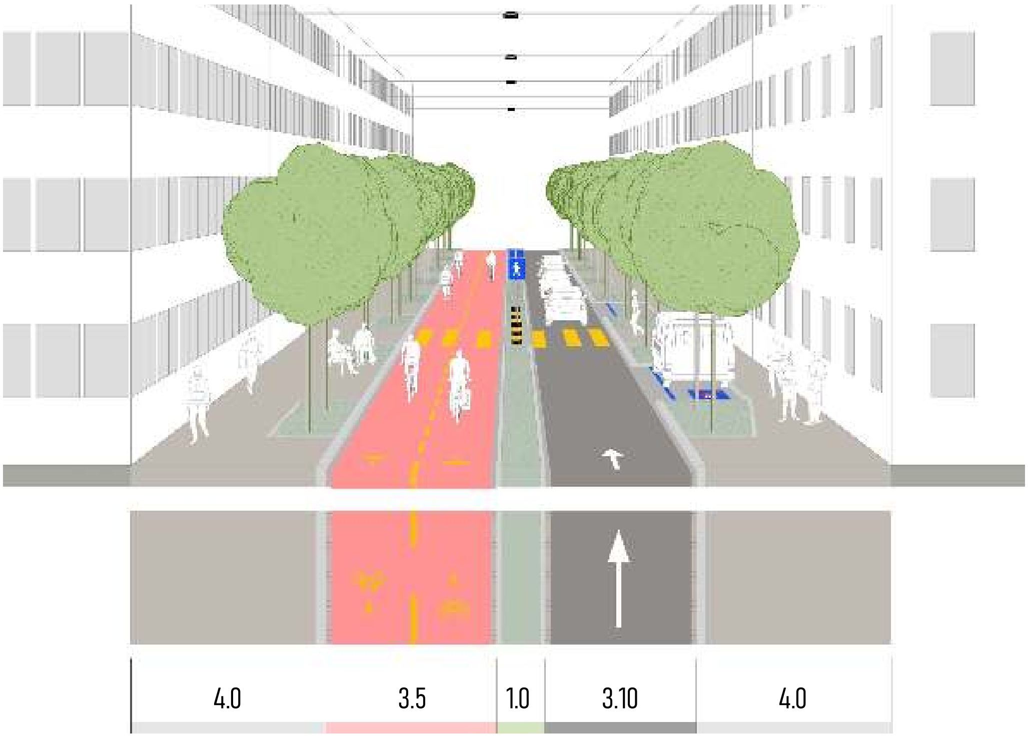


S1: Secondary street, without tram

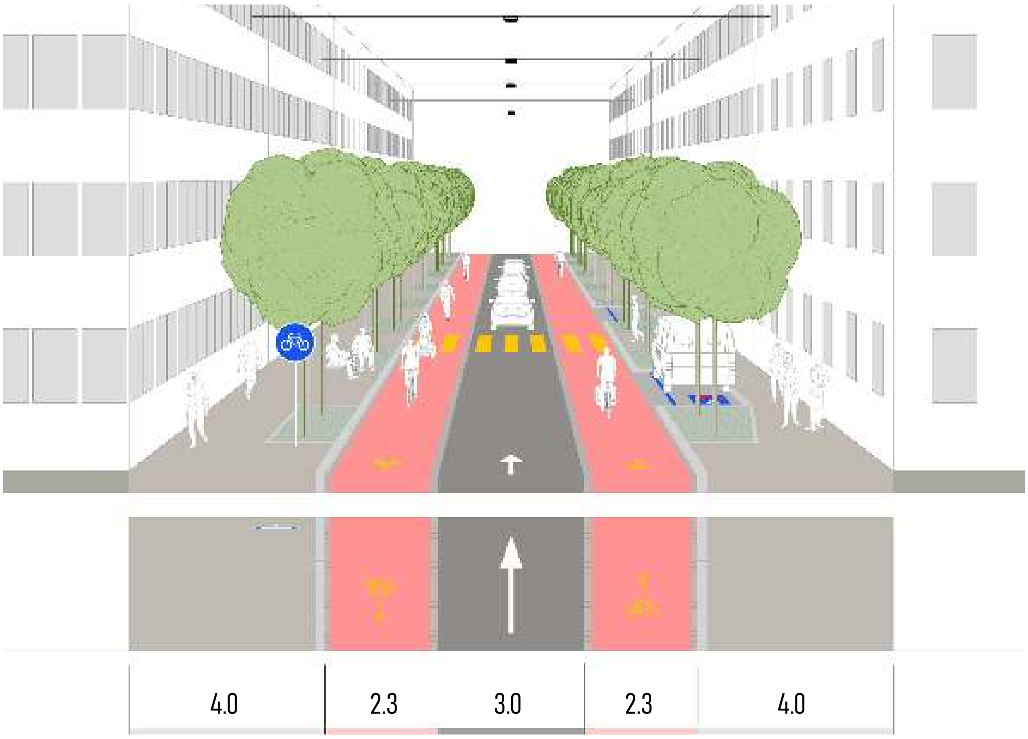
S1-Base: Two-way motorized traffic with advisory cycling lanes (status quo)



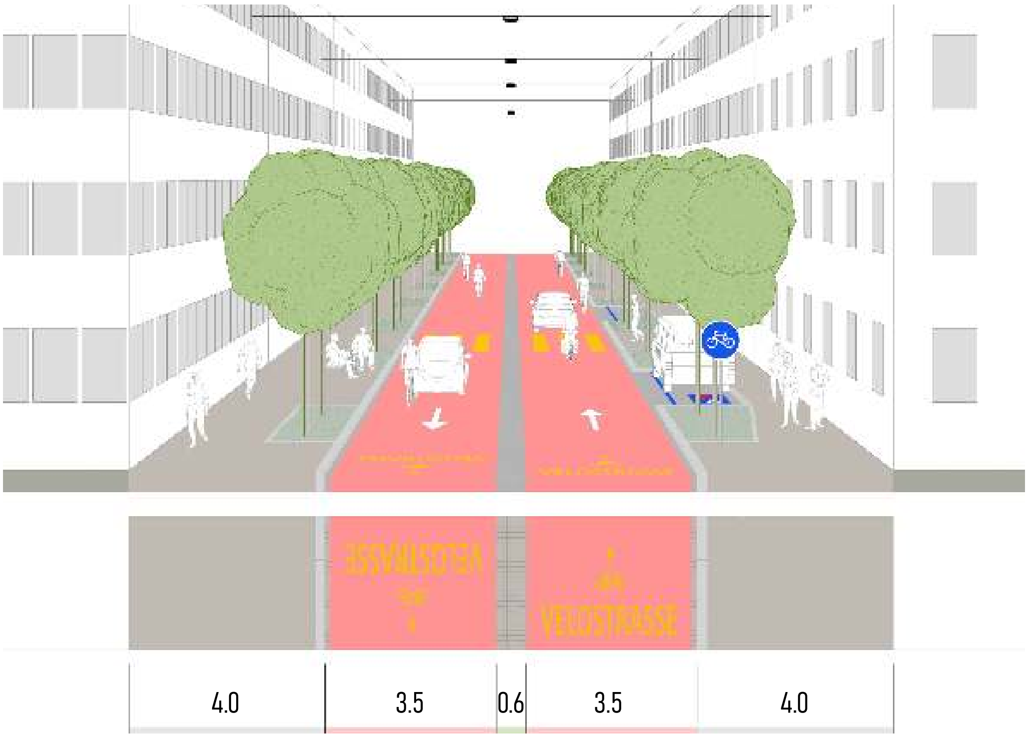
S1-A3: One-way motorized traffic, with separated cycling path



S1-A1: One-way motorized traffic, with separated cycling paths

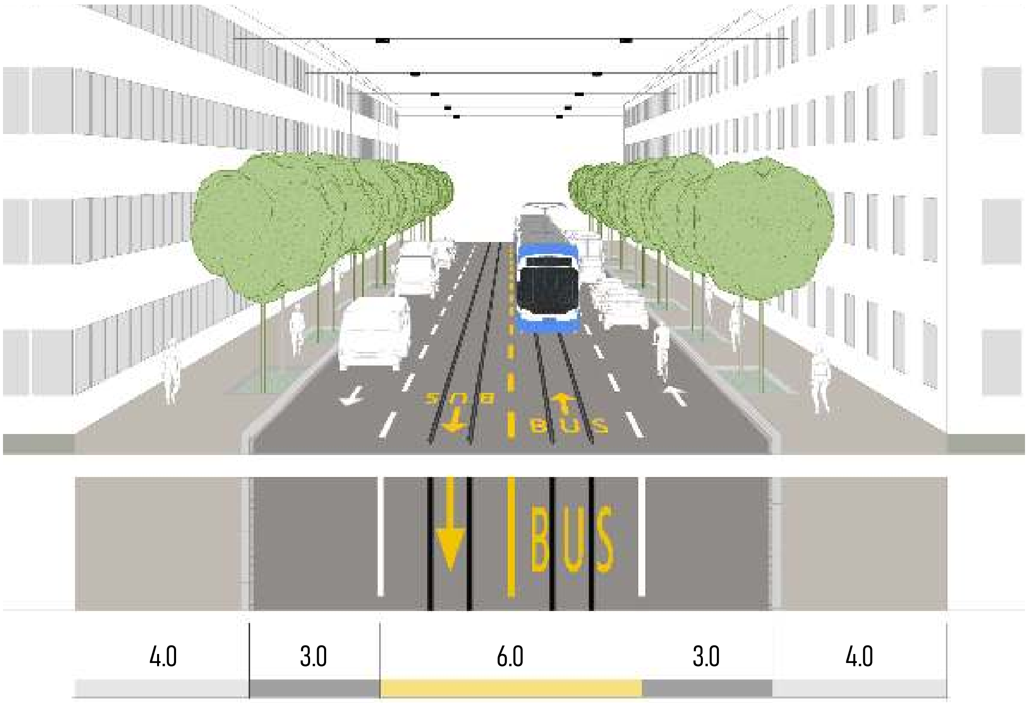


S1-A2: Cycling street

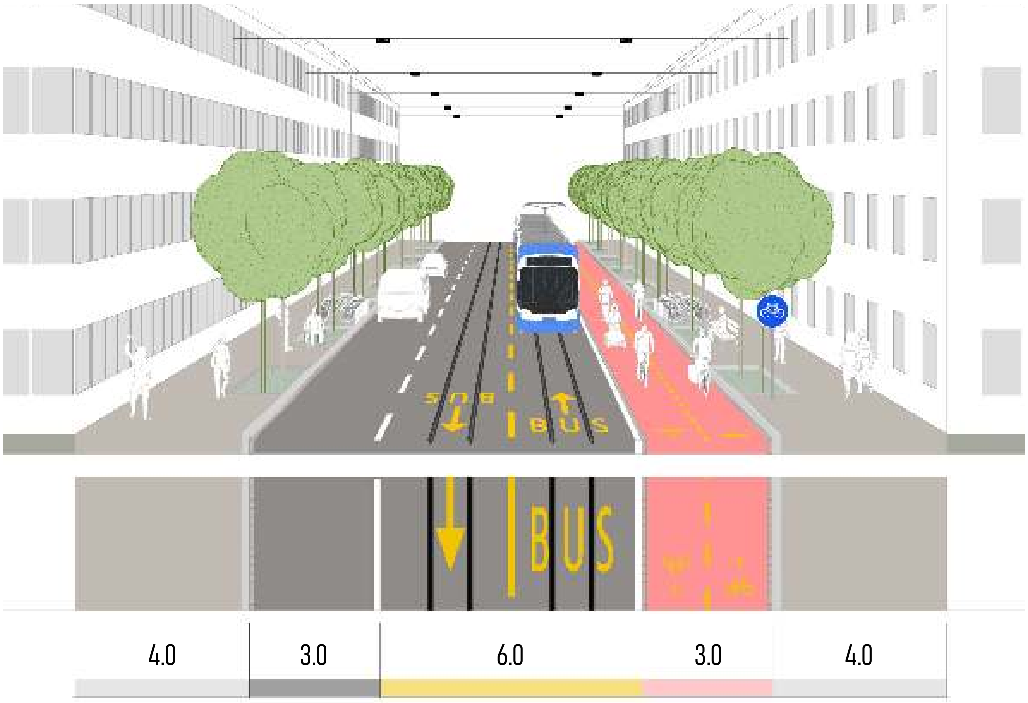


S2: Secondary street, with tram

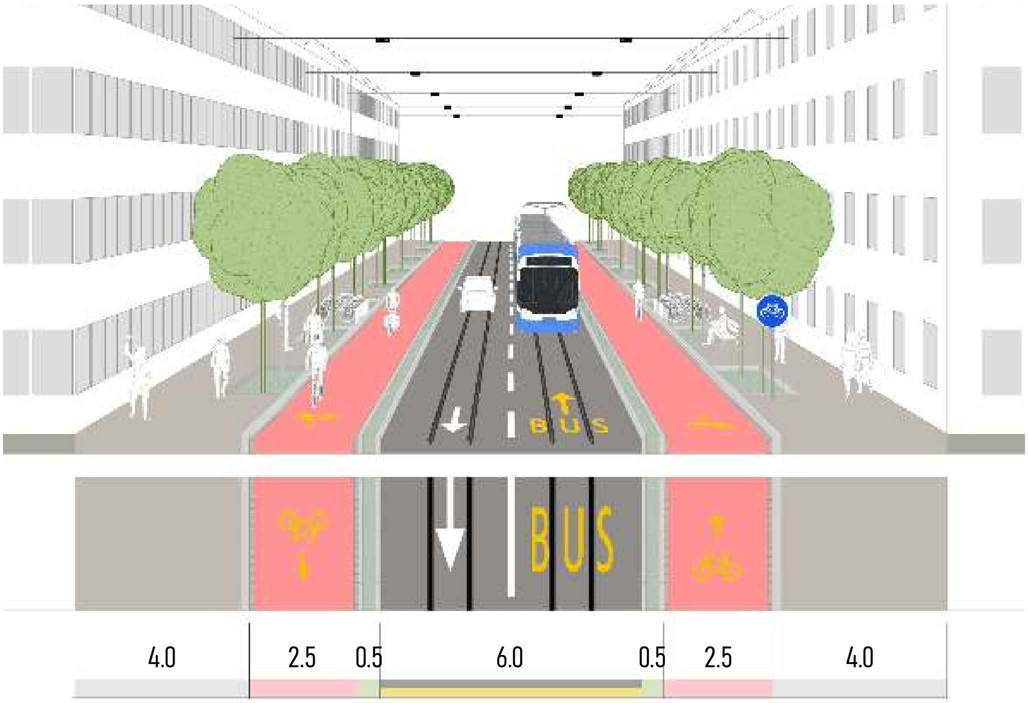
S2-Base: Two-way mixed traffic, with center-running bus/tram lanes (status quo)



S2-A1: One-way motorized traffic, with center-running bus/tram lanes, and minimalistic cycling path

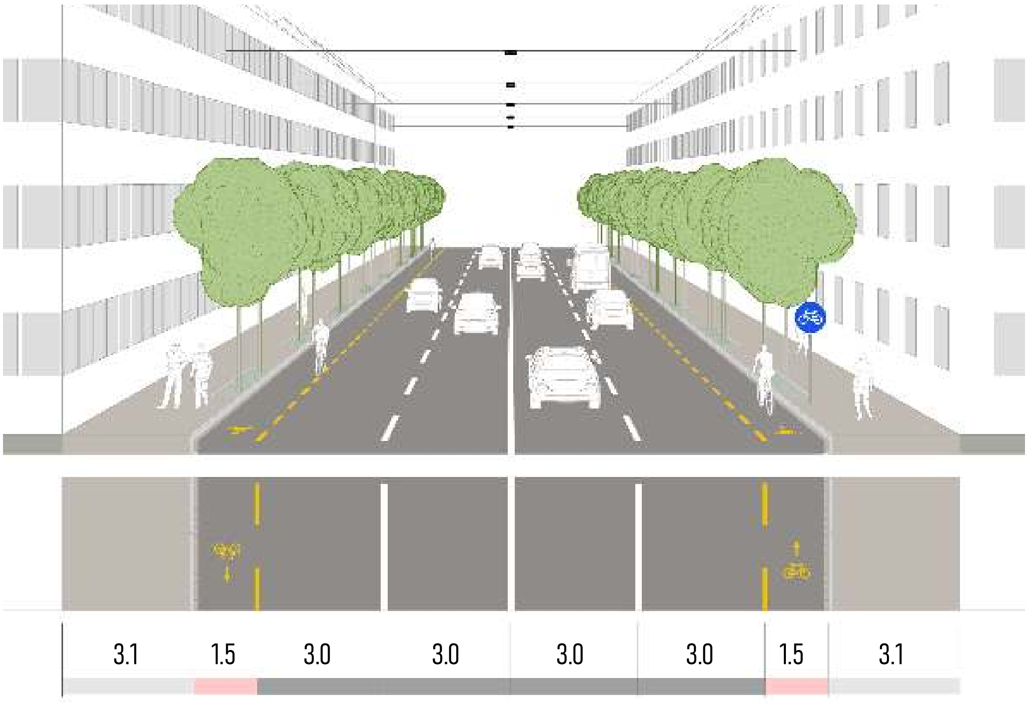


S1-A2: One-way motorized traffic, with contraflow bus/tram lane and high-comfort cycling paths

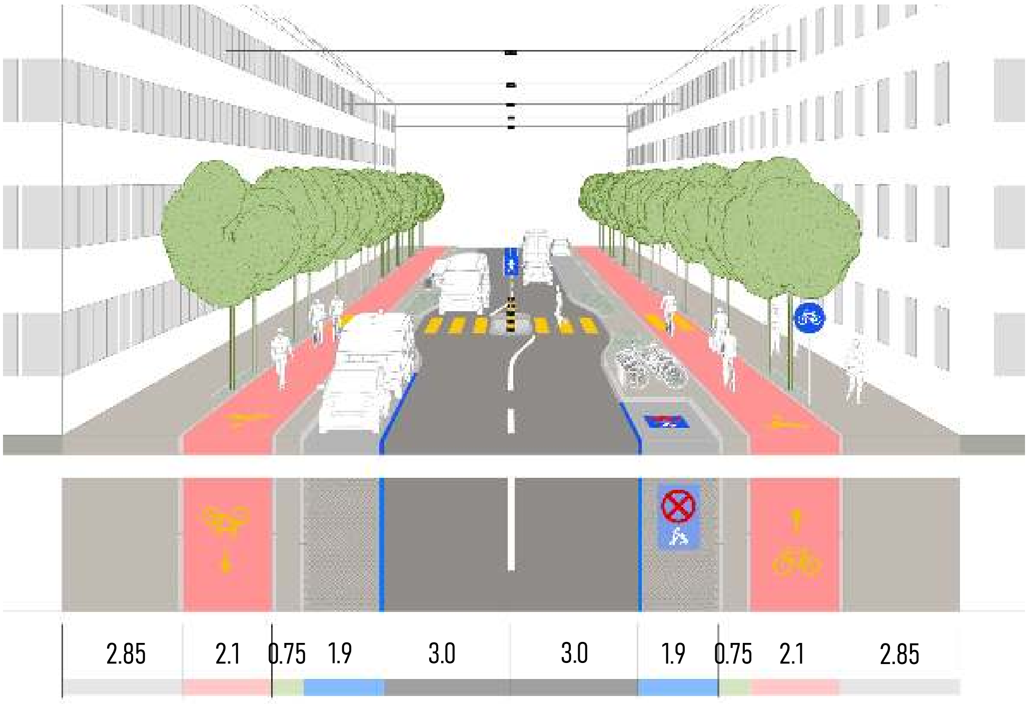


P2: Primary street, without tram

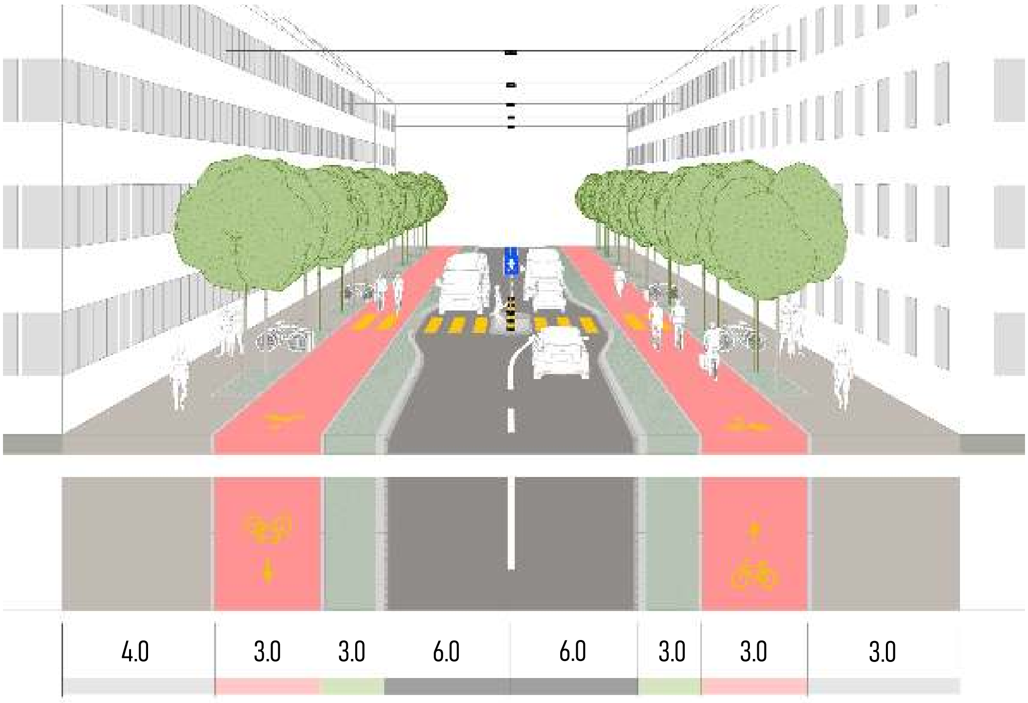
P2-Base: Two-way motorized traffic, with double lanes and advisory cycling lanes



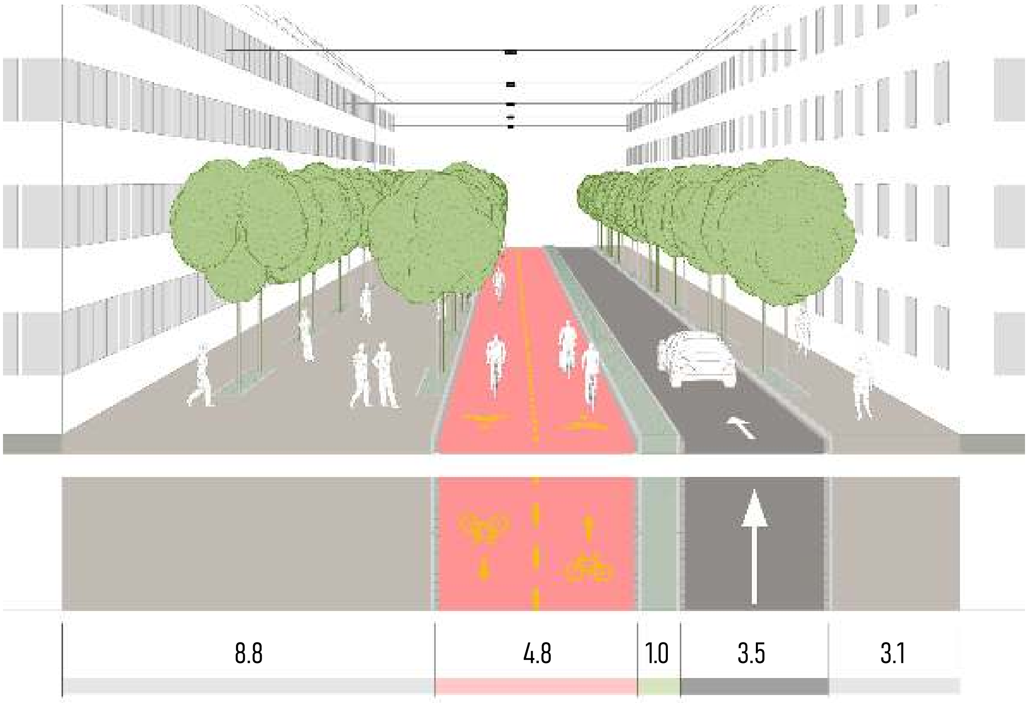
P2-A2: Two-way motorized traffic, with separated cycling paths and parking



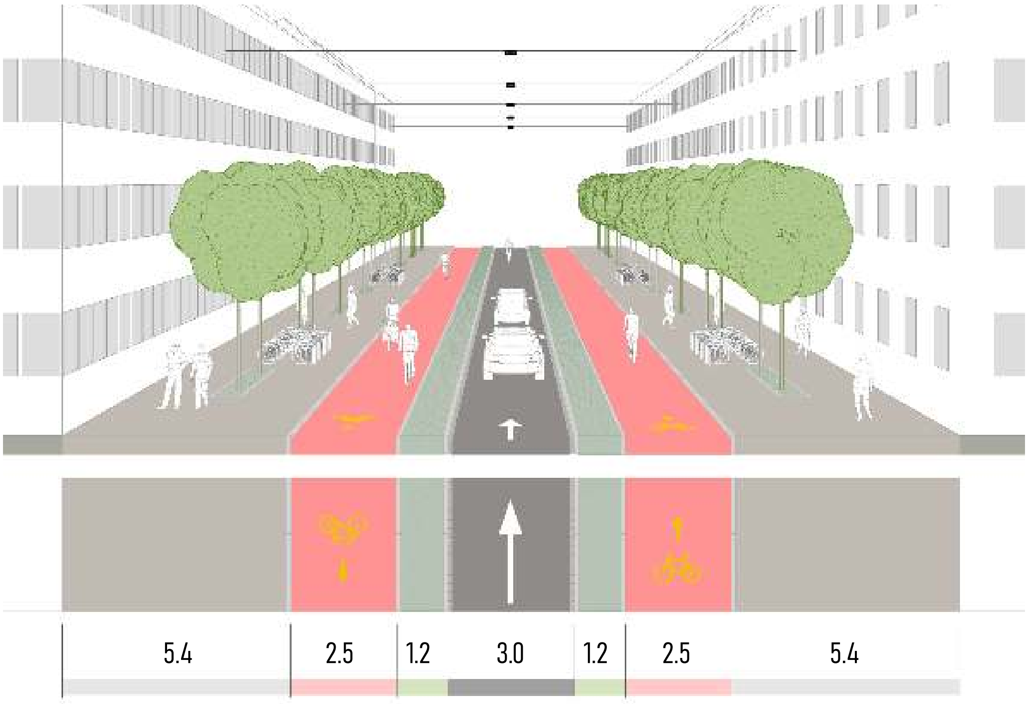
P2-A1: Two-way motorized traffic, with separated cycling paths



P2-A3: One-way motorized traffic, with very high-comfort separated cycling path

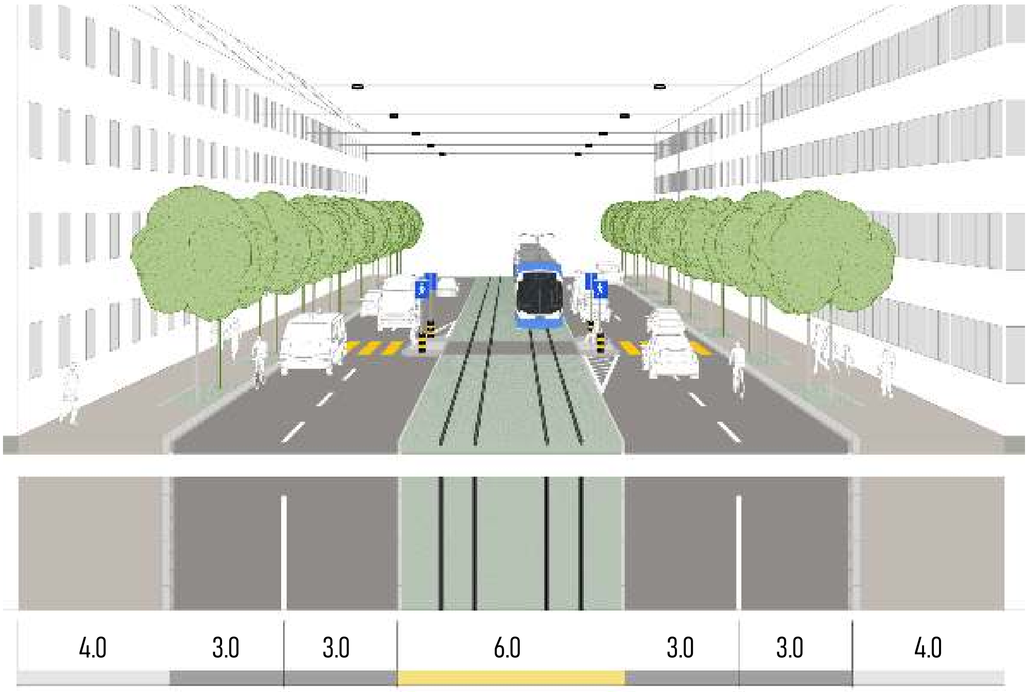


P2-A4: One-way motorized traffic, with very high-comfort separated cycling paths

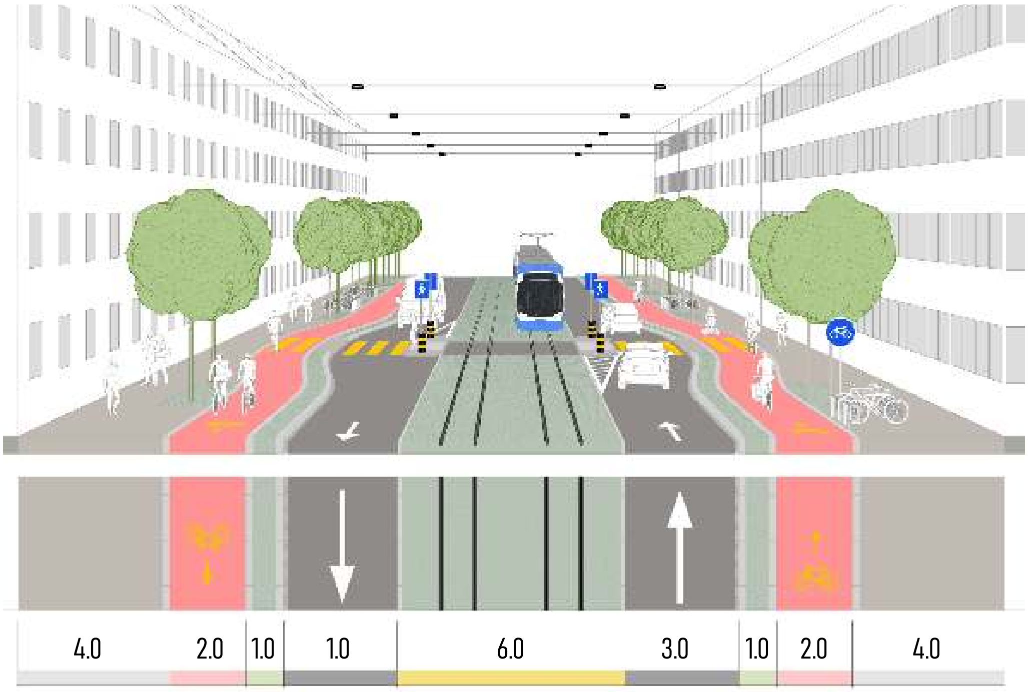


P1: Primary street, with tram

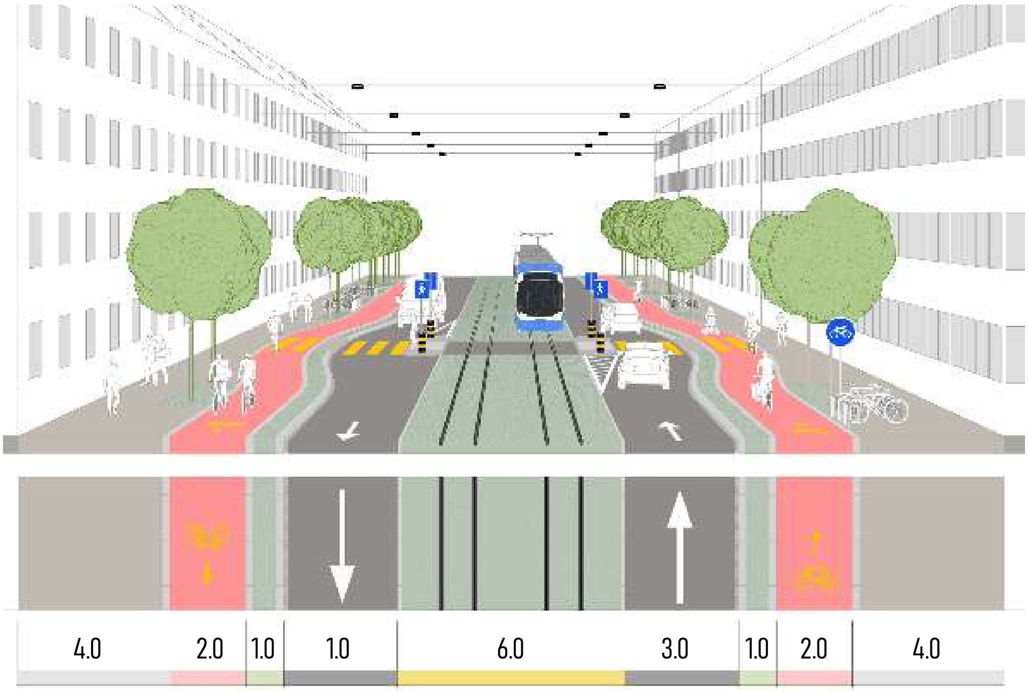
P1-Base: Two-way mixed traffic, with double lanes and center-running bus/tram lanes (status quo)



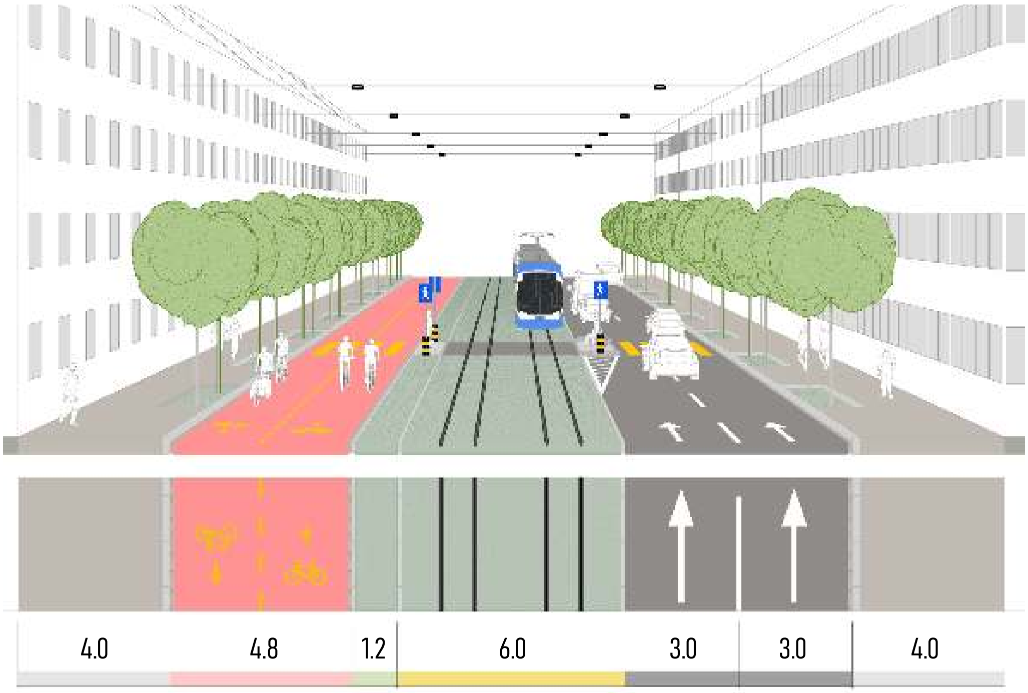
P1-A1: Two-way motorized traffic, with center-running bus/tram lanes, and separated cycling paths



P1-A1: Two-way motorized traffic, with center-running bus/tram lanes, and separated cycling paths



P1-A2: One-way motorized traffic, with center-running bus/tram lanes, and separated cycling path

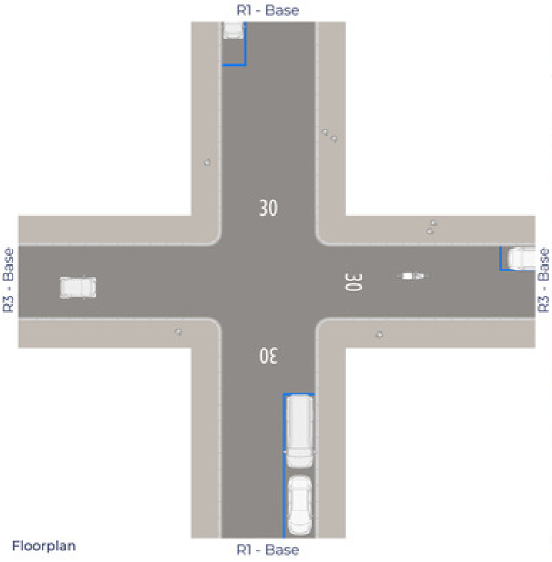


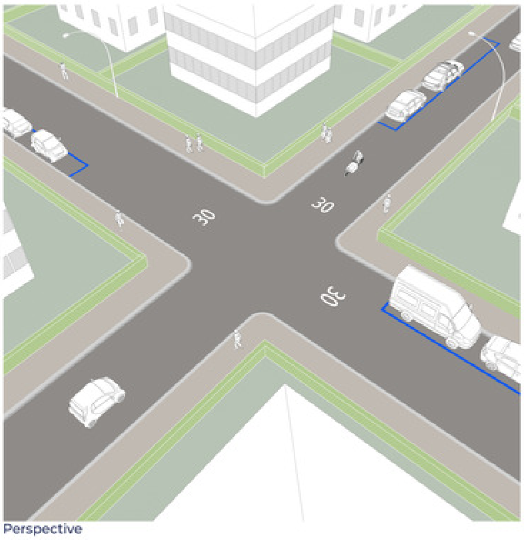
5.7 Standard designs for intersections

This section provides standard designs for intersections with combinations of street designs. The individual arms are labeled with their respective street types. Refer to the previous section for the typical dimensions.

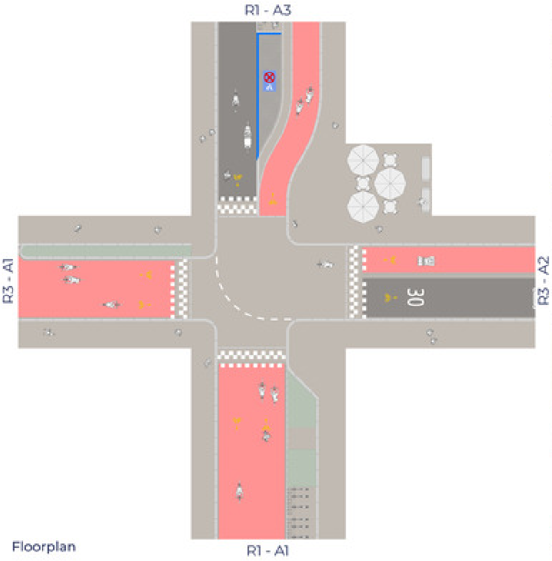
RR: Two residential streets

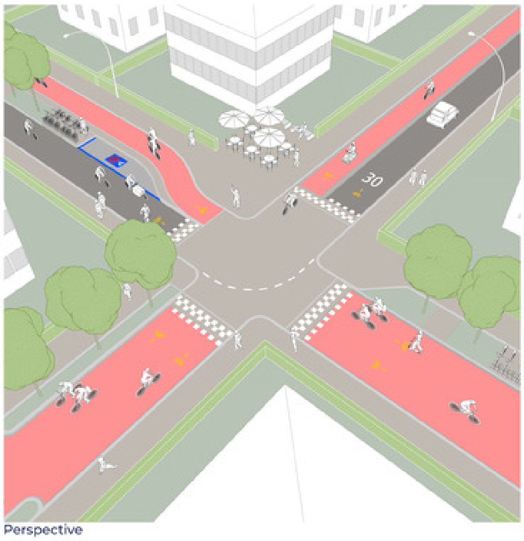
RR-Base: Mixed traffic (status quo)





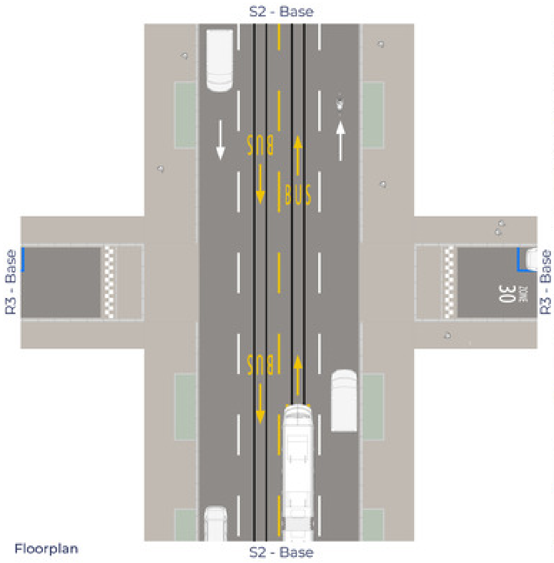
RR-A1: Cycling streets and some car lanes



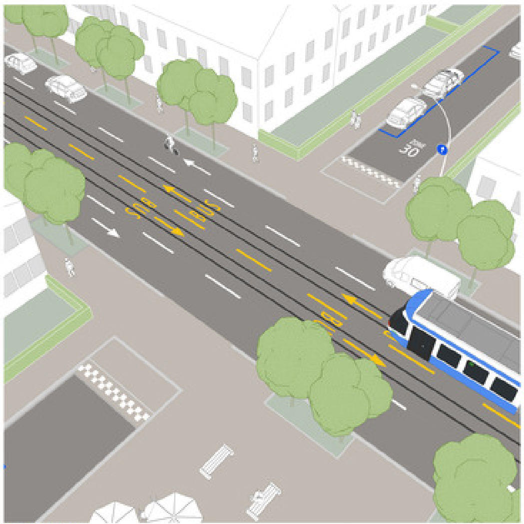


SR: Secondary and residential street

SR-Base: Mixed traffic (status quo)

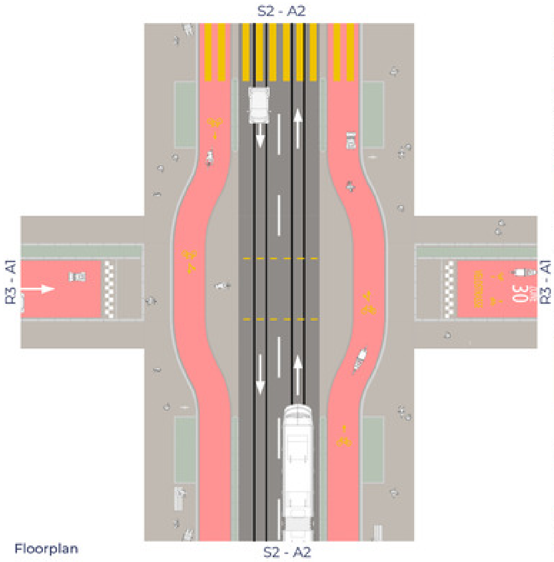


Floorplan

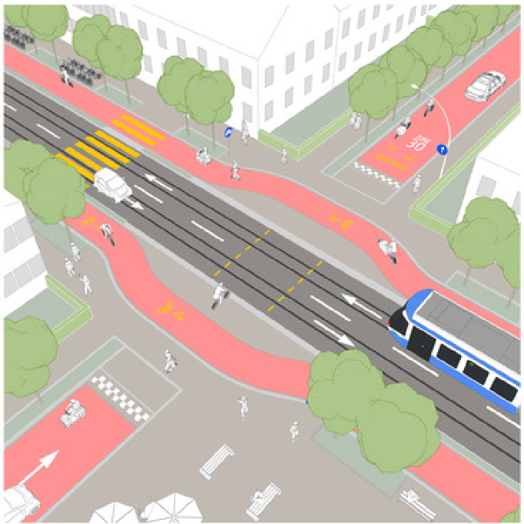


Perspective

SR-A1: Separated cycling paths

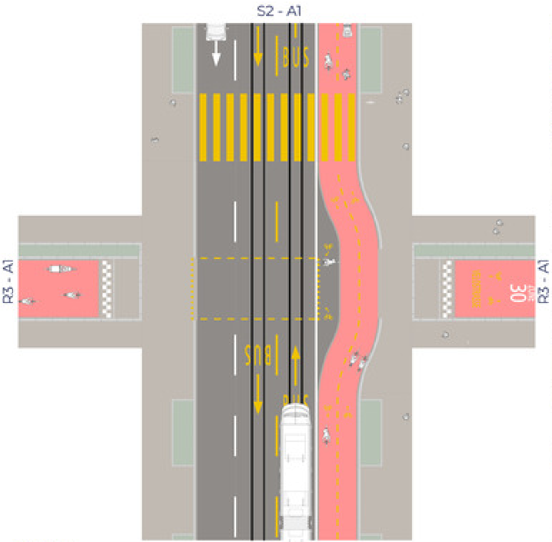


Floorplan

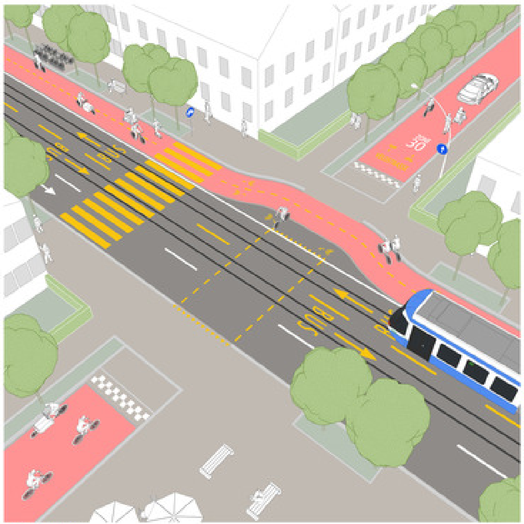


Perspective

SR-A3: Separated bidirectional cycling path

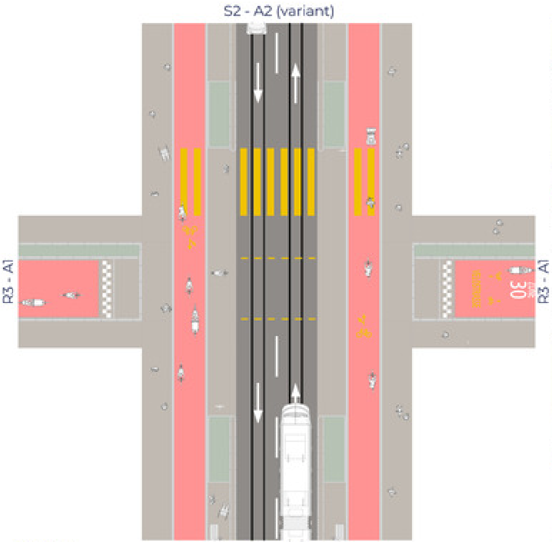


Floorplan

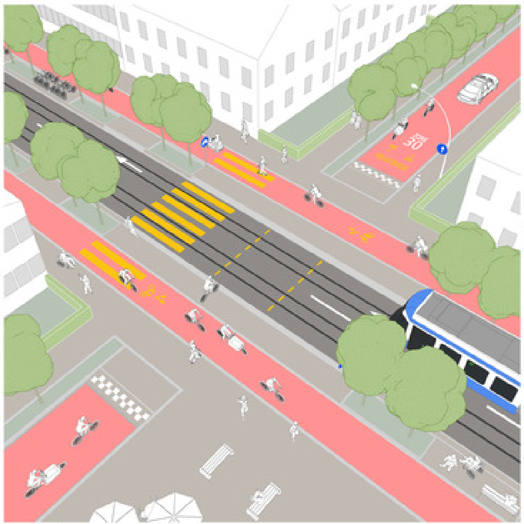


Perspective

SR-A2: Separated and protected cycling paths



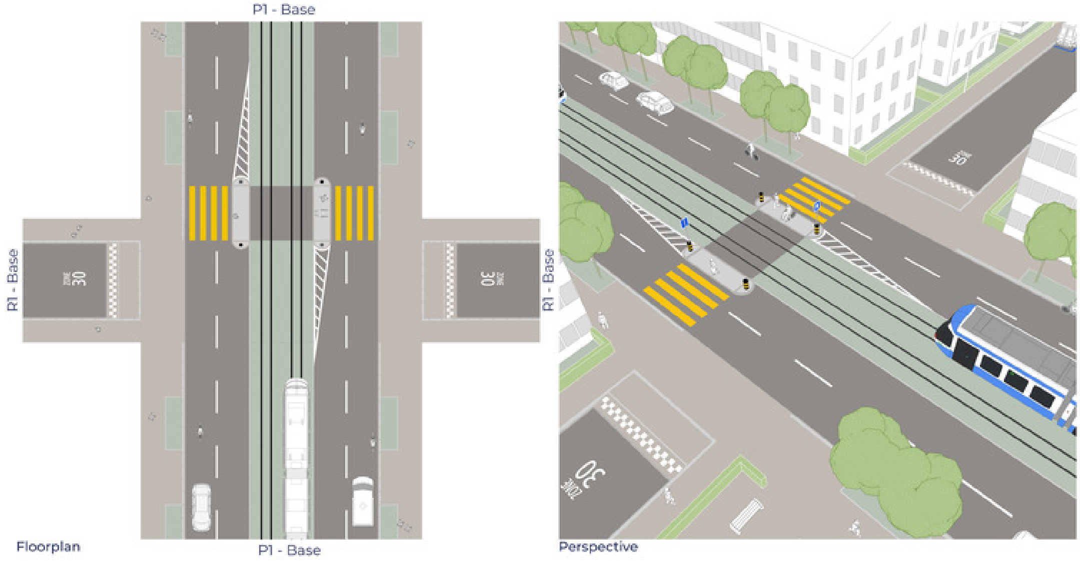
Floorplan



Perspective

PR: Primary and residential street

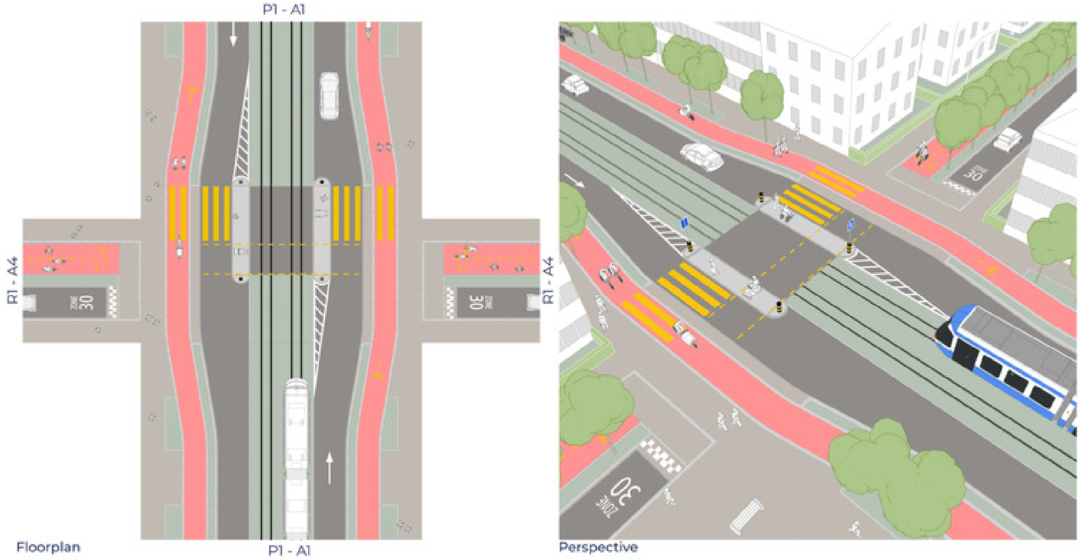
PR-Base: Mixed traffic (status quo)



Floorplan

Perspective

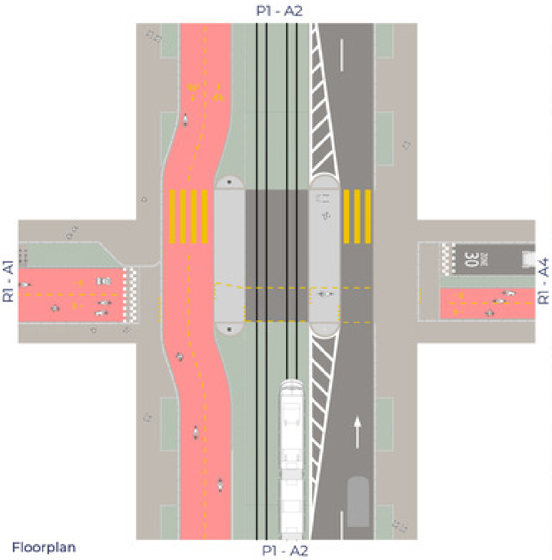
PR-A2: Separated cycling paths



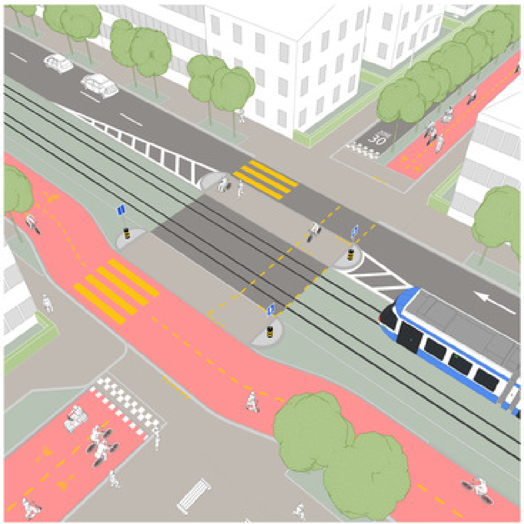
Floorplan

Perspective

PR-A1: Separated bidirectional cycling path



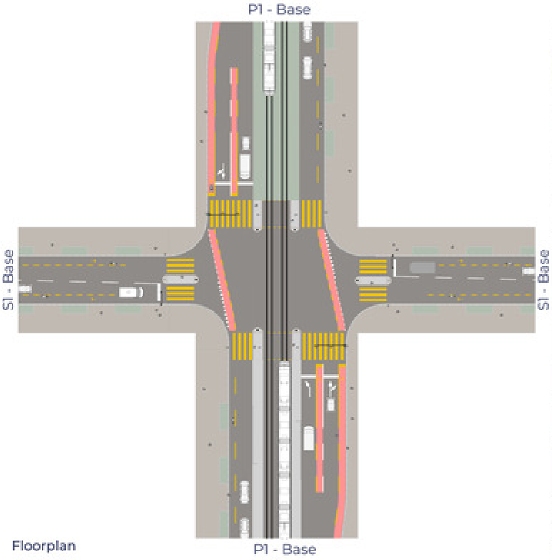
Floorplan



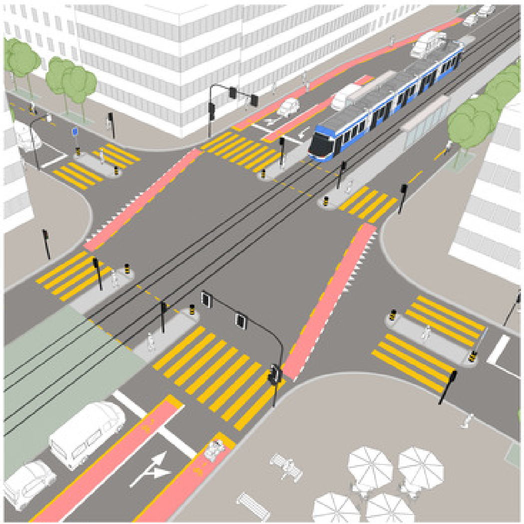
Perspective

PS: Primary and secondary street

PS-Base: Mixed traffic (status quo)

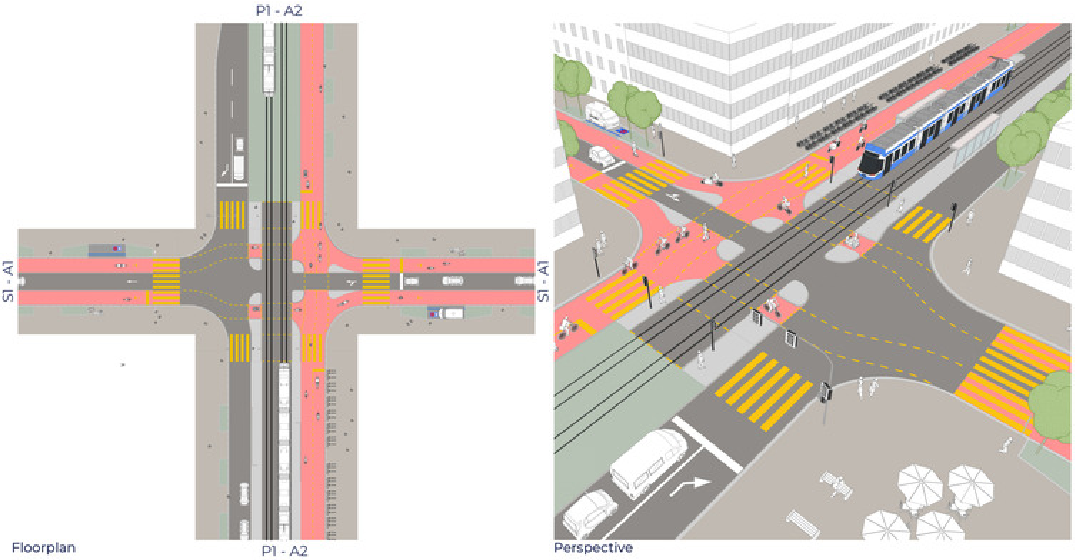


Floorplan



Perspective

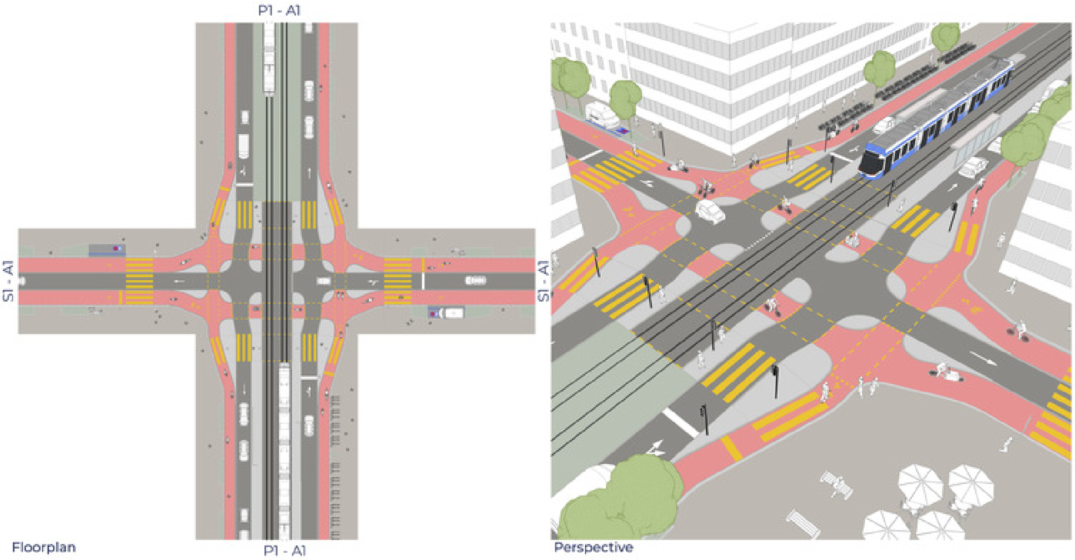
PS-A1: Separated cycling paths



Floorplan

Perspective

PS-A2: Separated and protected bidirectional cycling path



Floorplan

Perspective

Research projects

6. Multi-scale responsive public transport planning for bi-modal demand

William Andersson, Florian Fuchs, Zahra Ansarilari and Francesco Corman

Abstract Micromobility travel modes, such as e-bikes, are becoming increasingly popular. Travel demand is therefore more sensitive to people's bi-modal travel behavior, with changes in weather conditions causing variations in travel choices. This subproject aims to redesign the transit system to provide passengers with high-quality service and save operating expenses. For demand variations that may lead to high loads and surplus capacity, it is necessary to plan in advance, using minimal and easy-to-deploy actions. To address this issue, we developed a two-stage stochastic model using demand data from a MATSim simulation. Our model makes significant improvements to vehicle costs and passenger travel times.

In favorable weather, individuals with access to e-bikes may use them as their only mode of transport, or simply for access/egress to/from transit stops. In unfavorable weather, however, most such individuals will not use their e-bike at all, increasing the demand for public transport. Figure 6.1 shows the changes in mode share from favorable to unfavorable weather conditions in 2018 and the estimation of the change in mode share for the E-Bike City scenario.

This subproject aims to create a deeper understanding of transit demand fluctuations' impact due to micromobility users on the design of a transit network. Conventional approaches plan for an average demand scenario, on the other hand, our approach is concerned with the case where the system might be oscillating between scenarios that are noticeably different. This provides us with either low or excessive demand, but not a "nice to have" average demand. Our model ensures the network accommodates the increased demand caused by adverse weather conditions, while also avoiding inefficiencies on lower-demand days. A proactive approach to manage demand fluctuations is essential when designing a bi-modal transit system where the modal split demand depends on external factors.

Our model output defines key transit network elements, including route layouts, stop sequences, connection points, and line frequencies. We propose a two-stage stochastic mixed-integer programming model to design a transit network that accounts for demand variability, such as due to weather conditions. The model uses a large pool of candidate lines, based on those that currently run in Zurich, and reasonable frequencies to choose from. The plan should minimize costs and recommend implementable actions while ensuring high-quality service for all users. To balance network simplicity with adaptability, the model keeps line configurations consistent across all demand variations during peak (and off-peak) periods, regardless of weather conditions, adjusting only line frequencies to accommodate demand fluctuations.

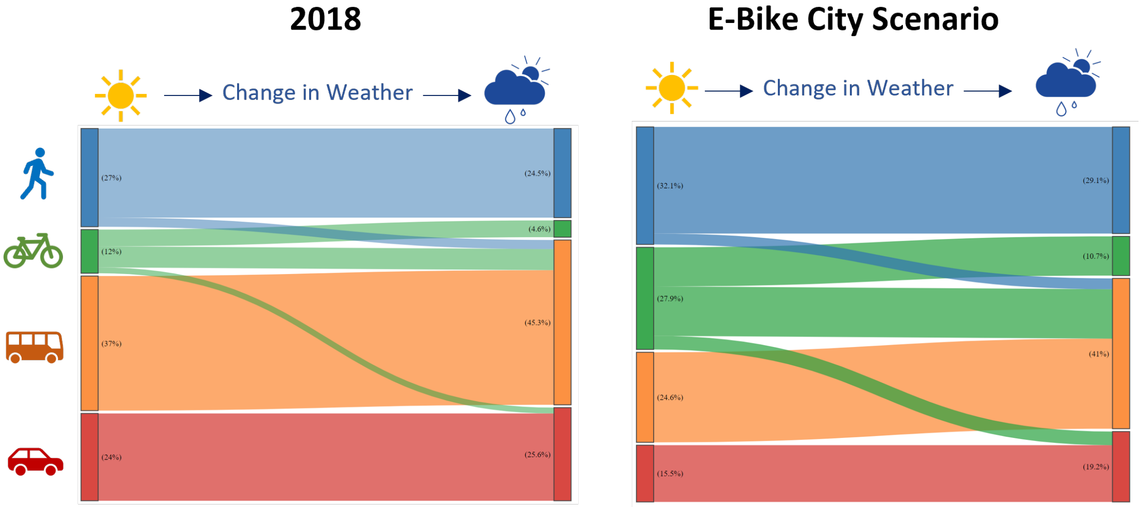


Figure 6.1: Impact of weather on transport modes, measured in 2018 (left) (Pleisch, 2023) and predicted for the E-Bike City scenario (right).

We focus on Zurich city. Our demand data comes from a MATSim simulation (Sonnak, 2024), generating 1000 demand relations. The model considers over 250 line configurations, with the MIP model containing 1.3M variables and 1.1M constraints. We use on-peak (07:00–09:00) and off-peak (14:00–16:00) demand data from the simulation for good weather scenarios and multiply the demand by 1.2 to create the bad weather scenarios. A visualization of the current (benchmark) transit networks as well as the optimized line networks for on-peak and off-peak demand both for good and bad weather scenarios are shown in Figure 6.2.

The changes are easy to see and are as expected: lines run at a higher frequency when there is more demand, especially comparing off-peak and on-peak demand. Similarly, in bad weather scenarios, we also see increased line frequencies due to the increased demand. For example, the stochastic model for the off-peak demand increases the frequency of line 11 (orange, running north to southeast) from 7 to 11 as the weather condition changes from good to bad. For on-peak demand, the stochastic model most notably changes the frequency for line 75 (blue loop in the north) from 2 to 7 during bad weather. Overall, the stochastic model removed 4 (of 41) lines from the off-peak benchmark and added 1; for the on-peak benchmark, the stochastic model removed 1 (of 36) and added 2. Furthermore, our model provides a 6.5% reduction in operating costs and a 1.7% improvement in passenger travel times during peak hours, while during off-peak hours it is 6.8% and 1.9%, respectively. We see this, for example, in how the frequencies for the same lines change between the benchmark and stochastic models. This demonstrates the benefit of planning in advance for fluctuations in demand.

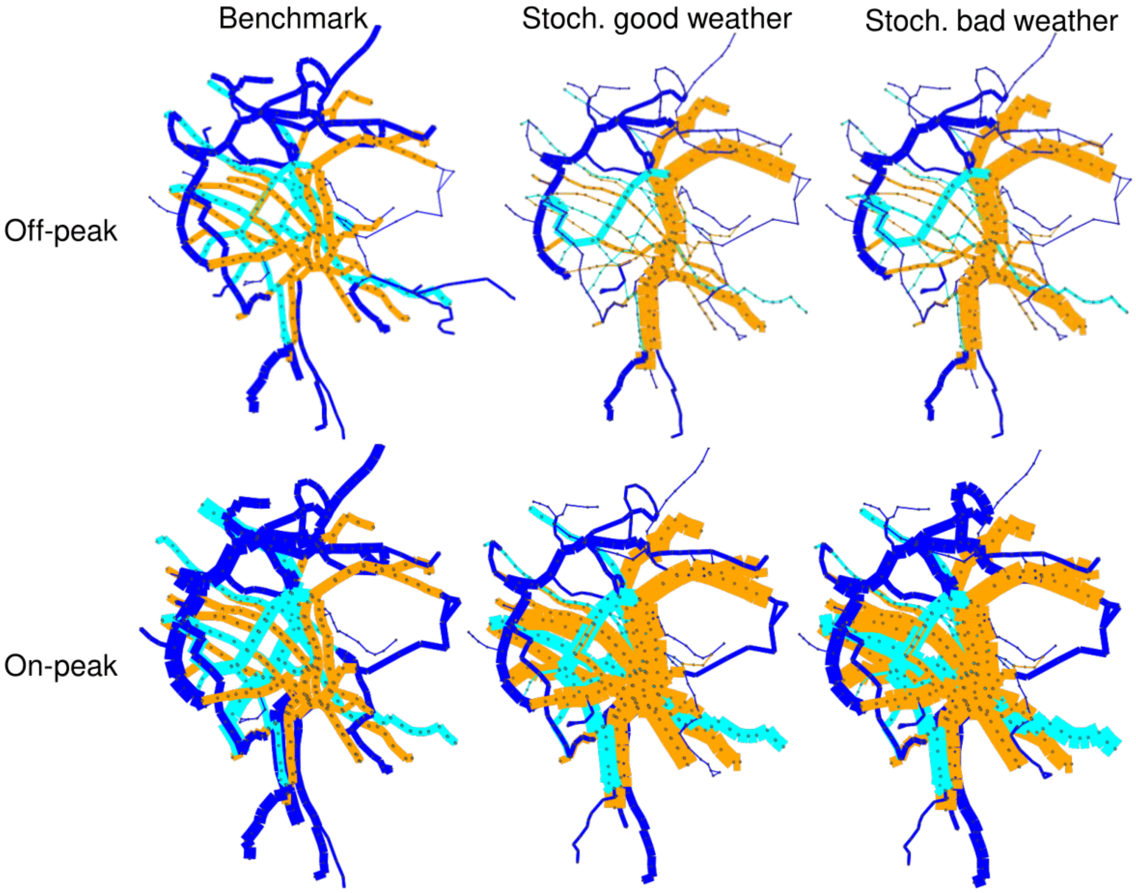


Figure 6.2: Thickness corresponds to line frequency. Buses in blue, trolleybuses in cyan, trams in orange.

7. Reorganizing the road network for an E-Bike City

Lukas Ballo, Martin Raubal and Kay W. Axhausen

Abstract We applied the SNMan tool to redesign the entire street network of Zurich according to the E-Bike City idea. The automated process reallocates road space to prioritize cycling infrastructure while preserving access by car, public transport operations, and basic on-street parking. Using real-world data and planning constraints, the proportion of cycling infrastructure increases from 12% to 54% of road space, illustrating the feasibility and trade-offs of a systemic, city-wide road space transformation.

We designed a new city-wide street network for Zurich using the SNMan tool (introduced in chapter 4), following the principles of the E-Bike City. The aim was to reallocate road space in a way that prioritizes cycling infrastructure while maintaining the high standard of public transport operations, access to buildings, and a minimum supply of on-street parking.

Starting from OpenStreetMap data, we constructed a digital twin of Zurich's road network, enriched with local datasets on tram and bus routes, publicly accessible parking spaces, elevation, and population data. The simplified and processed network consisted of approximately 5,000 nodes and 7,000 edges within the municipal boundary.

To guide the redesign, we divided the city into a network of main roads and 60 sub-networks in neighborhoods. Different logic was applied depending on the area type: On main roads, the goal was to channel car traffic efficiently, so the design guaranteed at least one motorized travel lane per street, ensuring continuous connectivity for through traffic. In contrast, within the neighborhoods, the focus shifted to minimizing car presence and reclaiming space for cycling. Here, only a minimal network of car lanes was retained—just enough to maintain access to the on-street parking spaces. This approach supports filtered permeability, discouraging through-traffic in residential areas while ensuring that essential motor vehicle access is preserved.

Throughout the process, key constraints were enforced: (1) All tram and bus routes had to remain fully operable. (2) Each residential location retains access to at least one on-street parking space within

200 meters. (3) The network must remain connected for all modes, with access and egress preserved.

In our design, building access is guaranteed by a minimum provision of on-street parking—one space per 60 residents—reachable within a 200-meter walking distance from every building. These parking locations are embedded in a network of travel lanes that allows local motorized access. All remaining space is allocated to separated cycling infrastructure, with exceptions for emergency and utility vehicles, and for legally protected access to existing private garages.

The results are summarized in Table 7.1. Cycling infrastructure expanded from 12.1% to 54.3% of the total road space—an increase of 360%. At the same time, the area allocated to general car lanes dropped from 66.6% to 35.1%, and on-street parking was reduced by 73%. While essential car access was maintained, average car trip lengths increased by 35.7% due to many one-way streets. Cycling trips, by contrast, became substantially more attractive: the generalized cost adjusted for comfort and slopes decreased by 24.1%. All dedicated lanes for trams and buses were preserved, and every neighborhood remained accessible by car, with a reduced supply of parking.

Figure 7.1 shows a preview of the network before and after the redesign. See the attached map for the full network after further development (Appendix B).

This design for Zurich demonstrates how SNMan enables an ambitious, yet realistic, constraint-aware transformation of existing urban street networks. It offers a tangible blueprint for city-scale shifts in mobility priorities grounded in data, responsive to access needs, and scalable for further simulation or planning refinement.

Metric		Status Quo		E-Bike City		Change
avg shortest path for cars	km		5.463		7.412	+35.7%
avg shortest path for bicycles	km		5.391		5.334	-1.1%
avg shortest path for bicycles, comfort-adjusted	km		4.824		3.661	-24.1%
road space general travel lanes	km^2	(66.6%)	3.7564	(35.1%)	2.0257	-46.1%
road space parking	km^2	(14.3%)	0.8040	(3.8%)	0.2188	-72.8%
road space bus and tram lanes	km^2	(7.0%)	0.3962	(6.9%)	0.3962	+0.0%
road space cycling infrastructure	km^2	(12.1%)	0.6816	(54.3%)	3.1340	+359.8%

Table 7.1: Network indicators

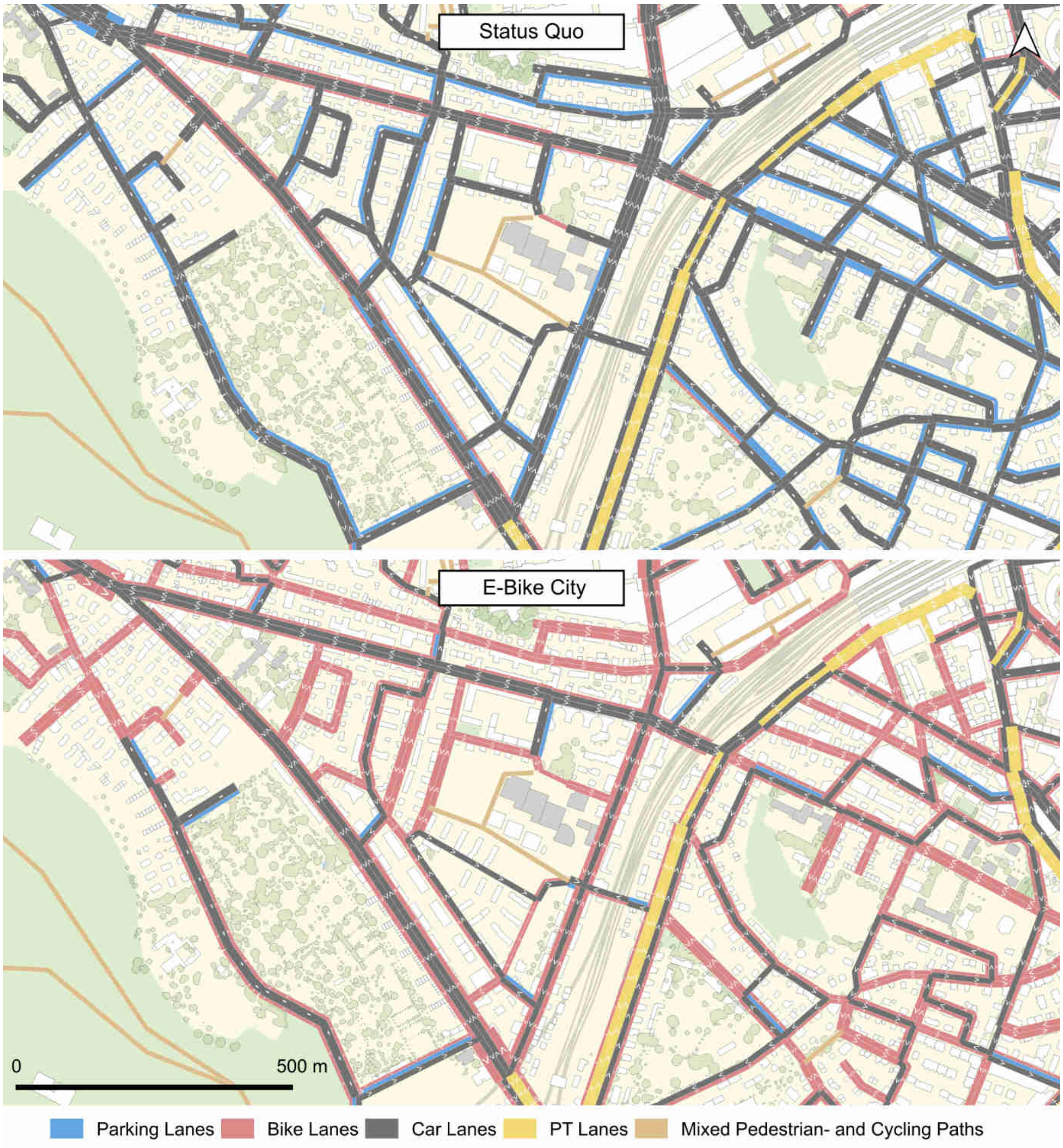


Figure 7.1: Comparison of the status quo and the redesigned network

8. Congestion-informed road space allocation for cars and bicycles

Ying-Chuan Ni, Michail A. Makridis, Anastasios Kouvelas

Abstract Although being an effective way to increase bicycle usage by enhancing users' safety and accessibility transport policies aiming to allocate more road space to bicycles often receive strong criticism from the public because of the concern of potential traffic congestion. Therefore, we first evaluate the traffic performance of a bike lane network design using a heuristic algorithm or only based on the accessibility measurement by simulating different modal share scenarios. To further ensure a congestion-free urban network for both cars and bicycles, an optimization framework actively considering bi-modal traffic performance is proposed to determine the optimal road space allocation scheme.

Allocating dedicated road space to bicycles can improve the accessibility and safety for active mode road users, with a long-term goal of motivating travelers to opt for these transport modes instead of private cars, leading to reduced car demand. Among various transport policy measures, it has also been widely-used due to its effectiveness in reducing delays caused by mixed-traffic interactions. However, space reserved for one mode is taken from another, which can potentially cause congestion due to local capacity reduction, e.g. in neighborhoods of infrequent usage or mode-inflexible demand, indicating that location selection plays an important role in the efficiency of space allocation strategy. A carefully-designed road space allocation plan can balance the trade-off between eco-friendly mode enhancement and general traffic performance by maximizing the road space utilization efficiency.

In Fulton *et al.* (2025), we evaluated the network traffic performance for the E-Bike City road network design in the city center of Zurich through microscopic traffic simulation in scenarios with different car-bicycle modal splits. Compared to the base scenario, the outcomes show that most of the OD pairs would not encounter severe increment of average travel time when the modal shift from cars to bicycles reaches 50%. By analyzing the network fundamental diagrams, as shown in the figure below, it is found that oversaturated traffic states, namely the breakdown of network traffic flow, can be avoided with the help of actuated signal control even if the bicycle modal share is only 25%. Traffic congestion can be completely eliminated when the modal shift becomes 75%. The improved traffic condition is mainly brought by the sufficient road space reallocated and the relatively small occupancy of bicycles. Congestion would not occur on the bike lane network even when the bicycle modal share is high. Even though the general network-mean speed decreases due to the slow cycling desired speed, road users would not experience the negative impact resulted from traffic congestion, which is a major advantage of such a radical urban road space transformation.

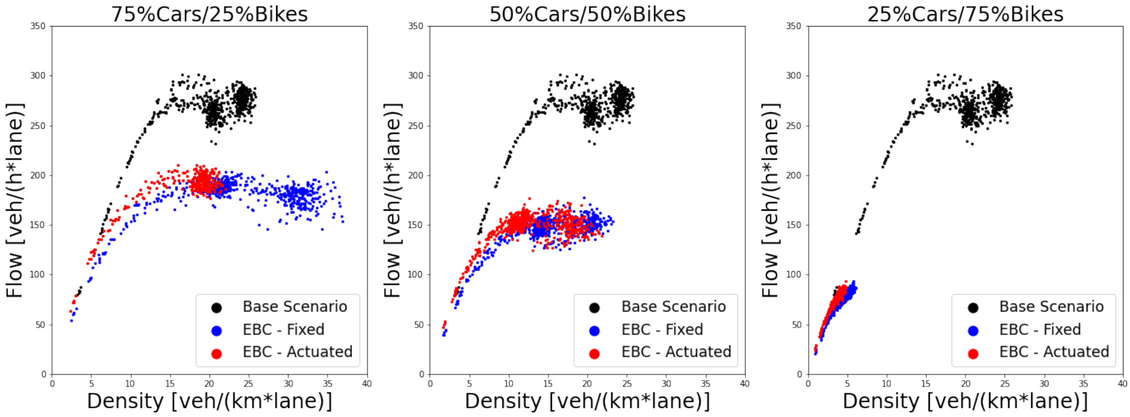
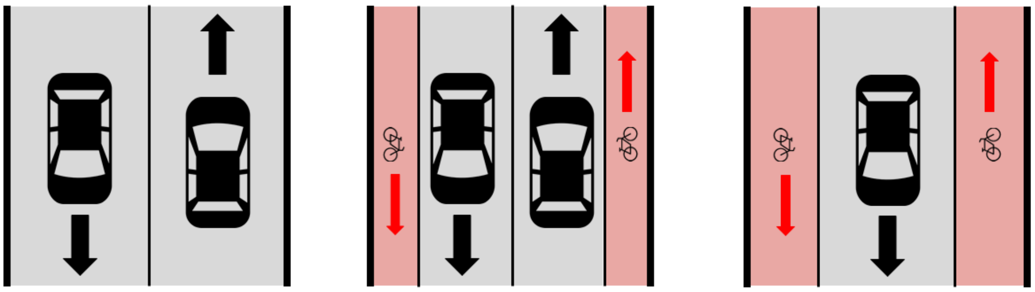


Figure 8.1: Car network fundamental diagrams in different scenarios

A road space allocation plan designed based on bi-modal traffic performance indicators can further prevent the degradation of network traffic performance even in a scenario with high car modal share. However, different from the allocation of dedicated bus lanes, such a decision-making problem is particularly challenging because of its multi-dimensionality. In the lane configurations considered, not only can the lane width for each mode vary on every road, but the direction of the car lane can also be changed. As illustrated in figure 8.2, after the reallocation, an 8-meter-wide road can either contain (1) narrow bike lanes and car lanes in both directions or (2) two wide bike lanes but only a one-way car street. For an urban network with limited road space, many one-way car streets are expected.

Besides car traffic flow, the unique non-lane-based traffic dynamics exhibited by bicycle traffic flow is also carefully considered based on the proposed simulation model and findings in Brunner *et al.* (2024) so that congestion on the bike lane network can also be avoided.

A novel simulation-based optimization framework is proposed to search for the optimal road space allocation plan considering the bi-modal congestion dynamics in the network (Ni *et al.*, 2025). The fitness of each solution is evaluated by analyzing the simulation output to obtain a weighted average route-mean speed over all OD pairs. By doing so, the congestion propagation due to queue spillback phenomena can be better mitigated for both modes compared to an allocation plan designed using a heuristic algorithm or an optimization approach only targeting at the accessibility aspect.



two-way wide car street
with speed limit: 50 km/h
(base scenario)

two-way narrow car street
with speed limit: 30 km/h
1-meter-wide bike lanes

one-way narrow car street
with speed limit: 30 km/h
2.5-meter-wide bike lanes

Figure 8.2: Possible lane configurations

To prioritize a certain mode according to the transport policy, a larger weight can be assigned to either car or bicycle. Different modal splits can also lead to different allocation plans. A larger amount of road space would be allocated to bicycles when more travelers decide to use bicycles to commute. In addition, it can be expanded to account for the changing OD demand pattern at different times of day, e.g., morning and evening peaks, to facilitate a dynamic and adaptable allocation of the urban road space.

9. Network optimization and multi-target evaluation

Nina Wiedemann, Ayda Grisiute, Henry Martin and Martin Raubal

Abstract A key component of the E-Bike City project is designing an optimal bike network, which is a multi-objective, combinatorial problem. We develop a mathematical optimization approach based on linear programming to balance the trade-offs between bike and car travel times, and compare our framework with methods from subproject C in chapter 7. Although this approach minimizes travel times by reallocating road space across Zurich, the resulting network's spatial distribution may impact safety, accessibility, connectivity, and attractiveness. To evaluate overall quality, we developed a Multi-Criteria Decision Analysis (MCDA) tool that integrates diverse data streams and evaluation metrics.

Developing an optimization algorithm for bike network planning

While cycling infrastructure promotes sustainability, health, and increased bike adoption, its implementation often sparks controversy due to the need to repurpose car lanes, parking spaces, or public transport routes. Thus, our approach aims to improve bikeability while minimizing negative impacts on other travel modes, in particular car accessibility. This trade-off is modeled through the concept of Pareto-optimality – solutions where no mode can be improved without worsening the other.

Unlike heuristic methods, which often lack transparency and neglect the broader implications of infrastructure changes, our approach systematically explores trade-offs between bike and car networks. To quantify bikeability, we use the concept of "perceived bike travel time", reflecting evidence that cyclists perceive dedicated bike lanes as faster. To optimize the network, we developed a linear programming approach that minimizes both (network-based) car travel times and perceived bike travel times (Wiedemann *et al.*, 2025). Experiments on real and synthetic data testify the effectiveness and superiority of this optimization approach compared to heuristic methods. In a full-city case study of Zurich, the approach yielded a redesigned bike network with a 43% reduction in perceived bike travel time, while maintaining acceptable levels of car accessibility.

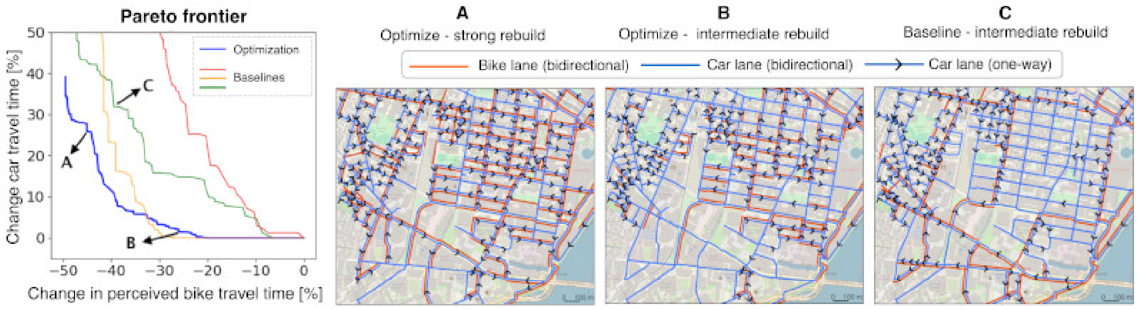


Figure 9.1: Comparison of network planning approaches via the Pareto frontier. Three examples generated with different algorithms and varying number of bike lanes are shown.

The output consists of a set of alternative lane reallocation scenarios, enabling planners to select network designs based on their preferred trade-offs. The framework is adaptable to different evaluation metrics, planning constraints, and urban contexts, making it a flexible decision-support tool for cities aiming to reallocate road space toward more sustainable mobility.

Developing a multi-factor evaluation for bike network designs

A robust evaluation of bike networks is essential to assess the effectiveness of envisioned bike network designs. Comprehensive evaluations typically involve complex decisions about evaluation methodology, which often requires systematically integrating diverse data sources and balancing multiple, sometimes conflicting, targets.

We developed a multi-target evaluation framework that combines a structured database of global bike network studies (Grisiute *et al.*, 2024) with advanced decision-making techniques. Our database includes over 270 bike network evaluation metrics and 41 qualitative criteria, such as safety. We combined this knowledge base with Multi-Criteria Decision Analysis (MCDA), a method used to structure and solve complex decision problems by considering multiple criteria and transparently capturing evaluation design choices. This integration reflects a collective understanding of what constitutes an effective bike network, blending various targets into a cohesive framework systematically.

We applied our methodology to the proposed E-Bike City network design, evaluating each street segment. A comparison of the results before and after road space optimization shows a notable improvement in overall bikeability, particularly in areas with previously poor overall cycling quality—resulting in an average increase in bikeability of 22.75%.

Webapp

A robust evaluation of bike networks is essential to assess the effectiveness of envisioned bike network designs. Comprehensive evaluations typically involve complex decisions about evaluation methodology, which often requires systematically integrating diverse data sources and balancing multiple, sometimes conflicting, targets. The approach is now part of SNMan and available as a web-app.

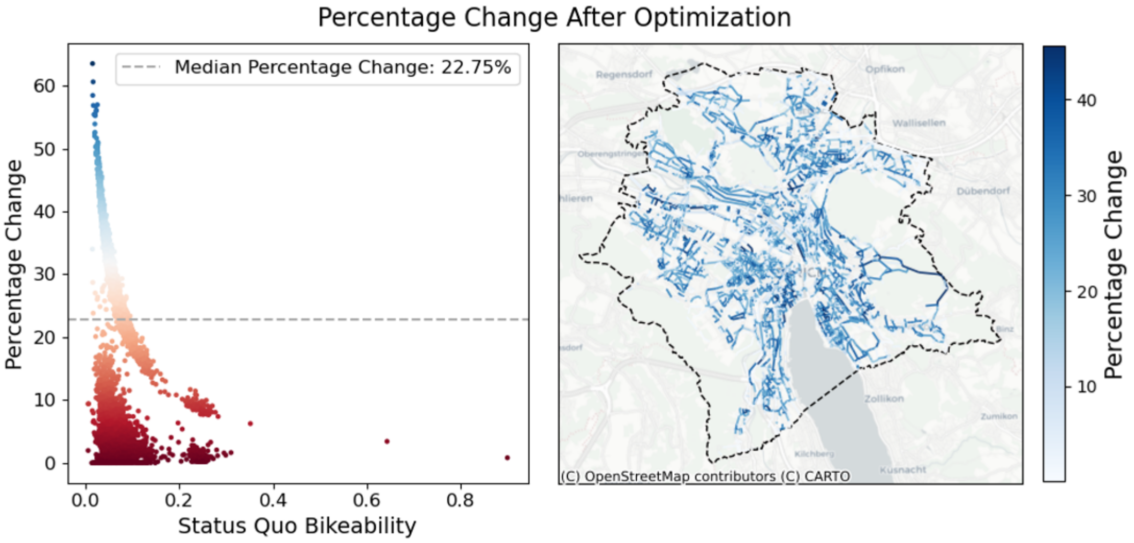


Figure 9.2: Percentage change of bikeability values between the status quo and the proposed road network design across Zurich.

10. Sustainability assessment of battery supply chains and externalities in e-bike mobility

Vanessa Schenker, Marco Miotti, Stephan Pfister

Abstract In the context of the E-Bike City, we assessed the environmental impacts of battery production and material sourcing to better understand the sustainability of electric mobility. Lithium, one of the key battery materials, shows highly variable environmental impacts depending on where and how it is produced, in most cases higher than previously estimated. These differences were integrated into updated emission factors and used to compare transport modes. Based on these findings, we report updated greenhouse gas emission intensities per km for different modes of transport, along with corresponding overall externalities.

Rethinking mobility also means rethinking materials. With the growing shift toward electrified transport, understanding the environmental impacts of the new technologies, such as Li-ion batteries, and materials involved is becoming increasingly important. This subproject explored the environmental impacts of Li-ion battery production, with a specific focus on the supply chains of key materials such as lithium, cobalt, nickel, and graphite. While all contribute to the battery's overall carbon footprint, lithium plays a particularly important role because of its soaring demand and the high variability in its environmental performance. These findings are then incorporated into mobility emission factors to allow assessing the benefits of an E-Bike City concerning environmental impacts.

Lithium mining and its environmental impacts

As the International Energy Agency IEA (2024) reports, lithium is experiencing the fastest growth in demand among battery metals. Current production levels are not sufficient to meet future needs. New mines must open, and each one brings a different environmental profile due to the geology, environmental conditions and applied technology. One key source of lithium is brines, salty underground or surface water bodies, which are increasingly important for meeting global demand. Based on the uniqueness of the sites, different technologies were developed to extract lithium and the amount of energy, water, and chemicals required for lithium mining varies greatly. However, how these differences translate into environmental impacts had not been investigated so far.

To better understand this variability, we performed life cycle assessments of lithium carbonate production from salt lakes, based on five operational sites in Chile, Argentina, and China. We developed a transparent and modular framework to systematically collect data from patents, technical and sustainability reports and to assess environmental impacts at a high spatial resolution. This approach allowed us to trace how local conditions, such as climate, energy source, reagent use, and brine composition, shape environmental performance. In a second step, we expanded this approach and investigated 90% of current production and key future projects across 25 sites worldwide. We revealed a substantial variability in environmental impacts driven by site-specific factors (mainly brine chemistry, energy sources, and processing technology). In particular, emerging extraction sites and technologies can lead to up to 7 times higher climate impacts and significantly greater water use compared to conventional methods, due to the need to process much larger volumes of low-grade or impure brines (figure 10.1). Importantly, this research highlights that future lithium projects are likely to be more resource- and energy-intensive than current operations because the quality of accessible brine resources is expected to decline over time, while resource prices probably increase and make its production economically viable. Therefore, environmental burden per unit of lithium carbonate produced may increase if no counteractions are employed.

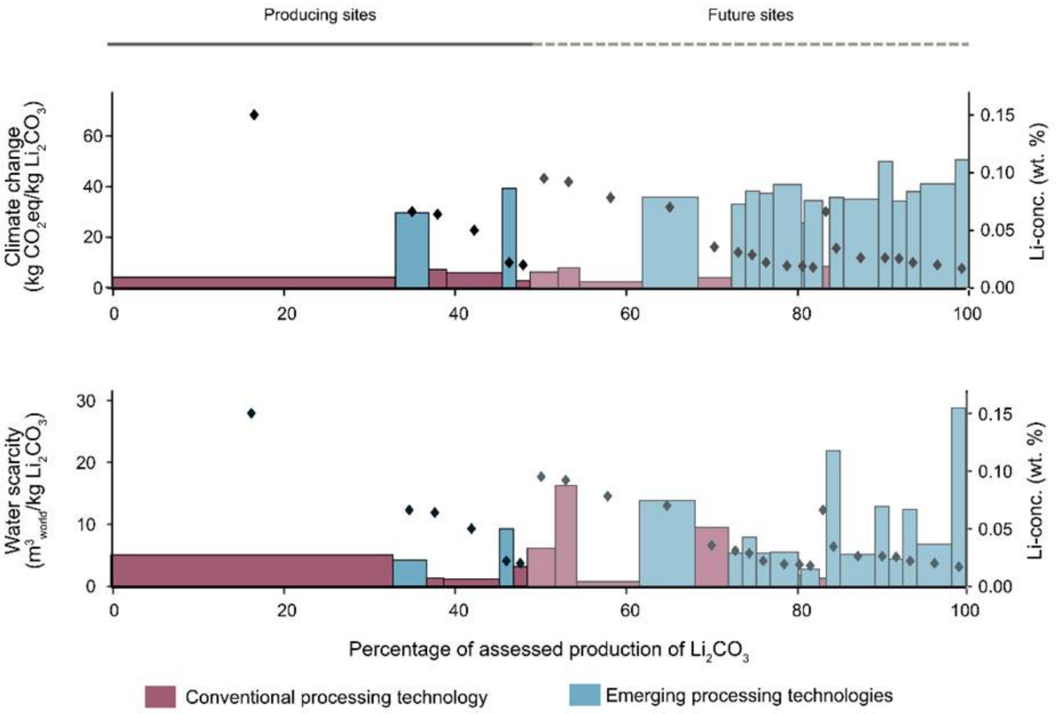


Figure 10.1: Climate change and water scarcity impacts of lithium carbonate production from brines. The right y axis indicates the Li concentration of the brines (represented by black diamonds).

Battery production and its materials

In parallel, we analyzed market data to estimate the carbon footprints of currently producing mines for lithium, cobalt, nickel, and graphite. These materials are core inputs for the two dominant battery chemistries used in e-mobility: NMC (nickel-manganese-cobalt) and LFP (lithium iron phosphate). A central finding of our research is that the carbon footprint per energy storage capacity of batteries varies substantially (NMC batteries: 59 – 115 kg CO2eq/kWh, LFP batteries: 54 – 69 kg CO2eq/kWh), and was misestimated in previous literature. One of the most important reasons is the source and production process of these materials.

Incorporating battery production emissions into mobility emission factors

We incorporated the updated inventories for lithium mining into existing assessments of lifecycle greenhouse gas emissions per transport service (measured as passenger-km) of different land-based modes of transport. Baseline GHG emissions (before the inventory updates) are based on mobitool and ecoinvent (Mobitool Association, 2023; ecoinvent, 2022; Sacchi and Bauer, 2023).

Mode	**Submode**	**GHG emissions** (gCO$_2$eq/p-km)	**All externalities** (CHF ct/p-km)			
			Total	Costs		Benefits
				Without accidents	Accidents only	Health
Walking		0	-95	0.5	2.5	-98
Bicycle	Regular	12	-36	1	24	-61
E-bike	(any)	20	-28	3	21	-52
Public transit	Bus (regular)	112	20	18	2	0
	Bus (trolley)	25	8	6	2	0
	Tram	16	3	1.5	1.5	0
	Rail (regional)	9	1	1	0	0
Car	Typical (gasoline)	226	12	9	3	0
	Typical (electric)	108	13	10	3	0

Table 10.1: GHG emissions and externalities per passenger-km for various transport modes.

In addition, we report overall externalities based on GHG emissions, air quality impact, ecology, biodiversity and landscape impact, and accidents for different land-based modes of transport. These externalities serve the assessment of the overall societal impact of the e-bike city and are based on a report produced for the Swiss federal government (Ecoplan and INFRAS, 2024). Aspects of this assessment also rely on mobitool lifecycle inventories, meaning that externalities are generally expected to be consistent with GHG emissions.

Results from the revised GHG emission inventories show that bicycles have substantially lower emissions and external costs per km as cars (Table 10.1). This is also true for e-bikes if they are used regularly despite their batteries (assuming a lifetime of 2,000 km per year over 10 years for regular e-bikes, and 3,000 km per year over 10 years for s-pedelecs; Sacchi and Bauer (2023)). Emissions of bicycles are also substantially lower than those of public transit if the latter predominantly consists of regular buses with diesel engines.

Total external costs for all active modes (walking, regular bicycles, and e-bikes) are negative, meaning that there is a net benefit from using these modes (Table 10.1). This is due to the positive impact of active mobility on personal health, compared to baseline physical activity levels that are typical for the Swiss population but without walking and cycling to get to specific destinations (Ecoplan and INFRAS, 2024). Accidents do substantially impact the external costs of bicycle-based modes, but not enough to compensate for their health benefits. Note that the accident rates underlying this assessment are based on the present infrastructure and behavior (i.e., not the E-Bike City).

11. Pedaling towards acceptance: Public preferences and cleavages in street transformation policies

Michael Wicki, Claudia Sinatra, Jake Stephan, Aura Huang, Alessio Guidon and David Kaufmann

Abstract Public acceptance of the E-Bike City transformation divides along political and lifestyle lines. A first experiment shows left-leaning individuals and frequent cyclists are more supportive, while drivers and right-leaning respondents express fairness and intrusiveness concerns. Ancillary measures like public transport help, but mainly among the supportive. A second experiment using visualized street redesigns reveals that greenery and social features increase acceptance, and willingness to cycle and live. Visuals also help bridge ideological divides by making benefits beyond infrastructure changes more tangible. These findings highlight the importance of justice perceptions and the role of design to communicate benefits in street transformations.

Cities today face two interlinked challenges: the negative externalities of car-dominated transport systems (including emissions, noise, and accidents) and the inefficient use of urban space, as private cars occupy a disproportionate share of it. In response, cities are increasingly seeking to reallocate street space to active mobility, public transport, and public life. Our subproject investigates public opinion on this transformation through the lens of the "E-Bike City" vision. This scenario entails a comprehensive reallocation of 50% of current street space to cycling, walking, and public transport, aiming to reduce car dependence and improve urban quality of life. Yet the successful implementation of such a far-reaching policy depends crucially on public support. To better understand public preferences, we conducted two large-scale survey experiments embedded in a nationally representative mobility panel of Swiss residents. Both experiments combine randomized design features with realistic framing to examine what drives acceptance and what inhibits it.

Experiments

Cleavages in acceptance: Transport habits, ideology and perceptions

The first experiment explored support for an E-Bike City policy proposal. Overall public opinion was split: 44.4% of respondents expressed support, while 43.4% were opposed. While the proposal was widely expected to be effective in fostering cycling, it was also perceived as restrictive individually and judged as unfair for society as a whole. Sociodemographic patterns emerged in expected ways, with urban residents, women, younger generations, and those with higher education showing more support.

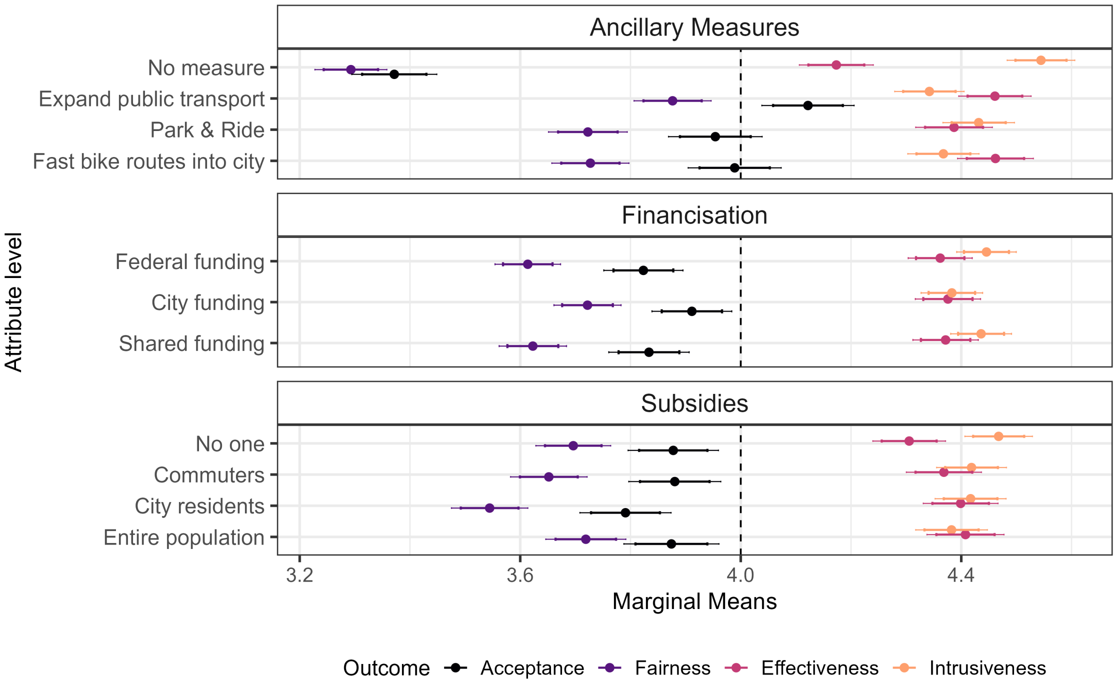


Figure 11.1: Marginal means of perceived acceptance, fairness, effectiveness, and intrusiveness for different levels of ancillary measures, financing models, and subsidy allocation in the E-Bike City policy vignette experiment. Values are based on pooled model estimates with 95% confidence intervals (N = 6495).

However, the most decisive cleavages were not demographic, but behavioral and ideological. Frequent cyclists and left-leaning respondents were substantially more supportive, while frequent drivers and right-leaning individuals tended to oppose the policy. These divides reflect deeper differences in values and mobility preferences, and they underscore the politicization of street space transformation. Importantly, the perception of effectiveness (e.g., improving cycling conditions or reducing emissions) is high across groups (see Figure 11.1). However, perceived effectiveness alone does not predict support. Instead, resistance is strongly associated with perceived unfairness and intrusiveness—suggesting that justice considerations are central to the public's evaluation. We also tested whether so-called ancillary measures, such as expanding public transport or creating park-and-ride infrastructure, increase acceptance. While such measures overall improve support slightly, their effect is most pronounced among those already inclined to support the policy, and they do little to bridge divides.

Street redesigns: Visualized implementation and public preferences

In the second experiment, we moved from abstract policy evaluation to concrete street reallocation scenarios. Participants evaluated pairs of redesigned streets based on visual representations (static or 360° images), varying across infrastructure, greenery, social space, cost, and financing. Here too, acceptance differed across transport lifestyles and ideological lines, but the cleavages were less pronounced. The visual nature of the designs shifted attention from political identity to spatial qualities. Greenery emerged as the most influential design feature across all outcomes (see Figure 11.2). It increased acceptance, made streets more attractive as residential environments, and enhanced willingness to cycle. Differences between main and side roads were also evident. Infrastructure improvements—such as protected cycle lanes—played a larger role on main roads. Side streets were generally more acceptable for residential use, even with minimal interventions. Visual format mattered as well. 360° images enhanced the salience of social spaces and generated higher acceptance levels than static images.

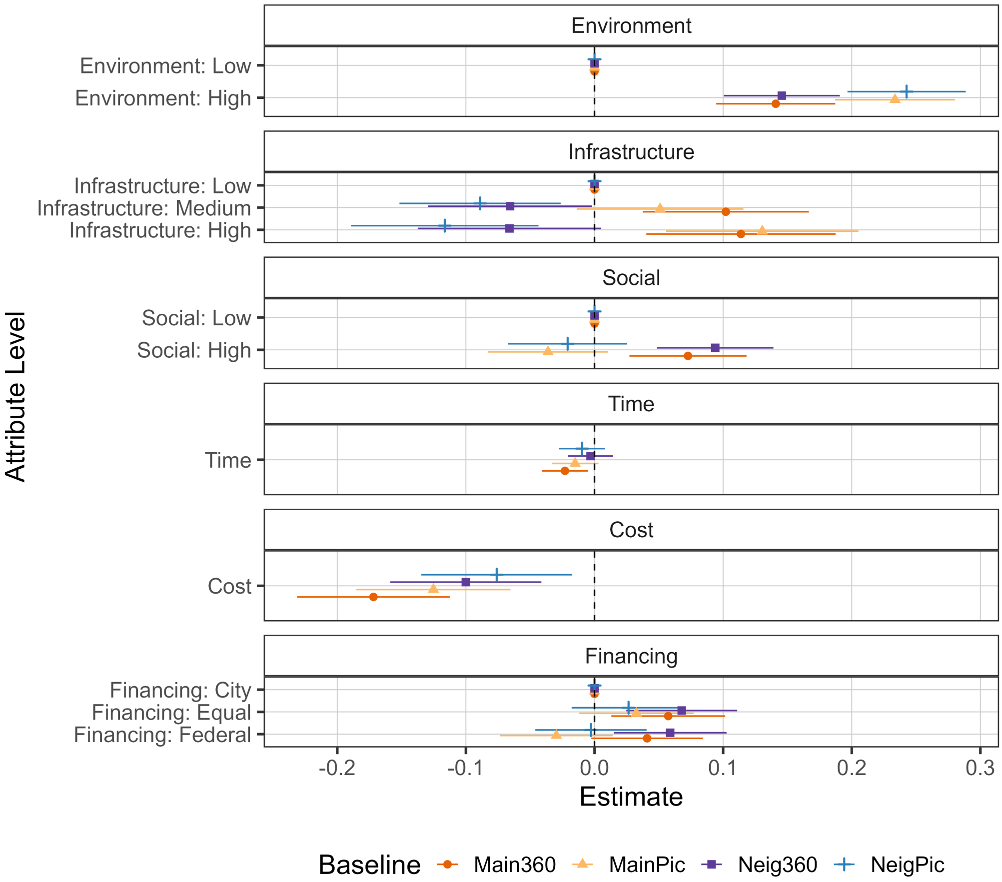


Figure 11.2: Estimated effects of built environment attributes on public acceptance of street redesigns across different street types and visual presentation formats. Values based on multilevel models of forced-choice responses between redesign scenarios (N = 5753).

Conclusion

Our results underline that public support for urban street reallocation is not merely a question of infrastructure provision. Rather, it is shaped by political and lifestyle cleavages, and depends on how people perceive the fairness, effectiveness, and everyday intrusiveness of the proposed changes. Abstract support remains polarized, but design and visualization can help bridge divides. Street transformations must therefore be more than technically sound; they must be just, legible, and meaningfully embedded in people's lived experience. Our findings show that integrating environmental and social qualities into street design – and making these qualities visible and tangible – can broaden support for ambitious urban mobility policies.

12. Mode-choice and the role of e-bikes in a sustainable mobility transition

Lucas Meyer de Freitas

Abstract Travel time increases for cars through road space reallocation is the most effective means of getting drivers out of their cars. At the same time, while attractive cycling infrastructure is imperative for making cycling attractive, e-bikes (25 km/h) and s-pedelecs (45 km/h) are more appealing to car drivers and can play a significant role in making cycling attractive for car drivers. At the same time, different car drivers have different attitudes towards cycling. In short, the bigger the car owned, the less the will to cycle by the driver.

A future mobility system that prioritizes cycling and public transport over car travel could dramatically shift how people move—especially if high-quality infrastructure supports modern bicycle types like e-bikes and s-pedelecs. We conducted a survey with 1'200 respondents in the Canton of Zurich as well as neighboring Cantons to find out the potentials as well as the reasons for choosing bikes, e-bikes and s-pedelecs. The key finding is that e-bikes and s-pedelecs can play an important role in replacing car trips, even for longer distances, while infrastructure quality and personal attitudes—especially car ownership—remain central in shaping travel choices.

To quantify the potential of this transformation, we implemented a two-step data collection approach. First, over 3,200 residents of Zurich and surrounding municipalities recorded a full day of travel in an interactive diary. Then, a subset of these respondents participated in a stated-preference survey based on a future scenario in which car lanes are replaced by wide, cohesive cycling infrastructure. The respondents were shown specific trips they had taken and were asked to choose between updated travel options, including e-bikes (up to 25 km/h) and s-pedelecs (up to 45 km/h), for those same journeys.

To provide realistic travel times, we used simulation tools that incorporate terrain, fitness level, and bicycle type. Car travel times were increased to reflect the removal of car lanes, based on a MATSim transport simulation. For example, morning peak car travel times increased by 80% due to reduced road capacity. These increased travel times were found to be a much stronger driver of behavioral change than pricing policies alone. The strongest proportional gains in mode share came from e-bikes and s-pedelecs, which together show a substantial increase in demand as shown in chapter 3. Interestingly, while public transport captured the largest absolute number of former car trips, the faster cycling modes showed the greatest growth in popularity—especially among car owners.

Elasticity results indicate that travel time has a much higher impact on people's choices than travel cost—especially for car drivers. The model estimates a car travel time elasticity of -0.71 in our E-Bike City scenario, compared to a baseline of just -0.17 in the Swiss national mobility survey (Gayda *et al.*, 2024). These results suggest that substantial reductions in car dependency require structural, supply-side changes—such as reallocating road space—rather than price signals alone.

Another interesting result of the mode choice model, is that different bicycle types appear to have trip distances for which demand for them is the highest: for trips up to 1.6km, conventional bikes have the highest demand across different bike types, followed by e-bikes (25 km/h) for trips up to 9km and s-pedelecs (45 km/h) for all trips with distances greater than that. The increased speed of s-pedelecs, which comes at a higher purchase cost, only seems to pay off for longer distance trips.

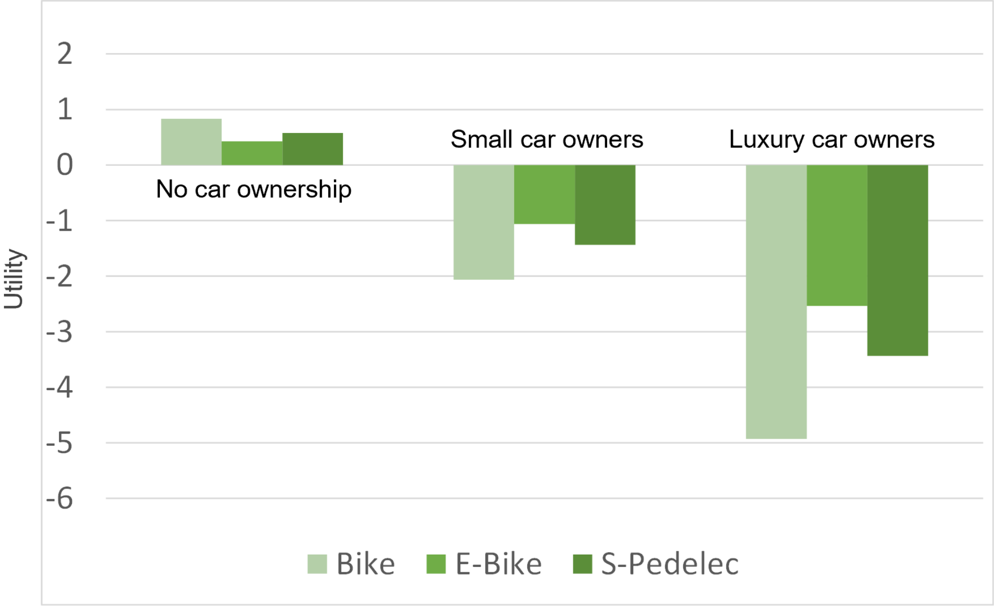


Figure 12.1: Utility of riding different bike types for different groups

In the mode-choice models we also introduced a novel variable in the model: a route-specific cycling infrastructure interaction term, which measures the share of the route that is safe and protected for cyclists. Our results show that this infrastructure quality strongly affects people's willingness to choose cycling—especially conventional bikes. For e-bikes and s-pedelecs, the influence of infrastructure is still present but somewhat less critical, possibly due to the higher speeds, which make the riders of these modes have less conflicts with cars.

Attitudes also play a key role. We used an Integrated Choice and Latent Variable (ICLV) model that links policy preferences (e.g., support for reducing parking or implementing 30 km/h zones) to deeper latent attitudes, which are in turn influenced by sociodemographic factors—especially car ownership. Owners of SUVs or luxury cars were much less supportive of cycling policies and much less willing to switch away from driving. Conversely, people without cars, or those who own small vehicles, were far more receptive to cycling and supportive of policy changes. Interestingly, among car drivers, the negative perception of e-bikes and s-pedelecs was lower than for conventional bicycles. This suggests that faster and more comfortable alternatives have a greater potential to trigger behavior change in a car-centric society. Figure 12.1 shows how the (dis-)utility of travelling by differing bicycle modes differ for those who do not own a car, versus small or luxury car owners.

For further reading see: Mode-choice modelling of a sustainable mobility transition considering different bicycle types (Meyer de Freitas *et al.*, 2025).

13. The cost of transforming into an E-Bike City and the resulting change in safety

David Zani and Bryan T. Adey

Abstract When thinking about a transition to an E-Bike City, two important factors are safety and construction costs. This subproject estimates the change in safety for cyclists resulting from infrastructure changes in the E-Bike City, and how much it will cost to build the infrastructure necessary for a transition to such a city. We used a machine learning model to quantify the amount of urban road space that needs to be transformed, and historical project data to estimate construction costs. To estimate the change in cyclist safety, we used official crash statistics and existing bicycle transport models.

Costs

Implementing the E-Bike City (EBC) will require financial investments in cycling infrastructure: new bike lanes, physical barriers between lanes, updated traffic signals, etc. These infrastructures are relatively cheap compared to building new roads or separated bike paths, but the costs can vary widely depending on the specific design that is implemented and the available road space. To make an estimate for the cost of implementing the EBC, three things are needed: a plan for how each type of road and intersection will be transformed; an overview of how many of each type of road and intersection currently exists in Zurich; and the costs for transforming each type of infrastructure into its new EBC version.

Other subprojects within EBC have provided the plans for how different road types and intersections will be transformed (Ballo and Cardoso, 2025). To create an overview of how much of each type of road exists in Zurich, we used a machine learning model (Zani and Adey, 2024). This model looks at aerial images of roads and is able to show with good accuracy where in the image the road is located.

With this approach, road space can be estimated for virtually any city that has existing aerial imagery. This method is therefore easy to apply in other cities and is also more accurate than conventional methods, including expert opinion and average lane width-based estimations. Lastly, for the transformation costs, we collected data on past cycling infrastructure projects from Swiss communes and cantons. This allowed us to estimate how much it would cost to transition each road type and intersection in Zurich into an EBC design, and then to summarise the costs for all road infrastructure in the city.

Safety

The safety of cyclists in the EBC can be expressed as the expected cyclist crash risk (the likelihood of being involved in a crash multiplied with the financial impact of such a crash). Crash likelihood is based on the number of crashes that occur on a road or at an intersection and the number of cyclists using that infrastructure. These data are provided by official crash statistics in Switzerland and cycling traffic models in Zurich (Amt für Mobilität, 2024), allowing us to calculate crash risk for Zurich's current roads and intersections, and for their transformed EBC versions. We can also think about safety in the EBC as being generally more similar to existing cycling cities, such as Amsterdam in The Netherlands or Bern in Switzerland. This comparison would capture other ways in which the EBC would be safer for cyclists, including a different culture and age of traffic participants and cyclists' feeling of safety that is difficult to quantify (Zani *et al.*, 2024).

Figure 13.1: The aerial image (left) used as input to the machine learning model and the resulting road space estimation (right).

Results

Based on these methods, we find that transitioning each type of road into an EBC road could cost as little as 41 million Swiss Francs (CHF), if the most cost-effective designs are chosen. The average cost of 58,300 CHF per kilometer shows how the EBC's focus on cost-efficient infrastructure transformations could result in relatively cheap implementation. More expensive designs are possible that could cost up to 320 million CHF, but the additional safety provided by these designs is small. Intersections are more expensive to transform, as these require the construction of physical barriers between lanes and traffic light reprogramming in many cases. The costs for transforming intersections are therefore around 256 - 315 million CHF, without a significantly cheaper option available.

The expected safety improvement can be quantified through a reduced cyclist crash risk, relative to the current crash rates, severities, and cycling volumes in Zurich. This reduction is likely to be around 22 million CHF per year, as safer infrastructure reduces both the likelihood (40% lower crash rate) and severity of bicycle crashes (71% fewer serious or fatal crashes) (see figure 13.2 for a map showing where the safety benefits in Zurich are expected). When comparing Zurich to cities with more developed cycling infrastructure (Amsterdam, Utrecht, Bern), a reduction of cycling crash rates by about 50% seems realistic. Considering the costs and safety improvements together, we can estimate that each CHF invested in cycling infrastructure could reduce the cycling crash risk by about 1.4 CHF over 25 years (Zani and Adey, 2025).

Conclusion

This subproject showed how an EBC could be implemented with relatively little financial investment in Zurich, and provide a significant benefit through improved cyclist safety. Together with other benefits through improved air quality, health, and public spaces, and reduced pollution and noise emissions, the financial investment required to create an EBC will most likely be worth the cost.

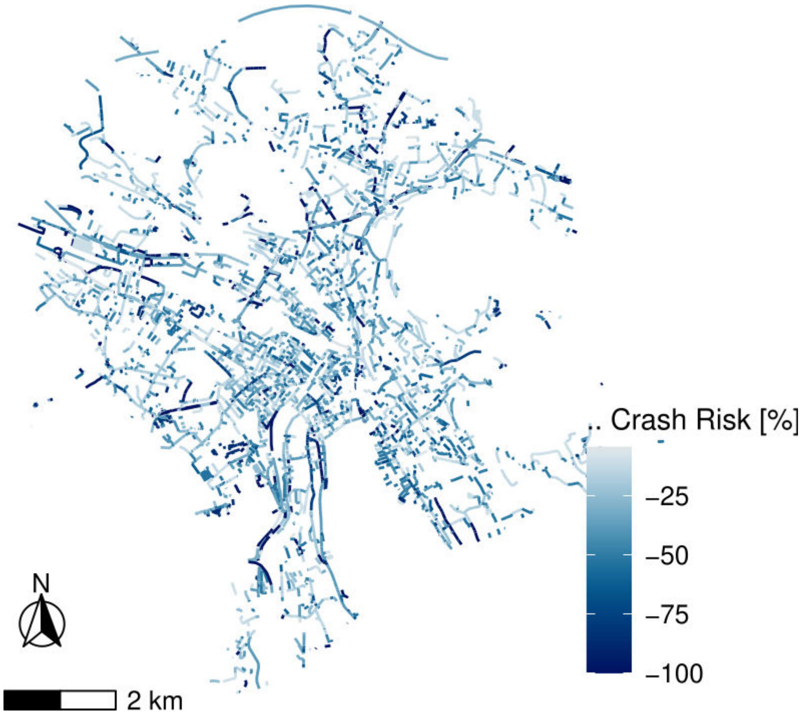


Figure 13.2: A map of Zurich's road network and the expected reduction in crash risk after implementing the E-Bike City designs.

14. Estimating choice models for daily schedules

Janody Pougala and Michel Bierlaire

Abstract This subproject applies the OASIS framework to estimate MATSim's schedule scoring function parameters, aiming for behaviorally realistic microsimulations. This method uses empirical data and a two-step estimation process, involving choice set generation via Metropolis-Hastings and parameter estimation through discrete choice models. Early results from Swiss data show realistic parameters and highlight the benefit of including start time in utility models. This approach supports the E-Bike City project by enabling more accurate scenario evaluations related to activity-travel behavior. Future work will refine travel-related parameters and explore how transport and land use shifts influence daily planning.

OASIS framework and parameter estimation

A drastic change in urban configuration is bound to affect activity and travel behavior in observable (differences in the choice of mode and location, distance traveled) and unobservable (changes in habits and preferences) ways. Quantifying the individual modifications induced by the E-Bike City is necessary to develop reliable indicators to assess the project's feasibility. In addition, understanding existing behavior and how individuals occupy and interact with their environment in time and space is necessary to develop the E-Bbike City appropriately. This collaboration applies the OASIS framework (Pougala *et al.*, 2023) to produce behaviorally realistic simulations of the E-Bike City scenarios.

OASIS is an activity-based simulation framework that outputs distributions of likely activity schedules for given individuals. It answers two main research gaps in the activity-based literature: (i) accurately modeling the behavior-activity-travel interactions, which explain the scheduling process while maintaining a high level of theoretical soundness and practical flexibility, (ii) dealing with the uncertainty due to the lack of data and knowledge on these interactions to estimate and calibrate scheduling models.

Each schedule is associated with a utility function, indicating the satisfaction an individual derives from an activity plan. The parameters of this function are notoriously difficult to estimate, given the infinite possible combinations of schedules, and the fact that the majority of these combinations are unknown even to the decision-maker. We propose a two-step strategy to estimate the utility function parameters:

1. We generate a choice set of feasible alternatives using the Metropolis-Hastings algorithm. This choice set contains a given number of schedules, each associated with a probability of being chosen. The set must contain the chosen schedule and both high and low probability alternatives to ensure the consistency of our estimates.
2. Based on this set of alternatives, we apply a discrete choice approach to derive the maximum likelihood estimators of the parameters.

Estimation of MATSim parameters

The primary tool used to simulate different scenarios is MATSim. Each agent in the microsimulation is characterised by a schedule of daily activities, scored by a utility function that is, among others, dependent on activity duration and network conditions (Charypar and Nagel, 2005). The scoring function parameters are typical values from Vickrey's model for departure time choice, and are not estimated.

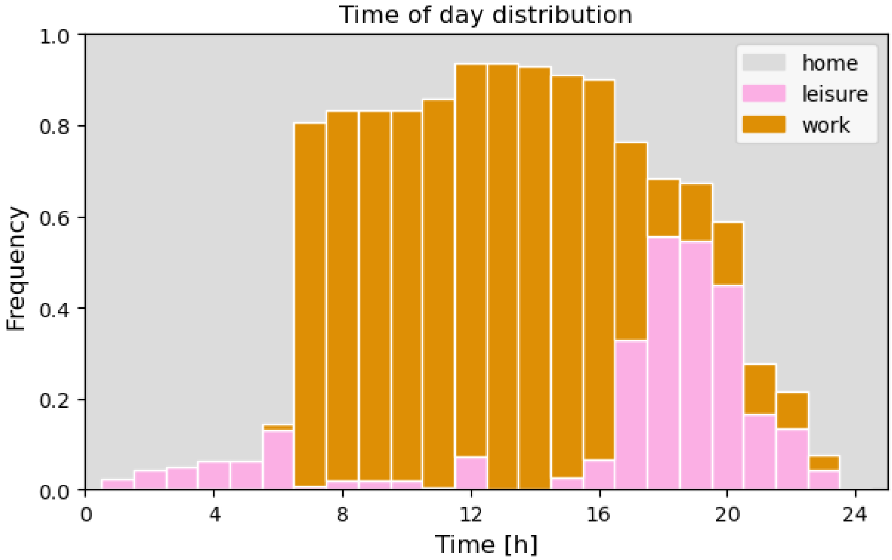


Figure 14.1: Example of output.

In this project, we estimate the scoring function parameters using the 2-step methodology presented above. We also compare the performance of the scoring function with two other utility specifications, the OASIS linear specification (Pougala *et al.*, 2022), and the PlanomatX function (Feil, 2010), to understand the importance and contribution of dimensions such as activity start time and duration on the utility function.

For all three specifications, we have estimated parameters for a small sample of the Swiss Mobility and Transport Microcensus (BFS and ARE, 2017) and choice sets of 10 alternatives per person. Regarding the utility specifications, initial compar-

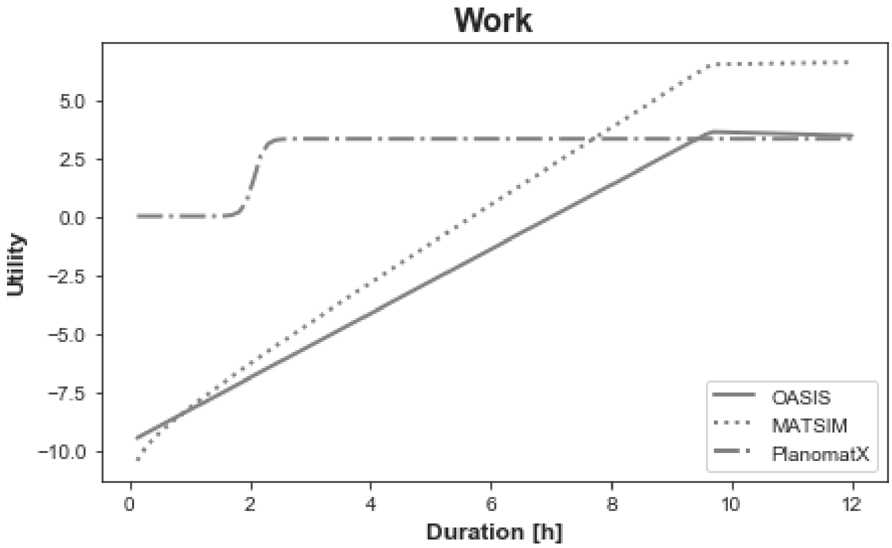


Figure 14.2: Comparison of work duration utility specifications.

isons of the impact of activity duration on utility (Figure 14.2) show that all specifications behave similarly for constraining activities (education and work), but differences can be observed for flexible activities (leisure and shopping). Comparing schedule simulation outputs between the OASIS and the PlanomatX function shows that the inclusion of start time in the utility function improves the realism of the results (Pougala *et al.*, 2023a).

E-Bike City output

Reviewed journal contributions

Ballo, L., K. W. Axhausen and M. Raubal (2024) Designing an E-Bike City: An automated process for network-wide multimodal road space reallocation, *Journal of Cycling and Micromobility Research*, **2**, 100048.

Ballo, L., L. Meyer de Freitas, A. Meister and K. W. Axhausen (2023) The E-Bike City as a radical shift toward zero-emission transport: Sustainable? Equitable? Desirable?, *Journal of Transport Geography*, **111**, 103663.

Brunner, J., Y.-C. Ni, A. Kouvelas and M. Makridis (2024) Microscopic simulation of bicycle traffic flow incorporating cyclists' heterogeneous dynamics and non-lane-based movement strategies, *Simulation Modelling Practice and Theory*, **135**, 102986.

Gallo, F., N. Sacco and F. Corman (2023) Network-wide public transport cccupancy prediction framework with multiple line interactions, *IEEE Open Journal of Intelligent Transportation Systems*, **4**, 815–832.

Grisiute, A., N. Wiedemann, P. Herthogs and M. Raubal (2024) An ontology-based approach for harmonizing metrics in bike network evaluations, *Computers, Environment and Urban Systems*, **113**, 102178.

Manser, P., T. Haering, T. Hillel, J. Pougala, R. Krueger and M. Bierlaire (2024) Estimating flexibility preferences to resolve temporal scheduling conflicts in activity-based modelling, *Transportation*, **51** (2) 501–528.

Meister, A., M. Felder, B. Schmid and K. W. Axhausen (2023) Route choice modelling for cyclists on urban networks, *Transportation Research Part A: Policy and Practice*, **173**, 103723.

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Allemann, D. and M. Raubal (2015) Usage differences between bikes and e-bikes, paper presented at the *18th International Conference on Geographic Information Science as an Enabler of Smarter Cities and Communities (AGILE 2015)*, Lisbon. June 2015.

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Gan, G., A. Meister and M. Balac (2024) Cycling mode choice: A revealed performance study in switzerland, paper presented at the *103rd Annual Meeting of the Transportation Research Board (TRB 2024)*, Washington, D.C., January 2024.

Kaufmann, D., M. Wicki, C. Sinatra and A. Huang (2025) Creating urban space: A visualization-based survey experiment for urban street redesign, paper presented at the *Conference Villes, Ecological Transition and Local Politics: A Comparative Perspective*, Paris, March 2025.

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Maurer, L., A. Meister and K. W. Axhausen (2025) GPS-based speed profiles for cyclists in Zurich, Switzerland, paper presented at the *104th Annual Meeting of the Transportation Research Board (TRB 2025)*, Washington, D.C., January 2025.

Meister, A., L. Zheng and M. Balac (2025) Probabilistic routing for agent-based simulations, paper presented at the *104th Annual Meeting of the Transportation Research Board (TRB 2025)*, Washington, D.C., January 2025.

Ni, Y.-C., M. Makridis and A. Kouvelas (2023) Investigating link- and network-level bicycle traffic flow characteristics using a microsimulation approach, paper presented at the *11th Symposium of the European Association for Research in Transportation (hEART 2023)*, Zurich, September 2023.

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Wicki, M. (2025) Public support for sustainable urban mobility: A survey experiment on the E-Bike City concept in Switzerland, paper presented at the *1st ETH Domain Conference on Social Sciences on Environment, Technology and Sustainability*, Dübendorf, January 2025.

Wicki, M., C. Sinatra, A. Huang and D. Kaufmann (2025) Exploring public preferences for urban street redesign: A visualization-based stated choice experiment in Switzerland, paper presented at the *Conference Creating Healthy and Successful Cities (EURA 2025)*, Bristol, June 2025.

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Gayda, S., A. Fedosseev, M. Ruyssen, M. Kouwenhoven, R. Tapia and M. Bierlaire (2024) Analysis of the stated preference survey 2021 on mode, route and departure time choices, *Final report*, Federal Office for Spatial Development (ARE), Berne.

Meyer de Freitas, L., M. Miotti and D. Zani (2024) Effects of an E-Bike City, *Cost-benefit analysis*, ETH Zurich, Zurich, April 2024.

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Ballo, L. (2025) Addressing large challenges with small infrastructure: Envisioning the E-Bike City, Doctoral Thesis, ETH Zurich, Zurich.

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Andersson, W., F. Fuchs, Z. Ansarilari and F. Corman (2025) Stochastic transit network design considering weather conditions, *Working Paper*, IVT, ETH Zurich, Zurich.

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Ballo, L., L. Meyer de Freitas, A. Meister and K. W. Axhausen (2022) Introducing the E-Bike City: Sustainable mobility through urban design?, *Arbeitsberichte Verkehrs- und Raumplanung*, **1770**, IVT, ETH Zurich, Zurich.

Ballo, L., A. Sallard, L. Meyer de Freitas and K. W. Axhausen (2024) Accessibility in an E-Bike City, paper presented at the *24th Swiss Transport Research Conference (STRC 2024)*, Ascona, May 2024.

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Meyer de Freitas, L. and K. W. Axhausen (2022a) Cycling potentials in Switzerland: An assessment of its determinants using health survey data and first results, paper presented at the *22nd Swiss Transport Research Conference (STRC 2022)*, Ascona, May 2022.

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Ni, Y.-C., M. Makridis and A. Kouvelas (2023) Three-dimensional macroscopic fundamental diagrams for dedicated bicycle and car traffic in an actuated signal control network, paper presented at the *23rd Swiss Transport Research Conference (STRC 2023)*, Ascona, April 2023.

Ni, Y.-C., A. Mohapatra, M. Makridis and A. Kouvelas (2025) Congestion-aware optimization of urban road space allocation for cars and bicycles, paper presented at the *25th Swiss Transport Research Conference (STRC 2025)*, Ascona, May 2025.

Pougala, J., T. Hillel and M. Bierlaire (2023) From one-day to multiday activity scheduling: Extending the OASIS Framework, paper presented at the *23rd Swiss Transport Research Conference (STRC 2023)*, Ascona, May 2023.

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Zani, D. (2025a) Cycle infrastructure implementation costs, paper presented at the *25th Swiss Transport Research Conference (STRC 2025)*, Ascona, May 2025.

Zani, D. (2025b) Cycling infrastructure evolution in Swiss cities, paper presented at the *25th Swiss Transport Research Conference (STRC 2025)*, Ascona, May 2025.

Zani, D., C. Kielhauser and B. T. Adey (2023) Overcoming challenges in cost-benefit analysis of urban cycling infrastructure, paper presented at the *23rd Swiss Transport Research Conference (STRC 2023)*, April 2023.

Public presentations and other invited talks

Axhausen, K. W. (2022) E-Bike City: Welcome, presentation at the E-Bike City: Designing sustainable streets - Kick-off Event, Zurich, November 2022.

Axhausen, K. W. (2023a) Could an E-Bike (+ walking, transit, scooter) City work?, presentation at the 5th Bridging Transportation Researchers Conference (BTR5), online, August 2023.

Axhausen, K. W. (2023b) E-Bike City: An answer to our transport dead-end?, presentation at the SUMO User Conference 2023, Berlin, May 2023.

Axhausen, K. W. (2023c) E-Bike City: Verifying a vison, presentation at the Guest Lecture at the Department of Civil Engineering, University of Sydney, online, October 2023.

Axhausen, K. W. (2023d) How to model the E-Bike City?, presentation at the Seminar "From Traffic Modeling to Smart Cities and Digital Democracies", ETH Zurich, October 2023.

Axhausen, K. W. (2023e) Projekt E-Bike-City, presentation at the DAV-Personalversammlung, Zurich, April 2023.

Axhausen, K. W. (2024a) Assessing major changes in the transport systems: The case of the E-Bike City, presentation at the TMI Wise Seminar, Takashima, September 2024.

Axhausen, K. W. (2024b) E-Bike City: Plan B for sustainable transport?, presentation at the ITLS Seminar 2024, University of Sydney, April 2024.

Axhausen, K. W. (2024c) How to assess a mayor network change? The case of the E-Bike City, presentation at the MSc Class, Kyoto University, Kyoto, October 2024.

Axhausen, K. W. (2024d) What next when BAU doesn't work anymore?, presentation at the MIT Mobility Forum, online, December 2024.

Axhausen, K. W., D. Kaufmann and C. Elliot (2023) E-Bike City, presentation for the Tiefbauamt, Zurich, November 2023.

Ballo, L. (2022a) E-Bike City: An urban transformation for a sustainable future?, presentation at the Center for Sustainable Future Mobility: Kick-off Symposium, May 2022.

Ballo, L. (2022b) E-Bike City: Nachhaltig? Gerecht? Wünschenswert?, presentation at the Universitätstagung Verkehrswesen 2022, Weimar, September 2022.

Ballo, L. (2023a) E-Bike City: Masterplan for Zurich, presentation at the Elcykelkommunen – en vej til klimavenlig og sund mobilitet? Gate 21 Webinar, online, December 2023.

Ballo, L. (2023b) Modeling transport networks resulting from alternative allocations of road space, poster presentation at the Center for Sustainable Future Mobility Symposium 2023 (CSFM 2023), Zurich, June 2023.

Ballo, L. (2023c) Modelling road space allocation on street networks for radical sustainable mobility transitions, presentation at the 23rd Swiss Transport Research Conference (STRC 2023), Ascona, May 2023.

Ballo, L. (2024a) E-Bike City, presentation at the US Mayors in Switzerland, Zurich, April 2024.

Ballo, L. (2024b) E-Bike City masterplan: Designing a car-reduced urban mobility future for Zurich, abstract presented at the International Scientific Conference on Mobility and Transport (mobil.TUM 2024), Munich, April 2024.

Ballo, L. and L. Meyer de Freitas (2022) E-Bike City: Konzept und Verlagerungspotentiale auf das Velo, presentation at the Alumni Verkehrsingenieurtag 2022, Zurich, April 2022.

Ballo, L., L. Meyer de Freitas, A. Meister and K. W. Axhausen (2022) Rebuilding streets for sustainable transport: The E-Bike City?, presentation at the 6th Annual Meeting of the Cycling Research Board (CRB 2022), Amsterdam, October 2022.

Ballo, L., A. Sallard, L. Meyer de Freitas and K. W. Axhausen (2024) How will an E-Bike City change our accessibility?, presentation at the 8th Annual Meeting of the Cycling Research Board (CRBAM 2024), Zurich, September 2024.

Brunner, J., M. Makridis and Y.-C. Ni (2023) An integrated microscopic bicycle simulation model considering non-lane-based traffic characteristics, presentation at the 23rd Swiss Transport Research Conference (STRC 2023), Ascona, May 2023.

Elliot, C. (2024a) E-Bike City, presentation at the Niederländisch-Schweizerische Netzwerk-Veranstaltung, Zurich, March 2024.

Elliot, C. (2024b) E-Bike City, presentation at the grand opening of M-Way E-Bike Store, Berne, March 2024.

Elliot, C. (2024c) E-Bike-City Zürich: Vision eines nachhaltigen Verkehrs, presentation for the Verein Klimagrosseltern Schweiz, Zurich, August 2024.

Elliot, C. (2024d) The future of sustainable commuting, presentaton at Deloitte, Zurich, June 2024.

Elliot, C. (2024e) Shifting cities towards micromobility: Understanding the citizen's perspective in an E-Bike City, presentation at the Future Cities Laboratory Seminar, online, February 2024.

Elliot, C. (2024f) Traffic evaporation through redesigning streets: The vision of E-Bike City and how to change the narrative, presentation at the public symposium Bike Sharing and Co - How to do it well, Wiesbaden, September 2024.

Elliot, C. (2024g) Weshalb eine E-Bike-City?, presentation at the E-Motion Jubiläumsveranstaltung, Dietikon, March 2024.

Elliot, C. (2025a) E-Bike City, presentation at the ETH Zurich Sustainability Day, Zurich, April 2025.

Elliot, C. (2025b) How an E-Bike City leads to safer cycling in cities: How can we use technology to address the increase in (e)bike accidents and encourage safer cycling in cities?, presentation at the Cycling Hack, Geneva, May 2025.

Elliot, C., K. W. Axhausen, A. D. Marra, F. Fuchs, F. Corman, L. Ballo, C. Livingston, M. Balac, Y.-C. Ni, M. Makridis, A. Kouvelas, N. Wiedemann, A. Grisiute, M. Raubal, V. Schenker, M. Miotti, S. Pfister, S. Hellweg, M. Wicki, C. Sinatra, D. Kaufmann, L. Meyer de Freitas, A. H. G. Meister, D. Zani, B. T. Adey, J. Pougala and M. Bierlaire (2024a) What we learned so far with the E-Bike City research D-BAUG lighthouse project, presentation at the IVT Seminar, Zurich, July 2024.

Elliot, C., D. Freitag, T. Hug and F. Perret (2024b) Strasse als Lebensraum, presentation at the Veloforum Schweiz, Zurich, May 2024.

Elliot, C., M. Wicki, R. Egan and K. W. Axhausen (2024c) Exploring the narrative behind Zurich's E-Bike City research project: A thematic analysis of self-identifying transport user types, presentation at the 8th Annual Meeting of the Cycling Research Board (CRBAM 2024), Zurich, September 2024.

Elvarsson, A. B., D. Zani and B. T. Adey (2024) Fast lane for planning cycling infrastructure, presentation at the 8th Annual Meeting of the Cycling Research Board (CRBAM 2024), Zurich, September 2024.

Felder, M., A. Meister and K. W. Axhausen (2022) Choice set generation for large-scale cycling networks, presentation at the 22nd Swiss Transport Research Conference (STRC 2022), Ascona, May 2022.

Fuchs, F. and F. Corman (2022) Multi-scale responsive public transport for bi-modal demand, poster presentation at the E-Bike City: Designing Sustainable Streets - Kick-off Event, Zurich, November 2022.

Fulton, E., Y.-C. Ni and A. Kouvelas (2024) Assessing the influence of bike lane allocation on network traffic performance using microsimulation, presentation at the 8th Annual Meeting of the Cycling Research Board (CRBAM 2024), Zurich, September 2024.

Grisiute, A., N. Wiedemann, H. Martin and M. Raubal (2023) Ontology-based approach for harmonizing metrics in bike network evaluations, presentation at the 7th Annual Meeting of the Cycling Research Board (CRBAM 2023), Wuppertal, October 2023.

Grisiute, A., N. Wiedemann and M. Raubal (2024) Network design and evaluation for the E-bike City vision, poster presentation at the Center for Sustainable Future Mobility Symposium 2024 (CSFM 2024), Zurich, May 2024.

Hintermann, B., J. Roth, L. Schwab, K. W. Axhausen, A. Meister, L. Meyer de Freitas and T. Götschi (2023) Mobility pricing to promote e-biking and reduce transportation externalities: A GPS-tracked experiment, presentation at the 23rd Swiss Transport Research Conference (STRC 2023), Ascona, May 2023.

Klasovitá, V. and F. Corman (2023) Line planning for time-varying passenger demand in railways, poster presentation at the 10th International Conference on Railway Operations Modelling and Analysis (RailBelgrade 2023), Belgrade, April 2023.

Livingston, C. (2022) E-Bike City: Designing sustainable streets, presentation at the E-Bike City: Designing sustainable streets - Kick-off Event, Zurich, November 2022.

Livingston, C. (2023a) E-Bike City: A vision of sustainable transport, presentation at the GreenBuzz Thematic Event: Driving Towards Zero Emissions - The Future of Sustainable Mobility, Zurich, October 2023.

Livingston, C. (2023b) Weshalb eine E-Bike-City?, presentation at Switzerland's Congress for Light Electric Mobility (SLEM), Berne, September 2023.

Livingston, C. and K. W. Axhausen (2023) Cycling norms for the E-Bike City: An interplay of policy, engineering, and culture, presentation at the 7th Annual Meeting of the Cycling Research Board (CRBAM 2023), Wuppertal, October 2023.

Marra, A. D., F. Gallo, T. Spanninger and F. Corman (2022) The impact of weather on transit demand, poster presentation at the E-Bike City: Designing Sustainable Streets - Kick-off Event, Zurich, November 2022.

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Meister, A., M. Balac, L. Zheng and K. W. Axhausen (2024) Route choice model integration into MATSim, presentation at the 8th Annual Meeting of the Cycling Research Board (CRBAM 2024), Zurich, September 2024.

Meister, A., M. Felder, B. Schmid and K. W. Axhausen (2023) Route choice modelling for cyclists on dense urban networks, presentation at the 102nd Annual Meeting of the Transportation Research Board (TRB 2023), Washington D.C., January 2023.

Meyer de Freitas, L. and K. W. Axhausen (2023a) Evaluating mode-shift potentials to cycling based on individual capabilities, poster presentation at the 102nd Annual Meeting of the Transportation Research Board (TRB 2023), Washington D.C., January 2023.

Meyer de Freitas, L. and K. W. Axhausen (2023b) Evaluating willingness-to-pay for cycling infrastructure in Switzerland, presentation at the 7th Annual Meeting of the Cycling Research Board (CRBAM 2023), Wuppertal, October 2023.

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Pougala, J., T. Hillel and M. Bierlaire (2022) Parameter estimation for activity-based models, presentation at the 22nd Swiss Transport Research Conference (STRC 2022), Ascona, May 2022.

Wicki, M. (2024) Pedaling towards acceptance, presentation at the NSL Forum & Cycling Research Board 2024, Zurich, September 2024.

Zani, D. (2024a) E-Bike City, presentation at the ETH Net Zero Day, Zurich, May 2024.

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Appendices

A. E-Bike City street visualizations

A.1 Albisriederplatz, Zurich: Overview

A.2 Albisriederplatz, Zurich: Cyclists

A.3 Albisriederplatz, Zurich: Pedestrians

A.4 Baslerstrasse, Zurich: Overview

A.5 Baslerstrasse, Zurich: Cyclists

A.6 Baslerstrasse, Zurich: Motorists

A.7 Langmauerstrasse, Zurich: Cyclists

A.8 Langmauerstrasse, Zurich: Motorists

A.9 Winterthurerstrasse, Zurich: Overview

A.10 Winterthurerstrasse, Zurich: Cyclists

A.11 Winterthurerstrasse, Zurich: Pedestrians

Scan the code for more visualizations of the E-Bike City:

B. E-Bike City network map of Zurich

Lukas Ballo

The attached map shows the redesigned road network of Zurich, created entirely through a reorganization of existing road space—no new roads were added. The majority of road space is dedicated to small vehicles such as bicycles and e-bikes, forming a dense and connected cycling network. A reduced set of motorized lanes ensures essential car access, primarily through a network of one-way streets. High-quality public transport is maintained throughout, with all existing tram and bus lanes preserved and the lane layout designed to support all current public transport routes. The network plan was generated using the SNMan tool, developed as part of the E-Bike City project and available open source at: https://github.com/lukasballo/snman/.

Scan the code for a digital version of the E-Bike City network map: