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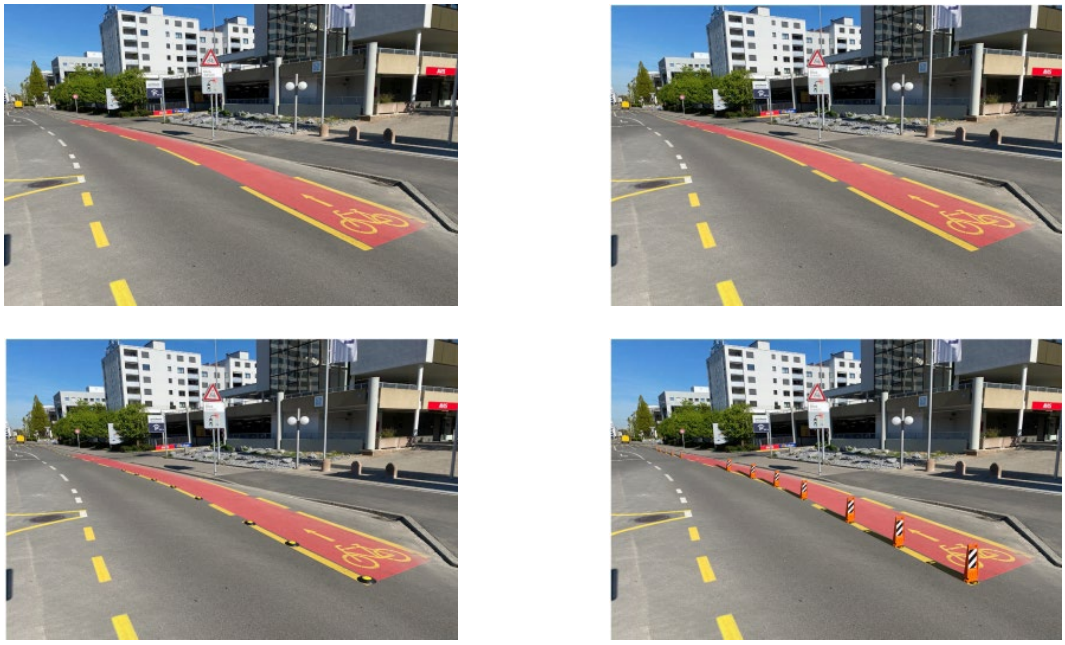

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Overcoming challenges in cost-benefit analysis of urban cycling infrastructure

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Abstract

This paper explores the challenges in conducting Cost-Benefit Analysis (CBA) for urban cycling infrastructure. The authors discuss two key difficulties: determining the objective safety benefits and estimating the costs associated with implementing the infrastructure. To overcome these challenges, the authors conducted a study in Zürich, aiming to convert the relative safety of cycling infrastructure to absolute safety benefits, and assess the impact of new infrastructure on different classes of riders. They also classified different types of cycling infrastructure and estimated their approximate implementation costs. The authors found that despite the challenges, cycling infrastructure consistently has a positive net benefit. Under reasonable assumptions, the infrastructure pays off within two years and provides a benefit-cost ratio of 9 to 31. This suggests that the investment in cycling infrastructure is a wise decision for policymakers and urban planners, even with the difficulties in accurately determining the costs and benefits. The findings of this study can inform future CBA research on cycling infrastructure and contribute to evidence-based decision-making in urban planning.

Keywords

Cost-benefit analysis; bicycling; infrastructure; accidents

Preferred citation style

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1 Introduction and background

1.1 Motivation

Bicycling is increasingly being considered an important mode for solving many urban transportation-related challenges. This includes traffic congestion, mobility justice, noise and particle emissions, accessibility, road safety, and quality of the urban space. The introduction of new technologies, especially the proliferation of e-bikes and cargo bikes, encourages new user groups to cycle (such as the elderly), while cargo bikes could be a useful tool for last-mile deliveries in cities, reducing the need for large trucks in urban environments. It is therefore timely to consider the ways in which bicycles could take on a bigger role in urban transportation, and specifically the costs and benefits that would be incurred when bicycling is promoted as a mode for urban transportation.

The costs and benefits of cycling in urban areas has received increasing attention, growing in tandem with the interest in cycling as an urban mode of transportation. Both governments and academics are launching research into bicycling. These range from studies on objective and subjective safety, external benefits such as health and pollution reduction, possibility of deliveries with cargo bikes, demand elasticities across other mode choices, induced demands, and the costs of implementing bicycle infrastructure. These studies are complicated for several reasons, including challenges in estimating the safety aspects of cycling and the estimation of cycling infrastructure costs. Moreover, the urban context strongly affects the implementation and effectiveness of cycling infrastructure, so research findings are usually not transferrable to other cases.

1.2 Challenge of estimating safety

The first challenge, estimation of safety, has several reasons, including the relatively low number of cyclists and therefore accidents, the high share of unreported accidents, and the role of culture in transportation. Safety is usually quantified as accident risk, i.e., the chance of having an accident multiplied with the consequence of the accident. This introduces two challenges: the chance of having an accident can only be calculated if both exposure and accident numbers are known. Both of these values are difficult to estimate. Estimating exposure requires counting of cyclists, usually automated, which has not been implemented as widely as vehicular traffic counts. Cyclist exposure values are therefore usually only available for a few links in a network. Accident numbers are also difficult to estimate, since about 80-90% of accidents (mostly self-accidents without injury) are not reported at all

(Ringel et al., 2022). Even if counts and accidents are consistently measured, another challenge in estimating safety is the impact of driving culture. Regions that have a widely accepted culture of cycling, such as cities in the Netherlands, observe different behavior of road users than a region that is not accustomed to cycling, such as many Swiss or North American cities. Even within a city, accident trends can vary between different parts (see for example Kielhauser et al., 2020). This means that findings about safety in one region are not necessarily applicable to another region, as the context might be different. Due to these challenges in estimating exposure, accident numbers, and impact of context, calculating the safety benefits of cycling infrastructure is difficult.

1.3 Challenge of estimating infrastructure costs

In addition to the safety benefits, costs of cycling infrastructure are not easily determined. This is mainly due to the fact that the cycling infrastructure itself is cheap and easily implemented relative to road infrastructure in general. When a road is built or maintained, cycling infrastructure is usually "added on". It often does not receive its own account (Taylor & Hiblin, 2017). In addition, there are many different types of cycling infrastructure, ranging from paint to physically separated infrastructure and bridges, tunnels, and parking structures. Linear facilities along a road are also different from intersections. Lastly, the context of the infrastructure matters, i.e., the urban infrastructure it is embedded in. For example, does the implementation require land purchases, change in signage, or removal of some existing elements (trees, tram tracks, parking spaces)? This has led to wide ranges in possible costs for cycling infrastructure when data is available. When no data is available, which is often the case in urban settings, an order of magnitude is usually the best possible estimate for costs. The general uncertainty around the type of infrastructure and its share of costs in urban road projects make it difficult to assign a specific cost to the construction of bicycling infrastructure, further complicating its evaluation.

Due to the challenges of measuring safety impacts and costs of cycling infrastructure, it is difficult to systematically quantify the costs and benefits of cycling infrastructure for use in transportation planning. This makes it difficult to argue for the implementation of cycling infrastructure in a quantitative way, which leads to resistance to or delays in its implementation. However, it has been shown that cycling infrastructure leads to higher numbers of cyclists and a high benefit for society. Cycling has been linked to reduced health costs, higher work productivity, lower emissions, lower traffic congestion, higher quality urban spaces, and more just transportation systems. Therefore, we aim to contribute to the analysis of the costs and benefits of cycling infrastructure to aid decision making about its implementation in urban settings.

1.4 Boundaries

This work focuses on the accident rates and implementation costs of urban cycling infrastructure. External costs and benefits are also quantified in relation to an estimate of induced demand for cycling. These external impacts have been researched extensively and will not be revisited here. Instead, values from Switzerland's Spatial Development Department are adopted (including environmental costs, emissions, and reduced work absences). Second-order effects caused by induced demands are not considered. This means that the impacts on other road users (i.e., cars) are not considered. This includes the changes in travel times, comfort, and safety of motor vehicle users. Regarding infrastructure types, we focus on urban contexts, so recreational, inter-urban, and/or unpaved cycling paths will not be considered. Lastly, we limit our geographical scope to the city of Zurich, Switzerland.

The rest of this paper is organized as follows: First, we present the work we have done on estimating the costs of different types of cycling infrastructures. Second, we present the work we have done to compile safety data of cycling infrastructure. Third, we combine these two works to present cost-benefit analyses for different types of infrastructures. Fourth, we discuss the results and their implications for urban transportation planning. Lastly, we make concluding remarks about the work and its importance for society.

2 Infrastructure costs

In this section, we categorize infrastructure types and provide ranges for their implementation costs. Since one of the challenges with cycling infrastructure is their diversity, the first step is to form categories of the types of infrastructures. Based on literature reviews and the existing infrastructure in Zurich, we define three broad categories, summarized in Table 1.

Table 1: Cycling infrastructure categories and their descriptions

Category	Infrastructure type	Includes:	Example
1	Paint	Dashed or solid lines, painted areas	
2	Protected	“Turtles”, low pillars	
3	Separate	Entirely, continuously separated from road, high pillars	

Pictures from FixMyBerlin.de.

These three categories are grouped by the extent of their intervention, i.e., the work required to implement them. Category 1 consists of only painting parts of the road, without constructing anything. Category 2 consists of placing low, individual elements on the existing roadway. Category 3 consists of larger or higher elements, or constructing a continuous, grade- or physically-separated bike path. These are in ascending implementation cost order.

In Table 2, we present a summary of the sources we collected regarding the costs of each category of infrastructure. The costs vary widely, due to aforementioned reasons including urban context and infrastructure quality. The costs are normalized to the year 2023 and converted into Swiss Francs (CHF) per kilometer as best as possible.

Table 2: Cycling infrastructure categories and their costs

Category	Infrastructure type	Range of costs (thousand CHF per kilometer)
1	Paint	5 – 20
2	Protected	40 – 200
3	Separate	>700
A complete overview of the sources is included in Appendix A.		

3 Accidents

In this section, we compile data on accident risk and link them to the infrastructure categories defined in the previous section. Since one of the challenges with cycling infrastructure safety is the underreporting and rarity of accidents, and contextual dependence, the accident risks have large ranges depending on the data source. Based on literature reviews and the accident data available in Switzerland, we define the following accident frequency ranges for the infrastructure categories, summarized in Table 3.

Table 3: Cycling infrastructure categories and their accident frequencies

Category	Infrastructure type	Range of accident frequency (accidents per million cycled kilometers)
1	Paint	2.32 – 5.96
2	Protected	3.38 – 3.76
3	Separate	2.56 – 2.85
Data adapted from Ammann, 2023.		

Note that there is a significant portion (80 – 90%) of accidents (particularly light ones) that are not reported. We cannot account for this underreporting for each of the data sources, so it should be considered that these numbers are skewed to lower-than-actual values. These numbers are presented as absolute accident probabilities (accidents per measure of exposure, in this case cycled kilometers), as opposed to relative probabilities (relative safety of one infrastructure type versus another, presented as a risk ratio or similar). This was done using Swiss statistics on accidents and exposure of cyclists, and allows us to communicate the absolute accident costs of cycling.

Another factor that is difficult to control for is accident severity, which is often not reported in literature. We use Swiss statistics on accident severities to estimate the distribution of the different accident severities and the social costs of each severity. This allows us to

communicate the absolute accident risk of each infrastructure type, in economic cost per cyclist exposure (CHF per cycled kilometer) (see Table 4).

Table 4: Cycling infrastructure categories and their accident risks

Category	Infrastructure type	Weighted cost of all accident severities on all road classes	Range of accident risk (CHF per cycled kilometer)
1	Paint	93,888 CHF per accident	0.22 – 0.56
2	Protected		0.32 – 0.35
3	Separate		0.24 – 0.27
The SNR 641 721 is used for the distribution of the accident severities and costs. Main roads are weighted by 0.9 and secondary roads by 0.1.			

4 Other costs and benefits of cycling infrastructure

In this section, we present an overview of the remaining external costs and benefits of cycling infrastructure that we adopted from existing studies. In this work, external costs and benefits are quantified in relation to an estimate of induced demand for cycling. Based on stated preference surveys, subjective safety and (in effect) the willingness to ride on different types of infrastructure were evaluated (FixMyCity, 2020). Using the difference in subjective safety between different infrastructure types, the expected induced cycled kilometers resulting from an infrastructure type for the city of Zurich was estimated (based on the latest estimate of yearly cycled kilometers by Zurich's population). The change in ridership was then quantified together with external costs and benefits to calculate the societal costs and benefits caused by the implementation of a certain type of infrastructure. The external costs and benefits have been adopted from the Swiss Spatial Development Department (including environmental costs, health benefits, emissions, and reduced work absences) (ARE, 2022). Overall, these costs (excluding accidents) are estimated to be 0.016 CHF per cycled kilometer and benefits are estimated to be 0.183 CHF per cycled kilometer. Weighting these rates with the additional cycled distance per infrastructure type gives the costs and benefits provided by each type (Table 5).

Table 5: Induced demands and resulting external costs and benefits provided by different infrastructure types

Category	Infrastructure type	Induced demand (million kilometers per year)	Induced external costs (million CHF per year)	Induced external benefits (million CHF per year)
1	Paint	5.6	0.09	1.0
2	Protected	23.9	0.38	4.4
3	Separate	17.5	0.28	3.2

5 Cost-benefit results

In this section, we compile the data on accident risk and infrastructure costs defined in the previous sections to estimate a range of benefit-cost ratios (BCR) for each infrastructure type (using the low and high estimates for construction costs and accident reductions). We then show the outcome of a sensitivity analysis to test the range of possible results. We estimate these values for a planning horizon of 20 years and using a discount rate of 3%. The benefit of accident reduction is computed as the reduced accident costs versus road infrastructure with no cycling facilities, i.e., the highest observed accident rate. For the construction costs, a length of 44 kilometers was chosen, which is the length of all roads in Zurich on which at least one avoidable accident involving bicycles occurred between 2014 and 2020. These results are presented in Table 6.

Table 6: Ranges of benefit-cost ratios over 20 years per infrastructure type

Category	Infrastructure type	Range of benefit-cost ratio
1	Paint	9.7 – 31.0
2	Protected	15.4 – 20.0
3	Separate	9.2 – 14.5

Painted infrastructure has the most favorable BCR, i.e., provides the most benefit for its cost over 20 years. However, it also has a wide BCR range, with the lower end (9.7) being less beneficial than the lowest BCR of protected infrastructure (15.4). The wide BCR range of painted infrastructure is due to the wide range of objective safety on painted infrastructure.

We also calculate the payoff duration for each type of infrastructure. This was done by considering the upfront investment cost of the infrastructure and the estimated (discounted) yearly benefit that is provided by the infrastructure. These results are presented in Table 7.

Table 7: Ranges of payoff durations per infrastructure type

Category	Infrastructure type	Range of payoff duration (years)
1	Paint	0.0034 – 0.045
2	Protected	0.036 – 0.20
3	Separate	0.51 – 1.1

Painted infrastructure has the shortest payoff duration, i.e., produces a net benefit the fastest – within the first year after implementation of the infrastructure. Only separated infrastructure takes more than one year to pay off (1.1 years).

For the sensitivity analysis, we changed several values to test the impact on the results, including a worst-case scenario:

- 100 kilometers of infrastructure are constructed (instead of 44).
- The highest per-kilometer costs for each infrastructure type are considered.
- The highest accident cost is considered.
- The amount of induced demand is doubled. Higher induced demand is considered worst-case from the perspective of costs, as more accidents will occur, which outweigh the additional external benefits.

An overview of the BCR values in the different cases case is presented in Table 8.

Table 8: Inputs and results of the sensitivity analysis for the different scenarios

Benefit-cost ratio	Paint	Protected	Separated
Best assumptions	20.3	17.5	11.4
100 kilometers	19.8	15.1	6.6
Highest construction costs	20.1	16.2	9.6
Highest accident costs	9.8	16.7	11
Double induced demand	19	14.3	10.6
Worst-case scenario	8.2	10.3	4.9
Worst-case scenario payoff duration	0.11 years	0.51 years	2.64 years

The sensitivity analysis reveals that, even under pessimistic assumptions, cycling infrastructure investment pays off within three years at a total BCR of at least 4.9 over 20 years.

6 Discussion

Based on our analysis of infrastructure implementation costs, change in accident risk, and external costs and benefits resulting from induced cycling demand, we showed that investment in cycling infrastructure creates a net benefit for society. BCRs are around 10 to 30, which is similar to the results for a specific project in Zurich, where values between five and 27 were found (ewp, 2017). Even under pessimistic assumptions, the payoff period is about one year at most (considering a network length of 44 kilometers). In the worst-case scenario sensitivity analysis, payoff duration is at most three years and BCR at least 4.9. In addition, this analysis does not consider the large share of unreported accidents (around 80 to 90%). Considering these would scale up the number of avoided accidents and therefore the benefits provided. In summary, our analysis has shown that cycling infrastructure investment pays for itself and should be implemented more frequently in urban settings.

Our analysis showed that investing more money for the construction of separated cycling infrastructure does not lead to more benefit than cheaper (protected or painted) infrastructure. This is due to the fact that separated infrastructure induces less demand yet costs significantly more than protected infrastructure. The finding that physically separated infrastructure may be subjectively less safe than a protected infrastructure, and therefore induce less demand, has been reported in other studies (e.g., Durner & Leitner, 2022). The fact that separated infrastructure may not provide the highest net benefit indicates that physically separated bicycle lanes may not be the most efficient investment in all cases and should be considered carefully.

The estimation of induced demand in this paper is likely also conservative, both in its magnitude and the “safety in numbers” effect that some research has shown. As cycling becomes increasingly popular, more accessible through better and cheaper technology, and trends such as climate change continue, ridership in urban contexts are expected to increase. This will have a positive feedback loop, as more riders leads to safer road conditions, leading again to more riders. This is currently not considered in our analysis, as is demonstrated by the higher overall costs resulting from higher induced demand estimates. However, our estimate of induced demand is based on stated preference surveys, which are less reliable than observed behavior. Overall, we still believe our results to be conservative.

Some higher-order effects were not considered in our analysis, e.g., the impact on vehicles using the road where cycling infrastructure is implemented. We do not analyze the effects, but there are arguments supporting higher costs of road use for vehicles when cycling infrastructure is expanded. Most simply, less road space for vehicles leads to reduced vehicle transportation comfort. Considering this would reduce the attractiveness of the investment in

cycling infrastructure. However, there are also benefits that were not considered, including urban quality and justice. These are difficult to quantify, but have a positive effect on the attractiveness of the investment in cycling infrastructure. Overall, we believe our results are conservative (that investment is actually more attractive than we have estimated).

7 Conclusion

In this paper, we outlined why it is difficult to make good cost-benefit analyses for cycling infrastructure investments. The main challenges are linked to accident risk estimates and identification of infrastructure investment costs. We collected literature and data to make best possible estimates for these costs and benefits. Compiling our findings showed that cycling infrastructure investment is likely to be attractive, providing a high net benefit to society. Based on our findings, urban transportation planners should consider cycling infrastructure investment as a feasible way to improve accessibility and reduce negative externalities linked to transportation.

Our study, while supporting cycling investment, also shows the remaining weaknesses of the state-of-the-art research concerning cycling. Accident risk and specifically cycling exposure remains difficult to estimate. Infrastructure implementation costs are poorly recorded and ill-defined. In the future, such data must be more consistently gathered and made available to planners so that better decisions are possible for the transportation development of urban areas.

8 Acknowledgements

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10 Glossary

BCR Benefit-cost ratio

CBA Cost-benefit analysis

CHF Swiss Francs

A Construction costs sources

Table 9: Different values of construction costs from different sources

Location	Costs per kilometer	Comment	Source
Zurich	40,000 CHF	Vertical elements	Personal communication
Berlin	9,500 EUR	Pillars	BA FHKB, 2020
Bogotá	222,973 USD		ITDP, 2022
Guangzhou	239,583 USD		ITDP, 2022
USA	5,200 – 10,500 USD	Paint	Andersen, 2017
USA	6,000 – 126,000 USD	Vertical elements	Andersen, 2017
USA	220,000 – 370,000 USD	Continuous concrete divider	Andersen, 2017
USA	5.5 – 16.5 M USD	New bike path	Andersen, 2017
Victoria, BC	18,100 – 29,100 CAD	Paint	Personal communication
Victoria, BC	770,000 – 2.5 M CAD	Constructed dividers, pillars	Personal communication

EUR = Euro, USD = US Dollars, M = million, CAD = Canadian Dollars. Adapted from Ammann, 2023.