

# The cost-effectiveness of bike lanes in New York City

Jing Gu, Babak Mohit, Peter Alexander Muennig

Mailman School of Public Health, Columbia University, New York, New York, USA

## Correspondence to

Dr Babak Mohit, Mailman School of Public Health, Columbia University, 722 W 168th St. Rm 480, New York, NY 10032, USA; [bm2762@cumc.columbia.edu](mailto:bm2762@cumc.columbia.edu)

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## ABSTRACT

**Background** Our objective is to evaluate the cost-effectiveness of investments in bike lanes using New York City's (NYC) fiscal year 2015 investment as a case study. We also provide a generalizable model, so that localities can estimate their return on bike lane investments.

**Methods and findings** We evaluate the cost-effectiveness of bike lane construction using a two-stage model. Our regression analysis, to estimate the marginal addition of lane miles on the expansion in bike ridership, reveals that the 45.5 miles of bike lanes NYC constructed in 2015 at a cost of \$8 109 511.47 may increase the probability of riding bikes by 9.32%. In the second stage, we constructed a Markov model to estimate the cost-effectiveness of bike lane construction. This model compares the status quo with the 2015 investment. We consider the reduced risk of injury and increased probability of ridership, costs associated with bike lane implementation and maintenance, and effectiveness due to physical activity and reduced pollution. We use Monte Carlo simulation and one-way sensitivity analysis to test the reliability of the base-case result. This model reveals that over the lifetime of all people in NYC, bike lane construction produces additional costs of \$2.79 and gain of 0.0022 quality-adjusted life years (QALYs) per person. This results in an incremental cost-effectiveness ratio of \$1297/QALY gained (95% CI –\$544/QALY gained to \$5038/QALY gained).

**Conclusions** We conclude that investments in bicycle lanes come with an exceptionally good value because they simultaneously address multiple public health problems. Investments in bike lanes are more cost-effective than the majority of preventive approaches used today.

## OBJECTIVE

The USA has 67 million bicyclists, making over 300 million trips per year in big cities alone,<sup>1</sup> with almost 700 deaths and 48 000 serious injuries per year.<sup>2</sup> This high level of casualties makes the USA the most dangerous place among wealthy nations to bicycle. Per kilometre and per trip cycled, US bicyclists are twice as likely to be killed as German cyclists and over three times as likely as Dutch cyclists.<sup>3</sup> One effective and intuitive way of preventing injury is to introduce bike lanes on all major cycling routes, an infrastructure intervention that reduces all forms of injury by 25%.<sup>4</sup> Unlike helmet laws, bike lanes do not require behavioural change on the part of the cyclist, and they come with other benefits. For example, they 'normalise' exercise behaviours, reduce pollution and may help address the obesity epidemic in the USA. In places where bike lanes have been installed, cycling (and possibly other forms of exercise) tends to increase

greatly. This creates a virtuous cycle, as the more people who bike, the safer it becomes to cycle.<sup>5</sup>

Well-designed bike lanes improve safety for people on bikes and reduce excessive speeding in cars, organise traffic flow and protect pedestrians. Bike lanes take three forms. 'Class I' bike lanes provide a route that is physically separated from moving traffic. 'Class II' bike lanes have a marked lane on the road. Finally, 'Class III' bike lanes merely provide shared road markings for drivers and add safety legislation. Each of these comes with a different set of risks and benefits. For example, Class II bike lanes often force cyclists to ride next to parked cars and place the cyclist at risk of colliding with suddenly opened car doors. Nevertheless, much of the academic literature on bike lanes treats all forms of bike lanes equally.

Our objective is to evaluate the more generic notion of a 'bike lane' investment using New York City's (NYC) 2015 investment as a case study. We use NYC because it provides a known investment in bicycle infrastructure. We use predicted 2015 values (rather than actual values) so that year-to-year variations in weather, road conditions or other factors are smoothed across many years. While we use NYC as an example, our intent is to provide a much more generalisable model, such that localities can estimate the return on their investment in bike paths. We undertake this study because, while investments in bike lanes appear to broadly benefit health, it is not clear that they bring more value than other types of health investments that a city or locality might make, such as expansion of healthcare services.

## DESIGN

We evaluated the cost-effectiveness of the construction of bike lanes in NYC in 2015 as a case study. We first used regression analysis to estimate miles of bike lanes constructed in 2015 and to model the effect of additional lane miles on the expansion in bike ridership. Using data through 2014, we use ordinary least squares (OLS) to predict values for 2015 so that analyses are not influenced by temporary change in the weather or road conditions that might influence bike path construction, ridership or injury. We then constructed a Markov model using TreeAge Software (TreeAge Software. TreeAge Pro 2015 (R 1.0). Williamstown, Massachusetts: TreeAge Software; available at <https://www.treeage.com>, 2015) to estimate the costs and effectiveness of bike lane construction in 2015 for people starting to ride bikes at the age of 36 (the average age of people riding within NYC) over the next 34 years. While we use NYC as an example, we also rely on broader sources of data so that the model outputs are more generalisable.



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## Participants

The Markov model (displayed in figure 1) targets the entire cohort of 8.5 million people who live in NYC in 2015,<sup>6</sup> including bike riders (both existing and new riders because of added bike lanes) and non-riders. The model has two major arms, namely the status quo arm, which simulates the situation without bike lane construction in 2015, and the bike lane arm, which simulates the situation after the construction of bike lanes in 2015. The latter arm is depicted in figure 1, and given the structural similarity of the two arms, the status quo arm has been collapsed. Both arms include the whole NYC population. Under both the status quo arm and the bike lane arm, a portion of NYC population chooses biking as their main way of transportation, while the others do not. Subsequently, both bike riders and non-riders have a probability of injury that is different from one another.

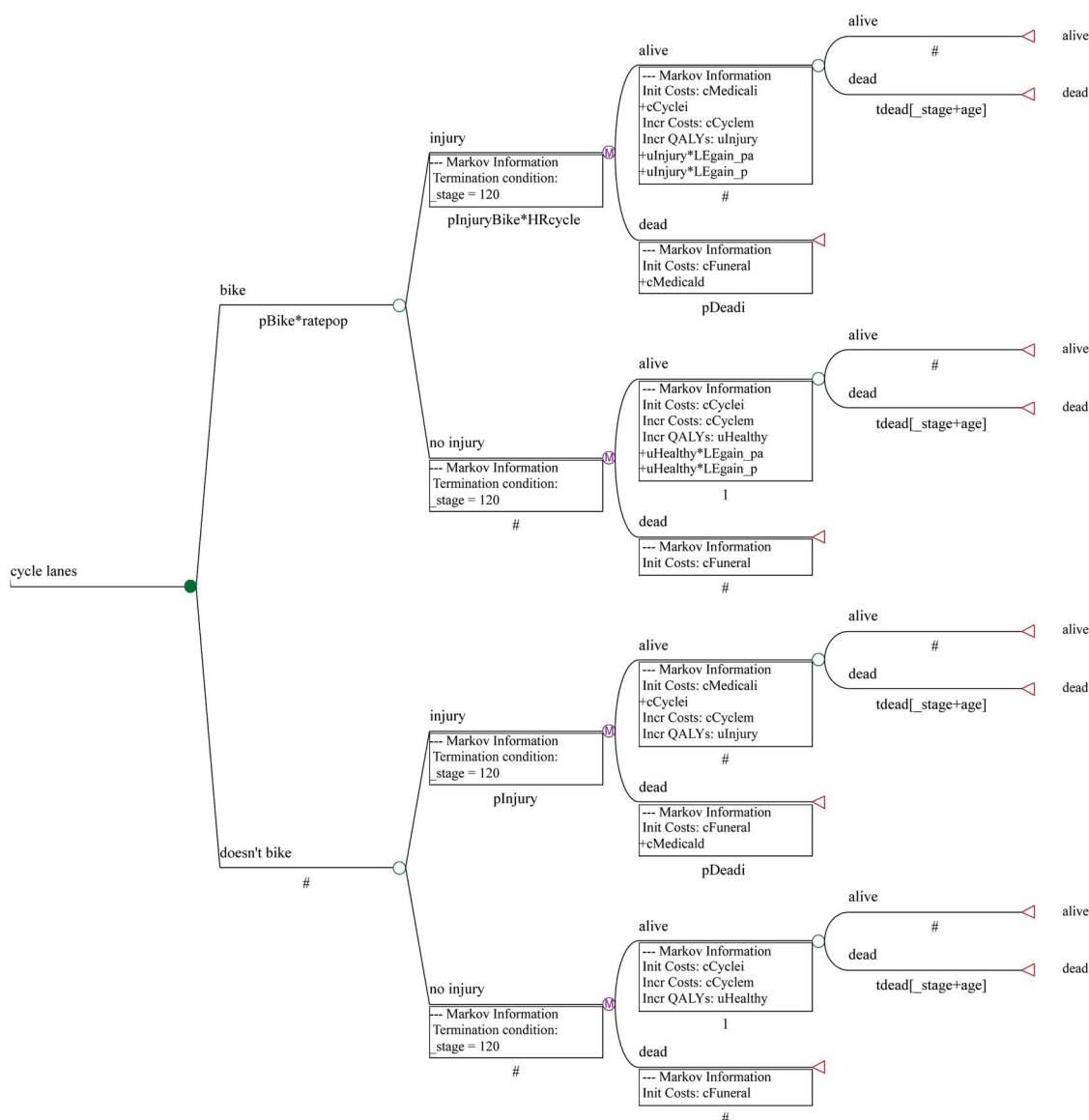
We estimate that with a population of 8.5 million people and a ridership probability of 0.013,<sup>7</sup> the number of bike riders in the status quo arm is 110 500 persons. With a 9.32% increase,<sup>8</sup> we estimate that there will be 120 445 riders in the intervention arm.

## Regression analysis

We obtained the number of bike lane miles constructed from 2007 to 2014 from the NYC Department of Transportation (NYC DOT).<sup>9</sup> Using these data, we estimated that the NYC DOT constructed 45.5 miles of bike lanes in 2015 at a cost of \$8 109 511. NYC DOT also tracks trends in NYC cycling using the In-Season Cycling Indicator, which is derived from counts of bicycle traffic at several locations.<sup>8</sup>

We ran a simple linear regression model with the percentage of increase in ridership as the independent variable and the additional bike lane miles constructed every year as the dependent variable from 2007 to 2014. The percentage of increase in ridership was calculated using the in-season cycling indicator of each year. The estimated model is  $Y=0.004X-0.0888$ , with  $R^2$  equals to 0.59, which indicates that the model is able to explain the variance of the dependent variable quite well.

This OLS analysis revealed that the percentage of expansion in bike ridership would increase by 0.4% for every additional one mile of bike lane construction. Using the fitted equation, we calculated that the probability of riding bikes would increase by 9.32% if 45.5 lane miles were constructed in 2015.



**Figure 1** Markov model of bike lane implementation in New York City (NYC).

**Table 1** Values used in the Markov model evaluating bike lane construction in 2015 versus the status quo

Variables	Abbreviation in tree diagram	Base	SD	Low	High	Data sources
Lifetime medical costs per capita (\$)						
Fatal injury	cMedicald	11 973	5000			CDC <sup>10</sup>
Non-fatal injury	cMedicali	57 764		53 210	136 067	
Death costs per capita (\$)	cFuneral	7306	5000			National Funeral Directors Association <sup>11</sup>
Programme costs total/per capita (\$)						
Implementation		8 109 511/0.97	0.77			Elvik <i>et al.</i> , <sup>13</sup> Bushell <i>et al.</i> , <sup>12</sup> Litman, <sup>14</sup> Zegeer <sup>15</sup>
Maintenance per year		532 971/0.06	0.06			
Probability of injury						
Non-riders	pInjury	0.0004		0	0.0008	NYS DMV; <sup>18</sup> NYS DOH <sup>19</sup>
Bike riders	pInjuryBike	0.0008	0.0003			CDC, <sup>10</sup> Statista <sup>7</sup>
Case fatality ratio	pDeadi	0.08		0	0.15	NYS DMV <sup>18</sup>
Probability of riding bikes, status quo	pBike	0.013	0.003			ACS, 2009–2013
Increase in bike ridership, Vision Zero (%)		9.32	1			NYC DOT (2015b)
HR, injury, Vision Zero	HRcycle	0.83	0.1			NYC DOT (2015c); Elvik <i>et al.</i> <sup>13</sup>
HRQL, injured	uInjury	0.55				EQ5D survey
Average age (years)		36	10			New York City Department of City Planning, 2012
LE gain, Vision Zero (years)						
From physical activity	LEgain_pa	0.033		0	0.04	Rabl and De Nazelle <sup>17</sup>
From reduced pollution	LEgain_p	0.047		0	0.05	Rabl and De Nazelle <sup>17</sup>

HRQL, health-related quality of life; LE, life expectancy; NYC, New York City.

Note: New York City Department of Transportation. 2015b. 2014 NYC In-Season Cycling Indicator - An Estimate of Trends in Regular Cycling for Transportation [Online]. <http://www.nyc.gov/html/dot/downloads/pdf/2014-isci.pdf> (accessed 13 Jul 2015).

New York City Department of Transportation. 2015c. Manhattan Pedestrian Safety Action Plan [Online]. <http://www.nyc.gov/html/dot/downloads/pdf/ped-safety-action-plan-manhattan.pdf> (accessed 14 Jul 2015).

New York City Department of City Planning. 2014. Population Facts [Online]. <http://www1.nyc.gov/site/planning/data-maps/nyc-population/population-facts.page> (accessed 8 Jan 2015).

## Costs

We adjusted monetary costs to constant 2015 US\$ using the general consumer price index as listed in table 1. We went on to obtain lifetime medical costs for non-fatal, hospitalised and fatal injuries per person from the 2010 US averages using the CDC's Web-based Injury Statistics Query and Reporting System (CDC WISQARS).<sup>10</sup> We also derived costs per person associated with death (funeral) from the 2009 National Funeral Director's survey.<sup>11</sup> We included the cost of death (burial costs) in the model, even though the entire cohort will eventually expire over time, and thus the monetary cost of death is the same over a lifetime, regardless of whether the cost of death is calculated at an earlier or later point in life. The rationale for including these costs in our calculations is that bike lanes have the potential to reduce premature deaths, allowing members of the population to die of other causes in the later stages of life. Because of this, the time course over which the death costs are discounted is longer in the speed-reduction branch and shorter in the non-intervention branch. This difference in the time of discounting leads to monetary differences significant enough to include in the model.

We obtained implementation cost and maintenance cost per mile of bike lanes through a review of the literature and reports.<sup>12–15</sup> We then multiplied the cost per mile by estimated lane miles constructed in 2015, which we had derived from the previous regression analysis.

We derived the literature sources for model input parameters of cost, quality-adjusted life years (QALY), probabilities and others through multiple keyword searches, related to the burden of injury of bicycle rider studies, on Google Scholar, Web of Science and PubMed. After sources were selected, they were ranked according to levels of evidence.

## Quality-adjusted life years

We assessed the impact of injury and death on victim's health-related quality of life (HRQL) using the EuroQol 5D (EQ5D-5L). HRQL is required to calculate QALYs, and effectively adjusts a year of life lived with a condition for health. HRQL is scaled from 0 to 1, with 0 representing death and 1 representing a state of perfect health. Our objective was to obtain a score that represented an injury that was serious enough to require hospital admission. We assumed that other injuries would only incur a transient decrease in HRQL and would therefore not incur a meaningful change in HRQL over the victim's life course.

The EQ5D captures the following five domains of health: mobility, anxiety/depression, self-care, usual activities and pain/discomfort. We used an earlier estimate of the HRQL score of a person who incurred an injury serious enough to be hospitalised. This score was obtained from two paediatric orthopaedic surgeons at Columbia University Medical Centre who had extensive experience following such individuals over the course of their lives.<sup>16</sup> We used the average value of their predicted EQ5D score, 0.55, in our model for injury victims who required hospitalisation.

We followed the logic from Rabl and De Nazelle<sup>17</sup> to estimate the additional gains in life expectancy (LE) due to increased physical activity (PA) and reduced pollution. The LE gain due to PA from 25 to 65 years old is 1.32 years. Thus, the LE gain from PA per year is 0.033.

For air pollution, the dose-response function for mortality due to chronic PM<sub>2.5</sub> exposure is linear and with slope:  $sDR=0.00065$  years of life lost per person per year per  $\mu\text{g}/\text{m}^3$  of PM<sub>2.5</sub>. Also the researchers estimated that avoided emissions due to shift to bicycling is 71.8 g PM<sub>2.5</sub>/year. Thus, the

LE gain due to reduced pollution is 0.04667 QALYs. Besides the QALYs gained from reduced injury, additional gain in LE due to increased PA and changes in air pollution were also taken into account using estimate obtained from the health literature. New bike riders gain an average of 0.033 QALYs per year from increased exercise and New Yorkers as a whole gain 0.047 QALYs per year from reduced exposure to pollution.

### Probabilities

Probabilities and related inputs are listed in table 1. We obtained the number of people seriously injured and killed from traffic crashes in 2013 from New York State Department of Motor Vehicles.<sup>18</sup> We used these numbers and the population in NYC to calculate the probability of injury and the case fatality ratio for both bike riders and non-riders.<sup>19</sup>

Bike riders have a higher probability of injury than those who use other forms of transportation. The number of traffic injuries of cyclists in the USA was first derived from CDC WISQARS.<sup>10</sup> Dividing the number of injuries by the total estimated number of cyclists in the USA,<sup>7</sup> we obtained the probability of getting all levels of injuries for cyclists. A ratio of serious injuries to all levels of injuries was then calculated using the numbers of injured cyclists and treated and released cyclists.<sup>10</sup> We then calculated the probability of serious injury for cyclists by multiplying the probability of all injuries and the ratio of serious injury. The HR injury when new bike lanes were constructed compared with the status quo (before 45.5 miles of bike lane were added) was obtained from a comprehensive review of the literature.<sup>13 20</sup> All outcomes in the model were adjusted to 2015 constant US\$ and discounted at a rate of 3% per year.<sup>21</sup>

### Markov model

Our Markov model is based on a societal perspective and, as we depict in figure 1, has two competing alternatives: adding bike lanes or the status quo. Both the bike lane arm and the status quo arm are the same except that the bike lane arm has an increased probability of riding bikes, a reduced risk of injury for bike riders, costs associated with bike lane implementation and maintenance and additional effectiveness because of PA and reduced pollution.

Irrespective of the arm of the model, a bike rider has a small risk of serious injury from traffic incidents and a significant

**Table 3** Costs and quality-adjusted life years (QALYs) of bike lane construction in 2015 versus status quo

	Point estimate	95% CI
Costs, status quo	31.28	(7.04 to 65.05)
Costs, bike lanes	34.07	(9.61 to 67.78)
Incremental costs	2.79	(−1.11 to 6.57)
QALYs, status quo	31.076	(24.8878 to 32.4646)
QALYs, bike lanes	31.0782	(24.8898 to 32.4673)
Incremental QALYs	0.0022	(0.0008 to 0.0038)
ICER	1296.5	(−544.08 to 5037.89)

ICER, incremental cost-effectiveness ratio.

chance of remaining healthy. Under the injury and non-injury arms of both the status quo and bike lane alternatives, we developed a two-state Markov process such that every subject is exposed to an annual, age-specific risk of death.<sup>22</sup> Survivors will gain one HRQL-adjusted life year from age 36 to age 70 years, reflecting the average age of cyclists in the city. If the rider remains healthy, we assigned no costs except the one-time implementation costs and annual maintenance costs of bike lanes in the bike lane alternative arm of the model. If the rider is injured, we assigned an annual medical cost associated with a serious injury and a decrement in HRQL over the average remaining LE of the injured cyclist. Uninjured bicyclists gain both HRQL and LE because of increased PA and reduced pollution. The underlying assumptions of the modelling approach are listed in table 2.

We used Monte Carlo simulation and one-way sensitivity analysis to test the reliability of the base-case result. We either included what we recognised as plausible boundaries for the values or included the known random error associated with an estimate in the Monte Carlo simulation. We also employed half-cycle corrections to adjust for related modelling uncertainties.

## RESULTS

### Cost-effectiveness of bike lanes

As shown in table 3, for all people in NYC, bike lane construction as a part of Vision Zero produced an additional cost of \$2.79 per person and an incremental gain of 0.0022 QALYs over their lifetimes, compared with the status quo. The incremental cost-effectiveness ratio (ICER) was \$1297/QALY gained (95% CI −\$544/QALY gained to \$5038/QALY gained).

### Sensitivity analysis

An influence analysis ('tornado' diagram) suggested that the most important variable in the analysis was the probability of injury. One-way sensitivity analysis showed that the value of ICER would drop as the probability of getting injury increased. However, the maximum value of the ICER was \$1318/QALY gained when the probability of injury was 0. Thus, our conclusion that the programme was highly favourable was robust to a wide variation in injury estimates based on exercise and pollution impacts alone.

## CONCLUSION

Bicycle lanes address multiple public health problems simultaneously. They reduce injury and death, they promote exercise, and they reduce pollution. We explored the cost-effectiveness of 1 year of investment in bike lanes in NYC as a case study. We do so after considering costs and health effects of the investment on New Yorkers and account for long-term benefits as well as maintenance costs of the lanes installed in the built

**Table 2** Assumptions used in the Markov model evaluating bike lane construction in 2015 versus status quo

Assumption	Rationale (impact on estimates)
Future lost productivity and leisure time costs of injury are included within the health-related quality-of-life score	EQ5D scores may implicitly include lost productivity and leisure time, however this has been debated (favours status quo)
Benefits of bike lane construction are limited to bike riders	Construction of bike lanes may also reduce injury risks for car drivers and pedestrians (favours status quo)
The trend of bike lane construction during the past 7 years will continue in 2015	Bike lane construction may be more emphasised because a citywide traffic safety programme initiated in 2014. (favours bike lane construction)
Mortality risk because of traffic injury occurs only at the time of injury	Injury victims may be at higher risk of future death both from physical limitations and economic impact of the injury on the victim's life (favours status quo)



environment. In NYC, the investment comes in at an exceptionally good value, costing just \$1297/QALY gained for the 2015 investment cycle. This is far more cost-effective than preventive approaches in medicine that few would argue should not be implemented. For instance, screening and treatment for HIV/AIDS in high-risk populations cost \$50 000/QALY gained—nearly 40 times as much.<sup>23</sup> It is also considerably more cost-effective than either providing private health insurance or expanding Medicaid.<sup>16 24</sup>

Our study was subject to a number of important limitations. Foremost, there are few causal estimates of the effects of bike lanes on safety or, particularly, usage.<sup>25</sup> While studies consistently show that bike lane construction is followed by increased cycling and reduced injury, these ‘outcomes’ might simply reflect national trends towards an increased interest in cycling. We managed this uncertainty by conducting broad sensitivity analyses on model inputs.

Our model also uses generic references for potentially important effects of bike lanes. Some of our references accounted for the lifelong impacts of injuries, reduced exposure to pollution and increased exercise afforded to the cyclist. However, they measure average effects for an average individual living in an average city.<sup>17</sup> Yet, this only provides a snapshot of the impact of a city’s investment in bike paths. As cycling grows more popular, it becomes safer to cycle. The resulting increase in cyclists may generate momentum for cycling or a change in political resistance to (or acceptance of) cyclists. Some cities (eg, Portland, OR and Washington, DC) have been able to tolerate a greater than 400% increase in cyclists over the past two decades with relatively little political resistance. Others, such as NYC, have seen the emergence of anticycling groups as bike lanes and cyclists have proliferated. To fully understand this relationship, it would be helpful to have a complex systems dynamics model that could be tailored to different urban contexts.

As the USA moves to invest more in non-medical policies in the name of health prevention under the Affordable Care Act, policymakers and payers are too often left wondering where their investments might produce good value. Bike lanes are one investment that certainly seems to fit the bill.

### What is already known on the subject?

- The USA has 67 million bicyclists, making over 300 million trips per year in big cities alone with 700 deaths and 48 000 serious injuries per year which makes the USA the most dangerous place among wealthy nations to bicycle.
- Bike lanes reduce all forms of injury by 25%.

### What this study adds?

- We demonstrate that the incremental cost-effectiveness ratio of bike lanes is \$1297/ quality-adjusted life years (QALY) gained (95% CI –\$544/QALY gained to \$5038/QALY gained).
- Our study considers multiple factors to highlight the need for further investment in bike lanes as a crucial part of urban infrastructure improvement.

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