Journal of Urban Mobility 5 (2024) 100071

Contents lists available at ScienceDirect

Journal of Urban Mobility

journal homepage: www.elsevier.com/locate/urbmob

The Traffic Calming Effect of Delineated Bicycle Lanes

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ARTICLE INFO

Keywords:
Safety
Bike lane
Speed
Tactical urbanism

ABSTRACT

We analyze the effect of a bicycle lane on traffic speeds. Computer vision techniques are used to detect and classify the speed and trajectory of over 9,000 motor-vehicles at an intersection that was part of a pilot demonstration in which a bicycle lane was temporarily implemented. After controlling for direction, hourly traffic flow, and the behavior of the vehicle (i.e., free-flowing or stopped at a red light), we found that the effect of the delineator-protected bicycle lane (marked with traffic cones and plastic delineators) was associated with a 28 % reduction in average maximum speeds and a 21 % decrease in average speeds for vehicles turning right. For those going straight, a smaller reduction of up to 8 % was observed. Traffic moving perpendicular to the bicycle lane experienced no decrease in speeds. Painted-only bike lanes were also associated with a small speed reduction of 11–15 %, but solely for vehicles turning right. These findings suggest an important secondary benefit of bicycle lanes: by having a traffic calming effect, delineated bicycle lanes may decrease the risk and severity of crashes for pedestrians and other road users.

Introduction

Motor-vehicle crashes are a leading cause of death in the U.S. among people younger than 55 (CDC, 2021). Non-motorists, such as pedestrians, cyclists, and e-scooter users are at a greater risk of fatality than motor-vehicle drivers and passengers. Active travel also has documented public health, economic, and environmental benefits. Providing bicycle facilities (e.g., bike lanes) can reduce the likelihood and severity of cyclist-involved crashes, while inducing active travel. Bicycle lanes can reduce between 30 and 49 % of crashes on urban local roads (FHWA, 2022). According to the National Highway Traffic Safety Administration (NHTSA), fatal bicyclist crashes in 2020 were at their highest level since 1987 in the United States. There were 938 cyclists that were killed in 2020, a 9.2 % increase over 2019 (NHTSA, 2022). Moreover, crashes often occur at intersections because road crossings have a higher potential for conflicts (NHTSA, 2010). The Federal Highway Administration (FHWA) estimates that more than 50 % of all fatal and injury crashes occur at or near intersections (FHWA, 2021).

Temporary bike lanes, or “pop-up” bike lanes, are a low-cost and flexible intervention aimed at creating a safe and separated space for cyclists and other micromobility users. Planners are starting to use these as a way to test the feasibility of a more permanent bicycle lane. Pop-up bike lanes rose in popularity in the early months of the COVID-19 pandemic to allow residents to safely travel and exercise outdoors while adhering to social distancing guidelines (UCI, 2020). Pop-up bike lanes were associated with rapid increases in cycling within the first four months of the pandemic (Kraus & Koch, 2021). Common configurations for bike lanes are painted only (striped or painted throughout), delineator protected (with traffic cones and bollards), or buffered with protective infrastructure. We analyze a delineator-protected bike lane and painted-only bike lane in this study. We refer to delineator-protected bike lanes more simply as delineated bike lanes throughout the study.

Our team implemented a temporary bike lane near a signalized intersection in the coastal town of Asbury Park, New Jersey in April 2022 (Fig. 1). The bike lane was delineated with orange cones, traffic delineators (i.e., bollards) and temporary chalk paint spray on Cookman Avenue and at the intersection, and with paint only on Asbury Avenue (due to road width restrictions). Both streets have a posted speed limit of 25 mph (40 kph). In this study, we focus mainly on traffic flowing to and from Cookman Avenue, where the greatest changes in road

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https://doi.org/10.1016/j.urbmob.2024.100071
Received 1 March 2023; Received in revised form 5 November 2023; Accepted 9 January 2024
Available online 10 February 2024

Fig. 1. Temporary bicycle lane. Note that we were unable to paint the entire width of the bicycle lanes in green. Paint was merely used to stripe the lanes.

configuration occurred (see Fig. 2). We had three different road configurations for the intersection and on Cookman Avenue: no bike lane, a painted-only bike lane, and a painted bike lane with traffic delineators (Fig. 3). Delineated bike lanes, or delineator-protected bike lanes, utilize plastic delineators and a buffer space to provide physical separation from motorized traffic (City of Minneapolis, 2021). Nine parking spots were removed and replaced with the bicycle lane; at the time of the pilot (off-season with little tourist traffic) there was no issue with this as parking was plentiful. Each traffic lane was reduced by at least one foot in order to provide a three-foot buffer between the bike and traffic. The existing and temporary configurations on Cookman Avenue, visualized in Streetmix (Streetmix, 2022), are shown in Fig. 2.

While the link between bike lanes and cyclist safety is well established in the literature, it is still not clear whether bike lanes can have secondary benefits on pedestrian and motor vehicle safety. In this study, we investigate the role of a pop-up bike lane in reducing motor-vehicle speeds at an intersection. We ask two questions: (1) *Is the presence of a delineated bike lane with traffic cones and plastic delineators associated with reduced motor-vehicle speed at an intersection* and (2) *is the presence of a painted bike lane associated with reduced motor-vehicle speeds at the same intersection.* Fig. 3 displays the two bicycle lane configurations on Cookman Avenue. We hypothesize that bike lanes with traffic delineators will have a stronger traffic calming effect (i.e., reductions in speed) than with painted-only bike lanes.

We analyze the speed and trajectories of 9575 vehicles using computer vision techniques. Each motor-vehicle's speed and direction are detected and classified via computer vision algorithms, allowing us to analyze data more efficiently. We use generalized linear modeling (GLM) to estimate the effect of the bike lane on vehicle speeds. Controlling for free-flowing vehicles, turning direction, time of day, and day of week, we show that on average vehicle speeds are reduced in the presence of a bike lane. In particular, vehicles turning right exhibit the strongest decrease in speed of 21 %, on average, when the delineated bike lane is present, after controlling for other factors.

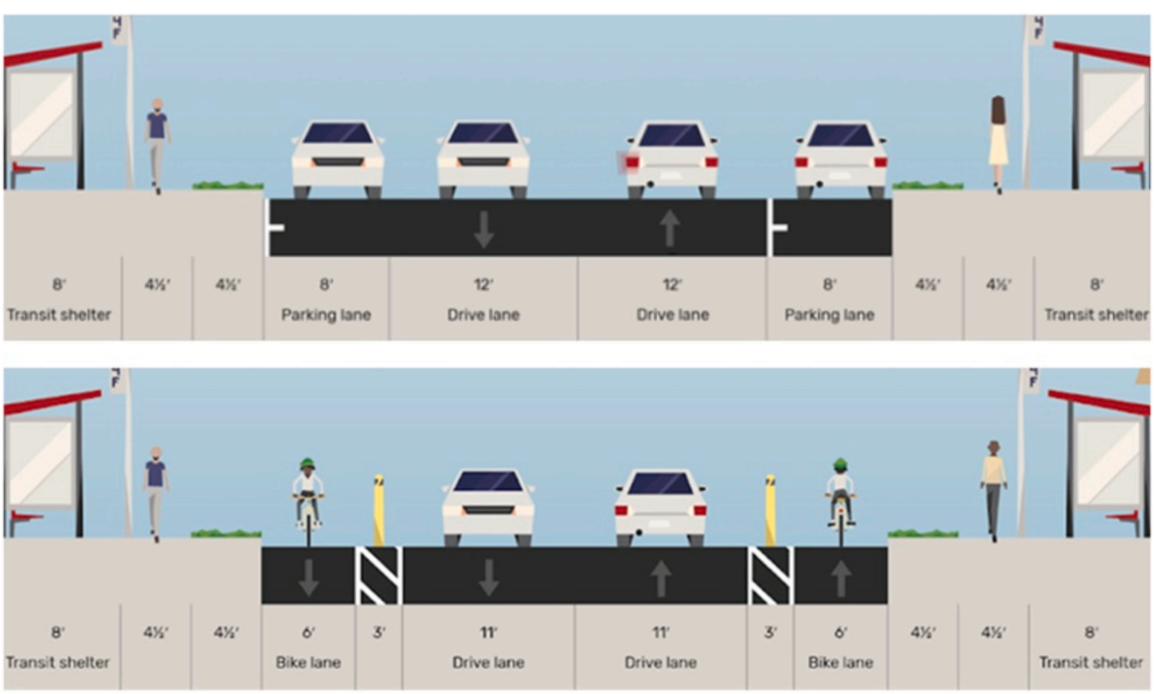

Fig. 2. Cookman Avenue street configuration before (top) and after (bottom) (Streetmix, 2022).

Fig. 3. Painted-only bike lane (top) and traffic bike lane with traffic delineators (bottom) on Cookman Avenue. Pictures taken by the research team.

Literature review

Protected bike lanes are an FHWA proven safety counter measure (FHWA, 2022). They are associated with both decreased likelihood and severity of cyclist-involved crashes (Alshehri et al., 2020; Behnood & Mannering, 2017; Helak et al., 2017; Morrison et al., 2019; Myhrmann et al., 2021). The speed of motor vehicles is also associated with non-motorist involved crash likelihood and severity (Dash et al., 2022; Hanson et al., 2013; Kim et al., 2017; Tay et al., 2011; Younes et al., 2023b). Places that have decreased the speed limits of motor-vehicles have seen a decrease in reported crashes (Nanayakkara et al., 2022).

The relationship between introducing a bike lane and motor-vehicle travel speeds has been a topic of conversation among cyclists and transportation planners, although there is a lack of empirical evidence on the topic. In Toronto, Canada, Streetlight data showed that auto speeds decreased 12–13 % after the implementation of a bike lane (Pekow, 2022). Using simulations, Nanayakkara et al. (2022) found that bike lanes increase car travel times by up to seven percent. In contrast, the NYC Department of Transportation found that on several road segments in Manhattan, the introduction of the bike lanes were associated with increased traffic speeds (Stromberg, 2014). There is evidence from aggregated spatial data that cities with protected bike facilities (not merely painted bike lanes) are associated with reduced crash fatalities for all road users, not just cyclists (Marshall & Ferenchak, 2019, 2020). Marshall and Ferenchak (2019) suggest that protected bike lanes may be associated with a traffic calming effect and facilitate safer speeds. Because such data was aggregated, the associations between speed and presence of protected bike lanes are speculative, and the actual speeds of passing vehicles were not included as part of the study.

In addition to the increased crash risks at an intersection and the speed of the motor-vehicle in the presence of a bike lane, we were interested in right turns on red. In New Jersey, as in most of the United States, it is legal to make a right turn at a red light after coming to a complete stop, unless stated otherwise. The intersection that we analyze allows right turns on red. Many cars fail to come to a complete stop, posing a crash risk to both pedestrians and cyclists (Cooper et al., 2012).

Bicycle lanes also have the potential to induce cycling, which offers public health and sustainability benefits (Fonseca et al., 2023; Kraus & Koch, 2021). In Asbury Park, Younes et al. (2023a) analyzed the behavioral differences between cyclists and e-scooter users. Cyclists were more likely to use the bicycle lane than e-scooter users. E-scooter users were also less likely to wear a helmet than cyclists, which suggests that they take fewer safety precautions and may be at an increased risk of injury (Younes et al., 2023a). There is mounting evidence that bicycle lanes reduce the risk of severe and fatal injuries for micromobility users. Secondary effects from bicycle lanes by means of motor-vehicle speed reduction to non-micromobility users are less known.

To the best of our knowledge, we are the first to analyze the associations between motor-vehicle speed and the presence of a painted and a delineator protected bike lane. In our study, we were interested in whether a bicycle lane with traffic delineators would help calm traffic and particularly for those turning right. We compare our results to directions in which traffic flow is not near the bike lane and to a different configuration: painted-only bike lanes. The comparisons provide further evidence that traffic may be calmer in the presence of a delineated bike lane. Our study has implications for traffic safety related to pedestrians and other road users, in addition to micromobility users.

Methodology

Description of camera and data

Traffic videos are collected with an AXIS P1427-LE network camera, ideal for 24/7 traffic conditions monitoring. We have 24-hour footage for ten dates between March 16 and April 30, 2022: three days when there was no bike lane, five days when the bike lane and cones were present, and two days when the paint was visible but cones were removed (see Table 1). The bike lane had two components: paint (including bicycle stencils) and cones. The orange traffic cones and plastic delineators were intended to separate micromobility users from motor-vehicles in addition to the paint. During the implementation period (April 1 to April 25), the cones and delineators were not present the entire time due to windy conditions and at times were toppled over by buses. For each of the ten days, we processed four hours: 7am-9am and 4pm-6pm.The temperature highs ranged between 52° and 74° Fahrenheit (11° to 23 ° Celsius) with clear or mostly clear skies and no precipitation. A summary of the footage collected is shown in Table 1.

The ten days of footage provide three configurations for comparison: (1) no cones and no paint, (2) paint but no cones and (3) paint and cones. In this study, we estimate a model where we investigate the effect of the bike lane configuration (where the reference is no bike lane) and control for traffic flow, functionality of the traffic signal, and whether the vehicle had to stop at the traffic signal. The view of the camera is shown in Fig. 4 for one of the days which had both traffic cones and delineators present. Traffic camera and street views of other configurations are available in the supplementary material.

Motor-vehicles can go in eleven different directions (making a right onto Cookman – top right corner in Fig. 4– is forbidden due to the sharp turning radius). We considered the top six most frequently used

Table 1
Summary of traffic camera footage.[1],[2].

Date	Day of the week	Weather	Bicycle lane conditions	Number of cars observed (four hours each day)
March 16, 2022	Wednesday	H: 63°F; L: 43°F (H: 17 °C; L: 6 °C)	Not implemented	857
March 19, 2022	Saturday	H: 73°F; L: 50°F (H: 23 °C; L: 10 °C)	Not implemented	1436
March 26, 2022	Saturday	H: 52°F L: 43°F (H: 11 °C; L: 6 °C)	Not implemented	1073
April 2, 2022	Saturday	H: 53°F L: 38°F (H: 12 °C; L: 3 °C)	Delineator-protected	1466
April 9, 2022	Saturday	H: 56°F L: 45°F (H: 13 °C; L: 7 °C)	Painted only	1240
April 12, 2022	Tuesday	H: 72°F L: 46°F (H: 22 °C; L: 8 °C)	Delineator-protected	922
April 13, 2022	Wednesday	H: 74°F; L: 50°F (H: 23 °C; L: 10 °C)	Delineator-protected	1010
April 16, 2022	Saturday	H: 73°F; L: 48°F (H: 23 °C; L: 9 °C)	Delineator-protected	1325
April 23, 2022	Saturday	H: 59°F L: 51°F (H: 15 °C; L: 11 °C)	Delineator-protected[2]	1365
April 30, 2022	Saturday	H: 63°F L: 39°F (H: 17 °C; L: 4 °C)	Painted only	1646

directions. We also considered the hourly traffic flow to ensure that speeds would not be affected by unusually light or heavy traffic. Hourly traffic is consistent before and during the implementation of the bike lane, and any unexpected situation (such as a crash, road detours, or adverse weather conditions) that led to an unusual amount of traffic was removed (e.g., a race on April 2 at 8 am that led to the road closure of the intersection). Table 2 shows the hourly traffic count per direction comparing traffic flow before the implementation of the bike lane and during the implementation of the delineated bike lane. Traffic flow per hour and per day is accounted for in our regression analyses.

Video interpretation methodology

Traffic camera footage can be helpful by providing the frequency of each mode, the speed of vehicles, the use of bicycle lanes, any near-miss, swerving, or crash, helmet use, and compliance with traffic laws. Our primary interest in this study is to analyze the speed of turning vehicles in the presence of the bike lane. We hypothesize that motor-vehicles making a right turn will have a slower turning speed once the delineators are present.

Fig. 4. View of intersection from traffic camera. The camera faces south. To the east (or the left in the image) is Asbury Avenue in the direction of the beach. To the south (or top in the image) is Cookman Avenue towards downtown. To the west (or right in the image) is Asbury Avenue in the direction of downtown. North (or the bottom of the image) is Kingsley Avenue, which runs parallel to the beach.

We use SiamMot (Shuai et al., 2021) to track pedestrians and vehicles (buses, cars, trucks and motorcycles) in the intersection. The persons-and-vehicles tracking model is trained using COCO-17 and VOC12 datasets. After obtaining the tracking results, bounding boxes are automatically drawn around the center of the objects on the videos to visualize the 2D trajectories. With these 2D trajectories, we can analyze the behavior of pedestrians and drivers, safety problems, and interactions. In order to measure the velocity of vehicles in the videos, we also transfer the 2D trajectories into 3D trajectories. A mobile mapping system which consists of a survey-grade LiDAR scanner and an inertia assisted Global Navigation Satellite System (GNSS) is used to collect 3D point cloud data and street-level imagery around the crossroads. We manually label 2D-3D correspondences on the video frame and point cloud data by picking 7–10 static corresponding features, such as corners of buildings and pavement marks, in the video frame and the point cloud, and then use RANSAC Perspective-n-Point (PnP) to estimate the pose of the camera in the 3D point cloud coordinates system (Fischler & Bolles, 1981; Li et al., 2012). This manual process only needs to be done once for any given intersection as the projection relationship between the point cloud and the traffic camera footage will remain fixed. The pose (i.e., position and orientation) of the camera is used to project the 3D point clouds onto 2D image coordinates, and the 2D-3D mapping relationship is combined with previous 2D trajectory to calculate the 3D trajectories of detected objects.

After computing the projection between the point cloud data and the traffic camera footage, we transfer the 2D trajectories in the pixel coordinates to 3D trajectories in metric units in the world coordinate system. Then we estimate the speed of each motor-vehicle by calculating 3D distance differences between neighboring frames and use a Gaussian filter to smooth the results. Because the video has 12 frames per second, we multiply the movement per frame by 12 to obtain the speed (meter per second). Each motor-vehicle will have a list of speeds (for each frame). Afterward, we detect the start point and the end point of each motor-vehicle to estimate the moving direction. We also classify the status of each motor-vehicle into free-flowing or stopping and restarting based on whether the speed of the motor-vehicle is less than 1 meter per second (2.24 mph) in three consecutive frames.

Generalized linear modeling

Once the speeds and direction of each vehicle have been estimated, we estimate two sets of generalized linear models (GLM). We specifically

Table 2
Average hourly traffic count per direction before and during the implementation of the bike lane delineated with traffic cones.

		Cookman to Kingsley (straight) 	Cookman to Asbury (right) 	Kingsley to Cookman (straight) 	Asbury eastbound (straight) 	Asbury to Cookman (left) 	Asbury westbound (straight) 
7am	No bike lane	30	21	22	5	5	4
	Painted-only	28	24	18	6	7	12
	Delineated	58	33	22	5	4	20
8am	No bike lane	33	29	30	5	7	5
	Painted-only	46	44	27	5	9	42
	Delineated	39	29	19	5	7	9
4pm	No bike lane	93	98	83	36	42	52
	Painted-only	113	137	92	52	54	72
	Delineated	114	99	73	34	46	51
5pm	No bike lane	113	111	38	24	44	56
	Painted-only	92	123	91	37	54	70
	Delineated	110	90	60	33	43	54

use log-linear Ordinary Least Square (OLS) models in which the dependent variables are the natural log of the average speed of each motor-vehicle and the natural log of the top speed (95th percentile speed) of each motor-vehicle. The independent variables of interest are two indicator variables representing the presence of the delineated bike lane or the presence of the painted-only bike lane, with the reference being the lack of a bike lane. We control for the hourly traffic flow specific to each direction, the behavior of the vehicle at the intersection (whether it was free flowing or stopped) and include a weekend dummy variable.

A separate regression is estimated for each direction of traffic in order to control for directions that were not affected by the bicycle lane. The purpose of analyzing multiple directions is to control for the corridor affected by the bike lane implementation. Motor-vehicles going to and from Cookman Avenue, where the temporary bike lane was implemented on both sides of the road, are expected to see a stronger effect. In particular, vehicles turning right onto Asbury Avenue (see Fig. 5) have the longest stretch along the temporary bike lane.

Results

Descriptive statistics

We analyzed the speed of right-turning vehicles (Fig. 5) with the hypothesis that once the corner of the intersection was delineated for micromobility users, motor-vehicles would slow down. While bicycle lanes are not explicitly considered traffic calming measures by the FHWA (Traffic Calming ePrimer, 2023), they often reduce the width of a vehicle travel lane or roadway and create a sharper turning radius. Street width reductions, such as chokers, median islands, and road diets, are established traffic calming measures by the FHWA. In addition to slowing traffic speeds from narrower lanes, pedestrians have a shorter distance to cross at intersections, which further reduces exposure to vehicular conflicts (ITE, 2018).

We hypothesized that the introduction of the bicycle lane with traffic delineators would slow down traffic turning at the corner of Cookman Avenue and Asbury Avenue, for those making a right-hand turn. There were 2655 vehicles that turned right at the intersection of Cookman Avenue and Asbury Avenue during our observations. For each motor-vehicle, a list of speeds (per frame) is calculated. We use the average of those speeds and the 95th percentile speed (in order to eliminate potential noise from maximum speeds) in this analysis. The average speed of those free-flowing turning vehicles was 11.1 mph (17.9 kph) while the average speed of turning vehicles who stopped at the light was 5.1 mph (8.2 kph). We break down the speed by behavior and bike lane availability in Table 3.

Given the average motor-vehicle speed decreased for vehicles turning right along Cookman Avenue, we sought to investigate the top average speed for each motor-vehicle. While in the camera view, the vehicle would be at its highest speed along Cookman, then either come to a complete stop due to the red light or slow down to turn, and then speed up again. We display the top speed (calculated by the 95th percentile speed for each vehicle throughout its trajectory) in Table 4.

We observe a more dramatic jump in top speed in the presence of the bike lane, compared to using average speed. As a result, we estimate a separate set of regressions using the top speed as the dependent variable, whilst controlling for other factors.

[1] We exclude 8-9 am due to a road closure. Although delineators were not present at the turn, we still consider this day as delineated in this study as cones were present on Cookman Avenue.

[2] The traffic lights were not functioning properly the entire days of 4/23 and 4/30. It flashed yellow for Asbury Avenue and red for Cookman/Kingsley.

Fig. 5. Aerial view of right-turn.

Generalized linear regression modeling

The delineated bicycle lane was associated with reduced speeds once controlling for traffic volume, weekends, and free-flowing behavior. For vehicles turning right, the interpretation is that the presence of the delineated bike lane was associated with a 21 % decrease in vehicle speed (Table 5). For vehicles going straight on Cookman Avenue, where the bike lane was available on both sides of the street, speeds were reduced by around 5 %. Traffic in other directions did not see significant reductions in speed from the implementation of the bike lane.

The painted-only lane was associated with a smaller (11 %), but significant decrease in speeds for vehicles turning right. Traffic in other directions were not associated with decreased speeds from the painted-only bike lane. As expected, free-flowing vehicles were significantly faster than vehicles that had to stop at a red light. Additionally, the flickering traffic light (on the two days where the light was improperly working) was associated with increased traffic speeds on average.

The implementation of the bike lane appeared to have a strong effect on top vehicle speeds for right-turning vehicles, based on descriptive statistics (Table 4). Once controlling for other factors, we found that the presence of the delineated bike lane was associated with a 27.6 % reduction in top speeds for vehicles turning right from Cookman to Asbury, and smaller reductions of 8.4 % and 3.7 % for vehicles traveling straight. The presence of the painted bike lane was also associated with a 14.3 % reduction in top speeds for vehicles turning right (Table 6).

Discussion

In this study, we sought to investigate how bike lanes affect motor-vehicle speeds at an intersection. We used traffic camera footage to analyze three pilot demonstrations of road configurations: (1) without a bike lane, (2) with a painted and delineated bike lane, and (3) with a painted-only bike lane. Over 9000 motor-vehicles were detected via computer vision in the intersection throughout 39 h of traffic camera footage. The intersection was chosen as a candidate site for the pop-up bike lane because it is a busy intersection for motor-vehicles, micro-mobility users, and pedestrians (Manzella et al., 2018). The bike-lane connected to a greater network of painted bike lanes in Asbury Park. We hypothesized a traffic calming effect (reduced speeds) in the presence of a bike lane with traffic delineators, but not in the presence of the painted-only bike lane. We further hypothesized that we would observe speed reductions from the bike lane solely along the sides of the road where the bike lane was available. We therefore estimated one regression per direction in order to isolate the impacts of the bike lane, and controlled for whether it was painted and delineated, or solely painted.

Both average and maximum speeds are lower in the presence of the painted and delineated bike lane for vehicles turning right. The bike lane appeared to have a stronger impact on top speeds than on average speeds, with a 28 % reduction in average top speeds compared to a 21 % reduction in average traffic speeds. The painted bike lane was associated with a smaller, but statistically significant, reduction of 14 % and 11 % for top and average speeds, respectively. For vehicles traveling straight on Cookman Avenue, along the new bike lane, we found that the delineated bike lane was associated with up to 8 % reduction in average maximum speeds and 5 % for average traffic speeds.

In the context of traffic safety and Vision Zero initiatives, this finding is significant in that it suggests that delineated bike lanes can reduce traffic speeds, making the overall road environment safer for all. The pop-up bike lane reduced the traffic lane width and created a sharper turning radius, which likely served as a traffic calming mechanism. The importance of traffic calming measures cannot be overstated, particularly in zones that have frequent non-motorist traffic.

We note that there are several unobserved factors that may have contributed to vehicles slowing down, such as vehicle type and presence of a bicycle while turning. We acknowledge the possibility that the design and materials used in the pop-up bike lane have a different impact on speed than they would on a permanent bike lane. Future studies could analyze differences in traffic calming depending on the material (such as solid green painted lanes, planter-protected, bollard-protected, etc.). We were also limited in geographical scale, as this analysis is focused on a single intersection. Nonetheless, the decreased

Table 3
Average speed of right-turning vehicles based on behavior and presence of bicycle lane with traffic delineators.

Right-turning vehicles (from Cookman Ave to Asbury Ave)	Average speed before the implementation of the bike lane (mph)	Average speed during the implementation of the painted-only lane (mph)	Average speed during the implementation of the delineated bike lane (mph)
Free-flowing	12.4	10.9	10.4
Stopped at red light	5.5	5.6	4.5

Table 4
Average top speed (95th percentile speed) of right-turning vehicles.

Right-turning vehicles (from Cookman Ave to Asbury Ave)	Average 95th speed before the implementation of the bike lane (mph)	Average 95th speed during the implementation of the painted-only lane (mph)	Average 95th speed during the implementation of the delineated bike lane (mph)
Free-flowing	25.3	20.2	15.9
Stopped at red light	15.9	14.2	12.9

Table 5
Regression results for the average speeds.

	Dependent variable: Natural log of (Average Motor Vehicle Speed)					
	Cookman to Asbury (right turn)	Kingsley to Cookman (straight)	Cookman to Kingsley (straight)	Straight on Asbury Avenue (westbound/ downtown)	Straight on Asbury Avenue (eastbound/ beach)	Asbury to Cookman (left turn)
						
Delineated Bike Lane Present	**−0.234*****	**−0.045*****	**−0.055*****	0.041	−0.008	0.015
	(0.020)	**(0.011)**	**(0.021)**	(0.040)	(0.034)	(0.033)
Painted Bike Lane Present	**−0.118*****	−0.016	−0.024	0.051	0.009	−0.0001
	(0.026)	(0.014)	(0.029)	(0.049)	(0.043)	(0.044)
Stopped at red light (ref: Free flowing)	−0.894***	−0.418***	−1.382***	−1.250***	−1.281***	−0.850***
	(0.016)	(0.015)	(0.018)	(0.034)	(0.028)	(0.027)
Weekend	0.019	−0.042***	−0.072***	0.052	0.122**	−0.068*
	(0.022)	(0.012)	(0.024)	(0.051)	(0.050)	(0.038)
Traffic volume (per hour, per direction, per day)	−0.001***	−0.001***	−0.0002	−0.0003	0.001*	0.002**
	(0.0002)	(0.0002)	(0.0003)	(0.001)	(0.001)	(0.001)
Traffic signal properly working	−0.190***	−0.026**	−0.543***	−0.219***	−0.221***	−0.280***
	(0.023)	(0.013)	(0.024)	(0.041)	(0.036)	(0.039)
Constant	1.935***	1.845***	2.373***	2.001***	1.826***	1.844***
	(0.039)	(0.023)	(0.040)	(0.074)	(0.068)	(0.063)
Observations	2655	1799	2928	787	1406	1029
Adjusted R^2	0.558	0.353	0.685	0.632	0.638	0.497
Residual Std. Error	0.415 (df = 2648)	0.190 (df = 1792)	0.456 (df = 2921)	0.444 (df = 780)	0.496 (df = 1399)	0.431 (df = 1022)
F Statistic	560.416*** (df = 6; 2648)	164.271*** (df = 6; 1792)	1063.626*** (df = 6; 2921)	226.242*** (df = 6; 780)	413.408*** (df = 6; 1399)	170.484*** (df = 6; 1022)

Note: *$p<0.10$; **$p<0.05$; ***$p<0.01$.

Table 6
Regression results for top (95th percentile speed) speeds.

	Dependent variable: Natural log of (95th percentile speed)					
	Cookman to Asbury (right turn)	Kingsley to Cookman (straight)	Cookman to Kingsley (straight)	Straight on Asbury Avenue (westbound/ downtown)	Straight on Asbury Avenue (eastbound/ beach)	Asbury to Cookman (left turn)
						
Delineated Bike Lane (with cones and plastic delineators) Present	**−0.323*****	**−0.088*****	**−0.037*****	−0.026	−0.007	−0.021*
	(0.012)	**(0.010)**	**(0.011)**	(0.017)	(0.017)	(0.012)
Painted Bike Lane Present	**−0.154*****	**−0.052*****	−0.009	−0.013	0.011	−0.026
	(0.015)	**(0.013)**	(0.015)	(0.021)	(0.021)	(0.017)
Stopped at red light (ref: Free flowing)	−0.302***	−0.158***	−0.461***	−0.335***	−0.397***	−0.190***
	(0.010)	(0.014)	(0.009)	(0.015)	(0.014)	(0.010)
Weekend	0.013	−0.035***	−0.054***	0.010	0.045*	−0.024
	(0.013)	(0.010)	(0.012)	(0.022)	(0.024)	(0.014)
Traffic volume (per hour, per direction, per day)	−0.001***	0.0004***	−0.0004***	−0.001***	−0.001*	−0.001***
	(0.0001)	(0.0002)	(0.0001)	(0.0004)	(0.0004)	(0.0003)
Traffic signal properly working	−0.020	0.109***	−0.162***	0.027	−0.038**	−0.008
	(0.014)	(0.012)	(0.013)	(0.018)	(0.018)	(0.015)
Constant	2.423***	2.154***	2.622***	2.349***	2.449***	2.107***
	(0.023)	(0.021)	(0.021)	(0.032)	(0.033)	(0.024)
Observations	2655	1799	2928	787	1406	1029
Adjusted R^2	0.428	0.241	0.476	0.404	0.400	0.266
Residual Std. Error	0.247 (df = 2648)	0.172 (df = 1792)	0.235 (df = 2921)	0.193 (df = 780)	0.242 (df = 1399)	0.162 (df = 1022)
F Statistic	331.341*** (df = 6; 2648)	96.199*** (df = 6; 1792)	444.828*** (df = 6; 2921)	89.617*** (df = 6; 780)	157.029*** (df = 6; 1399)	63.012*** (df = 6; 1022)

Note: *$p<0.10$; **$p<0.05$; ***$p<0.01$.

speed in the presence of the delineated bike lane is a promising finding that warrants further investigation, particularly because the sharpest decreases in speed occur in directions that are in close proximity to the delineated bike lane.

Conclusions

Slower traffic is associated with decreased severity of pedestrian and bicycle-involved crashes (Alshehri et al., 2020; Behnood & Mannering, 2017; Kim et al., 2017; Leaf, 1999) and thus, the addition of a protected, or at least delineated, bike lane could have an additional benefit with respect to traffic safety for pedestrians and cyclists. The higher the speed, the higher the likelihood of severe or fatal injury in the case of a crash with a non-motorist. Evidence suggests that the chances of surviving a crash between a car and a pedestrian decreases sharply above 19 mph (30 kph) impact speeds (Fildes et al., 2005). The FHWA suggests that speeds exceeding 30 mph (48.3 kph) will likely lead to fatal or serious injuries in the case of a conflict with a non-motorist (Leaf, 1999; Traffic Calming ePrimer, 2023). Right-hook turns (where a motor-vehicle turns right while a cyclist continues straight) have been found to be particularly more hazardous for cyclists than other crash typologies (Jannat et al., 2020; Shah et al., 2021). In particular, the sharper turning radius and traffic lane width reduction can serve as traffic calming measures that signal to drivers to slow down. A longitudinal study using aggregated data suggested that the density of protected bike lanes in a census block group (CBG) are associated with fewer traffic fatalities (Marshall & Ferenchak, 2019). Our study further supports that delineated bike lanes (cones are not sufficient to protect cyclists from vehicles) may have a traffic calming effect and provide safer conditions for both cyclists and pedestrians. In order to achieve Vision Zero initiatives, planners and policy makers should focus efforts on delineated bike lanes, not merely painted lanes. Delineated pop-up bike lanes are not necessarily costly, as much of the material can be borrowed. The costs associated with the materials are offset by the traffic calming benefits of the delineated bike lane. We recommend that future research analyze traffic calming benefits of different types of bike lanes, such as protected bike lanes.

CRediT authorship contribution statement

Hannah Younes: Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization. **Clinton Andrews:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Robert B. Noland:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Jiahao Xia:** Methodology, Formal analysis, Writing – original draft. **Song Wen:** Methodology, Formal analysis, Writing – original draft. **Wenwen Zhang:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Dimitri Metaxas:** Methodology, Formal analysis. **Leigh Ann Von Hagen:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Jie Gong:** Methodology, Formal analysis, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.urbmob.2024.100071.

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