FINAL REPORT

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Shared Bus-Bike Lane Safety Analysis: Assessing Multimodal Access and Conflicts

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16. Abstract

Dedicated bus facilities are being installed across the country with many jurisdictions allowing cyclists to use these facilities. Known as shared-bus bike lanes (SBBLs), these facilities are built with two, often opposing, goals in mind: (1) provide a high-speed travel lane for buses and (2) provide a safe travel lane for cyclists. Using video observation and survey data, the aim of this study is to analyze cyclist safety on SBBLs as a function of geometric configuration, bus frequency, and level of service. The safety of cyclins on SBBLs will be compared with separated bike facilities with adjacent bus routes.

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EXECUTIVE SUMMARY

Shared Bus-Bike Lanes (SBBLs) are traffic lanes next to the curb exclusively dedicated to buses, bicyclists, and right-turning vehicles. They have been implemented in cities with limited right-of-way, with the aim of accommodating buses and bicycles for safer and more efficient multimodal service. The Maryland Transit Administration (MTA) implemented a 5.5-mile network of dedicated bus lanes. These dedicated lanes were implemented on high-volume bus corridors in Downtown Baltimore between 2016 and 2017 through a cooperative effort with the City of Baltimore.

The key objective of this study was to evaluate the benefits, barriers, and effectiveness of the dedicated SBBLs in Baltimore, Maryland. The SBBLs were implemented to maximize the benefits of bus operations by limiting their competition for space in the heavily congested downtown Baltimore. A detailed literature review summarizes the findings' introduction of SBBLs across the U.S., including past relevant research on planning and design guidelines of SBBLs.

Nine SBBL corridors were selected for this study using a variety of criteria such as frequency of buses, likelihood of cyclists, traffic volume mix, and geometric configuration. A total of 6 hours of footage was collected for each full-time SBBL location, 7 am to 9 am (AM peak), 2-4 pm (Off peak) and 4-6 pm (PM peak) using a tethered, unmanned aerial vehicle (UAV). The data contained the count of vehicles in general purpose lanes, count and modal classification of vehicles in the shared bus-bike lane, and the travel time of each vehicle. Additionally, a visual inspection and survey of a subset of data was conducted to analyze vehicle maneuvers and travel behavior.

Eight percent of vehicles traversed the SBBL. More cyclists were present in PM peak opposed to AM peak. For the majority of facilities, the travel time on the SBBL was lower than the general purpose lanes. The presence of cyclists had no significant impact on bus travel time due to the low volume of cyclists. Of all instances where a bus or cyclist was on the SSBL with another vehicle only 6% involved a bus and cyclist. Bus operators always waited safely behind a cyclist and never attempted to pass.

Buses in the SBBL were most impacted by parked cars followed by moving passenger cars. For five of the nine facilities, buses were able to use the SBBL over 94% of the time; however, for other facilities buses often had to use the general purpose lanes to maneuver around parked or queued vehicles. The lowest SBBL utilization was 72%. Cyclists were not very impacted by other vehicles; only 20% of the time did cyclists have to slow down or maneuver around a vehicle in the SBBL.

This study found that the SBBLs minimize delays associated with auto traffic, particularly during rush hours. Enforcement of SBBLs is crucial for their success. Parked vehicles and through moving vehicles in the SBBL slowed buses. Clear and visible markings, especially red paint, are essential for the proper use of the SBBLs. When properly implemented and enforced, SBBLs offer the potential for increased speed, safety, reliability, and on-time performance for transit vehicles.

1. INTRODUCTION

With rapid urbanization, available roads often have inadequate space to provide separate facilities for all road users. Cities are exploring new options to allocate the limited right of way to multiple modes in a safe manner. Sharing the road with multiple modes is a tradeoff between the needs of all road users and their safety. Public transit and bicycling are being encouraged as these modes have fewer adverse effects on the environment, are more affordable, and can reduce congestion (*1*, *2*). Increased speed limits push bicyclists toward the curb for their own safety. Conversely, buses are also operating near the curb which increases vulnerability for bicyclists. The Transit Street Design Guide recommends building separated bike facilities adjacent to bus routes. However, in major cities where the right of way is inadequate and increased transit efficiency is anticipated, bicyclists can be accommodated using Shared Bus-Bike Lanes (SBBLs). According to the National Association of City Transportation Officials (NACTO) Transit Street Design Guide, dedicated bus lanes are a delimited section of a corridor in which the local authorities provide a preferential lane for buses by way of signs and pavement markings (*1*). Dedicated bus lanes reduce congestion, improve public transit travel times, provide greater safety and comfort for cyclists, and improve the corridor efficiency (*2–4*). SBBLs may not be as comfortable for cyclists as separated facilities, and high-volume bus routes should not be considered. Generally, the number of buses and bicycles using the road is fewer than other types of vehicles (*5*, *6*). So, buses and bicycles sharing the same lane could maintain the advantages for both roadway users and free up spaces for general purpose lanes. Since the bicyclists and buses often share the same curb space, shared facilities offer an option when limited right of way prohibits separated facilities (*1*, *7*). Ideally, the SBBLs will provide a free lane for buses to operate more efficiently while allowing the bicyclists to travel along the road. Since fewer passenger vehicles occupy SBBLs, bicyclists may feel a level of safety similar to traveling in dedicated bike infrastructure.

In city-centric cities, personal motor vehicles shaped urban road and highway planning, sidelining other modes of transportation that could threaten their hegemony. Fast-paced, ever-expanding large cities demand swift and efficient travel for their residents to achieve a satisfactory quality of life. Public transit, especially bus operations, has recently received much-needed interest, and research has been conducted to make it more efficient and effective. But the shared use of a bus lane with bicyclists has often been overlooked. Traffic congestion and fuel emissions can be considerably reduced by increasing public transportation usage, while bicycling can provide an alternate mode of transportation and better accessibility (*2*). Many cities have been trying to balance the promotion of both modes concurrently, but only a few are considering SBBLs as a solution. SBBLs are more prevalent in other parts of the world, including the United Kingdom, Austria, Australia, Belgium, Canada, Denmark, France, Germany, Ireland, and Switzerland (*3*, *7*) . There are 27 corridors reported to have SBBLs in the United States; cities like Panama Beach, Florida, and Fort Worth, Texas, implemented their first SBBL back in December 2011 (*8*). During the implementation of BaltimoreLink, the complete overhaul of the Maryland Transit Administration's bus system, dedicated bus lanes were installed on 10 high-frequency corridors throughout the city in 2017 (*9*, *10*). Out of the 5.5 lane miles of dedicated bus lanes, 4.9 miles are full-time lanes painted red with appropriate signage and markings. The remaining 0.5 miles are peak-only lanes with signage and pavement markings without red paint. These corridors were selected based on a set of criteria that includes person throughput, level of service, and vehicle delay. But bicyclists data were not included in the selected criteria (*8*, *9*, *11*).

Only brief mentions of SBBLs were found in some of the state departments of transportation guidelines for Maryland, Illinois, Florida, and Texas *(8, 12)*. Though an SBBL is likely to provide a safer travel environment for the bicyclist without hindering the operations and efficiency of the buses, nevertheless, in the U.S. they often are not considered as an option to improve public transit (*8*, *12*). Research is quite limited on the efficacy of this strategy. The objective of this comprehensive study is to quantify the safety impacts and efficiency of shared bus-bike lanes. This study evaluates i) types of unsafe maneuvers along the SBBL facilities; ii) delay incurred (if any) by the bicyclists on bus operation in a shared facility; iii) the safety and comfort of the bicyclists compared to other facilities; and iv) impact of enforcement, design, and education to improve SBBL operation. Video data is collected using an unmanned aerial vehicle (UAV) on selected Baltimore SBBLs and analyzed to draw efficiency comparisons of the implementation of the SBBLs. Additionally, the study quantifies the level of interaction between bus, cyclists, and other vehicles on these facilities.

2. LITERATURE REVIEW

This study explores the existing literature on SBBLs in the United States, where they are less common than in many cities in Europe (*8*). Most cities have implemented SBBLs after a street has been developed, when the functional class, access management class, and the design speed for the roadway are already fixed. This chapter provides a comprehensive review of existing literature on SBBLs and identifies the research gaps. The findings from existing literature were categorized into three broad categories: Design, Delay in Traffic Lane, and Safety along the Routes. If a study involved more than one topic, each of these topics was considered separately.

Design

The growing use of public transit indicates a paradigm shift in urban transport, and a well-planned transit system can provide better mobility, accessibility, and equity within the urban transportation network *(5, 13)*. Sharing the lane between bicyclists and buses needs appropriate design and policy guidelines to minimize conflicts and improve the efficiency of public transit. Most of the major cities in the U.S. have tried to optimize the design and configuration of travel lanes for buses and bicycles to mitigate the conflicts between them (*13*, *14*). The design and application of bicycle facilities as a function of shared use include wider outside curb lanes, general-purpose lanes with shared lane markings for bicyclists, and paved shoulders (*1*, *15*, *16*). Safety, delay, and level of stress are measures of effectiveness for a roadway design. A bicyclist's perception of safety, speed, and comfort on the road may influence their decision to ride – a consequence that can only be measured through surveying the riders (*5*, *15*, *16*). There are no national standard guidelines for SBBL design, but the Manual on Uniform Traffic Control Devices (MUTCD) discusses the emergence of a shared lane where bicyclists will share the lane with other motorized vehicles (*17*). The FHWA-approved experimental use of shared lane markings in right-turn lanes was proposed in the NACTO Urban Bikeway Design Guide (*15*).

Table 1. Selected SBBLs Roadway Speed Limit and Lane Width *(8)*

City	Street	Speed Limit (mph)	Width (feet)
Philadelphia, PA	Chestnut Street	25	10.5
Boston, MA	Washington Street	30	12
Chicago, IL	Milwaukee Avenue	25	13
Ft. Worth, TX	Throckmorton and Houston Streets	25-30	11
Denver, CO	Larimer Street	30	12
Washington, DC	7th St NW, 9th St NW	30	11 - 18
Baltimore, MD	W Lombard Street and Pratt Street	30	14 - 16
Portland, OR	Vancouver Avenue	30	10 - 15

In the absence of protected bike facilities, the posted speed limit is critical as bicyclists feel more comfortable next to slow-moving cars and are able to ride in the full width of the lanes (*1–3*). Lane markings and signage help demarcate the bike lane travel and ensure motorized vehicles pass with sufficient clearance (*15*). Roadways with speeds greater than 35 mph should not be considered for shared lane markings (*7*, *15*). For the SBBLs, it is common practice to allow right-turning general traffic; thus, cars turning right at higher speeds can endanger the bicyclist (*8*, *9*, *18*). There is no national standard lane width for the SBBLs. AASHTO recommends 5 feet for bike lanes and 12 feet for bus lanes, but there is no guideline for a shared lane (*15*). City roads are generally not wide enough to accommodate separate bike and bus lanes; however, a dedicated shared lane is feasible (*2*, *18*). Cities paint markings and place signage on the SBBLs and ensure the lane is wide enough for passing the bicyclist in compliance with the three feet law.

Allowing bikes in bus prioritized and bus exclusive lanes is a well-established and popular practice in the UK and Australia (*7*, *19*, *20*), where bicyclists can travel easily in the bus lanes. Australian and British guidelines (*7*, *21*) recommend that buses travel at a lower speed and have adequate width throughout the corridor to allow bicyclists to overtake buses dwelling at stops. But the U.S. does not have any national standard guidance; however, many local and municipal transportation agencies have adopted state-level guidelines. Maryland has set the minimum width for SBBLs to 16.5 feet (*9*, *22*). Washington State did not quantify any values, but they recommend areas where bus speed and volume are low. Countries like Australia, Canada, and the United Kingdom recommend transit-only lanes with 8.5 feet width, which should increase by at least 4.5 feet when used by bikes. The Netherlands, well-known as the "Country of Bicycles," does not have a lot of experience with SBBLs (*9*, *21*).

Delay in Travel Lanes

The delay to buses or bicyclists after an encounter is difficult to measure. Bicyclists can maneuver around obstacles relatively easier than the buses can. However, bicyclists may face an unsafe situation when their path is blocked by a bus or a stopped vehicle, and they have to wait for a clear passing lane (*7*, *23*). Buses might experience between 3 and 30 seconds of delay per encounter with a person riding a bike in the bus-only lanes (*8*, *21*, *23*). Dedicated bus lanes have less traffic volume compared to a general-purpose lane; however, the bicyclists must also share the road with right-turning vehicles. Such maneuvers could be very volatile, depending on enforcement and bus headway (*13*, *16*).

Even though buses are motorized vehicles, they travel at speeds similar to bicyclists in a city environment thanks to an abundance of bus stops, which is one reason for these modes to occupy a common space (*3*, *8*). Conversely, a large number of bus stops produce frequent leapfrogging between the bicyclist and the bus (*14*, *23*). The bicyclist will feel compelled to overtake the bus during the boarding process at a stop, while the bus driver will want to overtake the cyclist along the corridor after reaching cruising speed to maintain the bus schedule (*8*, *16*). According to the FHWA Average Vehicle Occupancy Factors for Computing Travel Time Reliability Measures and Total Peak Hour Excessive Delay Metrics, the average number of passengers per car (PPC) in Baltimore is 1.7; see Table 2. For buses, it is 15.9 PPC in Baltimore, Maryland; 12.2 PPC in Boston, Massachusetts; 8.9 PPC in Washington, DC, and in a large urban center like New York, this number is almost 10 times more (16.8) PPC than the average PPC of cars (*24*). Buses carry 300% more passengers per square ft than passenger vehicles (see Table 2) in Baltimore. Thus a successful dedicated bus lane should carry at least 80% more people than of the adjacent travel lane (*9*, *22*). As other vehicles are permitted to use bus lanes, congestion may occur. Separating the right-of-way from other vehicles can improve the operation and performances of buses (*4*, *13*). Studies found that bicyclists were generally not delayed by buses (*7*, *13*, *22*). If the width of the lane is less than 10 feet then the bus is more likely to be delayed. Thus a 12-foot lane width is generally recommended for SBBLs (see Table 1). The buses are most likely to be delayed when they wait behind bicyclists or approach roundabouts (*8*, *14*).

Table 2. Ratio of Average Passenger per Vehicle Occupied Road Area for Baltimore *(24)*

Vehicle	Average Passenger per Vehicle (PPC)	Occupied Area per Vehicle (sq ft)	Occupied Area/Passenger (sq ft/PPC)
Car	1.7	133	78.24
Bus	15.9	387	24.33
Bike	1	12	12.00

Safety along Bus Routes

Road expansion is often next to impossible for major cities; thus, transportation planners are exploring creative approaches to allocate limited right-of-way through lane markings and signage to designate use (*9*, *23*). Since these lanes are often not physically separated, vehicles can move between the shared, restricted or general-purpose lanes in the event of an accident or any obstacles. Buses stopping at designated bus stops along the curb, which is often the preferred travel path for the cyclists in the absence of a protected bike lane, is the most likely scenario for a conflict with a bike (*7*, *10*). A wider SBBL may have another potential type of conflict due to buses cutting off a bicyclist to reach the stop (*10*, *13*). In SBBLs, bus-bike crashes are relatively low compared to other types of crashes, but they are increasing with the emergence of bike-sharing. Bike lanes implemented alongside bus routes reduce the odds of a crash during interaction (*9*, *25*). A collision between these two modes puts the bicyclist at a greater risk for injury or fatality than the occupants of the bus. In Philadelphia, only 1.8% (46 total) of all bicycle crashes involved a bus. Out of these 46 bus-bike crashes, ten occurred on bike lanes in the downtown area (*26*). After the installation of SBBLs in Minneapolis, a study evaluated 36 hours of video recording at three locations. Out of 3,506 motor vehicles, 480 buses, and 442 bicyclists, there were only 21 interactions between buses and bicycles, and only 99 between bicycles and other motor vehicles (*2*, *8*, *26*). After the installation of green pavement in SBBLs, the crash rate decreased from 1.03 to 0.4 crashes per year per 100 estimated daily bikes (EDB), but the correlation between the SBBL and crash reduction was not studied (*8*, *26*).

The majority of bicycle crashes, as well as bike/bus conflicts, occur in the city centers (*10*, *18*). In the U.S., 40% of the bus crashes were rear-end crashes, and of those, 80% occurred when the bus was stationary (*14*, *27*). The risk of bus crashes increases when they operate in narrow lanes; studies found that buses can operate in a minimum 12-foot lane width (*1*, *8*, *27*). Shared lanes less than 12 feet wide are not recommended due to not having enough space for a safe overtaking maneuver unless localized widening is provided at points of interest such as bus stops or bus bays (*8*). The typical length of a bus is 30 to 50 feet, and a bicycle at 6 feet long and 2 feet wide may often be situated in the blind spot, which increases accident possibility (*20*). In Philadelphia only 22% of all bike/bus crashes took place on streets with bicycle lanes (*18*, *20*). For Baltimore, one of six bike crashes occurs at “right turn” and one of four crashes is defined as “rear-ended” (*10*, *28*). In Western Australia, less than 2% of the bicycle accidents involved a bus, and one out of every seven cyclists who were severely injured in a crash did not survive (*8*, *20*). An Auckland-based study concluded that out of all the incidents involving bicyclists, less than 5% of those are classified as the bicyclist’s fault. The majority of the incidents occurred due to poor observation or failure to give way by the other parties involved (*25*). The study argued that a separate bike facility reduces vulnerability for the cyclists and sharing the road with buses on a wider lane can also have a similar effect (*25*). Out of the 46 crashes in Philadelphia involving both a bus and bike, only one happened in an SBBL; 10 of the 46 crashes happened in streets with bike infrastructure (*26*). Both of those types of crashes are frequently a result of unsuccessful overtaking movements (*18*, *26*).

The SEPTA policy suggests averting the queuing of general traffic behind the stopped buses. When a bicyclist is traveling behind a bus and the bus is making weaving movement towards a bus stop, the bicyclist is responsible for speed adjustment to avoid any conflicts (*26*). The bicyclist must be aware enough to notice whether the driver is trying to reach the curb to pick up or drop off passengers and adjust accordingly since that maneuver may create a hazardous situation for the bicyclist (*14*, *27*). Both the cyclist and the bus driver must share the road responsibly and be aware of one another in order to maneuver alongside each other. Narrow lanes with bicycle infrastructure have higher rates of interactions between buses and bicycles; 57% of cyclists in the narrow lanes had to interact with buses compared to only 29% in the wider lane (*21*). Frequent interactions between buses and cyclists reduce traffic flow and increase the probability of conflict. Thus, installation of SBBLs is recommended along a stretch of a high-flow corridor where there are few bus stops. The recommended speeds found for an SBBL ranged from 25 to 45 mph with a median of 30 mph (*3*, *8*). Narrow SBBL lanes, those under 13 feet, are not recommended for safe passing. In central business districts (CBD), where the bus stops are closer together, there is a higher probability of conflicts between buses and bikes. One key concern with SBBLs is the enforcement of timely merging of right-turning general traffic into the

SBBLs. Often, they ended up traveling far more than they are supposed to before turning (*7*, *8*, *18*).

The literature on SBBLs was relatively sparse in comparison to other transportation topics as most scholars and planners still prefer to keep these modes detached (*4–6*). The review of existing literature is critical to this study to establish current practices regarding SBBLs. Both buses and the bikes are important modes of transportation, and their respective infrastructure would ideally work exclusively with a single mode. But to accommodate ever-growing city centers and work within the physical limitations of the current right-of-ways, decision-makers and advocates must accept that in some situations, multiple modes will have to share the same path. While shared bus-bike lanes have become more common, not enough applications are available for a standardized guideline. The majority of the literature recommends wide SBBLs to allow enough space for passing movements for both modes. The literature also showed that SBBLs are normally adopted where there are physical constraints to implementing an exclusive bicycle lane and the authorities want to promote both bus and bike usage. The first appearance of an SBBL in the United States was in the mid 1980s but only in the past few years have SBBLs been implemented more widely (8). The study found 27 corridors of SBBLs in the U.S., of which only four were studied extensively. For the international guidelines on SBBLs, there was a greater variety of examples from Australia and Europe. Most European transit-only lanes have around an 8.5-foot width, recommended, which is increased by 4.5 feet when used by bikes (*8*, *19*). For the U.S. guidelines, the lane width is recommended at a minimum of 12 feet. The speeds along SBBLs ranged from 25 to 45 mph with a median of 30 mph, reinforcing the urban aspect of SBBLs (*2*, *8*, *21*).

Limitations

City centers and downtowns are becoming very congested, and the limited available space may not allow for the provision of individual facilities for all road users. Allocating bicyclists to travel on the bus lanes is a compromise to offset the needs of other road users. The safety of bicyclists on bus lanes has scarcely been investigated. This study applies semi-automated video observation techniques with the aim of analyzing bicyclists' safety on bus lanes shared with bicyclists.

3. METHODOLOGY

Shared Bus-Bike Lane Implementation in Baltimore, Maryland

The City of Baltimore is located in the heart of Maryland and is a central transportation hub for the Northeast Corridor. The Maryland Transit Administration (MTA) serves the city and surrounding region, covering 2,000 miles of routes served by buses, light rail, subway, and commuter rail (MARC) (*3*, *4*). As part of the bus system redesign branded as BaltimoreLink, dedicated bus lanes were installed on several high frequency corridors throughout the city in 2017. School buses, emergency vehicles and bicycles may also travel in these lanes. Nearly 5.5 lane miles of dedicated bus lanes were installed – 4.9 miles of full-time lanes with red paint and appropriate signage and markings, and 0.5 miles of peak-only lanes with signage and pavement markings, but no paint. Candidate routes (Figure 1) were selected based on a set of criteria (Table 3) that included person throughput, level of service and vehicle delay; see Table 3. Cyclists were not included in the selection criteria (*5*, *6*). Figure 2 shows the streets selected for dedicated bus lanes.

Table 3. Corridor Screening Criteria (*7*)

Performance Area	Performance Measures
Mobility	Person Throughput
	Person Delay
	Volume (peak hour, peak direction)/Frequency
	Passengers per Hour
	Travel Time
	Average Speed
	Level of Service, Delay, and Volume to Capacity Ratio
Access	Parking and Loading/Unloading Impacts
	Population Near Routes
	Transit Dependent Population Near Routes
	Access to Jobs
	Connectivity/Transfers
	Emergency Routes
	Freight Routes
	Lane Width
	Right Turns at Intersections
Design Adequacy	Lane Width
	Right Turns at Intersection

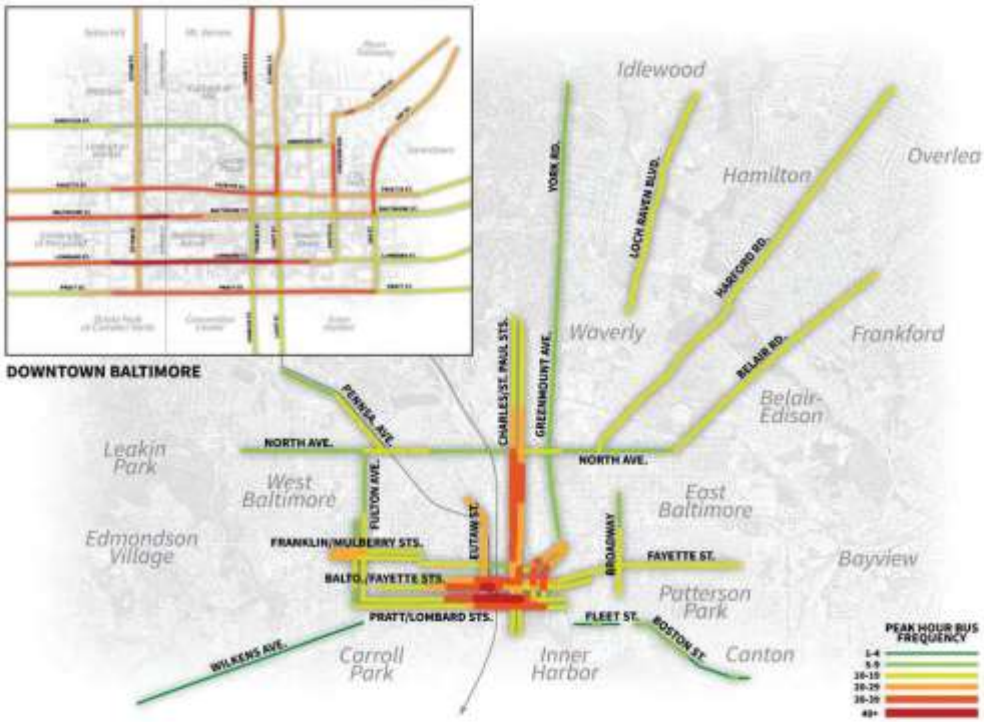


Figure 1. High Frequency Bus Corridor (9)

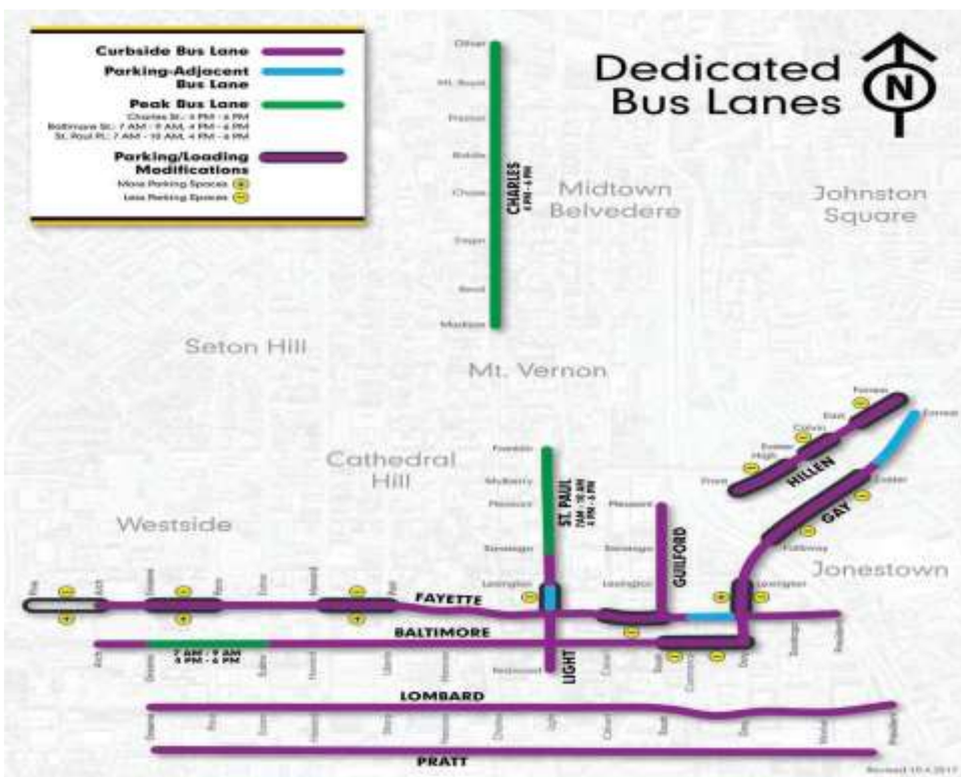


Figure 2. Dedicated Bus Lanes in Baltimore (9)

In 2019, the MTA conducted a before and after analysis of the SBBLs to assess their effectiveness. The study focused on three measures of effectiveness: bus travel time, general purpose lanes travel time, and bus crashes. The interaction between buses and cyclists was not evaluated. As shown in Table 4 below, the average travel time for buses decreased on all lanes with the exception of Charles Street, Lombard Street between Market and Howard in the AM Peak, and Pratt Street between Greene and Howard in the AM Peak. The average change in travel time in the general purpose lanes across all corridors is an increase of less than one minute (*29*).

Table 4. Average Travel Times for Buses Before and After Bus Lane Implementation *(29)*

Street Location	**Peak Period**	**Travel Times Before (min)**	**Travel Times After (min)**	**Change in Travel Time (min)**
Baltimore Street Calvert to Paca	AM	4.3	4.1	-4.7%
	PM	5.7	5.3	-7.0%
Charles Street Mt Vernon Pl to Preston	AM	Bus lane not operational in AM		
	PM	2.6	3.2	**23.1%**
Fayette Street Calvert to Greene	AM	7.1	5.8	-18.3%
	PM	7.3	6.9	-5.5%
Gay Street Fayette to Forrest	AM	3.1	2.5	-19.4%
	PM	3.0	2.6	-13.3%
Hillen St/Guilford Ave East to Saratoga	AM	4.0	3.3	-17.5%
	PM	4.1	2.8	-31.7%
Lombard Street Market to Howard	AM	5.5	5.8	**5.5%**
	PM	6.7	6.0	-10.5%
Lombard Street President to Market / Howard to Green	AM	1.8	1.7	-5.6%
	PM	1.5	1.5	0.0%
Pratt Street Greene to Howard	AM	5.8	6.1	**5.7%**
	PM	9.4	8.6	-8.5%
Pratt Street Howard to Market	AM	1.5	1.3	-13.3%
	PM	2.5	2.0	-20.0%
St. Paul St Chase to Redwood	AM	8.6	7.2	-16.3%
	PM	7.7	6.2	-19.5%

Site Selection for the Study

Nine SBBL corridors were selected for this study. The corridors met a variety of criteria such as frequency of buses, likelihood of cyclists, traffic volume mix, and geometric configuration. Researchers consulted with the MTA to select the locations and indicators. Geometric configuration, bus frequency, traffic incidents, and bike volumes were calculated for each location; see Table 5. Selected indicators were obtained from the MTA and Baltimore Open Data Portal (*3*, *8*, *9*). Ridership data is presented as the average daily weekday ridership per stop. The crash data (for all modes) were analyzed from 2015 to 2018. The slope was calculated using ArcGIS tools from the Digital Elevation Model (DEM) of Baltimore. The slope is calculated as the maximum rate of change in value from that cell to its neighbors. Roadway slope was included due to the potential speed differential between buses and cyclists as well as the fact that studies have shown that cyclists feel more comfortable riding on level surfaces (*1*, *10*). The data summary is presented below.

Table 5. Geometric Profile of the Selected SBBL Locations

SL No	SBBL Locations	Length (ft)	Lane Width (ft)	AADT	Bus AADT	Bike AADT	Slope (%)	Crash ('15-'18)	Fatal Crash	Bus Stop	Rider Count	Routes Served
1	Guilford Ave btwn Lexington St & E Fayette St	450	16	5214	20	54	7.52	48	2	2	59, 373	115,80 YW,54,56,154,BL,RD,YW
2	Fayette St btwn Calvert St & Saint Paul St	400	11	16140	135	17	12.68	262	0	1	1109	RD,56,71,78,105,150,160,420, OR,PR
3	W Baltimore St btwn S Arch St & S Greene St	425	11	9733	38	16	6.38	76	0	2	336 625	78,OR,PR 69,69,70,70,75,75,RD
4	W Baltimore St btwn N Hanover St & S Charles St	375	09	12995	184	36	1.20	180	0	1	1732	RD,56,71,78,105,120,150,160, 210,215,310,OR, PR
5	W Lombard St btwn Hopkins Plaza and S Hanover St	400	09	35081	328	265	10.69	185	0	1	229	YW,54,76,94,154,210,215,310, BR,NV
6	E Pratt St btwn S Calvert St & Commerce St	600	12	14186	171	53	5.00	222	2	2	185 666	YW,54,65,154,BR,NV YW,54,76,94,120,154,210,215, 310,410,411,BR,NV
7	E Fayette St btwn Holliday St & N Gay St	300	12	5214	30	54	4.00	163	0	1	64	67,76,78,105,150,160,OR,PR
8	Charles St btwn W Preston St & W Biddle St	400	11	9850	232	55	7.57	64	0	1	358	SV,51,95,103,GR
9	Saint Paul Pl btwn E Mulberry St & E Saratoga St	400	16	16140	135	17	6.68	228	0	1	137	SV,95,103,410,411,GR

Data Collection

To analyze the travel behavior, conflicts, and issues between buses and bicycles in the SBBLs, video data was collected for the selected sites. Having the data collected through cameras gave the researchers the opportunity to analyze the traffic patterns along the whole corridor. Quality Counts, a specialty data collection company, conducted the video data collection (*9*). The high-definition video camera was mounted on a tethered, unmanned aerial vehicle (UAV) and stayed afloat at the top of the selected sites. To ensure uninterrupted footage for the duration of the study, the UAVs were equipped with a power bank, and the local storage capacity was sufficient to record for the entire duration as well. Table 6 shows the collection days at each intersection. Data was collected on clear days in October. A total of 6 hours of footage was collected for each full-time SBBL location, 7 am to 9 am (AM peak), 2-4 pm (Off peak) and 4-6 pm (PM peak).

Wind pattern, favorable weather, no electromagnetic interference, and no flying zones were taken into consideration while operating the UAVs. The locations of the cameras are shown in the study area map (Figure 3) along with observed corridors. Figure 4 illustrates screenshots of four representative corridors with the SBBLs shown in red and general traffic lanes shown in green plots. The traffic direction is marked with a yellow arrow and the length of the corridor is bounded by the cyan solid lines. Images of each study location are provided in Appendix A.

Table 6. Data Collection Days

#	Site Location	Morning	Evening	Notes
1	Guilford Ave btwn Lexington St & E Fayette St	10/7/2019	10/7/2019	
2	Fayette St btwn Calvert St & Saint Paul St	10/22/2019	10/18/2019	Evening video ends at 5:38 PM
3	W Baltimore St btwn S Arch St & S Greene St	10/28/2019	10/28/2019	
4	W Baltimore St btwn N Hanover St & S Charles St	10/17/2019	10/21/2019	
5	W Lombard St btwn Hopkins Plaza and S Hanover St	10/4/2019	10/4/2019	
6	E Pratt St btwn S Calvert St & Commerce St	10/21/2019	10/18/2019	Helicopter disruption from 2:40-3:15
7	E Fayette St btwn Holliday St & N Gay St	10/22/2019	10/18/2019	Light rain in AM
8	Charles St btwn W Preston St & W Biddle St	N/A	10/3/2019	PM Peak only lane
9	Saint Paul Pl btwn E Mulberry St & E Saratoga St	10/21/2019	11/1/2019	AM & PM Peak only lane

Figure 3. Study Corridors and Bike Network

Figure 4. Screenlines of SBBLs

Data Analysis

Quality Counts conducted the first stage of the data analysis process. The data contains the time each vehicle enters and exits the cordon lines (shown by the blue lines in Figure 4). Vehicles were tracked from the moment they entered the segment until the moment they left the segment. Thus, queuing at traffic lights affected travel time. Vehicles were classified according to the lane that they primarily occupied with the exception of vehicles that turned right using the SBBL. They were classified to the SBBL regardless of the amount of time they occupied the lane. Vehicles in the SBBL were classified by mode (bus, vehicles, cyclists, scooters); modal classification was not conducted for vehicles in the general purpose lanes. Any vehicles that entered midway through a road segment were excluded from the analysis. Lastly, the number of vehicles present along the corridor (running block total) was calculated in 15 second increments.

Next, a visual inspection survey was completed for each bike and a subset of buses on the shared bus-bike lanes. We analyzed all instances in which a bus was in the SBBL at the same time as another vehicle or bike. Of the total buses traveling in the SBBLs, 822 (66.13%) were analyzed further by watching the videos in real time. By watching the footage, for each bus and bike surveyed we determined which lane the bus/bike was in the majority of the time, which vehicle types it interacted with, the behavior of the bus/bike and interacting vehicles, delays to the bus/bike, the presence of SBBL enforcement, any near-miss Collison's or dangerous interactions, whether the bus/bike was stopped at the red light, and, lastly, what turn movement did the bus/bike do when proceeding through the intersection. Appendix B shows the data collection forms as well as a sample data sheet from Quality Counts.

PERFORMANCE OF SHARED BUS-BIKE LANES

Overview

Using the data reported by Quality Counts, this section investigates the traffic volume by mode and travel times on the shared bus-bike lane corridors. This study analyzed nine shared bus-bike facilities in downtown Baltimore. Forty-eight hours of high-definition video recording were captured over a month. A total of 41,244 vehicles were counted during the study period; among them only 3,327 (8.07%) traveled in the SBBLs. There were 1,243 (3.01%) buses, 167 (0.40%) bicycles, 30 (0.07%) scooters, and 1887 (4.58%) vehicles of other types traveling on the shared bus bike lane facility and 37,917 (91.93%) vehicles in the general purpose lanes during the study period.

Figure 5 shows the traffic volume (veh/hr/lane) for each of the nine study sites. We normalized the counts by time since two locations – Location 2: Fayette St. at Calvert and Location 6: E. Pratt St. – had disruptions in the data collection as noted in Table 6. Scooter volume was minimal and was aggregated with the cyclists. Location 1: Guilford Avenue has the highest volume of traffic in the shared bus-bike lane due to a large number of right-turning vehicles. This is the only facility where the volume in the SBBL is comparable to the volume in the general purpose lane. Additionally, the most bikes and scooters were present on this corridor (18 per hour in the AM peak). The next facility that had a large amount of cyclists and scooters in the morning was Location 6: East Pratt St. At this location the SBBL intersects with a protected bike facility. Location 6 also has the highest volume of general purpose traffic at all time periods. In the AM, bus volume in SBBLs ranged from 20-40 buses/hr. The highest AM bus volume in the SBBLs occurred at Location 4: W. Baltimore between Hanover and Charles and Location 5: W. Lombard St. The Charles Center metro station is located at Location 4. Despite having the Maryland Ave. cycle track intersecting with Location 5, only 7 cyclists/scooters in total were on this facility in the morning.

Between 2PM-4PM, bus volume in the SBBLs dropped to a rate of around 20-30 buses/hr. Location 6: E. Pratt St. had the highest rate of bicyclists and scooters (8) followed by Location 1: Guilford Ave. (6) and Location 4: W. Baltimore St. at Hanover St. (5). In the afternoon and evening, general purpose traffic at Location 5: W. Lombard St. increases as it leads to the highway; however, bus and cyclist volume is comparable to the AM peak. With the exception of Location 1: Guilford Ave., all locations saw more cyclists and scooters in the PM peak than in the AM peak. In the PM, bus volume in the SBBLs is approximately 20-40 buses/hr.

Two peak only lanes were studied. Location 8: Charles St. operates only in the PM peak. Five cyclists/scooters per hour used this facility as did 19 buses per hour. Location 9: St. Paul Place, which operates in both the AM and PM peak, only saw 1 cyclist in the morning and 3 cyclists in total in the afternoon. Bus volume is also the lowest on this facility in the afternoon.

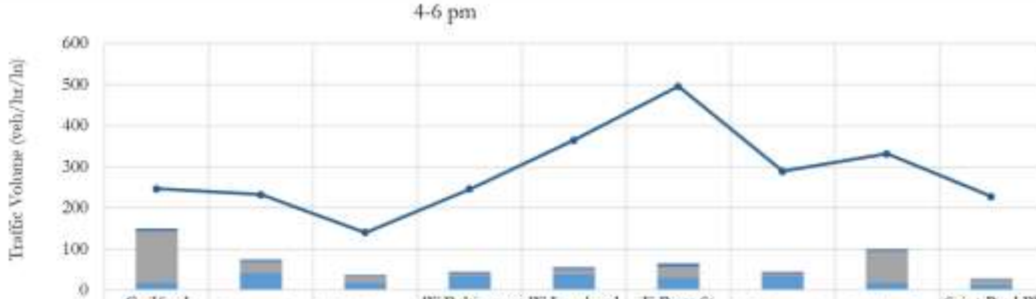
7-9 am

	Guilford Ave btwn Lexington St & E Fayette St	Fayette St btwn Calvert St & Saint Paul St	W Baltimore St btwn S Arch St & S Greene St	W Baltimore St btwn N Hanover St & S Charles St	W Lombard St btwn Hopkins Plaza and S Hanover St	E Pratt St btwn S Calvert St & Commerce St	E Fayette St btwn Holliday St & N Gay St	Charles St btwn W Preston St & W Biddle St	Saint Paul Pl btwn E Mulberry St & E Saratoga St
Bus Lane: Cyclists & Scooter	18	3	1	2	4	7	2	0	1
Bus Lane: Vehicles	343	13	23	3	10	18	9	0	25
Bus Lane: Buses	26	27	22	41	38	34	21	0	20
GP: All Traffic (per lane)	354	311	213	290	255	556	325	0	261

2 - 4 pm

	Guilford Ave btwn Lexington St & E Fayette St	Fayette St btwn Calvert St & Saint Paul St	W Baltimore St btwn S Arch St & S Greene St	W Baltimore St btwn N Hanover St & S Charles St	W Lombard St btwn Hopkins Plaza and S Hanover St	E Pratt St btwn S Calvert St & Commerce St	E Fayette St btwn Holliday St & N Gay St	Charles St btwn W Preston St & W Biddle St	Saint Paul Pl btwn E Mulberry St & E Saratoga St
Bus Lane: Cyclists & Scooter	6	2	1	5	1	8	2	0	0
Bus Lane: Vehicles	134	10	14	4	7	22	12	0	0
Bus Lane: Buses	23	23	19	24	28	28	20	0	0
GP: All Traffic (per lane)	178	249	133	213	380	500	342	0	0

4-6 pm



	Guilford Ave btwn Lexington St & E Fayette St	Fayette St btwn Calvert St & Saint Paul St	W Baltimore St btwn S Arch St & S Greene St	W Baltimore St btwn N Hanover St & S Charles St	W Lombard St btwn Hopkins Plaza and S Hanover St	E Pratt St btwn S Calvert St & Commerce St	E Fayette St btwn Holliday St & N Gay St	Charles St btwn W Preston St & W Biddle St	Saint Paul Pl btwn E Mulberry St & E Saratoga St
Bus Lane: Cyclists & Scooter	7	4	3	6	4	9	4	5	2
Bus Lane: Vehicles	125	29	16	6	12	27	7	77	14
Bus Lane: Buses	19	42	19	34	39	31	34	19	14
GP: All Traffic (per lane)	247	233	141	246	365	496	290	332	228

Figure 5. Traffic Volume Summary

Table 7. Vehicle Travel Time and Running Block Summary

		Median Travel Time (s)				Average Block Density (veh/mi/ln)	
Site Locations	**Period**	**Bus Lane: Bus**	**Bus Lane: Vehs**	**Bus Lane: Cyclists**	**General Purpose**	**Bus Lane**	**General Purpose**
1. **Guilford Ave btwn Lexington St & E Fayette St**	7-9	60	57	19	53	59.8	55.3
	2-4	23	35	15	39	16.3	20.5
	4-6	31	38	17	42	18.7	29.3
2. Fayette St btwn Calvert St & Saint Paul St	7-9	48	57	30	28	8.5	35.7
	2-4	87	56	16	105	9.4	113.1
	4-6	95	40	29	107	18.0	108.9
3. W Baltimore St btwn S Arch St & S Greene St	7-9	63	21	9	13	14.0	14.7
	2-4	87	39	20	40	18.5	20.4
	4-6	73	34	25	20	20.6	15.7
4. W Baltimore St btwn N Hanover St & S Charles St	7-9	72	59	36	18	10.9	36.0
	2-4	71	49	18	51	7.7	40.3
	4-6	59	18	19	51	9.8	53.2
5. W Lombard St btwn Hopkins Plaza and S Hanover St	7-9	49	29	43	28	7.0	31.3
	2-4	15	10	15	14	3.0	28.5
	4-6	29	12	19	17	5.5	33.8
6. E Pratt St btwn S Calvert St & Commerce St	7-9	14	11	21	16	2.2	28.6
	2-4	32	24	29	24	2.8	25.4
	4-6	50	31	27	42	6.2	50.3
7. E Fayette St btwn Holliday St & N Gay St	7-9	21	24	15	14	4.4	36.1
	2-4	19	24	16	15	3.6	61.4
	4-6	23	25	15	58	6.0	92.7
8. Charles St btwn W Preston St & W Biddle St	4-6	69	47	18	70	21.2	98.6
9. Saint Paul Pl btwn E Mulberry St & E Saratoga St	7-9	45	102	--	50	15.4	70.2
	4-6	38	30	26	29	6.1	31.6

Table 7 shows the median travel times (sec) and average block volumes (veh/mi/ln). Median travel times are reported due to outlying data due to stopped vehicles. The travel times include delays due to red lights and queues. Generally, the travel time for vehicles in the SBBL was less than the general purpose lane. At Location 1: Guilford Ave the travel time for buses and other vehicles in the lane was slightly more than the general purpose lane (around 60 sec). However, cyclist travel time was much less (19 sec). Location 2: Fayette at Calvert was busiest in the afternoon, and travel times for the bus nearly doubled. This location was the most congested of all locations in the evening as noted by a block density of 113 and 109 veh/mi/ln in the afternoon and PM peak, respectively, in the general purpose lanes. Location 7: E. Fayette at Holiday St. (93 veh/mi/ln) and Location 8: Charles St. (99 veh/mi/ln) also were very congested in the PM peak.

Traffic flowed a bit better in the morning. The most congested general purpose lane (at 70 veh/mi/ln) was at Location 9, the peak only lane along St. Paul Pl. This was reflected in long travel times (102 sec) for vehicles traveling in the SBBL. Location 1: Guilford Ave had a high density of vehicles in both the general purpose lanes (55 veh/mi/lm) and SBBL (60 veh/mi/ln).

Location 1: Guilford between E. Lexington St. and E. Fayette St.

Figure 6. Screenshot from AM Footage at Location 1

Figure 7 shows the box and whisker plot for travel time at Location 1. This location has a high volume of vehicles using the shared bus bike lane to turn right. The entire corridor is permissible to right-turning vehicles. Bikes have a significantly lower travel time than all other modes; however, the most variability in bicycle travel times occurs in the PM peak. Despite the high number of vehicles in the SBBL in the morning, there was less variability in travel time. In the PM, the travel time for vehicles in the SBBL is longer and more variable than the general purpose lanes in the morning.

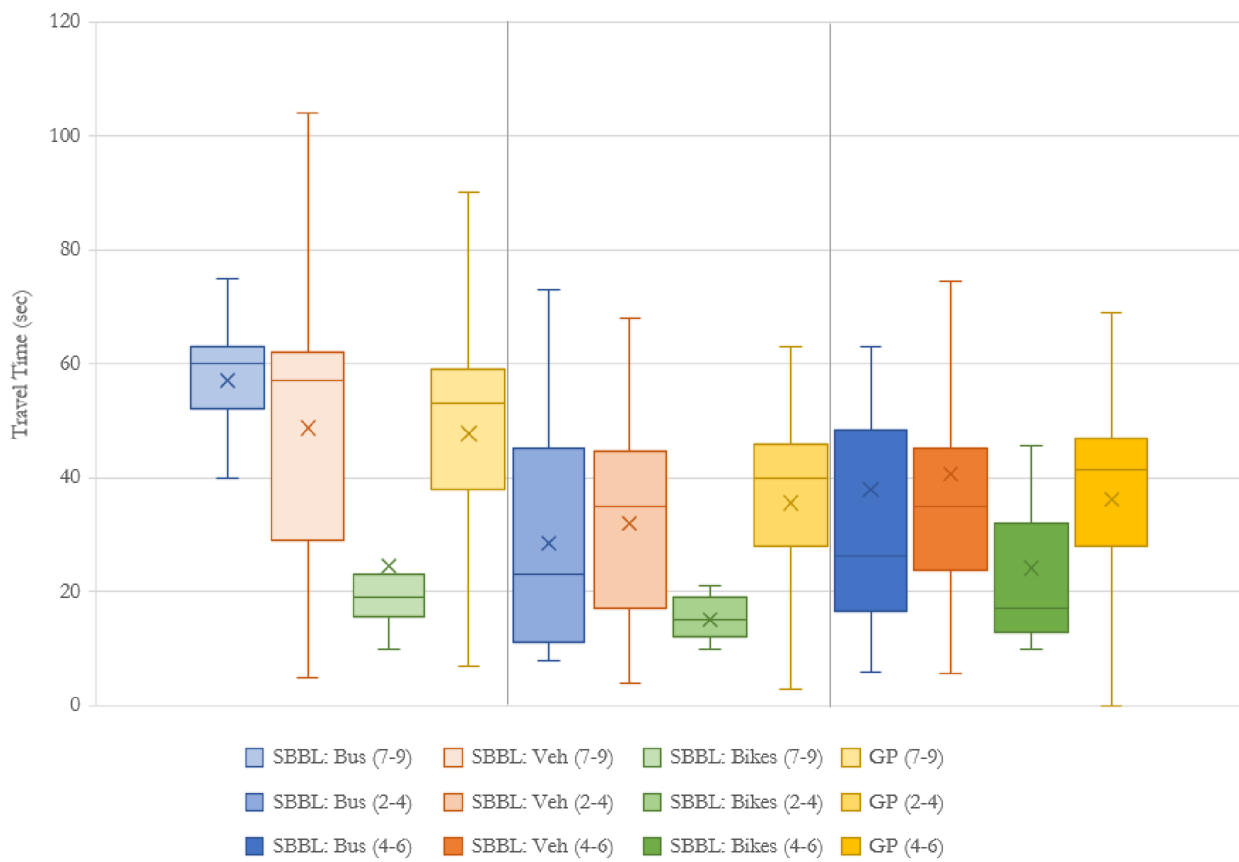


Figure 7. Box and Whisker Travel Time Plot at Guilford between Lexington & Fayette Sts.

We performed a regression to see if bus travel time was impacted by the number of bikes and buses in the SBBL simultaneously. Due to the presence of outlying data, a robust linear regression was performed in Matlab at each study site on the travel time for buses and bikes separately. The robust regression utilizes the iteratively reweighted least squares method to assign weights to each data point (*30*). As shown in Model 1 in Table 8, the number of vehicles was significant in estimating the travel time; a vehicle in the SBBL resulted in an increase in the travel time by 4.4 seconds. However, the number of bikes was insignificant. A second model was run with only the number of vehicles.

We also ran a robust regression on bike travel time; see Table 9. The travel time for bikes significantly increased as the number of vehicles and buses increased on the SBBLs. Since buses stop for passenger boarding and alighting, buses affected bicycle travel times much more than other vehicles on the SBBL. A bus resulted in an additional 15 seconds of travel time whereas a vehicle caused about 1 second.

Table 8. Bus Travel Time Regression for Guilford Ave. between Lexington & Fayette Sts.

	Model 1				Model 2			
	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
Intercept	19.844	2.6585	7.4641	0.000	19.978	2.6355	7.5803	0.000
# of Vehs	4.4096	0.50929	8.6583	0.000	4.5452	0.48921	9.2909	0.000
# of Bikes	4.7576	3.8599	1.2325	0.220				
	# Obs = 134, Adj R^2 = 0.394 F-stat model: 44.3, p-value = 0.000				# Obs = 134, Adj R^2 = 0.395 F-stat model: 5.23, p-value = 0.0237			

Table 9. Bike Travel Time Regression for Guilford Ave. between Lexington & Fayette Sts.

	Estimate	SE	tStat	pValue
Intercept	12.361	1.7917	6.8991	0.000
# of Vehs	0.81327	0.31638	2.5705	0.013
# of Buses	15.13	1.2862	11.764	0.000
	# Obs = 57, Adj R^2 = 0.724 F-stat model: 74.5, p-value = 0.000			

Figure 8. Screenshot from PM Footage at Location 2

Location 2: E. Fayette St. between St. Paul St. and N. Calvert St.

As shown in Figure 8, the drone was positioned a block away from the data collection segment which impeded the vision. PM data collection at this location ended early at 5:38 pm. While travel time was lower in the morning than in the afternoon, travel times in the SBBL were higher than the general purpose lane. In the PM, travel time in the general purpose lanes was higher than in the shared bus-bike lane. Consistent with the bus travel time regression performed at Location 2, only the number of vehicles in the SBBL significantly affected the travel time for buses; see Table 10. For each vehicle in the SBBL, travel time increased by about 7 seconds (or approximately 10%). During the period of observation, the cyclist travel time regression was insignificant due to a limited number of observations (N=12, p-value=0.498).

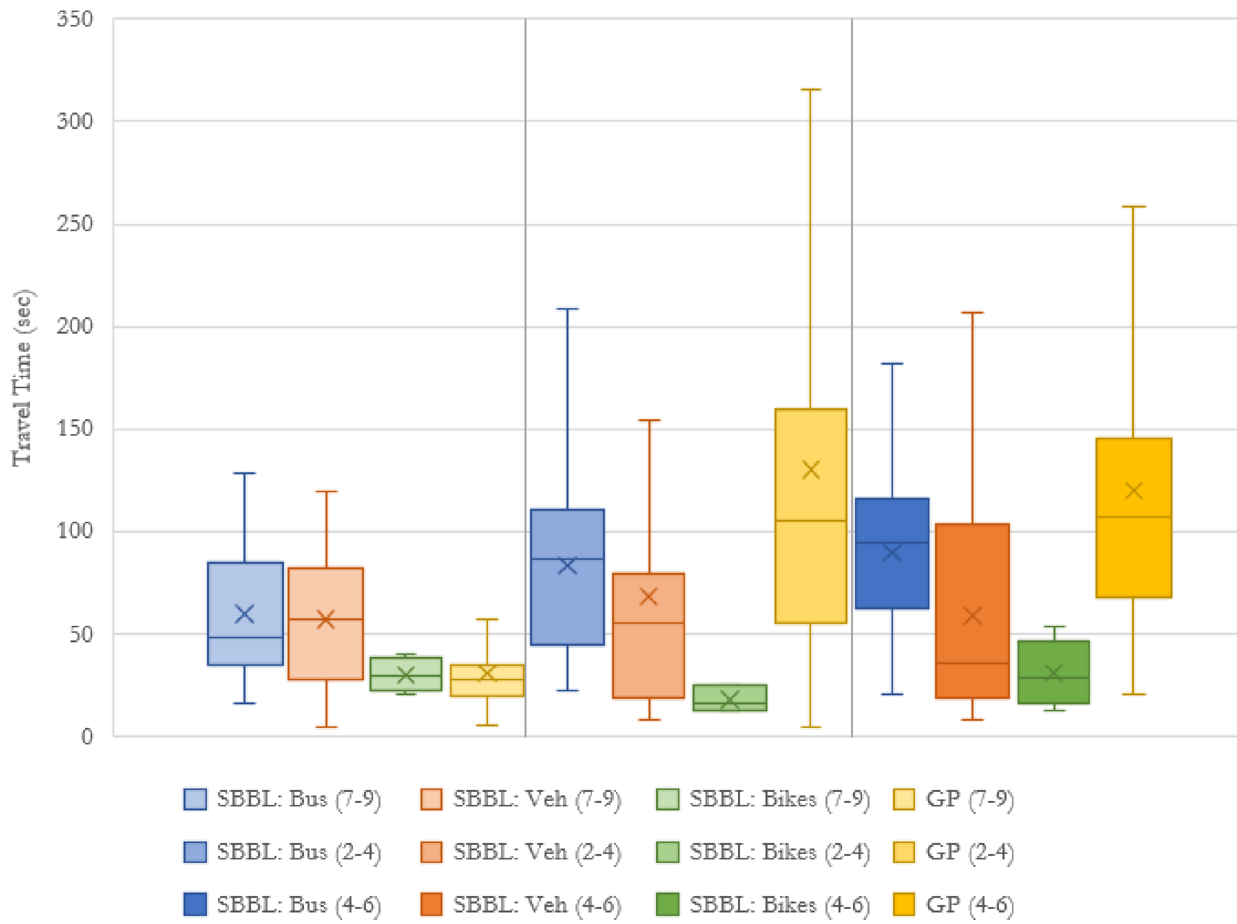


Figure 9. Box and Whisker Travel Time Plot at E. Fayette St. between St. Paul and Calvert Sts.

Table 10. Bus Travel Time Regression for E. Fayette St. between St. Paul and Calvert Sts.

	Model 1				**Model 2**			
	Estimate	**SE**	**tStat**	**pValue**	**Estimate**	**SE**	**tStat**	**pValue**
Intercept	71.458	3.7487	19.062	0.000	71.431	3.7822	18.886	0.000
# of Vehs	8.2346	3.2437	2.5387	0.012	7.3282	3.2295	2.2692	0.025
# of Bikes	-41.912	27.268	-1.6104	0.109	--	--	--	--
	# Obs = 148, Adj R2 = 0.0392 F-stat model: 4.0, p-value = 0.0204				# Obs = 148, Adj R2 = 0.0346 F-stat model: 5.23, p-value = 0.024			

Location 3: W. Baltimore St. between Arch St. and Greene St.

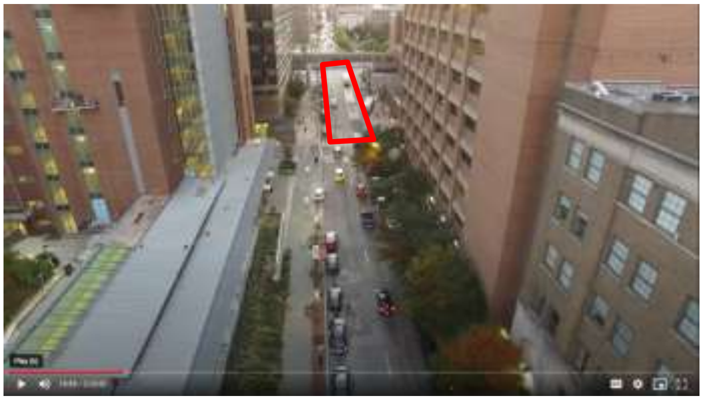


Figure 10. Screenshot from AM Footage at Location 3

Location 3: W. Baltimore St. at Arch St. contains bus bays that allow buses to stop without blocking the SBBL. Downstream there is a curbside bus stop which obstructs the SBBL. A pedestrian walkway slightly obstructed the view. At all time periods, the travel times along the SBBL were longer than in the general purpose lane. The travel time for buses was longer and more variable in the afternoon and evening. As shown in Model 2 in Table 11, a vehicle occupying the SBBL resulted in an additional 12.8 second of travel time. The volume of bikes was insignificant. The cyclist regression was insignificant due to a limited number of observations (N=7, p-value=0.797).

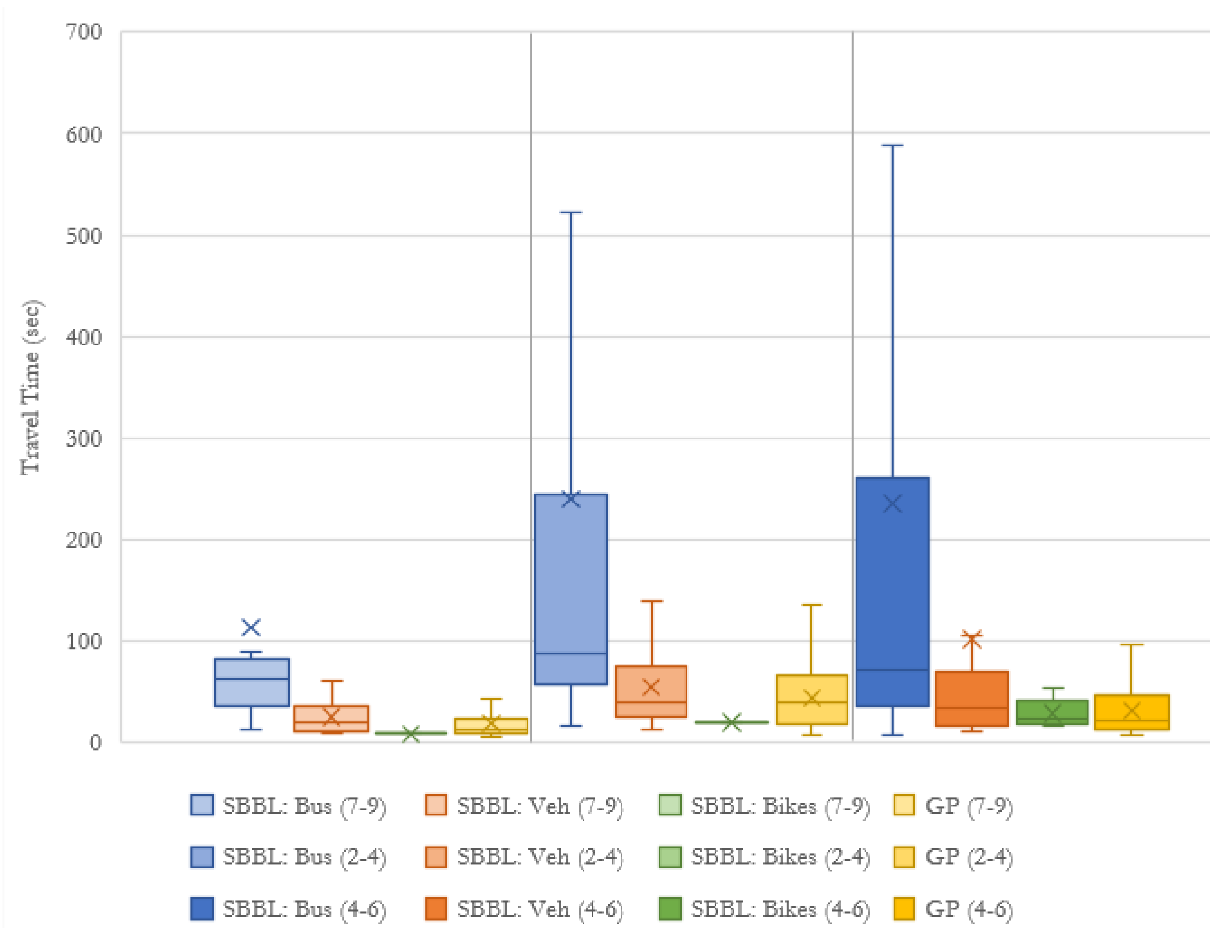


Figure 11. Box and Whisker Travel Time Plot at E. Fayette St. between St. Paul and Calvert Sts.

Table 11. Bus Travel Time Regression for E. Fayette St. between St. Paul and Calvert Sts.

	Model 1				Model 2			
	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
Intercept	58.277	8.8393	6.593	0.000	57.8	6.8636	8.4213	0.000
# of Vehs	12.719	7.4331	1.7112	0.090	12.864	5.4965	2.3404	0.021
# of Bikes	-19.145	37.416	-0.51167	0.610	--	--	--	--
	# Obs = 118, Adj R2 = 0.726 F-stat model: 156, p-value = 0.000				# Obs = 118, Adj R2 = 0.815 F-stat model: 515, p-value = 0.000			

Location 4: W. Baltimore St. between N. Hanover St. and S. Charles St.

Figure 12. Screenshot from AM Footage at Location 4

Location 4 is located along the Charles Center Metro stop. There was more variability in bus travel time in the morning. The bus travel time model was insignificant (N=195, p-value=0.125). This is due to the low volume of bikes and vehicles in the SBBL. The cyclist regression was insignificant due to a limited number of observations (N=16, p-value=0.199).

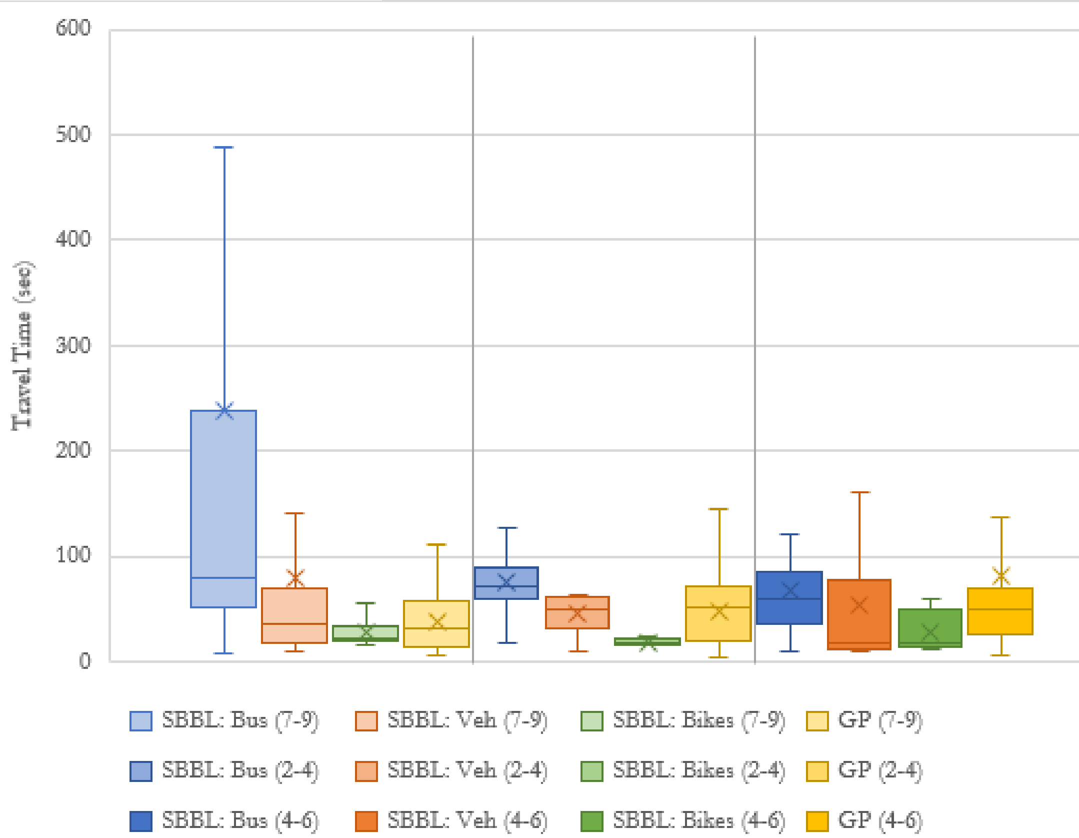


Figure 13. Box and Whisker Travel Time Plot at W. Baltimore St. between N. Hanover St. and S. Charles St.

Location 5: W. Lombard St. between Hopkins Plaza and Hanover St.

Figure 14. Screenshot from AM Footage at Location 5

Travel times were the longest in the morning, with similar travel times for vehicles in the SBBL and general purpose lanes. However, in the afternoon and evening, travel times for vehicles using the SBBL are less. Only buses and cyclists are legally allowed in this corridor as right turns are prohibited at this intersection. The roadway slope along this corridor is 11%. Cyclist travel times were more varied at this location and the median times were longer than vehicles in the SBBL and comparable to buses, including boarding and alighting time. The bus (N=210, p-value = 0.303) and bike (N=16, p-value=0.372) regressions were both insignificant due to a low number of bikes and vehicles in the shared bus lanes.

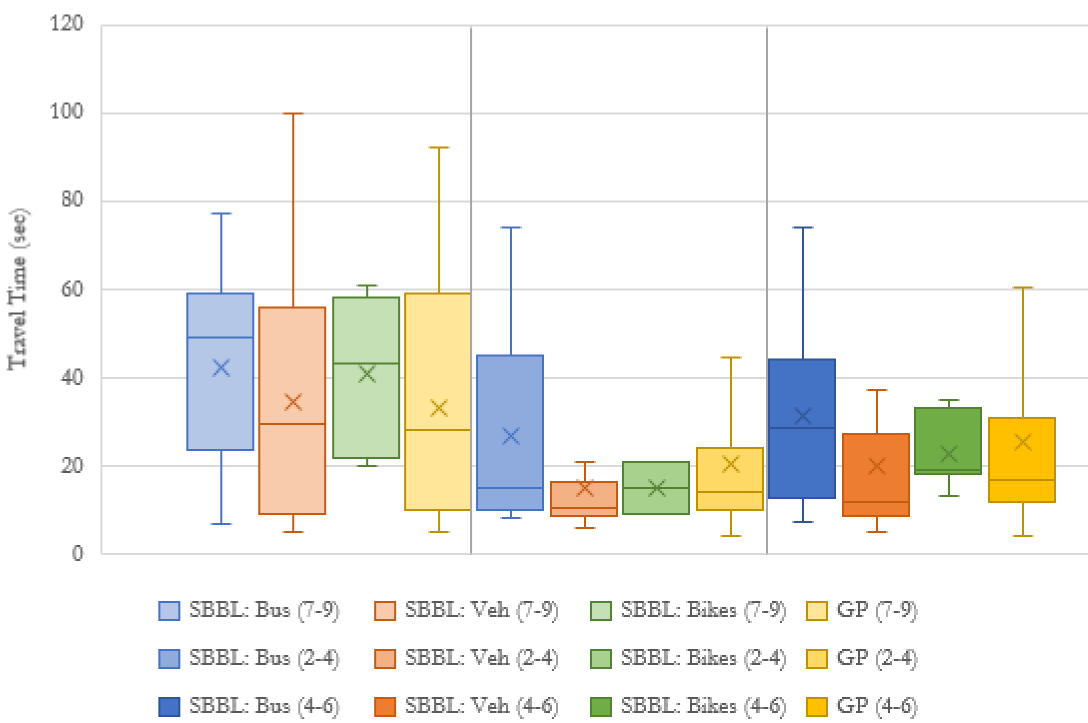


Figure 15. Box and Whisker Travel Time Plot at W. Lombard St. between Hopkins Plaza and Hanover St.

Location 6: E. Pratt St. between S. Calvert St. and Commerce St.

Location 6 looked at a two-block stretch of E. Pratt St. between S. Calvert St. and Commerce St. The SBBL has a weaving section with vehicles turning right from Light St. along the channelized right turn lane. Additionally, this facility has a parallel separated bicycle lane called the E. Coast Greenway which borders the harbor. This location provides critical access to the Inner Harbor tourist area. With the

Figure 16. Screenshot from PM Footage at Location 6

exception of vehicles merging from Light St., vehicles should not be using the SBBL as there are no right turns at this location. There is one stop along the corridor which is served by a bus bay.

In the morning, travel time in the SBBL was low. Bikes had the longest median travel time (~20 sec). Traffic volumes increased in the afternoon, resulting in increased and more variable travel times for buses and vehicles in all lanes. Cyclist travel time was pretty consistent and the median travel time increased by about 10 seconds in the afternoon and PM peak. Despite the robust linear regression showing as significant (p-value = 0.000), neither the number of vehicles nor the number of bikes significantly contributed to travel time; see Table 12. The bike regression was insignificant (N=13, p-value=0.658).

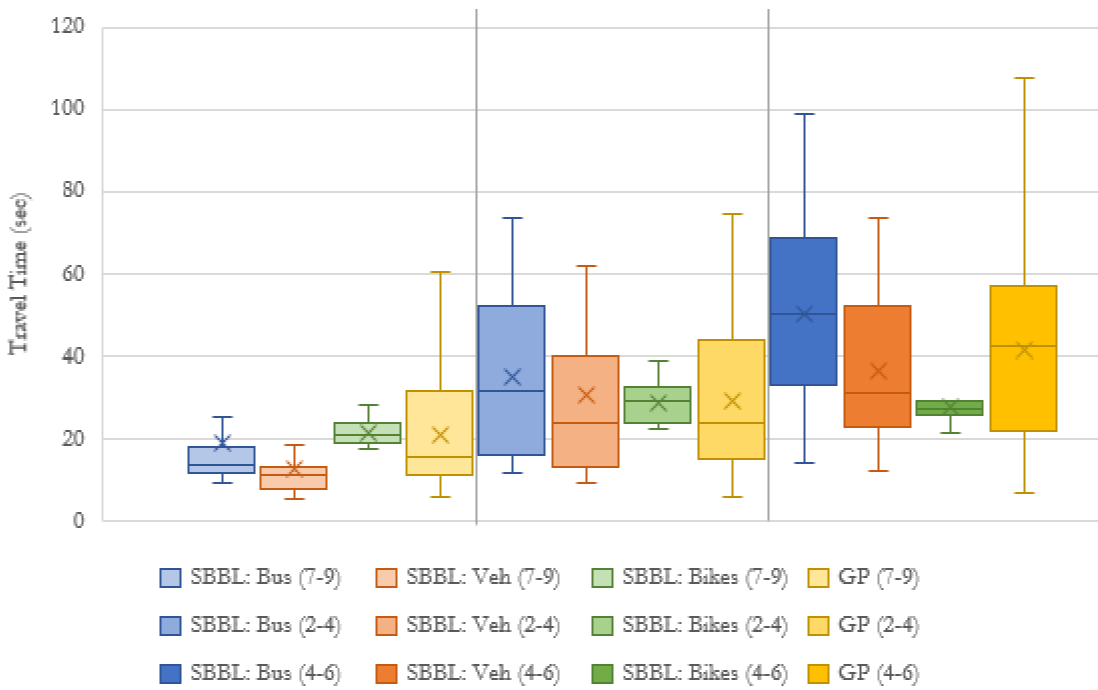


Figure 17. Box and Whisker Travel Time Plot at E. Pratt St. between S. Calvert St. and Commerce St.

Table 12. Bus Travel Time Regression for E. Pratt St. between S. Calvert St. and Commerce St.

	Estimate	SE	tStat	pValue
Intercept	13.429	0.70955	18.927	0.000
# of Vehs	1.5927	2.0069	0.79362	0.430
# of Bikes	-0.90811	1.6571	-0.54799	0.5856
	# Obs = 67, Adj R2 = 0.565 F-stat model: 43.8, p-value = 0.000			

Location 7: E. Fayette St. between N. Gay St. and Holliday St.

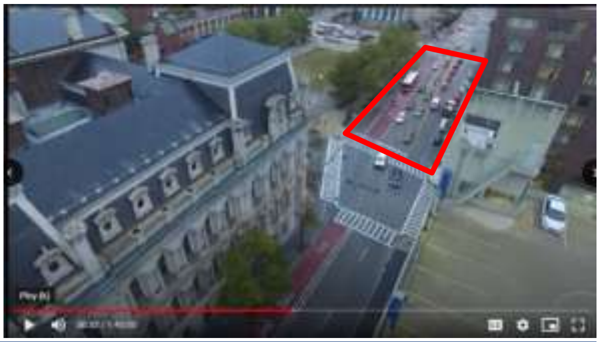


Figure 18. Screenshot from AM Footage at Location 7

The corridor along E. Fayette St. between N. Gay St. and Holiday St. has a parking lane adjacent SBBL. This corridor is the only one of the study sites with two-way traffic, but the SBBL only runs in the westbound direction. Periodic light rain occurred during the morning data collection period.

In the morning, the travel time in the general purpose lanes is low. In the afternoon, travel times in the general purpose lanes begin to increase. The travel time for buses is relatively consistent across time periods. Similar to Location 6, the number of vehicles and bikes in the shared bus-bike lane did not significantly affect the corridor's travel time. While the previous models showed that bicycles were insignificant, vehicles did not adversely impact travel time; see Table 13. Since few vehicles are turning from the SBBL, their impact on bus travel time is minimal.

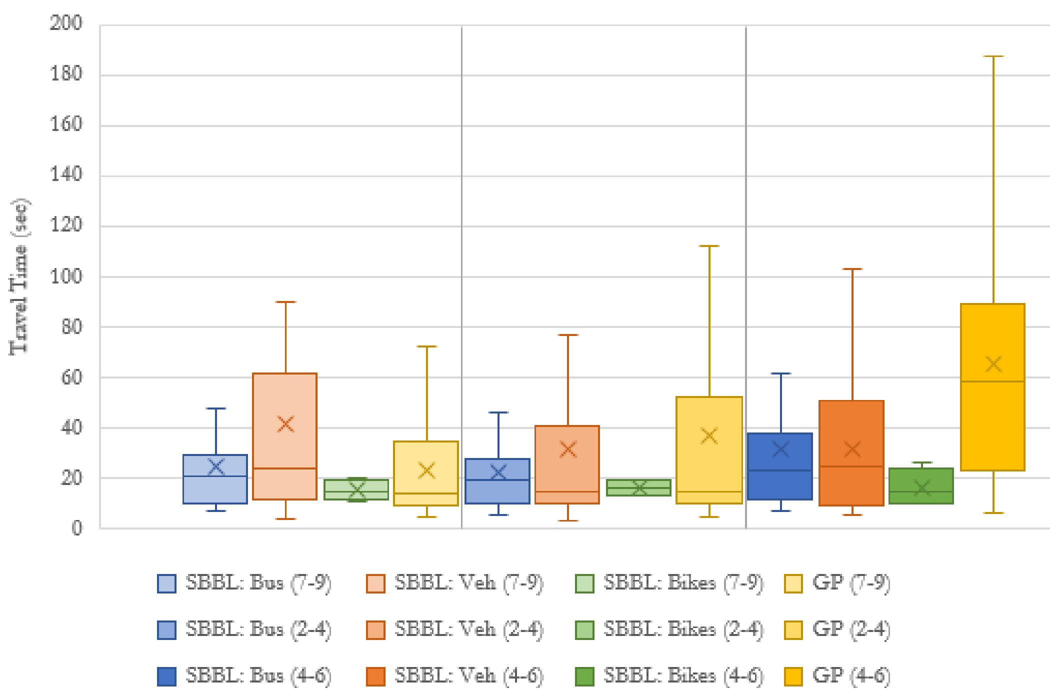


Figure 19. Box and Whisker Travel Time Plot at E. Fayette between Holliday St. and N. Gay St.

Table 14 shows the bicycle robust travel time regression. Model 1 includes the number of buses and vehicles in the SBBLs as explanatory variables and Model 2 the number of vehicles in the SBBL solely; both models were significant. Despite the number of buses being insignificant, Model 1 performed better (p-value = 0.0182, Adj R^2=0.498 vs p-value = 0.0191, Adj R^2=0.382). Conversely to Location 1, vehicles (estimate=7.7443) in the SBBL had a greater impact on cyclist travel time compared to buses (estimate = 3.4632).

Table 13. Bus Travel Time Regression for E. Fayette between Holliday St. and N. Gay St.

	Model 1			
	Estimate	SE	tStat	pValue
Intercept	13.429	0.70955	18.927	0.000
# of Vehs	1.5927	2.0069	0.79362	0.430
# of Bikes	-0.90811	1.6571	-0.54799	0.586
	# Obs = 67, Adj R^2 = 0.565 F-stat model: 43.8, p-value = 0.000			

Table 14. Bike Travel Time Regression for E. Fayette between Holliday St. and N. Gay St.

	Model 1				Model 2			
	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
Intercept	11.831	1.5127	7.8211	0.000	13.208	1.476	8.9486	0.000
# of Vehs	7.7443	2.37	3.2677	0.010	7.067	2.5565	2.7643	0.020
# of Buses	3.4632	2.5801	1.3423	0.212				
	# Obs = 12, Adj R^2 = 0.498 F-stat model: 6.47, p-value = 0.0182				# Obs = 12, Adj R^2 = 0.382 F-stat model: 7.79, p-value = 0.0191			

Location 8: N. Charles St. between W. Biddle St. and W. Preston St.

Figure 20. Screenshot from Footage at Location 8

N. Charles St. contains a peak-only SBBL that operates from 4-6 pm. This lane is not painted but contains signage and lane markings indicating the hours the SBBL is active. Parked cars often blocked the SBBL, resulting in buses using the general purpose lane as shown in Figure 20. While bikes traversed through the SBBL quickly, buses on average traveled at a speed similar to that of the general purpose lane; see Figure 21. Since vehicle travel time in the SBBL includes the time vehicles are stopped, there is high variability in travel time for vehicles in the SBBL.

Table 15 presents the bus robust travel time regression. In Model 1, the number of vehicles in the SBBL was significant while the number of bikes in the SBBL was an insignificant predictor of bus travel time. When vehicles are the sole predictor of bus travel time (Model 2), a vehicle resulted in an additional 2.87 sec of travel time for the bus. In Model 1 in the bike travel time regression, vehicles in the SBBL did not significantly impact bike travel time whereas a bus in the bike lane did; see Table 16. By only including the volume of buses in the SBBL (Model 2), the model improved slightly. Having a bus in the SBBL doubled the travel time of bikes in the SBBL.

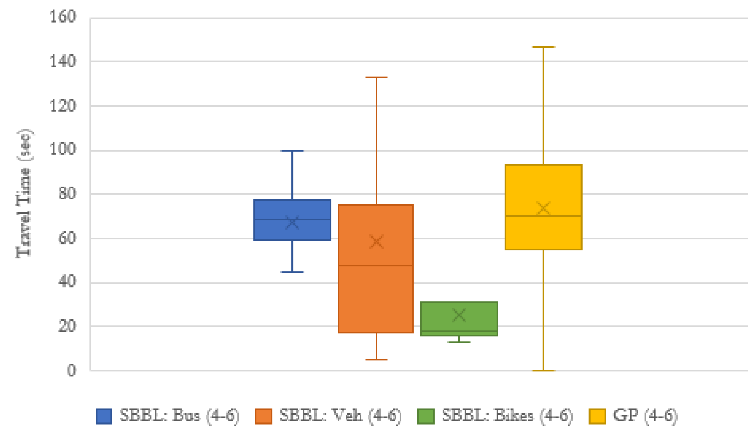


Figure 21. Box and Whisker Travel Time Plot at Charles St. between W. Preston St. and W. Biddle St.

Table 15. Bus Travel Time Regression for Charles St. between W. Preston St. and W. Biddle St.

	Model 1				Model 2			
	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
Intercept	63.931	3.2265	19.814	0.000	62.185	2.8301	21.973	0.000
# of Vehs	2.5169	0.99853	2.5206	0.017	2.8671	0.91366	3.138	0.003
# of Bikes	-9.5066	7.8138	-1.2166	0.232				
	# Obs = 37, Adj R^2 = 0.208 F-stat model: 5.72, p-value = 0.00724				# Obs = 37, Adj R^2 = 0.207 F-stat model: 10.4, p-value = 0.00275			

Table 16. Bike Travel Time Regression for Charles St. between W. Preston St. and W. Biddle St.

	Model 1				Model 2			
	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
Intercept	15.341	6.2806	2.4427	0.092	17.674	2.8147	6.2792	0.003
# of Vehs	-2.3413	12.871	-0.1819	0.867				
# of Buses	20.395	6.2806	3.2473	0.048	23.163	3.0833	7.5124	0.002
	# Obs = 6, Adj R^2 = 0.666 F-stat model: 5.97, p-value = 0.0899				# Obs = 6, Adj R^2 = 0.922 F-stat model: 59.7, p-value = 0.00151			

Location 9. St. Paul Place between E. Mulberry St. and E. Saratoga St.

Figure 22. Screenshot from AM Footage at Location 9

Location 9: St. Paul Place has one general purpose lane and an SBBL lane that operates during the hours of 7-9 am and 4-6 pm. There was more traffic along this corridor in the morning. No bikes were present in the AM peak and only two in the PM peak. In the morning, the median travel time for vehicles in the SBBL was higher than the travel time in the general purpose lane due to vehicles stopping. Travel time for buses in the SBBL was comparable to the travel time in the general purpose lanes in the morning. Travel times were lower in the PM peak; travel times in the SBBL were slightly longer than the general purpose lane.

The bus travel time regression was insignificant (N=67, p-value = 0.204). A bike regression was not performed since only two bikes were observed during the study period.

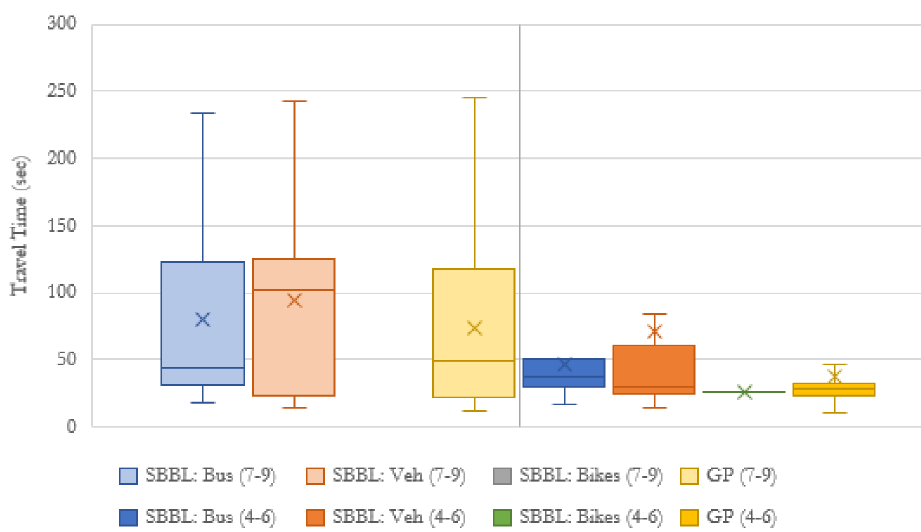


Figure 23. Box and Whisker Travel Time Plot at St. Paul Place between E. Mulberry St. and E. Saratoga St.

INTERACTIONS ANALYSIS

Summary

From the Quality Counts data, there were 1,243 buses, 167 cyclists, and 1887 vehicles on the SBBLs, resulting in a total of 1,342 instances where buses and cyclists on the SBBLs co-occupied the lane with another vehicle. The number of instances where a bus or cyclist co-occupies the SBBL with another vehicle will henceforth be known as "lane-shares". Out of 1,342 lane-sharing instances, only 6.0% involved a bus and a bike, 23.2% involved a bike and a (non-bus) vehicle, and 70.7% involved a bus and other vehicles.

Table 17. Summary of Lane Sharing Instances

		Total # of Lane-Share Instances			Average # of Lane-Shares per Bus		% of Buses with at least one Lane-Share		Average # of Lane-Shares per Bike		% of Bikes with at least one Lane-Share	
		A	B	C	D	E	F	G	H	I	J	K
SBBL Locations	**Time**	**Bus-Bike**	**Bus-Veh**	**Bike-Veh**	**Bus-Bike**	**Bus-Veh**	**Bus-Bike**	**Bus-Veh**	**Bus-Bike**	**Bike-Veh**	**Bus-Bike**	**Bike-Veh**
1. Guilford Ave btwn Lexington St & E Fayette St	7-9	14	367	208	0.27	7.20	24%	100%	0.42	6.3	26%	100%
	2-4	2	118	23	0.04	2.50	4%	89%	0.18	2.1	18%	73%
	4-6	5	37	40	0.14	3.00	14%	84%	0.38	3.1	23%	100%
2. Fayette St btwn Calvert St & Saint Paul St	7-9	2	54	4	0.04	0.50	4%	43%	0.67	1.0	50%	50%
	2-4	4	12	0	0.09	0.30	9%	22%	1.33	0.0	66%	0%
	4-6	2	63	1	0.03	0.90	3%	54%	0.40	0.2	20%	20%
3. W Baltimore St btwn S Arch St & S Greene St	7-9	1	30	0	0.02	0.70	2%	42%	1.00	0.0	100%	0%
	2-4	1	17	1	0.03	0.45	3%	34%	1.00	1.0	100%	100%
	4-6	3	39	4	0.08	1.05	8%	62%	0.60	0.8	40%	80%
4. W Baltimore St btwn N Hanover St & S Charles St	7-9	0	1	0	0.00	0.01	0%	1%	0.00	0.0	0%	0%
	2-4	1	7	1	0.02	0.15	2%	15%	0.17	0.2	17%	17%
	4-6	3	5	1	0.04	0.07	4%	7%	0.43	0.1	43%	14%
5. W Lombard St btwn Hopkins Plaza and S Hanover St	7-9	7	12	2	0.09	0.16	8%	16%	1.00	0.3	100%	29%
	2-4	1	1	0	0.02	0.02	2%	2%	0.50	0.0	50%	0%
	4-6	4	15	2	0.05	0.19	5%	18%	0.57	0.3	43%	29%
6. E Pratt St btwn S Calvert St & Commerce St*	7-9	11	7	4	0.16	0.10	16%	10%	0.85	0.3	46%	23%
	2-4	4	14	2	0.10	0.35	8%	25%	0.40	0.2	40%	20%
	4-6	9	24	14	0.15	0.39	13%	25%	0.53	0.8	53%	47%
7. E Fayette St btwn Holliday St & N Gay St	7-9	1	11	1	0.02	0.27	2%	22%	0.25	0.25	25%	25%
	2-4	0	4	1	0.00	0.10	0%	8%	0.00	0.50	0%	50%
	4-6	2	13	2	0.03	0.19	3%	19%	0.33	0.3	33%	33%
8. Charles St btwn W Preston St & W Biddle St	4-6	3	83	1	0.08	2.24	8%	76%	0.50	0.17	33%	17%
9. Saint Paul Pl btwn E Mulberry St & E Saratoga St	4-6	0	0	0	0.00	0.00	0	0%	0.00	0	0%	0%
	4-6	1	15	0	0.04	0.56	4%	44%	1.00	0	100%	0%

*Pratt St has a separated bicycle facility in addition to the SBBL. Quality Counts counted all vehicles regardless of if they were in the separated bike lane or SBBL.

Table 17 displays the total number of lane-share instances per location. Lane-shares between bus and bike were minimal (81 total). Location 1: Guilford Ave between Lexington and E. Fayette had the most lane-sharing instances (21) with the majority (14) occurring in the morning. Nearly 1 out of every 4 bikes were in the lane at the same time as the bus (Column J). However, 100% of the time a bus or bike was in the lane at the same time as a vehicle (Columns G, K). On average there were 6-7 vehicles in the lane at the same time as the bus or bike (Columns E, I).

Following Location 1, Location 6 and Location 5 had the most bus-bike lane-shares. However, Location 6: E. Pratt St has a separated bike facility in addition to the SBBL. Quality Counts did not distinguish between cyclists in the SBBL and separated bike lane. At Location 5: W. Lombard St between Hopkins Plaza and S. Hanover St, each observed bikes sharing the SBBL with a bus (Column J). However, due to the high bus volume, only 8% of buses were on the lane at the same time as bicyclists (Column F). Buses had more lane-shares with vehicles (Columns B, G). Location 8, the peak only SBBL on Charles St, had a high number of bus-vehicle lane shares (Column B). On average, each bus shared the lane with 2 vehicles (Column E).

Video Review

While the above analysis provides some insights into the safety of SBBLs, simply knowing when vehicles occupy a SBBL together doesn't provide any understandings as to how they interacted with one another. Thus, video footage of each location was analyzed further to identify the types of interactions and decisions occurring on the SBBLs. Of the 1,243 buses observed on our corridor, we reviewed 822 buses. These included buses that interacted with at least one other vehicle and buses that had a travel time that was twice the mean travel time. Additionally, we reviewed all cyclists that we had at the time of review (132 of 167 cyclists). Upon completing the data analysis, it came to our attention that three files had missing data periods due to a compiling error from Quality Counts:

- Location 1: Guilford between Lexington and Fayette St. (4:30-5:04 pm missing)
- Location 2: Fayette between Calvert and Saint Paul St. (3:24-3:54, 4:28-5:01 missing)
- Location 4: W Lombard St between Hopkins Plaza and S Hanover St (4:14-4:33 pm missing)

While this missing data was accounted for in the performance and lane-share analyses presented above, resources prevented us from going back and reviewing the video data at these locations.

Appendix B shows the surveying tools used for video review. The survey asked about vehicle interactions with buses and bikes. An interaction is defined as an instance where a bus (or bike) occupies the SBBL at the same time of another vehicle AND the bus (or bike's) progression was inhibited by the vehicle. Additionally, we asked questions pertaining to passing vehicles, proper use of the SBBL, enforcement, and travel direction.

Bus Interaction Analysis

Interactions

We identified a total of 822 lane-share instances between a bus and another vehicle in the SBBL. Out of those 822, only 91 instances (or 11% of the reviewed buses) involved interactions between buses and other vehicles; see Table 18. An instance of interaction is defined as when the bus and any other vehicle are traveling at close proximity and the bus engages in any passing or turning maneuvers. Three locations had a high percentage of bus interactions with other vehicles: Location 2: Fayette St between Calvert St. and St. Paul St., Location 8: Charles St. between W. Preston St. and W. Biddle St., and Location 9: St. Paul St. between E. Mulberry St. and E. Saratoga St. It should be noted that Locations 8 and 9 are peak hour only SBBLs.

Table 18: Summary of Bus Interactions

Location	None	Vehicles	Pedestrians	Total
1. Guilford Ave btwn Lexington St & E Fayette St	40 (83%)	7 (15%)	1 (2%)	48
2. Fayette St btwn Calvert St & Saint Paul St	50 (67%)	25 (33%)		75
3. W Baltimore St btwn S Arch St & S Greene St	81 (94%)	5 (6%)		86
4. W Baltimore St btwn N Hanover St & S Charles St	119 (96%)	5 (4%)		124
5. W Lombard St btwn Hopkins Plaza and S Hanover St	111 (95%)	6 (5%)		117
6. E Pratt St btwn S Calvert St & Commerce St	143 (99%)	2 (1%)		145
7. E Fayette St btwn Holliday St & N Gay St	120 (98%)	3 (2%)		123
8. Charles St btwn W Preston St & W Biddle St	27 (73%)	10 (27%)		37
9. Saint Paul Pl btwn E Mulberry St & E Saratoga St	38 (57%)	28 (42%)	1 (1%)	67
Total	**729 (89%)**	**91 (11%)**	**2 (0%)**	**822**

Table 19 shows the types of interactions observed at each location. Most of the interactions were with parked vehicles (62.38%) followed by passenger cars (15.84%) and other buses (13.86%). Of the observed data, bikes and pedestrians were only 4.95% and 2.97% of the interactions, respectively. The three locations with the most interactions (Location 2, 8, and 9) were dominated by parked vehicles in the SBBL. As shown in Table 21, parked vehicles delayed buses 39.7% of the time and passenger vehicles 75.0% of the time. Bikes only slowed buses 20.0% of the observed interactions and another bus 21.4% of time.

As illustrated in Figure 24, MTA buses waited behind the pedestrians and bicyclists 100% of the time. But when they encountered a parked vehicle in the shared lane, the bus passed the vehicle on the left by merging into general traffic. 67% of the time the bus waited behind a passenger vehicle in the SBBL and 57% of the time for another bus.

Table 19: Types of Interactions

Location	Parked Vehicle	Passenger Vehicle	Peds	Bike	Bus	Total
1. Guilford Ave btwn Lexington St & E Fayette St	1	5	1	--	1	8
2. Fayette St btwn Calvert St & Saint Paul St	16	7	--	--	2	25
3. W Baltimore St btwn S Arch St & S Greene St	2	--	--	--	3	5
4. W Baltimore St btwn N Hanover St & S Charles St	2	2	--	--	1	5
5. W Lombard St btwn Hopkins Plaza and S Hanover St	2	--	--	3	1	6
6. E Pratt St btwn S Calvert St & Commerce St	--	1	1	2	1	5
7. E Fayette St btwn Holliday St & N Gay St	1	--	--	--	2	3
8. Charles St btwn W Preston St & W Biddle St	10	--	--	--	1	11
9. Saint Paul Pl btwn E Mulberry St & E Saratoga St	29	1	1	--	2	33
Total	**63**	**16**	**3**	**5**	**14**	**101**

Table 20: Bus Travel Lane for Majority of Time

Location	General Purpose	SBBL
1. Guilford Ave btwn Lexington St & E Fayette St	3 (6%)	45 (94%)
2. Fayette St btwn Calvert St & Saint Paul St	0 (0%)	75 (100%)
3. W Baltimore St btwn S Arch St & S Greene St	24 (28%)	62 (72%)
4. W Baltimore St btwn N Hanover St & S Charles St	2 (2%)	122 (98%)
5. W Lombard St btwn Hopkins Plaza and S Hanover St	1 (1%)	116 (99%)
6. E Pratt St btwn S Calvert St & Commerce St	30 (21%)	115 (79%)
7. E Fayette St btwn Holliday St & N Gay St	2 (2%)	121 (98%)
8. Charles St btwn W Preston St & W Biddle St	7 (19%)	30 (81%)
9. Saint Paul Pl btwn E Mulberry St & E Saratoga St	10 (15%)	57 (85%)
Total	**79 (10%)**	**743 (90%)**

Table 21: Percent of Interactions Which Slows Bus By Interaction Type

Parked Vehicle	Passenger Vehicle	Pedestrians	Bike	Bus	Total
39.7%	75.0%	0.0%	20.0%	21.4%	**40.6%**

Figure 24: Bus Interaction Type and Passing Manuever

Near Miss Collisions with Buses

There were four (04) near-miss collisions observed in the videos. The Guilford-Lexington location had two (02) incidents while W Baltimore-Charles St and St Paul-Saratoga location had one each. The majority (75%) of the near-miss collisions happened during the afternoon while the bus was traveling on a SBBL. The most notable interaction was at the St Paul-Saratoga location between a bus and a police car (see Figure 25). A police car traveling in the general purpose lane attempted to merge into the SBBL when an MTA bus was coming and nearly side-swiped the bus. The police vehicle yielded to the bus without incident and remained parked in the SBBL for nearly 30 minutes.

The other near-miss collision occurred at the Guilford-Lexington location between bus and smaller truck (see Figure 26). The mini truck got impatient due to the regular bus moving slower and went around the regular bus which slowed down the regular bus. The other two incidents were more minor and evasive actions were taken earlier.

Figure 25: Near Miss Collision at St. Paul and Saratoga

Figure 26: Bus Interaction Type and Passing Manuever

Bike Interaction Analysis

The more bicyclists traveling on a road, the higher the need to provide safe infrastructure for bicyclists. The higher bike volume also increases the probability of bike/bus interactions and potential conflicts in an SBBL. We reviewed video footage for 132 bikes (see Table 22). In only 20 instances (or 15% of the time) did a bicyclist interact with any other vehicle. We did not review bicycle interaction at Location 3: W. Baltimore between S. Arch St. and S. Green St. because the angle of the video prohibited us from clearly viewing bicycle movement.

Table 22: Summary of Bike Interactions

Location	None	Parked Veh	Bus	Passenger Car	Total
1. Guilford Ave btwn Lexington St & E Fayette St	43	3	3	4	53
2. Fayette St btwn Calvert St & Saint Paul St	--	--	1	--	1
3. W Baltimore St btwn S Arch St & S Greene St	--	--	--	--	--
4. W Baltimore St btwn N Hanover St & S Charles St	13	1	3	--	16
5. W Lombard St btwn Hopkins Plaza and S Hanover St	12	--	3	--	15
6. E Pratt St btwn S Calvert St & Commerce St	28	--	--	--	28
7. E Fayette St btwn Holliday St & N Gay St	10	--	2	--	12
8. Charles St btwn W Preston St & W Biddle St	5	--	1	--	6
9. Saint Paul Pl btwn E Mulberry St & E Saratoga St	1	--	--	--	1
Total	**112**	**4**	**13**	**4**	**132**

When encountering parked vehicles, 100% of the riders are seen traveling on sidewalks, and 16.70% when they encounter a bus. Most the interactions with parked vehicles occurred during the afternoon (2 – 6 PM). As shown in Table 23, bicyclists rarely used the general purpose lane and primarily used the SBBL (85% of the time). The table shows a high percentage of bicyclists using the sidewalk along E Pratt St. These bikes were actually along a parallel bike lane that runs at the sidewalk level; see Figure 16.

Vehicles Entering SBBL

The SBBLs are painted red with two locations in each block with text denoting "Bus Only." The red is in a skip pattern with a white right turn arrow where a right turn is allowed. The sharrows (or shared lane markings) are used on every block to show that bicycles are allowed in the lanes. A solid white line separates the bus lane from the adjacent general-purpose lane. All the transit vehicles, right-turning vehicles, parallel-parking cars, bicycles, and emergency vehicles are permitted to use the dedicated bus lanes. Through traffic, and parked, standing, or loading vehicles (including taxis and ridesharing vehicles) are prohibited. The Code of Maryland specifies a fine of $90 and one point on the driver's license for failure to comply with a traffic control device, and the Baltimore City charter was recently amended to create a fine of $250 for driving or parking in a bus lane.

This study found that 31.68% (32/101) of the time passenger vehicles entered the SBBLs early. Of those vehicles who entered the lane early most of the vehicles (68.75% (22/32)) were violators as they were not turning right. Of those who did not turn right, 63.63% (14/22) caused the bus to slow down.

Table 23. Bike Travel Lane for Majority of Time

Location	General Purpose	SBBL	Sidewalk
1. Guilford Ave btwn Lexington St & E Fayette St	3 (6%)	48 (90%)	2 (4%)
2. Fayette St btwn Calvert St & Saint Paul St	0 (0%)	1 (100%)	0 (0%)
3. W Baltimore St btwn S Arch St & S Greene St	--	--	--
4. W Baltimore St btwn N Hanover St & S Charles St	0 (0%)	15 (94%)	1 (6%)
5. W Lombard St btwn Hopkins Plaza and S Hanover St	0 (0%)	14 (93%)	1 (7%)
6. E Pratt St btwn S Calvert St & Commerce St	0 (0%)	7 (25%)	21 (75%)*
7. E Fayette St btwn Holliday St & N Gay St	0 (0%)	12 (100%)	0 (0%)
8. Charles St btwn W Preston St & W Biddle St	0 (0%)	6 (100%)	0 (0%)
9. Saint Paul Pl btwn E Mulberry St & E Saratoga St	0 (0%)	1 (100%)	0 (0%)
Total	**3 (2%)**	**104 (79%)**	**25 (19%)**

*E. Pratt Street has a parallel running bike path on the sidewalk

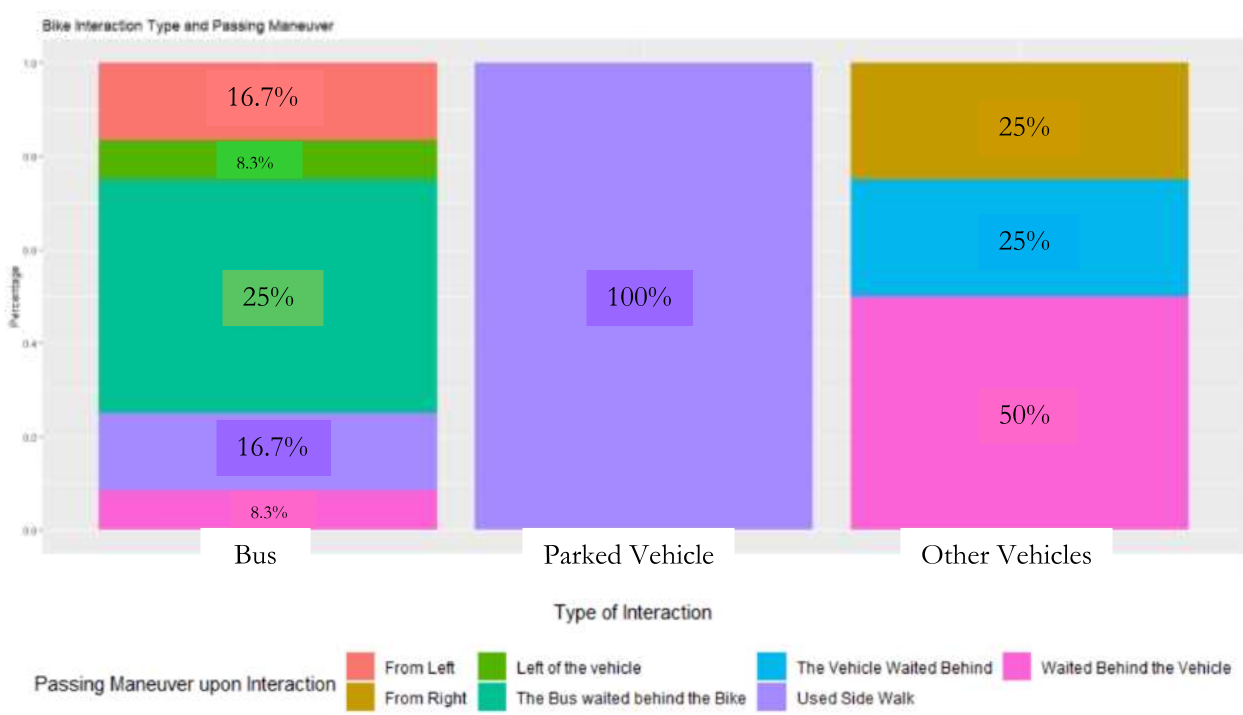


Figure 27. Bike Interaction Type and Maneuver

Figure 28. Dedicated Bus Lane Leaflet *(22)*

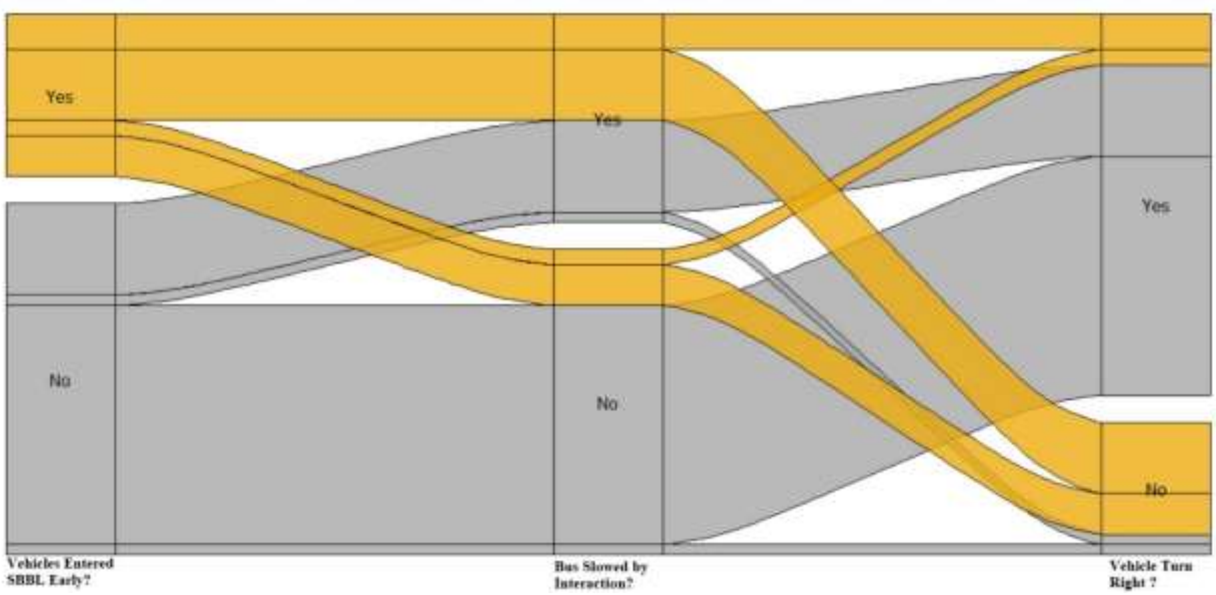


Figure 29. Alluvium Plot Showing Vehicle Arrival Location, Turn Movement, and Delay to Bus

CONCLUSIONS

Throughout the U.S., transportation agencies are increasingly looking for ways to promote equitable and sustainable transportation. The results of this study will help transportation agencies better plan for buses and bikes along the same right of way by providing clear guidelines for installing SBBLs. By focusing on people throughput as opposed to vehicle throughput, dedicated transit lanes provide more equitable use of right-of-way given sufficient bus volumes.

For Baltimore City, this work is timely. The results show that accommodating cyclists on bus-only lanes have little impact on buses due to low volumes. In a properly implemented SBBL, the bikers only have to share the lane with buses and will therefore have fewer conflicts to worry about. But due to lack of enforcement and awareness, passenger vehicles encroach on SBBLs, slowing buses and endangering bicyclists. Allowing cyclists to use these facilities appears to be a win-win on the surface; however, more work is needed to ensure that cyclists, an extremely vulnerable roadway group, aren't put in undue harm in an attempt to provide them access without removing right-of-way from vehicles.

Regardless of MDOT campaigns, well-painted and well-marked lanes, the SBBLs are frequently violated by general motorists. This affects multimodal safety and level of service. The study found that unauthorized vehicles in the SBBL deteriorated the operation of SBBLs. This was especially evident in peak-only lanes which have limited hours of operation and are not painted red. Enforcement of parked cars on these facilities would greatly improve bus travel times.

There is very little research focused on SBBLs, and additional research is needed to evaluate the safety, mobility, and performance of SBBLs. Additional research is needed to provide generalizable conclusions about the operation of SBBLs as study limitations restricted data collection to once per time period per site. More research is needed on how cyclists use bus lanes. Specifically, on the comfort of cyclists on these facilities and on the impact of higher bike and bus volumes on the safety and operation of SBBLs.

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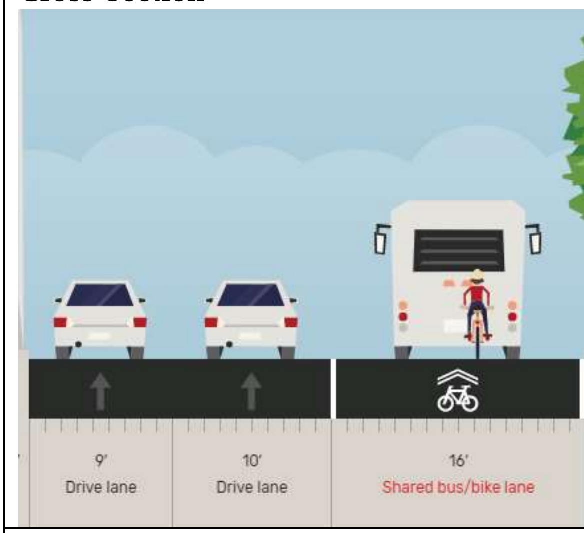
APPENDIX A: STUDY SITES

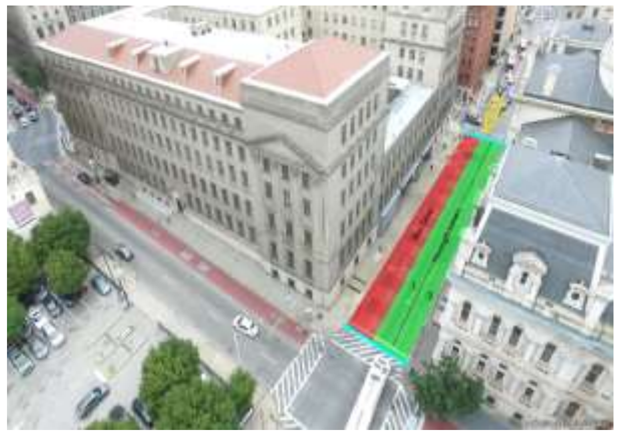
1. Guilford Ave between Lexington St & E Fayette St

	Vehicle Counts			
	Bus Lane: Buses	Bus Lane: Vehicles	Bus Lane: Cyclists & Scooters	General Purpose Lanes
7-9	51	685	35	708
2-4	46	268	12	356
4-6	37	250	14	494

Cross-Section



Screenline



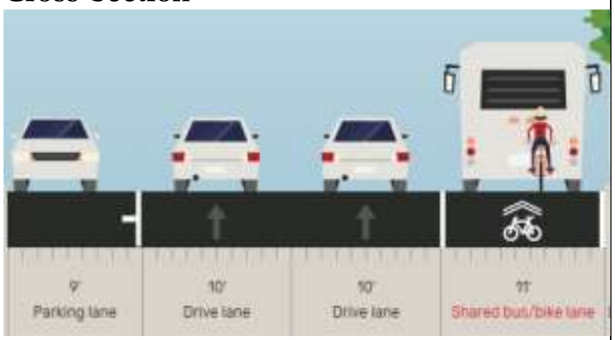
Morning Video Screenshot (10/07/2019)

Afternoon Video Screenshot (10/07/2019)

2. Fayette St between Calvert St & Saint Paul St

	Vehicle Counts			
	Bus Lane: Buses	Bus Lane: Vehicles	Bus Lane: Cyclists & Scooters	General Purpose Lanes
7-9	54	25	6	622
2-4	45	20	3	498
4-6	68	47	7	380

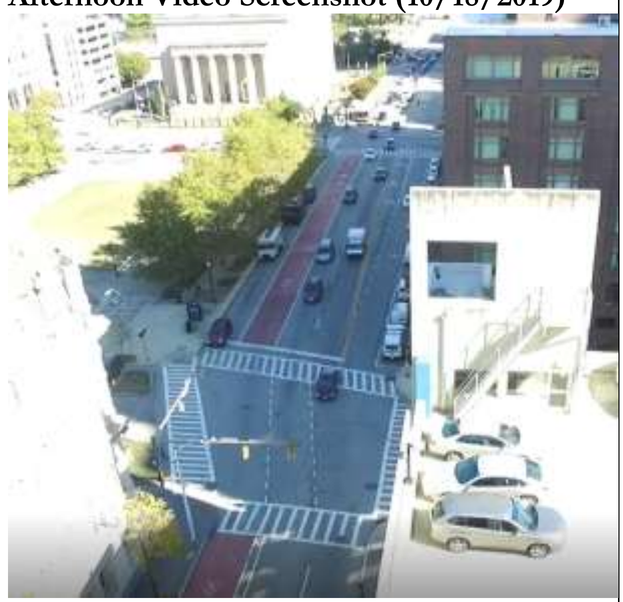
Cross-Section



Screenline

Morning Video Screenshot (10/22/2019)

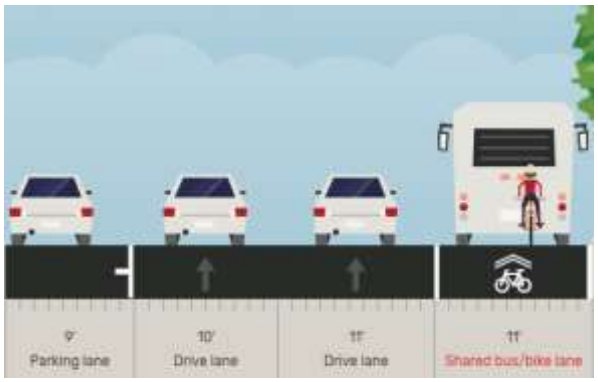
Afternoon Video Screenshot (10/18/2019)



3. W Baltimore St between S Arch St & S Greene St

	Vehicle Counts			
	Bus Lane: Buses	**Bus Lane: Vehicles**	**Bus Lane: Cyclists & Scooters**	**General Purpose Lanes**
7-9	43	45	1	426
2-4	38	28	1	267
4-6	37	31	6	281

Cross-Section



Screenline

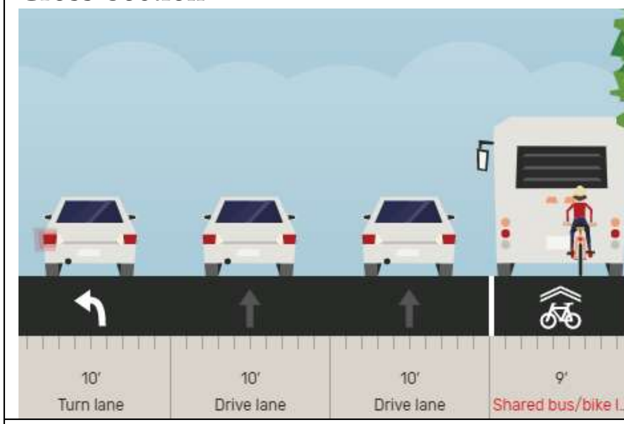
Morning Video Screenshot (10/28/2019)

Afternoon Video Screenshot (10/28/2019)

4. W Baltimore St between N Hanover St & S Charles St

	Vehicle Counts			
	Bus Lane: Buses	Bus Lane: Vehicles	Bus Lane: Cyclists & Scooters	General Purpose Lanes
7-9	81	5	4	580
2-4	47	8	9	425
4-6	67	12	11	492

Cross-Section



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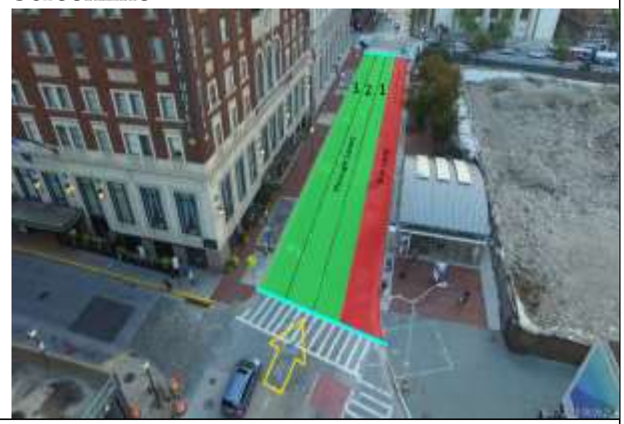
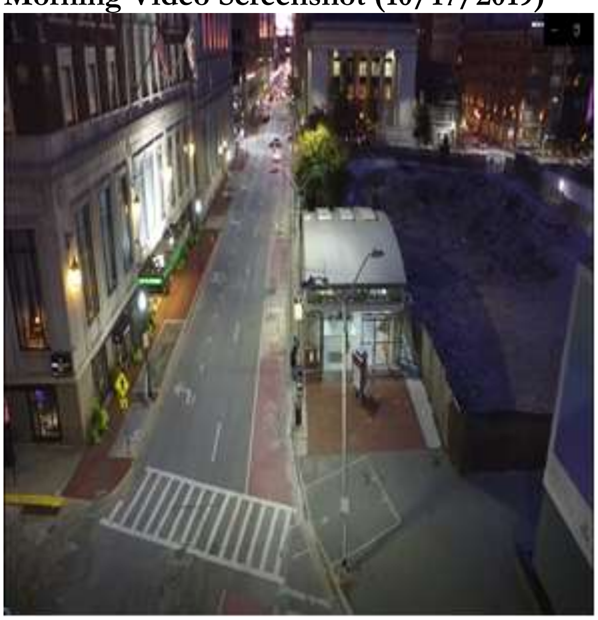


Morning Video Screenshot (10/17/2019)

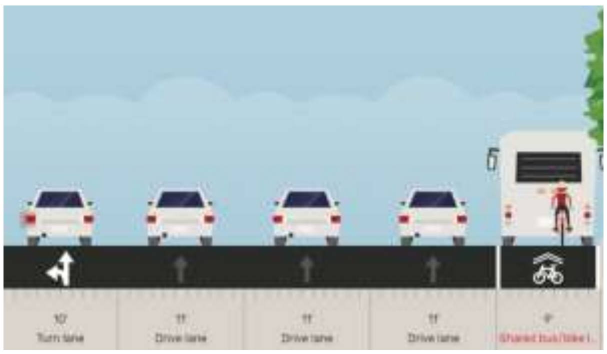


Afternoon Video Screenshot (10/21/2019)

5. W Lombard St between Hopkins Plaza and S Hanover St

	Vehicle Counts			
	Bus Lane: Buses	Bus Lane: Vehicles	Bus Lane: Cyclists & Scooters	General Purpose Lanes
7-9	76	20	7	510
2-4	56	14	2	759
4-6	78	24	8	729

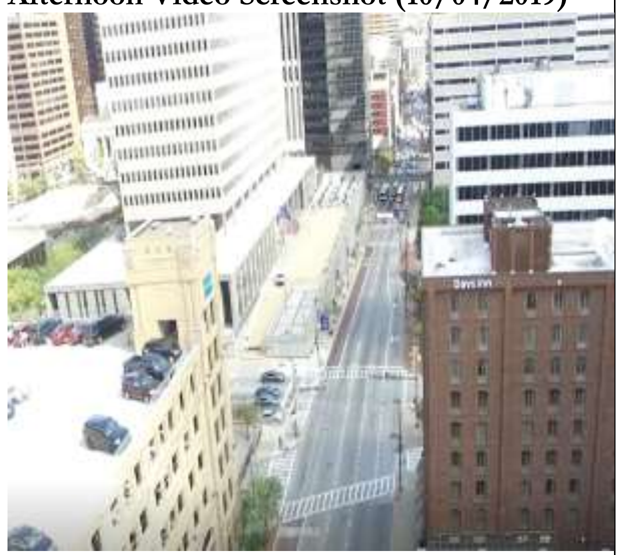
Cross-Section



Screenline

Morning Video Screenshot (10/04/2019)

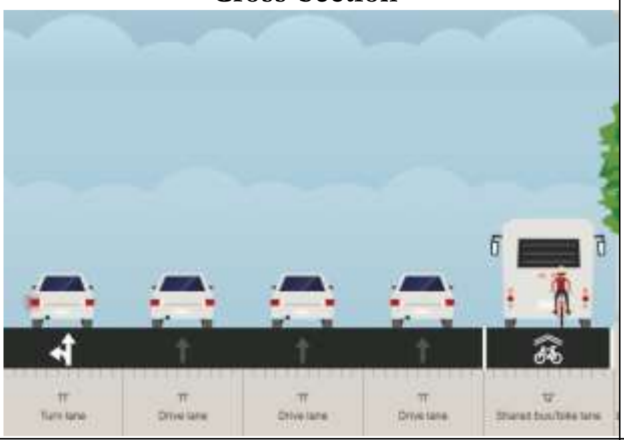
Afternoon Video Screenshot (10/04/2019)



6. E Pratt St between S Calvert St & Commerce St

	Vehicle Counts			
	Bus Lane: Buses	**Bus Lane: Vehicles**	**Bus Lane: Cyclists & Scooters**	**General Purpose Lanes**
7-9	67	36	14	1111
2-4	40	31	11	708
4-6	61	53	17	991

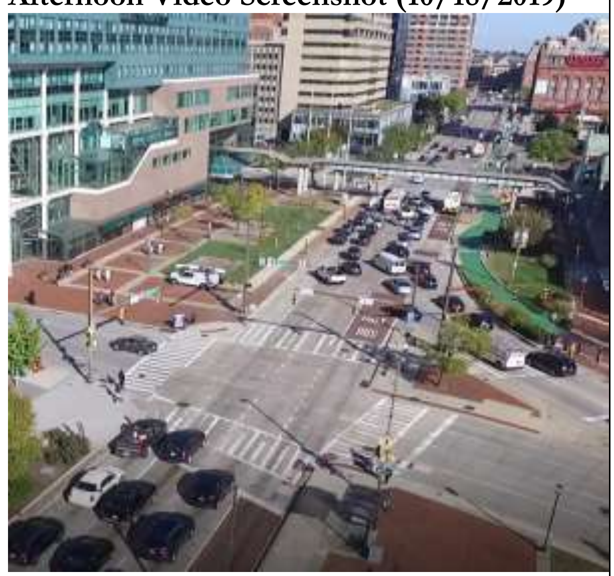
Cross-Section



Screenline

Morning Video Screenshot (10/21/2019)

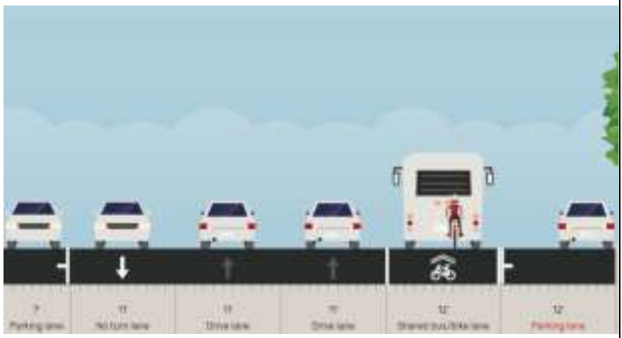
Afternoon Video Screenshot (10/18/2019)



7. E Fayette St between Holliday St & N Gay St

	Vehicle Counts			
	Bus Lane: Buses	Bus Lane: Vehicles	Bus Lane: Cyclists & Scooters	General Purpose Lanes
7-9	41	18	4	649
2-4	39	23	3	683
4-6	67	13	8	579

Cross-Section



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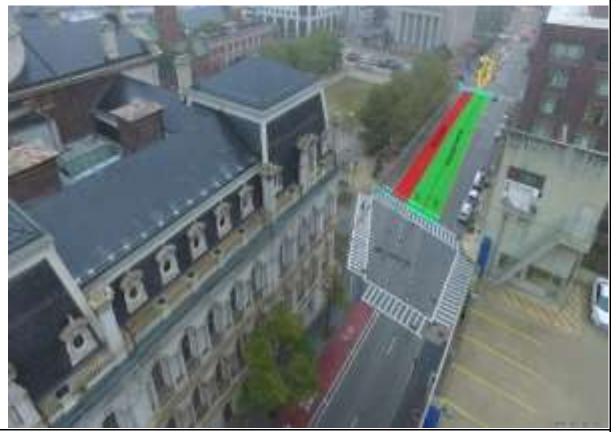


Morning Video Screenshot (10/22/2019)

Afternoon Video Screenshot (10/18/2019)

8. Charles St between W Preston St & W Biddle St

	Vehicle Counts			
	Bus Lane: Buses	Bus Lane: Vehicles	Bus Lane: Cyclists & Scooters	General Purpose Lanes
4-6	37	154	10	665

Cross-Section

Screenline

Afternoon Video Screenshot (10/03/2019)

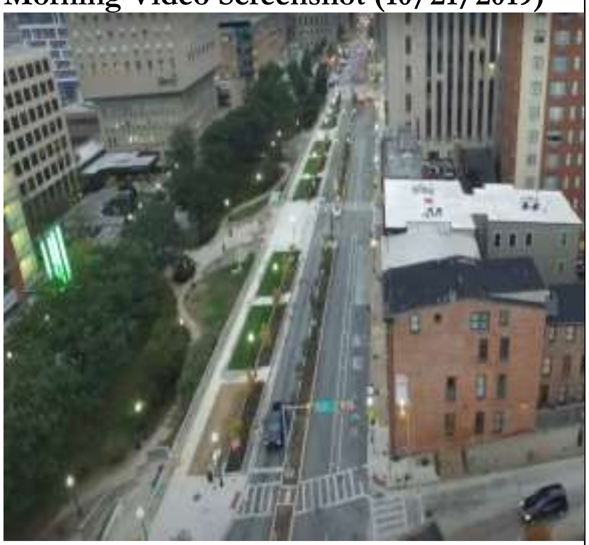
9. Saint Paul Pl between E Mulberry St & E Saratoga St

	Vehicle Counts			
	Bus Lane: Buses	Bus Lane: Vehicles	Bus Lane: Cyclists & Scooters	General Purpose Lanes
7-9	40	49	1	522
4-6	27	28	3	456

Cross-Section

Screenline

Morning Video Screenshot (10/21/2019)



Afternoon Video Screenshot (11/01/2019)

APPENDIX B: DATA COLLECTION FORMS

Quality Counts Data Sheet Example

Table 24. Example Travel Time Data Sheet

Quality Counts
DATA THAT DRIVES COMMUNITIES

Project: Baltimore Shared Bus/Bike Lane
Location: E Fayette St btwn St Paul St & N Calvert St
Date: 10/18/2019
Time: 2:00 PM - 5:30 PM

Travel Time Information

	Bus Lane: Bus Traffic			Bus Lane: Vehicle Traffic			Bus Lane: Cyclists			Bus Lane: Scooters			Non-Bus Lane: All Traffic		
	Bus Enters Segment	Bus Exits Segment	Bus Travel Time	Vehicle Enters Segment	Vehicle Exits Segment	Vehicle Travel Time	Cyclist Enters Segment	Cyclist Exits Segment	Cyclist Travel Time	Scooter Enters Segment	Scooter Exits Segment	Scooter Travel Time	Traffic Enters Segment	Traffic Exits Segment	Travel Time
1	2:00:28 PM	2:01:10 PM	0:42	2:02:10 PM	2:02:25 PM	0:15	2:41:13 PM	2:41:29 PM	0:16	4:07:56 PM	4:08:16 PM	0:20	2:00:17 PM	2:01:07 PM	0:50
2	2:05:18 PM	2:05:51 PM	0:33	2:08:36 PM	2:09:00 PM	0:24	3:24:33 PM	3:24:46 PM	0:13	4:46:49 AM	4:47:11 AM	0:22	2:00:20 PM	2:00:38 PM	0:18
3	2:05:27 PM	2:07:21 PM	1:54	2:13:56 PM	2:14:12 PM	0:16	3:30:37 PM	3:31:02 PM	0:25				2:00:20 PM	2:01:09 PM	0:49
4	2:06:58 PM	2:07:27 PM	0:29	2:17:52 PM	2:19:26 PM	1:34	4:04:07 PM	4:04:20 PM	0:13				2:00:22 PM	2:00:42 PM	0:20
5	2:07:15 PM	2:08:58 PM	1:43	2:17:52 PM	2:19:12 PM	1:20	4:35:43 AM	4:36:37 AM	0:54				2:00:23 PM	2:00:45 PM	0:22
6	2:10:29 PM	2:12:19 PM	1:50	2:20:09 PM	2:21:07 PM	0:58	4:36:51 AM	4:37:31 AM	0:40				2:00:23 PM	2:02:22 PM	1:59
7	2:12:13 PM	2:14:00 PM	1:47	2:21:02 PM	2:21:33 PM	0:31	4:48:36 AM	4:49:05 AM	0:29				2:00:25 PM	2:02:29 PM	2:04
8	2:13:08 PM	2:14:07 PM	0:59	2:22:38 PM	2:23:00 PM	0:22	4:58:45 AM	4:59:04 AM	0:19				2:00:27 PM	2:00:51 PM	0:24
9	2:20:38 PM	2:21:14 PM	0:36	2:23:12 PM	2:27:08 PM	3:56							2:00:30 PM	2:00:54 PM	0:24
10	2:26:48 PM	2:27:35 PM	0:47	2:26:41 PM	2:27:37 PM	0:56							2:00:32 PM	2:01:02 PM	0:30
11	2:29:43 PM	2:30:21 PM	0:38	2:28:18 PM	2:28:49 PM	0:31							2:00:35 PM	2:01:06 PM	0:31
12	2:36:51 PM	2:38:15 PM	1:24	2:44:29 PM	2:45:25 PM	0:56							2:00:38 PM	2:02:23 PM	1:45
13	2:37:08 PM	2:38:18 PM	1:10	2:45:26 PM	2:46:31 PM	1:05							2:00:42 PM	2:01:09 PM	0:27
14	2:46:37 PM	2:50:06 PM	3:29	2:51:13 PM	2:55:23 PM	4:10							2:00:43 PM	2:02:26 PM	1:43
15	2:51:22 PM	2:53:11 PM	1:49	2:56:53 PM	2:58:12 PM	1:19							2:00:45 PM	2:02:25 PM	1:40
16	2:54:26 PM	2:56:32 PM	2:06	3:16:59 PM	3:19:33 PM	2:34							2:00:49 PM	2:02:27 PM	1:38
17	2:56:13 PM	2:58:09 PM	1:56	3:20:17 PM	3:21:17 PM	1:00							2:00:51 PM	2:02:34 PM	1:43
18	2:58:39 PM	2:59:52 PM	1:13	3:40:33 PM	3:40:51 PM	0:18							2:00:57 PM	2:02:27 PM	1:30
19	3:01:12 PM	3:02:00 PM	0:48	3:48:59 PM	3:49:07 PM	0:08							2:01:19 PM	2:02:36 PM	1:17
20	3:02:53 PM	3:04:53 PM	2:00	3:57:06 PM	3:57:20 PM	0:14							2:01:37 PM	2:02:41 PM	1:04
21	3:03:04 PM	3:04:58 PM	1:54	4:00:34 PM	4:01:57 PM	1:23							2:01:42 PM	2:02:34 PM	0:52
22	3:09:36 PM	3:11:28 PM	1:52	4:03:35 PM	4:03:43 PM	0:08							2:01:44 PM	2:03:58 PM	2:14
23	3:11:30 PM	3:13:10 PM	1:40	4:03:48 PM	4:07:15 PM	3:27							2:01:57 PM	2:02:36 PM	0:39
24	3:11:53 PM	3:13:13 PM	1:20	4:07:34 PM	4:08:57 PM	1:23							2:01:57 PM	2:04:00 PM	2:03
25	3:15:23 PM	3:18:03 PM	2:40	4:08:20 PM	4:09:06 PM	0:46							2:01:58 PM	2:02:37 PM	0:39
26	3:21:51 PM	3:23:26 PM	1:35	4:08:23 PM	4:08:59 PM	0:36							2:02:00 PM	2:04:02 PM	2:02
27	3:23:13 PM	3:24:40 PM	1:27	4:09:50 PM	4:10:37 PM	0:47							2:02:11 PM	2:02:39 PM	0:28
28	3:26:48 PM	3:28:43 PM	1:55	4:11:14 PM	4:12:21 PM	1:07							2:02:14 PM	2:02:42 PM	0:28
29	3:27:25 PM	3:28:56 PM	1:31	4:11:17 PM	4:11:52 PM	0:35							2:02:14 PM	2:02:47 PM	0:33
30	3:28:37 PM	3:30:23 PM	1:46	4:13:59 PM	4:15:24 PM	1:25							2:02:14 PM	2:04:04 PM	1:50
31	3:29:11 PM	3:30:34 PM	1:23	4:16:38 PM	4:18:43 PM	2:05							2:02:16 PM	2:02:44 PM	0:28
32	3:29:29 PM	3:30:40 PM	1:11	4:16:56 PM	4:19:02 PM	2:06							2:02:19 PM	2:04:06 PM	1:47
33	3:30:03 PM	3:30:43 PM	0:40	4:18:52 PM	4:20:13 PM	1:21							2:02:22 PM	2:02:49 PM	0:27
34	3:30:13 PM	3:32:10 PM	1:57	4:22:00 PM	4:22:15 PM	0:15							2:02:23 PM	2:04:07 PM	1:44
35	3:31:44 PM	3:32:19 PM	0:35	4:26:39 PM	4:27:14 PM	0:35							2:02:39 PM	2:04:00 PM	1:21
36	3:33:26 PM	3:34:10 PM	0:44	4:26:59 PM	4:27:18 PM	0:18							2:02:40 PM	2:04:08 PM	1:28
37	3:42:11 PM	3:43:44 PM	1:33	4:30:11 PM	4:30:28 PM	0:17							2:02:41 PM	2:04:02 PM	1:21
38	3:42:25 PM	3:43:52 PM	1:27	4:30:10 PM	4:30:27 PM	0:17							2:02:47 PM	2:04:10 PM	1:23
39	3:43:42 PM	3:45:25 PM	1:43	4:31:18 PM	4:31:40 PM	0:22							2:02:49 PM	2:04:11 PM	1:22

Table 25. Running Block Total and Travel Time Summary Data Sheet

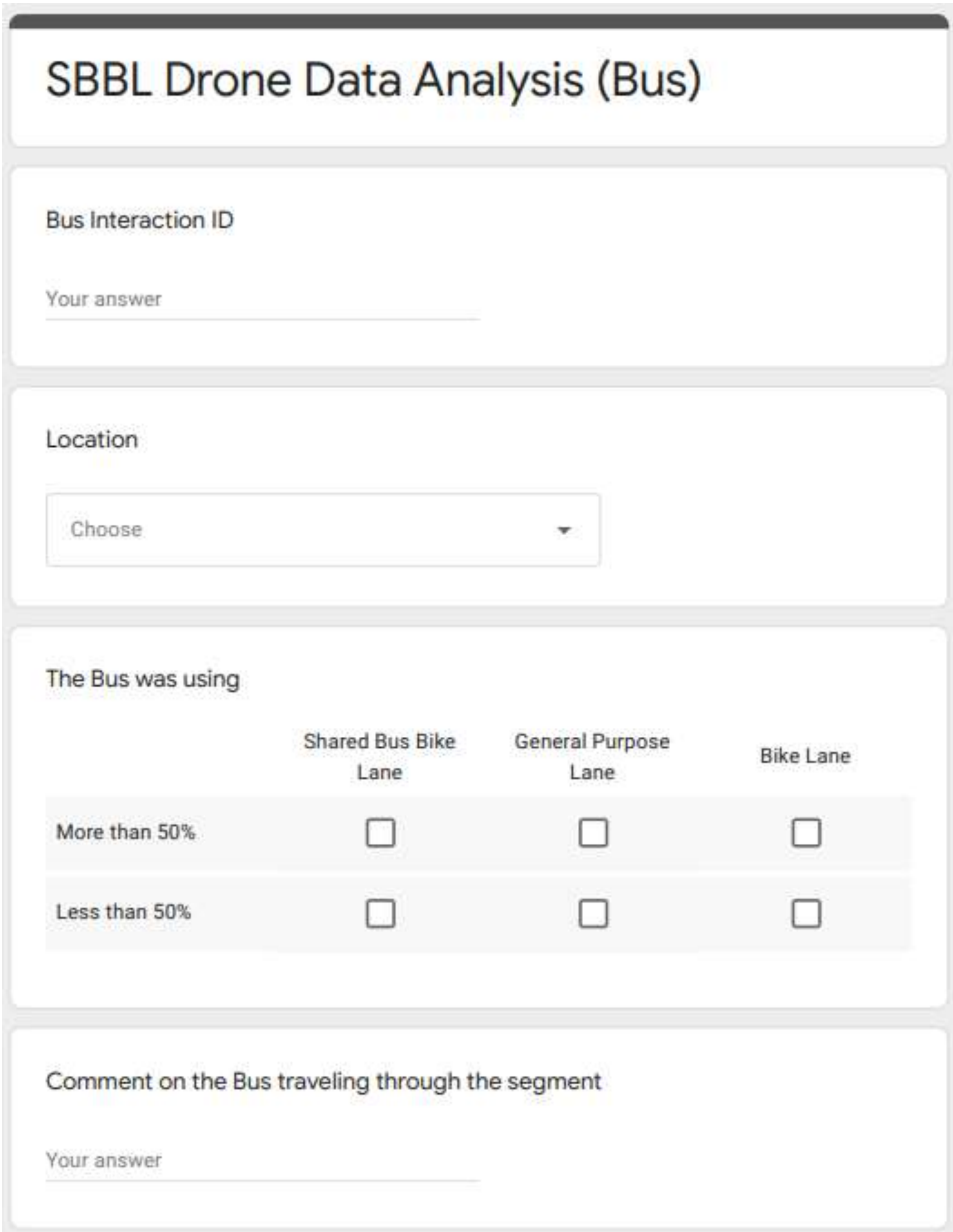
	Bus Lane: Bus Traffic	Bus Lane: Vehicle Traffic	Non-Bus Lanes: All Traffic
	Running Block Total	Running Block Total	Running Block Total
2:00:00 PM	0	0	2
2:00:15 PM	0	0	2
2:00:30 PM	1	0	11
2:00:45 PM	1	0	14
2:01:00 PM	1	0	13
2:01:15 PM	0	0	8
2:01:30 PM	0	0	9
2:01:45 PM	0	0	12
2:02:00 PM	0	0	16
2:02:15 PM	0	1	20
2:02:30 PM	0	0	17
2:02:45 PM	0	0	11
2:03:00 PM	0	0	15
2:03:15 PM	0	0	14
2:03:30 PM	0	0	13
2:03:45 PM	0	0	19
2:04:00 PM	0	0	20
2:04:15 PM	0	0	9
2:04:30 PM	0	0	5
2:04:45 PM	0	0	4
2:05:00 PM	0	0	4
2:05:15 PM	0	0	4
2:05:30 PM	2	0	15
2:05:45 PM	2	0	16
2:06:00 PM	1	0	9
2:06:15 PM	1	0	6
2:06:30 PM	1	0	8
2:06:45 PM	1	0	8
2:07:00 PM	2	0	9
2:07:15 PM	3	0	19
2:07:30 PM	1	0	18
2:07:45 PM	1	0	15
2:08:00 PM	1	0	13
2:08:15 PM	1	0	11
2:08:30 PM	1	0	9
2:08:45 PM	1	1	15
2:09:00 PM	0	0	14
2:09:15 PM	0	0	10
2:09:30 PM	0	0	7
2:09:45 PM	0	0	5
2:10:00 PM	0	0	6
2:10:15 PM	0	0	7
2:10:30 PM	1	0	15
2:10:45 PM	1	0	14
2:11:00 PM	1	0	12
2:11:15 PM	1	0	10
2:11:30 PM	1	0	10
2:11:45 PM	1	0	10
2:12:00 PM	1	0	14
2:12:15 PM	2	0	23
2:12:30 PM	1	0	18

Estimated Free-Flow Travel Time	
Bus Lane: Bus Traffic	
Bus Lane: Vehicle Traffic	
Non-Bus Lanes: All Traffic	

Bus Traffic (Bus Lane)	Average Travel Time:	1:26
	Average Block Volume:	0.63
Non-Bus Traffic (Bus Lane)	Average Travel Time:	1:02
	Average Block Volume:	0.28
All Traffic (Non-Bus Lanes)	Average Travel Time:	2:06
	Average Block Volume:	15.36

Includes vehicles in queue before start time

Bus Interaction Form



SBBL Drone Data Analysis (Bus)

Bus Interaction ID

Your answer

Location

Choose

The Bus was using

	Shared Bus Bike Lane	General Purpose Lane	Bike Lane
More than 50%	☐	☐	☐
Less than 50%	☐	☐	☐

Comment on the Bus traveling through the segment

Your answer

The Bus had an interaction with

- ☐ The Bike
- ☐ E-Scooter
- ☐ Passenger Vehicle
- ☐ Parked Vehicle
- ☐ Other: ____________

Comment on the Bus interaction (apx count)

Your answer ____________

While interacting with the other vehicles, the Bus passed

- ☐ Left of the vehicle
- ☐ Right of the vehicle
- ☐ Waited behind the vehicle
- ☐ Other: ____________

Other Vehicles entered the Shared Lane before the broken lines

- ○ Yes
- ○ No

Did all Passenger Vehicles in the SBBL turn right?

- ◯ Yes
- ◯ No

Comment on the Vehicles entering the SBBL

Your answer

Was the Bus slowed down or caused delay the

	Yes	No
Bike	◯	◯
E-Scooter	◯	◯
Other Vehicle	◯	◯

Did the Bus stopped at the Bus Stop

- ◯ Yes
- ◯ No
- ◯ No Bus Stop

Did the Bus pick up/Drop of Passengers

- Yes
- No

How long the Bus was stationary (for pick up/drop of)

Hrs Min Sec

__ : __ : __

Was there any Enforcement

- Yes
- No

Comment on the Enforcement Scenario

Your answer

Was there any Near-Miss collusion

- Yes
- No

Bike Interaction Form

SBBL Drone Data Analysis (Bike)

Bike Interaction ID

Your answer

Location

Choose

The Bike was in

	Bike Lane	Shared Bus Bike Lane	General Purpose Lane	Side Walk
More than 50%	☐	☐	☐	☐
Less than 50%	☐	☐	☐	☐

Comment on the Bike traveling through the segment

Your answer

The Bike had an interaction with

- ☐ The Bus
- ☐ The Passenger Car
- ☐ Parked Vehicle
- ☐ No Interaction
- ☐ Other: ________

Comment on the Bike interaction with other vehicles

Your answer

While interacting with the other vehicles (Bus), the Bike passed

Choose ▾

While interacting with the other vehicles (Passenger Car), the Bike passed

Choose ▾

Comment on the Bike and Other Vehicle Interaction

Your answer

Is the bike slowing down the bus

- ◯ Yes
- ◯ No

Comment on the Bike slowing down other vehicles

Your answer

Was there any enforcement

- ◯ Yes
- ◯ No

Comment on the Enforcement Scenario

Your answer

Was there any near-miss collision or dangerous interactions

- ◯ Yes
- ◯ No

Comment on the Near-Miss Scenario

Your answer

Was the Bike stopped at the traffic signal ?

- ◯ Yes
- ◯ No

After reaching the intersection, the Bike turned

- ◯ Left
- ◯ Right
- ◯ Went Through

Additional Notes

Your answer

Submit