Freight in a Bicycle-Friendly City

Exploratory Analysis with New York City Open Data

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This project employs a variety of open data sets to examine how New York City's growing bicycle infrastructure has had an impact on travel and parking conditions for commercial vehicles (CVs), and to investigate the interactions that occur between CVs and bicycles on multimodal urban streets. The project was conducted in three stages. First, a spatial analysis of the city's dedicated bicycle and local truck routes was performed to quantify the extent of network overlap and changes that have occurred since 2000. Next, a spatial and statistical analysis of bicycle collisions extracted from the New York Police Department's motor vehicle collision database was conducted to explore infrastructure and demand characteristics indicative of freight–bicycle conflicts. Finally, CV–bicycle lane parking violations were extracted from a New York City Department of Finance's parking violation database to examine parking challenges in bicycle-friendly areas; field data were also collection in three critical locations. The project identified several challenges for CV operations. Potential future research efforts to address emerging questions requiring further investigation are also discussed.

New York City (NYC) has been a leader in the Complete Streets movement, rapidly transforming its streets over the last decade. Some changes have been implemented with the aim of reducing passenger transportation externalities and improving safety for all roadway users. Included are installation of more than 400 mi of bike lanes since 2007 (*1*); launch of the Citi Bike bike sharing system in 2011, with expansion in 2015 (*2*); implementation of more than 60 Complete Streets projects that have installed pedestrian islands, sidewalk extensions, and other pedestrian-friendly infrastructure and 15 Neighborhood Slow Zone projects that lower speed limits and install speed-reduction infrastructure in residential neighborhoods (*3*); reduction of the city's default speed limit from 30 to 25 mph (*4*); and implementation of Select Bus services with dedicated bus lanes along eight corridors since 2008 (*5*). The recently launched OneNYC plan seeks to continue this trajectory, including goals to massively expand the transit network and to increase the size of the city's bike network (*6*).

These measures have been considered widely successful in their intended aim; according to the New York City Department of Transportation's (DOT's) own estimates, bike ridership is up (*7*) and cycling risk is down (*8*). Internationally, some studies have concluded that bicycle lane implementations are good for local economic activity; Jaffe summarizes those works (*9*). However, while studies have focused on the positive aspects of street redesign for nonmotorized travelers and for local businesses, little critical analysis has been done to determine the broader impacts of these implementations on motor vehicle movements and resulting costs, including congestion, emissions, and, in the case of freight, supply chain impacts. Advocates note some potentially positive impacts on congestion from Complete Streets implementations, such as the potential to reduce signal time allocations for pedestrian crossings (*10*). A 2012 DOT analysis of midtown Manhattan using taxi GPS data suggested that average traffic speeds increased following implementation of protected bicycles lanes and dedicated pedestrian infrastructure; however, the study offers little information on if or how estimates controlled for the impact of other variables such as changes in traffic demand (*11*).

While this study does not aim to provide a detailed analysis of networkwide congestion impacts from street design changes and increasing multimodal interactions, it does seek to offer a starting point in examining the consequences of recent street redesigns for a unique class of operators—commercial vehicles (CVs) performing first- and last-mile goods movements in the city. Previous researchers have already documented the extremely challenging conditions that CVs face in NYC, including heavy traffic delays and related congestion costs (*12*), inadequate parking (*13*) and building access (*14*), and high parking fines (*15*). While CVs are critical to support economic activity and the residential livelihood, they are often an afterthought in urban street redesign projects. For example, the popular *Urban Street Design Guide* from the National Association of City Transportation Officials has only recently been updated to provide guidance on accommodating trucks at intersections (*16*). One commonly considered solution to reduce interactions, shifting deliveries to off-peak hours, has proved effective in enabling efficient deliveries and reducing congestion and emissions impacts, but pilot studies have also identified several economic realities and practical constraints that have so far limited widespread adoption of this solution (*15, 17, 18*). While a few studies have noted that bicycles pose specific challenges for urban truck operations (*19, 20*), fewer have specifically explored broader interactions between CVs and bicycles on urban networks (*21, 22*).

Changes in street design and permitted movements along a designated truck network can have important consequences for truck movements. Lane narrowing that reduces capacity and intersection designs requiring multipoint turns that obstruct travel lanes will cause delays to the driver, and they may increase congestion and related emissions on surrounding streets. Changes in street directionality on designated routes may add considerable distance to CV trips, increasing time and

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fuel costs for the driver. Longer truck trips increase total heavy vehicle mileage on the network, affecting congestion and accident exposure. Alternatively, trucks may choose to operate illegally on nondesignated truck routes not designed for their use. At final delivery locations, curbside bicycle lanes and other pedestrian-friendly infrastructure that consumes limited parking may reduce or eliminate direct curb access. Illegally parked CVs are likely to obstruct through traffic and present a safety risk to pedestrians, cyclists, and drivers. This project seeks to better understand the potential operational impacts of widespread bicycle lane implementations on local goods movement in NYC, while remaining alert to how potential street design changes may affect CV activity.

PROJECT ORGANIZATION

This project includes three separate but related analyses. First, a basic evaluation of the extent of overlap between the city's designated bicycle and local truck routes was conducted to better understand the truck route mileage affected by bicycle lane implementations. Next, motor vehicle collisions involving bicycles were examined to identify their spatial distribution, to determine the extent to which they occur on truck routes, and to examine unique characteristics of collisions between CVs and bicycles. Finally, the spatial distribution of parking violations for CVs stopping, standing, or parking within a marked bicycle lane was examined to identify challenging locations for deliveries. Field observation was conducted in three locations in Manhattan and the Bronx to examine the factors affecting drivers' decisions to park in the bicycle lane. While the specific vehicles examined in the safety and parking analyses vary slightly, results from all three analyses together provide a picture of how CVs operate on NYC's new bicycle-friendly streets.

NETWORK OVERLAP

Trucks originating in or destined to NYC are required to travel on a designated network of local truck routes. CVs are permitted to use nondesignated routes only to reach a final pickup or delivery destination. This analysis seeks to roughly quantify the extent to which NYC truck routes have been affected by bicycle lane implementations.

Method of Analysis

To quantify the extent of network overlap and changes that have occurred to the network since 2000, affected mileage was estimated in ArcGIS by using NYC DOT's 2014 local truck and bicycle route maps. The bicycle map file includes lane installations and modifications through April 2014. While both maps were developed based on the NYC Department of City Planning's LION file, a street centerline map, the routes are not in perfect alignment; as a result, a 20-ft buffer was created by using the truck route file to approximate the total width of the street. Bicycle lanes falling completely within this buffer were then selected to identify overlapping segments, and the overlapping network was isolated for analysis.

To understand impacts on truck route capacities from bicycle lane implementations, bicycle lane segments on this overlapping network were sorted by lane type. Bicycle lane segments were sorted into three categories: known on-street lanes, known off-street lanes, and unknown lanes. The unknown category includes segments with more than one lane type on a block or segments for which no type is designated. Six on-street lane types include signed and sharrowed routes, which provide no dedicated space for bicycles; bicycle-friendly parking lanes wide enough to permit a bicycle to ride next to parked cars (usually 14 ft); 4-ft-wide dedicated curbside and standard lanes; and protected lanes that are physically separated from vehicle traffic, either by a raised curb or by parked vehicles. Following this sorting, a limited on-street network consisting only of known on-street segments was identified for further evaluation.

Results and Discussion

In 2014, the total bicycle route network extended over 604 mi, including both on-street and off-street lanes. Of this, 378 mi (63%) were installed since the year 2000. Approximately 89 mi overlapped the city's 794-mi local truck network, a length covering 15% of the bicycle network and 11% of the truck network. Much of the overlapping mileage is on major high-traffic thoroughfares in lower Manhattan and in Brooklyn neighborhoods closest to Manhattan (Figure 1). About two-thirds of bike lanes installed on the truck network were installed after 2000. For lane type analysis, the limited on-street network examined totaled 363.4 mi, including 70.5 mi of bike lanes on local truck routes.

Table 1 shows the distribution of lane types. It is clear that the majority of bicycle network implementations on the truck route network are lane types that require moderate to high allocation of dedicated space for bicycle use. More than 10% of all mileage installed on truck routes includes protected lanes, which generally require the most dedicated space of all bicycle lane types. The 10.6% share of protected lanes on the truck routes is nearly triple that on the overall on-street network. Since 2000, protected lanes have been installed at an even higher rate, constituting 12.1% of new mileage on truck routes.

BICYCLE COLLISIONS

Safety is a major concern when bikes and large CVs operate in proximity. International studies have recognized high fatality rates for bicycle collisions involving heavy vehicles (*23–27*). Previous research has also investigated relationships between traffic demand, built environment factors, and collision rates; Chen provides a comprehensive summary (*28*). While a few studies have identified relationships of overall bicycle collision frequencies with freight-related variables such as large vehicle demand (*29*) and commercial land uses (*30*), none have specifically evaluated freight demand impacts on CV-bicycle collisions. This analysis seeks to evaluate two separate but related questions: To what extent do bicycle collisions occur on truck routes? What unique characteristics of infrastructure and demand are related to collision frequencies?

Method of Analysis

Bicycle collisions were identified from a constantly updated database on motor vehicle collisions from the New York Police Department. This database includes only collisions that resulted in police involvement, and therefore may exclude minor incidents. Owing to the low share of recorded collisions involving bicycles and the small percentage of those involving CVs, data from multiple years (July 1, 2012, to July 25, 2015) were evaluated. From the detailed

FIGURE 1 Bicycle and truck route overlap in NYC.

records, these collisions could be sorted to determine involved motor vehicle types. While the primary vehicle types of interest are large CVs (6+ tires) and small CVs (4 tires), collisions involving buses, taxi or livery vehicles, and personal vehicles (passenger car, SUV, or pickup) were also identified for comparison. Once a final data set of collisions was identified and classified, maps were generated to examine the dispersion of different vehicle-type collisions.

To examine the characteristics of infrastructure at collision locations, collisions were mapped to the limited on-street network as described. Collisions not occurring in an on-street bike lane were excluded from the lane type analysis. Via this mapping, the shares of collisions occurring on truck routes and in each lane type could be estimated. There may be small errors in lane type identification owing to dynamic changes in bicycle lane configurations over the

TABLE 1 Bicycle Lane Type

	On-Street Bicycle Lanes		Truck Route Overlap		Truck Route Overlap Installed Since 2000	
Lane Type	Length (mi)	Percent	Length (mi)	Percent	Length (mi)	Percent
Signed route	27.7	7.6	3.9	5.5	3.0	5.5
Sharrows	57.4	15.8	14.0	19.9	11.2	20.3
Bicycle-friendly parking	23.4	6.4	7.2	10.3	7.2	13.1
Standard	218.4	60.1	31.3	44.4	23.3	42.3
Curbside	25.0	6.9	6.6	9.4	3.7	6.7
Protected path	11.7	3.2	7.5	10.6	6.7	12.1
Total	363.4		70.5		55.1	

analysis period; however, these are not expected to affect general conclusions significantly.

In the absence of local truck volumes and submetropolitan freight trip demand estimates, this study relied on a basic difference of medians test to investigate the relationship between freight activity and CV-bicycle collisions. Employment in freight-related sectors was used as a proxy estimator of freight trip demand; Holguín-Veras et al. have demonstrated the relationship between these variables. Population estimates were obtained from the 2010 U.S. Census (*31*). Total employment and estimated employment in various NAICS sectors (i.e., North American Industry Classification System) for each census tract were identified from Longitudinal Employer-Household Dynamics data. Sectors evaluated include construction, manufacturing, wholesale trade, retail trade, and transportation and warehousing. Employment categories for arts, entertainment, and recreation as well as accommodation and food services were combined to create a single entertainment category. Remaining service sectors were combined in a general service category. As collisions are coded by intersections, and those intersections frequently lie on the edge between two or more census tracts, collisions were labeled with average characteristics of census tracts intersecting a 50-ft buffer surrounding the intersection. Ultimately, collisions were labeled with nine characteristics: the percentage of employment in each of the seven sectors as mentioned and the densities of population and employment. To examine the influence of these demand factors on CV collision rates, two sets of collision records were paired for comparison: (*a*) large CV collisions versus collisions not involving large CVs and (*b*) small CV collisions versus collisions not involving small CVs. Assuming nonnormality for the variables, a Wilcoxon difference of medians test was employed to test whether the distributions of these variables were equivalent across the data sets.

Results and Discussion

Records from 15,437 bicycle-involved collisions (2.5%) were extracted from an original data set containing 629,232 collisions involving all vehicle types. In all, 4,358 on-street bicycle collisions were identified. Of them, 68 involved a bus, 122 a CV, 2,948 a personal vehicle, 785 a taxi or livery cab, 21 only bicycle(s), and 446 another or unknown vehicle type. Some incidents involved more than one motor vehicle or bicycle. Notably, the percentage of CV-involved collisions is higher in the on-street bicycle lanes (2.9%) than as a share of citywide observed bicycle collisions (1.9%). Injury rates were similar across all vehicle types, with shares of collisions resulting in injury ranging from 66% for bicycle only to 76% for other and unknown vehicle types. From Figure 2, it is clear that bus, CV, and personal vehicle collisions all appear to be concentrated in roughly the same areas of Manhattan and Brooklyn, while for taxis, a different pattern is observed. While bus and CV collisions constitute a very small share of collisions, they are frequently located along specific corridors; for example, truck collisions are concentrated along the Grand Street corridor, a local truck route that connects industrial areas in East Williamsburg to the Williamsburg Bridge.

Table 2 shows the share of total collisions and CV-involved collisions occurring on each infrastructure type. Most notably, more

FIGURE 2 Dispersion of bicycle collisions by type of vehicle involved: (*a*) bus accidents and (*b*) commercial vehicle accidents.

(continued)

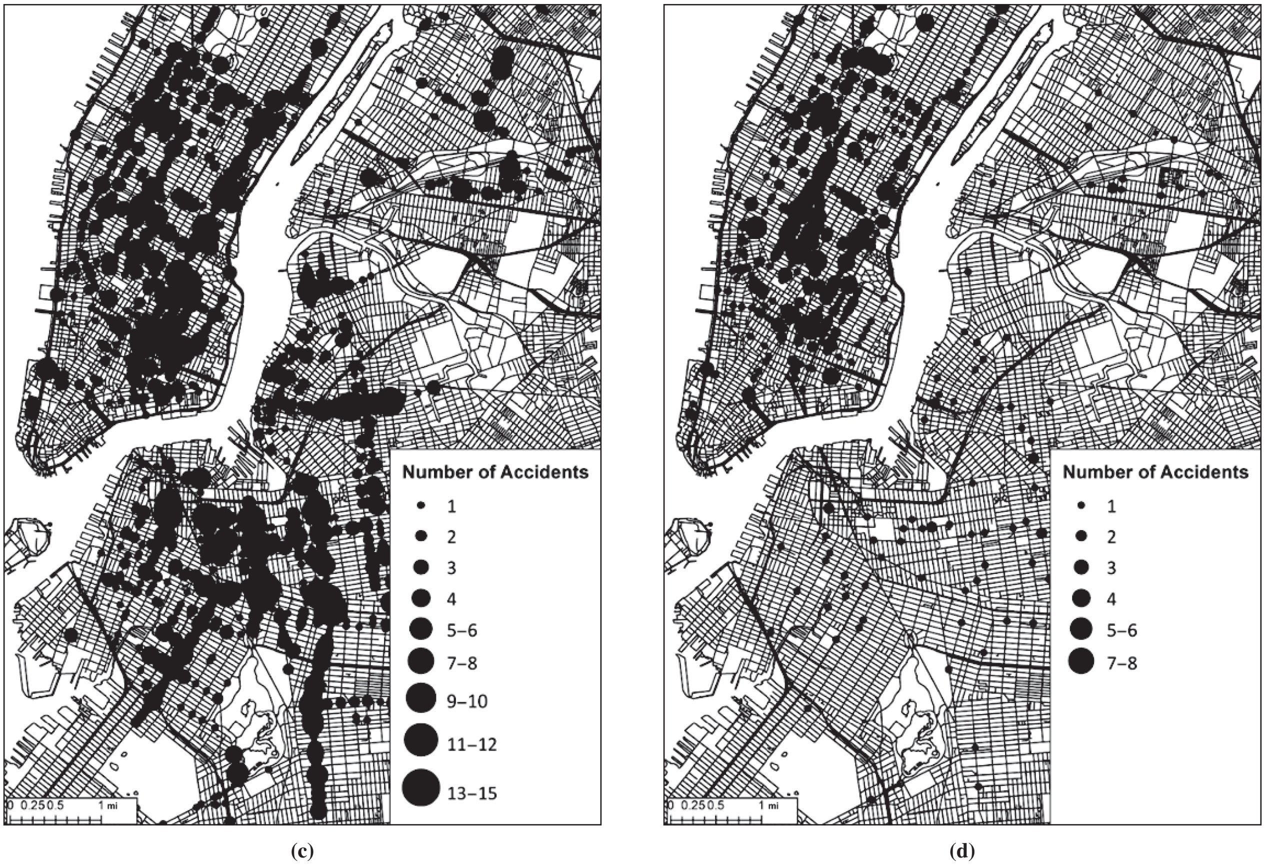

FIGURE 2 *(continued)* **Dispersion of bicycle collisions by type of vehicle involved: (*c*) personal vehicle accidents and (*d*) taxi–livery accidents.**

than half of all bicycle collisions occur on truck route segments that make up only 19% of the on-street bicycle network. For CV-involved collisions, 65% occur on the truck routes. These high collision rates may result primarily from higher traffic volumes of both bicycles and motor vehicles on these routes. The finding appears consistent with a Seattle study that found that bicycle collision rates are significantly higher on arterials compared with nonarterials (*28*). However, testing of this hypothesis is difficult owing to the unavailability of bicycle count data or vehicle classifications for many local streets.

In examining collision distributions across lane types, it is notable that collision frequencies are very high on protected paths compared with their total mileage. This result is counterintuitive, since protected paths are installed to protect bikes from collisions. Mapping reveals that many of these collisions occur on major Manhattan avenue corridors, including First, Second, Eighth, and Ninth Avenues, and Broadway, where vehicle and bicycle volumes are likely high; however, further examination is necessary to determine collision causality, because it is possible that factors such as driver visibility during turning movements

TABLE 2 Collisions by Lane Type

	On-Street Bicycle Lanes (%)			Truck Route Overlap (%)		
		Number of Collisions			Number of Collisions	
Lane Type	Infrastructure Length (mi)	All	CV	Infrastructure Length (mi)	All	CV
Signed route	7.6	3.9	4.9	3.9	3	2.6
Sharrows	15.8	18.4	16.4	14	18.2	12.8
Bicycle-friendly parking	6.4	2.5	0	7.2	1.6	0
Standard	60.1	53.2	46.7	31.3	44.4	39.7
Curbside	6.9	6	9	6.6	4.3	11.5
Protected path	3.2	15.9	23	7.5	28.5	33.3
Total	363.4	4,358	122	70.5	2,282	78

TABLE 3 Wilcoxon Difference of Medians Results

	Large CV Collisions			Small CV Collisions		
Characteristic	Median		*p*-Value	Median		*p*-Value
Population density	29,824	17,194	.123	38,350	17,041	.001**
Employment density	51,023	59,104	.360	71,079	59,035	.097
Share of employment in sector						
Construction	1.37	1.49	.940	1.83	1.49	.428
Manufacturing	1.04	0.84	.172	1.44	0.83	.052*
Wholesale	3.28	1.88	.014**	2.60	1.91	.064
Retail	6.87	9.60	.072*	8.89	9.60	.191
Transportation and warehousing	0.78	0.44	.040**	0.77	0.44	.039**
Service	60.91	58.32	.952	61.26	58.32	.853
Entertainment	12.19	14.34	.260	15.68	14.29	.720

NOTE: For large CV collisions, the number of observations were yes = 50 and no = 4,308. For small CV collisions, the number of observations were yes = 73 and no = 4,285.
*Significant with 95% confidence; **significant with 90% confidence.

may pose specific risks on protected paths. While the New York Police Department database does identify general contributing factors (e.g., driver distraction, alcohol involvement) for some accident records, this information is neither complete nor specific enough to reveal actions of the involved parties that caused the collisions.

Results from the difference of medians tests (Table 3) suggest that there is a relationship between freight demand and CV involvement in bicycle collisions. Large CV collisions occurred in locations with higher employment shares in freight-dependent industries—wholesale, transportation and warehousing, and retail. Small CV collisions also occurred in locations with expected generators of freight demand—those with high employment shares in transportation and warehousing and manufacturing, and with high population densities.

PARKING ANALYSIS

The third and final analysis conducted as part of this study was an evaluation of CV parking behavior on bicycle-friendly streets. Overall, parking challenges for CVs operating in NYC have been documented in previous research (*13–15, 32*). However, no study has yet focused specifically on CV parking along bicycle routes. This analysis aims to characterize the parking options that drivers face and their resulting parking choices.

Method of Analysis

To begin this analysis, a NYC Department of Finance database of parking violations was evaluated. This database includes records only for illegally parked vehicles that were issued a citation, likely underestimating violations in low enforcement areas. The geocoded data set included violations issued between July 29 and October 28, 2013 (*33*). This database included detailed records on the vehicle to which a citation was issued, location where the ticket was issued, and violation for which the vehicle was cited. While the data set does include a vehicle registration type variable, preliminary analysis revealed that this was inadequate to identify out-of-state CVs. CV violations were extracted from the database based on vehicle body type. The three body types examined were delivery vehicles, semitrailers, and vans. This database was further constrained only to records for a single violation, #48—"stopping, standing or parking within a marked bicycle lane." Once final violations were identified, they were mapped to the nearest street segment by using the Department of City Planning's LION map to identify total violations issued on each block. Figure 3 provides an example.

After critical block locations were identified, field data were collected in three areas to investigate the factors contributing to the driver's decision to park in the lane (see Table 4). The temporal distribution of observed parking violations was examined to identify appropriate observation times in each location. In the field, student research assistants observed truck arrivals and kept detailed records on vehicle and delivery characteristics, parking availability, parking choices for every arriving CV, and the activity of enforcement officers. Six specific activity types were examined:

- Grocery deliveries, including movement to grocery stores as well as directly to homes;
- Other food and beverage deliveries;
- Major parcel deliveries by UPS, FedEx, and the U.S. Postal Service;
- Other parcel deliveries by small, specialized companies;
- Moving trucks; and
- Service vehicles, including contractors and plumbers, utility companies, and technology services, among others.

Results from these observations were then evaluated to characterize parking behavior and drivers of parking decisions.

Results and Discussion

Initial processing of the violation database containing 1,048,576 total parking violations yielded 4,452 CV–bicycle lane violations. Of the 4,271 of these occurring on known on-street lane types, 80.9% were in standard lanes, 4.0% in protected lanes, and 3.0% in curbside lanes. Mapping these violations to individual blocks identified 23 blocks on which 20 or more violations were issued over the 3-month observation period; 19 of these blocks included standard bicycle lanes. Together, these critical locations accounted for

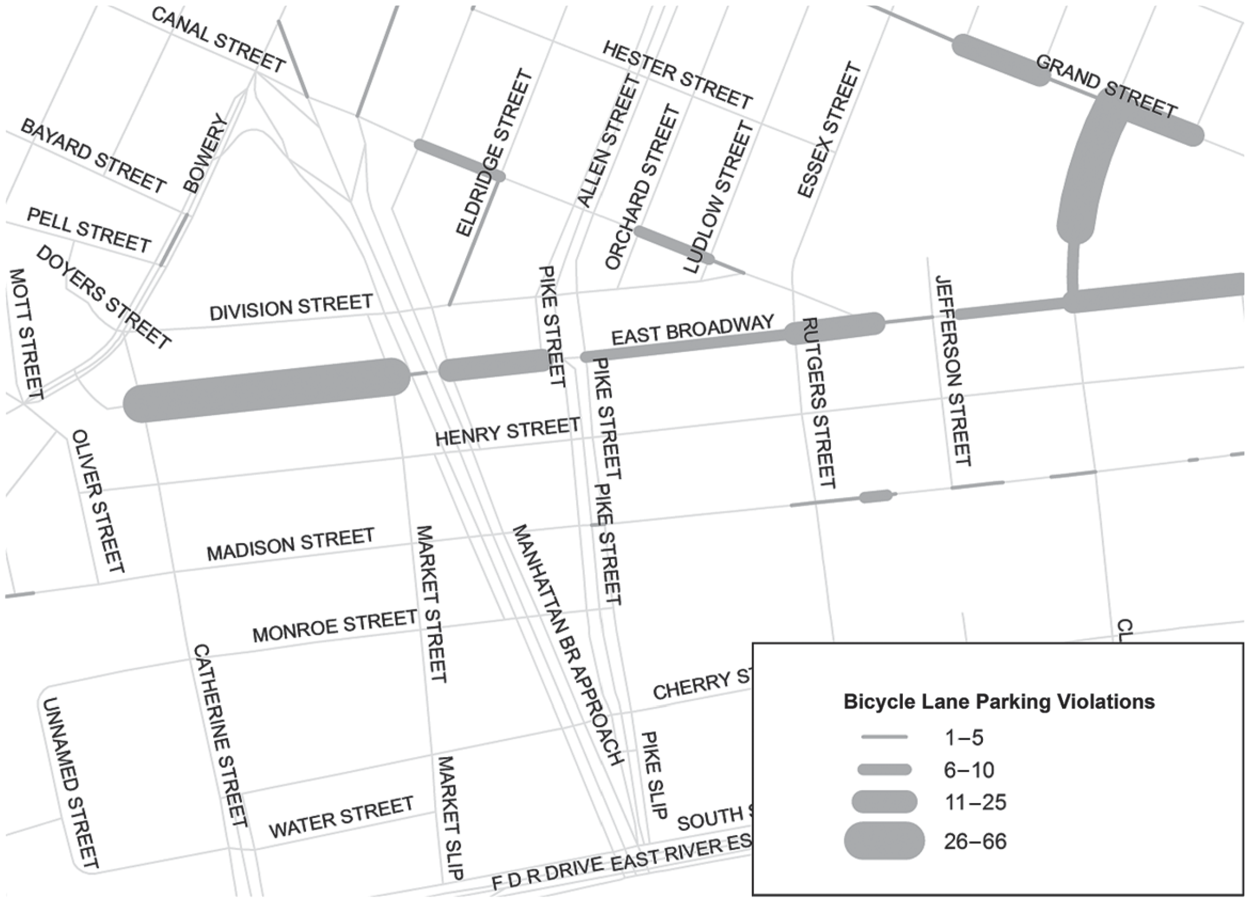

FIGURE 3 East Broadway commercial vehicle bicycle lane parking violations by block.

616 violations. Somewhat surprisingly, critical blocks were dispersed across four NYC boroughs, including 15 in Manhattan, five in the Bronx, two in Brooklyn, and one in Queens. These areas have land uses ranging from heavily commercial to primarily residential.

Table 4 summarizes results from the three field observation locations. The highest average truck arrival rate was observed on commercial East Broadway, although arrival rates here were found to be variable over time with a clear peak in the early part of the observation period. Goods movements here included a large share of food and beverage deliveries, many made by single-unit trucks. On West 77th Street, a primarily residential street, demand was dominated by parcel delivery and service vehicles relying more on cargo vans. While in commercial areas parcel deliveries were dominated by the major carriers, on the residential street a higher share of small parcel companies were observed. Interestingly, average demand was higher on West 77th Street than on the Grand Concourse, a primarily retail area. On the Grand Concourse, an even greater share of parcel deliveries was observed, with 80% conducted by the major carriers.

Figure 4 demonstrates the parking available to and choices made by drivers at the individual observation locations. Categories of parking observed included legal parking in a curbside spot; double-parking in a travel lane—which is also legal for deliveries in the three observation locations; illegal parking at a bus stop, in a bicycle lane, or in front of a fire hydrant; illegal parking in a "No Parking" or "No Standing" zone; and parking in any other illegal on-street spot (e.g., in the median). From the limited observations, it appears that driver parking aligns somewhat with availability. On East Broadway, dedicated commercial metered parking provides time-restricted, dedicated access to storefronts for delivery; here, about half of vehicles had a legal curbside spot available directly in front of delivery location, and another one-fourth had a legal spot available on the block. As a result, a fairly high share of drivers was able to legally park. Alternatively, on West 77th Street, unrestricted residential parking spaces experienced little turnover during the observation period. In this location, very few CVs had the option to park legally at the curb, which resulted in higher illegal parking rates and bicycle lane obstructions.

Table 5 describes observed parking behavior for vehicles making different types of deliveries. Some parking durations may be truncated if the vehicle arrived before the beginning of the observation period or departed after the end. Results indicate that for both food and parcel deliveries, the majority of CVs parked for less than 10 min. Longer durations observed for these vehicle types included trucks making multiple pallet food deliveries and major parcel companies serving many locations from a single parked vehicle. Service vehicles and moving trucks parked for longer durations.

More than half of the drivers making grocery or other food and beverage deliveries had an option to park directly in front of their delivery locations (Table 5). Few drivers making parcel deliveries

TABLE 4 Parking Case Study Location Characteristics and Vehicle Observations

Variable	East Broadway	Grand Concourse	West 77th Street
Cross streets	Catherine Street and Market Street	184th Street and Fordham Road	Columbus Avenue and Central Park West
Primary land use	Chinatown commercial district; includes many independent food markets and small retailers	Major Bronx commercial corridor; observed blocks dominated by retail stores; some vacant buildings	Museum of Natural History spans block on north side; primarily midrise prewar residential on south side; bordered by Central Park to the west
Motor vehicle travel lanes	Local street with single travel lane in each direction	Separated arterial with single local lane in each direction	Local street with single travel lane in each direction
Bicycle infrastructure	Standard bicycle lanes in both directions	Buffered bicycle lanes in both directions	Buffered bicycle lanes in both directions
Parking regulations	1-h metered north side; commercial meter (8:00 a.m. to 1:00 p.m.) 44% of south side, remainder 1-h metered	1-h metered parking with bus stops on both sides	Open parking on south side; school bus loading 37% of north side school bus loading, remainder open
Date observed	May 13, 2015	April 27, 2015	April 30, 2015; May 7, 2015
Hours observed	9:00 a.m. to 1:00 p.m.	9:00 a.m. to 1:00 p.m.	8:00 a.m. to 12:00 p.m., 12:00 p.m. to 4:00 p.m.
Total trucks	70	25	67
Average trucks/h	17.5	6.25	8.38
Minimum trucks/h	11	1	0
Maximum trucks/h	26	12	21
Vehicle Type: Percentage of Observed Vehicles			
Single-unit truck	65.7	52	35.8
Refrigerator truck	2.9	0	1.5
Semitrailer	0	0	3
Van	28.6	40	52.2
Other	2.9	8	7.5
Delivery Type: Percentage of Observed Vehicles			
Grocery	8.6	0	7.5
Other food and beverage	38.6	4	6
Major parcel	21.4	32	20.9
Other parcel	1.4	8	10.4
Moving truck	0	12	4.5
Service vehicle	10	24	25.4
Other	10	16	25.4
Unknown	10	4	0

had legal curbside parking options available at their delivery location, and even when a legal spot was available, parcel companies did not necessarily choose to use it. Only four of seven observed parcel vehicles with available parking directly in front of a delivery location chose to use the space. Alternatively, service vehicles were the only delivery type to frequently use legal curbside parking located elsewhere on the block.

Enforcement rates were also observed to vary by location. On the Grand Concourse, where freight vehicle arrival rates were lowest, 32% of all parked vehicles were passed by an enforcement officer, and three of 14 illegally parked vehicles were issued a citation. In this location, several major parcel trucks were observed moving between multiple illegal parking spots throughout the duration of the data collection period, and none received multiple citations. Those cited reacted little, continuing with their unloading operations without notice of or reaction to the enforcement officer. On West 77th Street and East Broadway, enforcement officers passed much lower shares (15% and 17%) of total parked vehicles; citations were issued to only three of 57 illegally parked vehicles on the former and to none of the 36 illegally parked vehicles on the latter.

DISCUSSION OF RESULTS AND FUTURE RESEARCH

Results from these analyses provide insights on the impacts of NYC's growing on-street bicycle network for CV operations. About 11% of the city's designated local truck route network now overlaps with its bicycle network, and bicycle lanes have consumed previous motor vehicle capacity to provide dedicated space for cyclists. Future research is needed to measure the short- and long-term implications of these reduced capacities for CV operations, costs, and externalities. One approach to address these questions may be simulation modeling of the urban street network to quantify traffic delays and emissions from capacity changes. This would require collection of traffic volumes, including vehicle classifications, for a denser network of

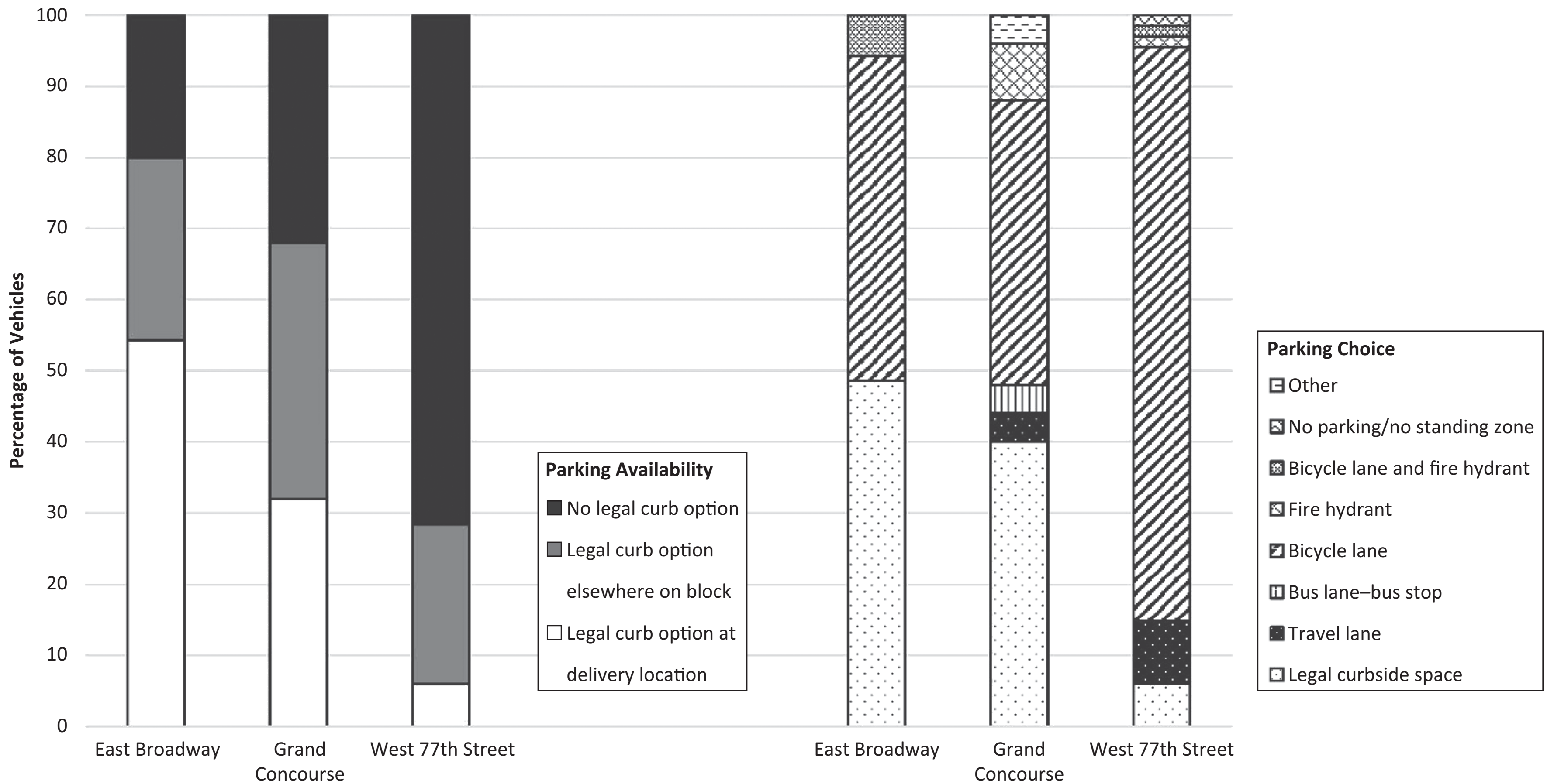

FIGURE 4 Parking by location.

TABLE 5 Parking by Delivery Type

		Observed Vehicles (%)							
							Legal Curbside Parking		
		Parking Duration (min)					Available		
Delivery Type	Total Vehicles	<5	5–10	10–30	30–60	60+	Directly in Front	On Block	Used
Grocery	11	18.2	36.4	27.3	9.1	9.1	54.5	9.1	54.5
Other food and beverage	31	46.7	26.7	16.7	10	0.0	51.6	25.8	41.9
Major parcel	38	54.1	24.3	13.5	5.4	2.7	13.2	18.4	7.9
Other parcel	10	40.0	50.0	10	0.0	0.0	20.0	40.0	10.0
Moving truck	6	0.0	33.3	16.7	33.3	16.7	16.7	0.0	16.7
Service vehicle	30	37	7.4	22.2	22.2	11.1	16.7	40.0	43.3
Other–unknown	36	57.1	14.3	17.1	8.6	2.9	41.7	27.8	30.6

local streets than that for which data are currently readily accessible. A second approach could be evaluation of GPS spot speed data—whether from trucks or other vehicles—to measure vehicle speeds and progression on truck routes with and without bicycle infrastructure.

Bicycle collisions of all types are heavily concentrated on local truck corridors. Particularly given the severe outcomes for non-motorized travelers from CV-involved collisions, findings warrant future research to directly evaluate the relationships of vehicle and bicycle traffic volumes and collision rates; to examine detailed accident causality on specific types of bicycle infrastructure; to identify the resulting safety implications from redesigning high-traffic corridors for multimodal operations; and to determine the congestion impacts, related externalities, and downstream industry costs to carriers, shippers, and receivers from frequent bicycle–vehicle collisions along major truck corridors. Each of these areas of focus demands further data collection. Local street CV and bicycle volumes are also needed to adequately assess the relationship between traffic demand and bicycle collision rates and to estimate the congestion impacts from these collisions. To assess collision factors and the severity of collision outcomes on different lane types, either collision records or hospital records frequently evaluated in accident severity studies must identify two important factors. The first factor is a detailed description of the bicycle and vehicle operator actions that resulted in a collision, and the second factor is the exact location of the incidents, including the specific type of bicycle infrastructure on which the collision occurred. As bicycle networks continue to expand, time-series analysis of collision data before and after infrastructure implementations may also reveal trends on collision frequencies and outcomes.

CVs in NYC struggle to access curbside parking on multimodal streets; as a result, CV–bicycle lane parking violations are widespread and costly. Management strategies are required to provide adequate curb access, not only on commercial and retail streets traditionally recognized as freight trip generators but now also in residential areas. However, the effectiveness of both curb management strategies and enforcement to curb parking violations will vary for different carrier types. Future research is needed to identify parking strategies appropriate for implementation on multimodal streets that better take into consideration the behavior of specific types of operators. Direct outreach is needed to better understand the constraints and costs that drive operator decision making and the likely impact of these constraints on responses to proposed regulations and enforcement.

In conclusion, this paper demonstrates that CVs in NYC do face new challenges following expansion of the city's bicycle network. These challenges should be given explicit consideration in discussions about future street design changes. While only general impacts are presented, much future research is needed to better quantify both the costs to industry and the networkwide impacts on safety, congestion, and related emissions from further growth in truck–bicycle interactions.

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