University Transportation Research Center - Region 2

Final Report

An Examination of Commercial Vehicle Access to Residential Buildings in New York City

Performing Organization: City University of New York (CUNY)

June 2019

Sponsor:
University Transportation Research Center - Region 2

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The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

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16. Abstract

Recent growth in ecommerce has quickly impacted the distribution of parcel deliveries in urban areas, with residential deliveries accounting for a rapidly growing share of freight movement. Through field observation and development of a simulation model, this study aims to investigate the characteristics of parcel delivery activity in a heavily residential area of Manhattan, New York City, and to investigate the expected traffic impacts of double parking parcel delivery vehicles. Field observations revealed a number of unique characteristics of parcel deliveries and of individual carriers. Analysis of simulation results identifies two major conclusions: (1) different double parking location choice along the estimated corridor resulted in a corridor capacity drop of 6%-12%; (2) at moderate flow, the average parking duration was found to have a significant impact on vehicle delay along the corridor for some vehicles.

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1. Introduction

In the U.S., online retail sales have increased by about 15% annually since 2006 and the trend is only expected to continue (U.S. Department of Commerce 2016). In 2014, UPS, one of the three primary logistics providers serving the U.S. residential market, predicted that residential deliveries would reach 50 percent of its business within five years (Carey 2014). In the UK, a study showed that 12% of residential deliveries require multiple attempts. Although alternative parcel receiving strategies exist, customers still prefer delivery to home (Morganti, Dablanc, and Fortin 2014). These facts have led to a continually rising need for direct-to-home delivery. In addition to having broad implications for the organization of retail logistics (Jones Lang Lasalle 2013), this trend has changed the volume of freight parking and loading/unloading activity in front of residential buildings, where neither the street nor the building itself were designed with the expectation of frequent deliveries (Strauss-Wieder 2016).

Recognizing the growing demand for direct-to-home deliveries, many cities in the U.S. are trying to understand the new travel patterns to conduct these deliveries, and to identify what updates are needed to existing regulations. For instance, in many residential areas in New York, zoning requirements and curb regulations have not been updated to account for residential buildings as a freight trip generator (Chen, Conway, and Cheng 2017). However, few effective planning strategies have been identified due to a lack of reliable data at the block level. Primary reasons for the limited availability of data include a lack of historical mandates for measuring freight activity in local and regional planning, as well as privacy concerns from the freight industry (Zaleski 2017).

This study aims to examine parking patterns of home delivery vehicles while conducting deliveries and to evaluate the associated traffic impacts. This paper is structured as follows: Literature section provides a review of literature relevant to freight parking and micro-simulation. Data and methodology section discusses data collection, simulation model establishment and implementation, and the methodology for analysis of results; Field observation results and discussion section presents the results from field data observations; Simulation results and discussion section discusses the simulation results; and data limitations, conclusions, policy implications, and future research needs are provided in last two sections.

1. Literature Review

2.1 Freight Operational Patterns

Cherret et.al have identified four key patterns that need to be understood for freight planning; these include: 1) deliveries by time of day, day of week and time of year; 2) types of vehicles utilized to perform delivery and/or pick up; 3) freight vehicle delivery dwell time, and 4) unloading locations including off-street and on-street spaces (Cherrett et al. 2012). For commercial deliveries to businesses, many studies have examined these patterns and associated freight accessibility concerns in dense commercial areas. Studies in several cities found a similar truck arrival peak for business related deliveries; the time period from 6 AM to 12 PM is the most reported peak period (Allen et al. 2008) (Mckinnon and Leuchars 2003) (Jaller, Holguín-Veras, and Hodge 2013). The average truck parking duration (delivery dwell time) varies across studies, ranging from just a few minutes to more than one hour (Allen et al. 2008) (Browne et al. 2010)(Wang et al. 2013) (Figliozzi and Tipagornwong 2016) (Keegan and Gonzales 2016) (Khan and Machemehl 2017). A number of problematic commercial vehicle parking behaviors have been identified; these include cruising for parking space, illegal parking, and double parking. These behaviors are driven by a mismatch between delivery requirements (delivery frequency and duration) and the availability of parking and loading space. High freight demand in a short morning peak hours often leads to overcrowding in central business areas (Malik et al. 2017). In addition, poor dimensioned loading/unloading bays and road network characteristics - such as lane structure or street directionality - can also result in inefficient parking operations for delivery (Alho and de Abreu e Silva 2015).

Direct-to-home deliveries are different from traditional commercial goods movements. Previous research has shown that, unlike the commercial delivery market, the home delivery market has been dominated a small number of delivery and transport players (Rodrigue 2017)(Morganti, Dablanc, and Fortin 2014). Visser et.al noted that most home delivery services use a time frame from 9 AM to 7 PM without a clear peak hour (Visser, Nemoto, and Browne 2014). Studies from different sources have reported different mean dwell time for parcel distribution; these are usually relatively short durations. Researchers from the UK indicated means of 8 minutes and 9 minutes for parcel delivery dwell time from two different studies (Cherrett et al. 2012). Researchers in Spain noted that courier service times range from 1 minutes to 5 minutes, with most parking illegally in front of their destination, blocking the street entirely (Muñuzuri et al. 2012).

In summary, previous research has predominantly focused on understanding and addressing parking behavior for traditional commercial vehicle deliveries. A few studies, mostly from Europe, have discussed operational patterns of parcel distributors; however, observed parking characteristics have varied across cities. A research gap exists for understanding home delivery parking activities in US cites, and particularly in New York City (NYC). The first aim of this study is to characterize home delivery parking activities in a case study area of NYC.

2.2 Simulation Tools

To study commercial vehicle parking impacts and evaluate potential management strategies, a number of recent efforts have employed micro-simulation models. Muñuzuri et al. used a micro-simulation method to evaluate truck drivers' parking location choice (legal curb space, load/unload zone, double parking space, and sidewalk) (J. Muñuzuri, Racero, and Larrañeta 2002). Nourinejad et al. developed an integrated parking behavior-simulation model to evaluate the potential impact of parking policy (reserved freight parking streets) on urban freight in Toronto (Nourinejad et al. 2014). Alho et al. presented a quantitative method to evaluate loading/unloading bay systems in two relative large case study areas in Lisbon; their study evaluated different loading/unloading bay provision methods – including the number and size of spaced - with aim to reduce double-parking impacts in mobility (Alho et al. 2017).

Although not specifically focused on freight movement, Kladeftiras and Antoniou used simulation to estimate the traffic impacts from a double-parked vehicle. Their study used field observed data to determine illegal double-parking duration, with a mean 5 minutes and a standard deviation of 1.67 minutes (100 seconds) (Kladeftiras and Antoniou 2013). Chiabaut also developed a modeling framework to investigate the impacts of delivery activity on traffic flow; the author concluded that delivery trucks' double-parking behavior has a major impact on traffic conditions near maximum capacity, and that dedicated parking policies may be an effective way to improve both the efficiency of the transportation network and the logistics system (Chiabaut 2015). By incorporating field truck parking observation results, Keegan and Gonzales employed the AIMSUN simulation tool to examine the capacity and delay effects of freight delivery on a signalized urban block (Keegan and Gonzales 2016). Lopez et al. presented a framework, incorporated with freight generation demand estimation, to evaluate the impact of double-parked vehicles on an urban arterial (Lopez et al. 2016). The second aim of this study is to employ microsimulation to evaluate the traffic impacts from home delivery vehicle parking behavior within a small study area, and to investigate the potential impacts of different management strategies.

2. Data and Methodology

This study employed two main approaches:

(1) Field observation to characterize the behavior of home delivery vehicles conducting activities in the case study area;

(2) Micro-simulation modeling to evaluate 1) traffic flow impacts from home delivery vehicle double parking and 2) the influence of parking duration on expected delay. Simulation scenarios are developed in a micro-simulation model integrating findings from the field observation.

The study area is a primarily residential area in Manhattan’s Upper East Side (Figure 1). This area was identified as a problematic area for commercial vehicle parking in previous research (Chen, Conway, and Cheng 2017). The study area is dominated by buildings serving residential and mixed land uses, although some large commercial buildings are also located in the study area (NYC Department of City Planning 2016). Much of the “commercial” activity in the area includes religious institutions and community services. Residences on the cross-streets are primarily traditional brownstones containing multiple apartments. The majority of mixed-use lots include mid- to high-rise residential buildings with ground level retail.

Figure 1. Study Area

3.1 Field Observation

In this study, direct field observation was conducted to collect detailed data on multiple aspects of parking behavior. This method was selected to allow for observation of multiple variables (Browne et al. 2010). Field observations were conducted on Lexington Avenue on April 19th, 2016 and on East 79th Street on April 20th, 2016. Both observations were undertaken between 8:30 AM - 5 PM. For each parcel delivery vehicle that made a delivery attempt in the observed area, the arrival time, departure time, parking location choice, and operator type were recorded. Due to resource limitations, data was collected only for a single day on each roadway type; however, this data was compared with results from a related study to evaluate the consistency of patterns observed. This comparison is discussed in the Observation Results Discussion section.

3.2 Micro-Simulation Model Development

A microscopic model was developed in VISSIM 7.0. Traffic data collection was conducted on October 28th, 2015 to record volumes, turning movements, traffic compositions, and signal controller settings. Network configuration data, including links and connectors, were obtained from Google Earth (Google 2016). Bus volumes were determined using MTA bus schedules (NYC Metropolitan Transportation Authority 2016). Pedestrian crossing volumes were assumed to account for interactions between pedestrian and turning vehicles. The share of trucks attempting to park was adjusted to approximate arrival rates from observed data. The model was calibrated using morning data (10 AM to 11 AM), and validated using afternoon data (4 PM to 5 PM).

3.3 Parking Location Impact Analysis

Once the model was established, a procedure was developed to examine the impact of double parking in different locations on corridor capacity. Previous studies have shown that within a signalized block, a change in the distance between a double parking location and an downstream signal will change the impacts on road capacity and traffic delay. Lu and Viegas found that double parking along a block produces more delay when a double parked vehicle is parked at the exit of the block than when it is parked at the entrance to the block. Using one signalized road segment, Keegan and Gonzales (2016) and Gonzales and Christofa (2017) also discuss that that shorter the distance that a double parked vehicle is parked from a stop line, the greater the decrease in the saturation flow rate and the increase in average traffic delay.

Keeping all other variables constant, four double parking locations on the Lexington Ave. corridor were examined. In all, five cases were evaluated, including the base case (no double parking) and four sensitivity analysis cases (double parking in approximate preferred locations – see Figure 2). In each sensitivity case, one of the coded double parking locations was occupied. In the simulated network, all four locations were set to have a constant distance from the upcoming signal to control the potential capacity impact difference introduced by the length of the block. For each case, 10 runs were conducted with different random seeds. Each run took 6.5 hours including a half hour warm-up period.

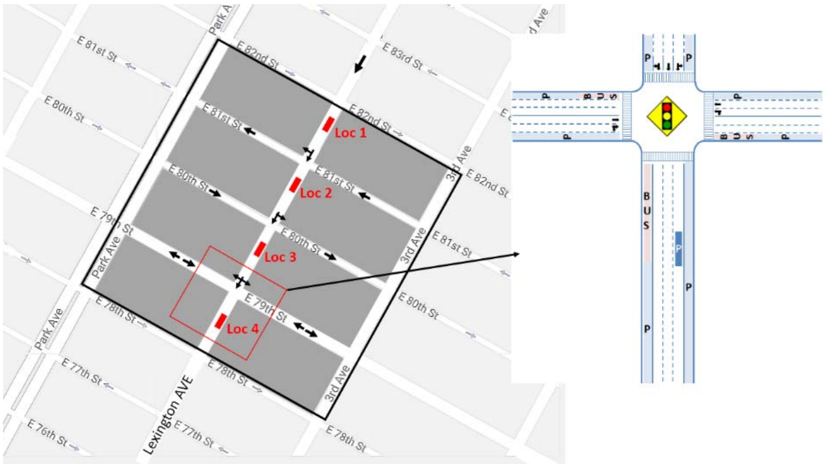

Figure 2. Scenario Parking Locations

Results from these runs were used to develop Macroscopic Fundamental Diagrams (MFD) for estimation of corridor capacities. MFD enables the analysis of the flow-density relationship in a network with interrupted flow (Geroliminis and Daganzo 2008). Effects of local capacity reductions on the urban arterial global performance can be detected by the MFD method (Chiabaut, Lopez, and Leclercq 2016). Therefore, MFD can be utilized for estimating the impacts of truck double parking on traffic flow dynamics. Different MFD shapes could result from different double parking choices (Kladeftiras and Antoniou 2013). As outputs of VISSIM, mean states of link flow and density were aggregated using a 10 minute time segment. The weighted average corridor flow and the corresponding weighted density were used to obtain the MFD figure by applying Edie's definitions (Eq. 1-3), which can be found in previous research (Leclercq, Chiabaut, and Trinquier 2014; Saberi and Mahmassani 2013).

$$l = \sum_{i}^{n} l_i \qquad \text{(Eq. 1)}$$

$$q^w = \left(\sum_{i}^{n} q_i l_i\right) / \left(\sum_{i}^{n} l_i\right) \qquad \text{(Eq. 2)}$$

$$k^w = \left(\sum_{i}^{n} k_i\, l_i\right) / \left(\sum_{i}^{n} l_i\right) \qquad \text{(Eq. 3)}$$

Where

i: Link i (i=1, 2, …, n, in A: the set of link segments in the VISSIM study corridor)

n: number of links

l_i: Length of link i

q^w: Weighted average corridor flow;

k^w: Weighted average corridor density.

In the MFD figure, the corridor capacity is estimated as the maximum flow (peak) of the MFD curve, or the maximum number of vehicles which can traverse the corridor as a unit during one hour. To get a complete MFD curve, gradually increased demand was loaded onto the simulated corridor. To test the maximum difference between no double parking and permanent double parking at one of the test locations, the vehicle that double parked was given a fixed parking duration of 6 hours.

3.4 Parking Duration Impact Analysis

In addition to parking location, parking duration is expected to affect the traffic impacts from a double parked vehicle. Based on field observation, two common types of operations were identified: (1) high arrival frequency with short parking duration (Operator1 and 2) and (2) low arrival frequency with long parking duration (Operator 3). To investigate the impact of parking duration on corridor delay, a scenario analysis was conducted to examine impacts on delay from variable parking durations if the total double parking duration is fixed. For the purpose of this analysis, Location 4 in Scenario 1 was selected for implementation. Seven different sensitivity analysis cases were conducted with average double parking durations of 10 minutes, 20 minutes, 30 minutes, 40 minutes, 60 minutes, 80 minutes and 120 minutes. In order to obtain total parking durations that were approximately the same, in addition to average double parking duration, the percentage of trucks intending to double park was adjusted.

Ten simulation runs were performed for each case; again, each run was 6.5 hours with a first half hour warm-up period. During the six-hour simulation process, double-parking activities in Location 4 were given flexible arrival times and uniform duration. The truck percentage of trucks intending to double park was adjusted to obtain four hours total parking duration at Location 4. It is worth to note here, due to the stochastic nature of the micro simulation, in the simulated runs, total parking duration cannot be exactly controlled at four hours. However, it can be controlled in an acceptable range. Statistical tests were performed to assure those the chosen runs did not have significantly different total parking durations. Traffic volumes in all cases were set at 800 vehicles per hour as this represents the moderate demand case during non-peak times of day (e.g. 11 AM to 3 PM). In a simulated urban corridor, Chiabaut et al. found that, in free-flow and very congested conditions, only small differences in delay resulted from changes in freight operations (Chiabaut, Lopez, and Leclercq 2016).

Individual vehicle delay records and double parking event durations were estimated from VISSIM output raw records (.fzp, .rsr). The distributions of delays experienced by individual vehicles were initially investigated by plotting the mean, median, 25th percentile, 75th percentile, and 95th percentile observed values for each case. Paired comparisons between sensitivity cases were then performed using a bootstrap hypothesis test. Bootstrapping can be used to compare the difference of statistical measures (e.g. mean, median) between two groups when the data is not normally distributed. The null hypothesis of each bootstrap hypothesis test was that measures from two compared cases were equal. Using two groups of data, random sampling with replacement was performed 1000 times, and a p-value calculated to determine significance.

3. Field Observation Results and Discussion

In total, 55 residential delivery vehicle parking events were observed in the study area. These delivery events included two major types of deliveries: parcel deliveries and grocery deliveries. All but one parcel delivery made during the study period were made by three major logistics operators; this result confirmed findings from previous studies that traditional major couriers dominate the parcel delivery market, while new players tackle market niches (Ducret 2014). However, it should be noted that this field observation was conducted before Amazon, the largest online retailer in the US, began operating their own logistics network, which now relies on local contractors rather than the major parcel companies. The online grocery retailer operated very differently from the major parcel companies. Unlike the majority of parcel deliveries, grocery delivery times are determined at the discretion of the customer within a two-hour window.

Forty-nine out of 55 observed vehicles were operated by the three major parcel carriers (Operators 1, 2, and 3), and five were operated by the large online grocery retailer (Operator 4). One vehicle was operated by a smaller parcel company (Operator 5).

4.1 Arrival Time

Unlike other types of commercial vehicles that have a clear morning arrival peak, both parcel deliveries and grocery deliveries occurred throughout the work day (as shown in Figure 3). Overall, home deliveries in the study area peaked in the early afternoon between 12 PM and 2 PM. Deliveries during other periods varied by carrier. On the commercial corridor (Lexington Avenue), parcel trucks arrivals peaked at around 1-2 PM. On the primarily residential street (79th Street), parcel truck arrivals peaked at around 10 AM.

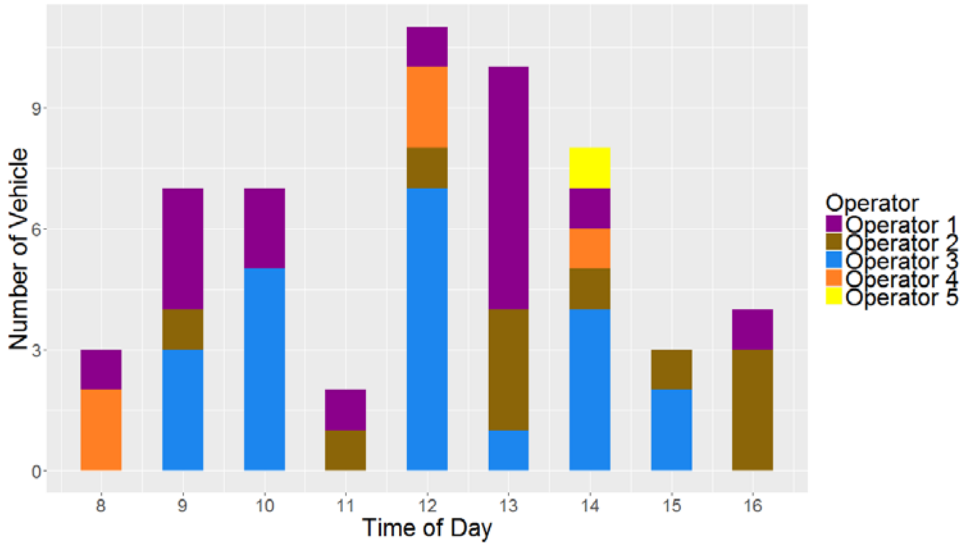

Figure 3. Vehicle Arrival Times

4.2 Parking Duration

The observed median parking duration for all home delivery vehicles was 8 minutes; however, the mean was 26.22 minutes, and the standard deviation 40.79 minutes. These results indicate that while many vehicles park for very short durations, some park for much longer. Figure 4 shows the parking durations of all vehicles.

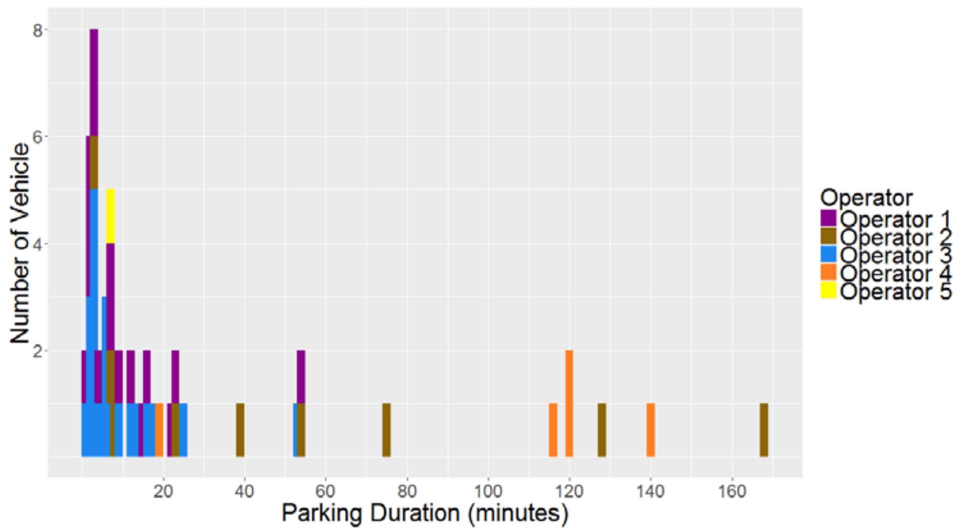

Figure 4. Vehicle Parking Durations

The majority of the parcel (not grocery) delivery vehicles (43 out of 50) parked for less than 25 minutes. Six parked for over 50 minutes, with the highest parking duration of 168 minutes. Five of these long parked vehicles arrived after 12 PM. Parking durations varied based on the number of parcels delivered and as a function of curbside logistics. Different behaviors were observed for each parcel operator.

- Operator 2 primarily operated with a single driver who made all deliveries from the vehicle; when this driver had to make more than two or three deliveries of 15 or more parcels per delivery, the truck parked for very long durations.
- On some occasions, Operator 1 followed the same model as Operator 2 with a single driver making all deliveries. Under this model, when a large number of packages needed to be delivered, a long time was required for sorting. However, Operator 1 also operated a second model for larger deliveries; a single driver would arrive and meet a team of local delivery persons, who would assist with offloading and sorting, and would make deliveries using hand carts. For this type of delivery, the parking duration was shorter.
- Operator 3 generally made short stops both to deliver parcels and to make mail pick-ups or drop-offs.
- Operator 4 (Grocery): By coordinating vehicle arrivals and departures, the company occupied a single curb parking space with multiple trucks for much of the day, with new trucks arriving approximately every two hours. Each truck would wait for the next to arrive before moving from the space. Several uniformed delivery persons remained in the area to make deliveries throughout the day via hand carts.

4.3 Parking Location Choice

Parcel delivery vehicles parked on Lexington Ave were primarily distributing parcels to addresses on 80th, 81st, and 82nd Streets. These are narrow, single-lane residential streets where double parking would result in total obstruction of the travel way. Some vehicles parked on Lexington Ave did also make deliveries to businesses on Lexington Avenue. As they were delivering to cross streets, the drivers preferred to park at the ends of the block to minimize their walking distance---75% of parcel vehicles on Lexington Avenue parked at the end of the block. Vehicles which delivered to 79th Street addresses always parked on 79th Street.

Fewer than 5% of the vehicles operated by the three major parcel operators parked at a legal curbside space; most (77.55%) double parked in the travel lane (Figure 5). It should be noted that double parking in a travel lane to make a delivery is legal in this part of Manhattan. A few Operator 3 vehicles parked at bus stops or in front of fire hydrants for short durations; this unique behavior can likely be attributed to differences in parking enforcement for each carrier. While Operator 1 and 2 pay reduced fines for parking violations as participants in a NYC Department of Finance discounting program, vehicles of Operator 3 are essentially immune from local parking enforcement (Stock 2014).

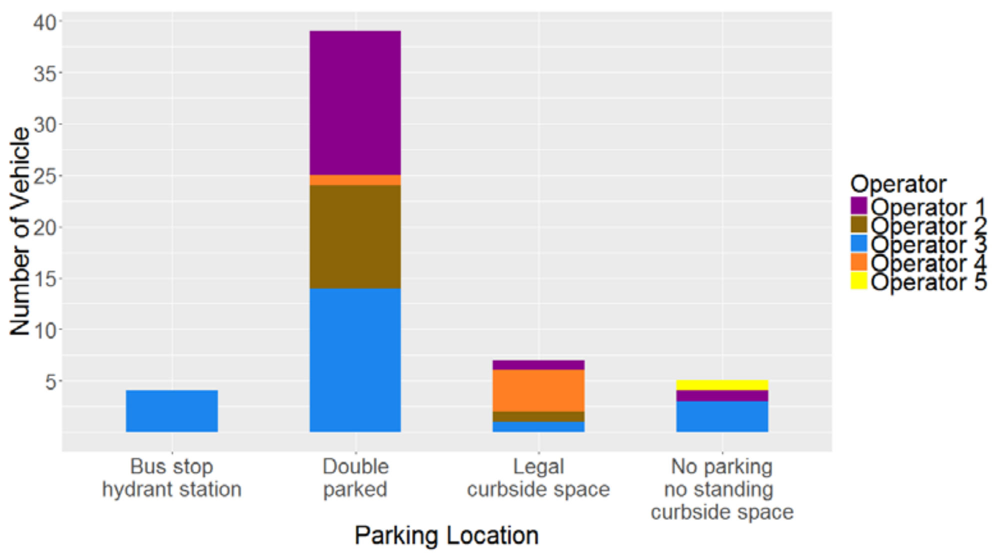

Figure 5. Vehicle Parking Location Choice

The curb regulations reflect a fact that a relatively small amount of dedicated truck parking space was available during the observed period. Curb regulations on Lexington

Avenue vary throughout the day; during the morning rush hour, no parking is permitted on the west side of Lexington Avenue, as the curbside is reserved for bus operations. From 7 AM to 10 AM, all parking on the east side of the street is designated for commercial loading; after 10 AM, both sides become one-hour metered parking. Parking on 79th Street and the other two side streets is unregulated except for twice-weekly street cleaning.

4.4 Observation Results Discussion

Given the very small sample size for the observed data, records were compared to a similar dataset collected for previous research (Conway et al. 2016). Time-of-day, parking duration, and parking location choice patterns identified in field observation were found to be consistent with this previous research. In summary, the observation revealed the following patterns: 1) the parcel vehicle arrival time distribution was different from traditional morning peak delivery time; 2) the majority of vehicles did not have legal curbside spaces available for parking, resulting in large amounts of double parking; 3) Vehicles typically parked at block ends along the major corridor for parcel delivery to side streets; and 4) the majority of deliveries are less than 25 minutes while some deliveries were longer than 1 hour.

It was also observed that different operators choose very different strategies to conduct the last 100 meters of delivery. The grocery delivery company occupied legal curb space for very long durations, using the truck as a mobile warehouse to complete final deliveries to a dense network of local customers Even after completing deliveries, truck were observed to wait for the same company's next vehicle to arrive before departing. While curbside parking is expected to generate a lower traffic impact on the adjacent travel lanes than the double parking observed for the other operators, this type of operation is not suitable for operators with a less dense customer base. This type of operation may also result in considerable over-consumption of curbside space if deliveries from the first truck are completed long before arrival of the second truck.

For the major parcel operators, double parking was very frequent. In order to reduce the total duration of double parking, either more dedicated space for commercial vehicle loading/unloading must be provided, or the duration of delivery events must be reduced.

4. Simulation Results and Discussion

The following section summarizes major findings from the scenario analyses.

5.1 Scenario 1 - Corridor Capacity Results

Capacity analysis relies on MFD figures to compare changes in corridor capacity resulting from double-parking in four different locations. Figure 6(a) is the estimated MFD curve for the base scenario, when no parcel trucks double park. The corridor capacity is estimated as 1080 vehicles/hour. Please note, this capacity is for mixed traffic, counting trucks and buses as a single vehicle rather than a passenger car equivalent. Figure 6(b) provides the MFDs for the corridor under four different cases: Location 1, Location 2, Location 3, and Location 4 respectively. The estimated capacities for the four locations were: Location 1:1010 vehicles/hour; Location 2: 960 vehicles/hour, Location 3: 950 vehicles/hour, and Location 4: 990 vehicles/hour. Compared to the capacity of the base case, the capacity drop of these four cases ranges from 6.48% to 12.03%. Among the four cases, Location 3 had the greatest and Location 2 had the second greatest capacity reduction. This result is unsurprising, as Location 2 and Location 3 both obstruct the left turn travel lanes as shown in Figure 2. Compared to Location 2, Location 3 has a greater impact on capacity as a higher percentage of the traffic on Lexington Avenue is making a left turning maneuver onto East 79 Street.

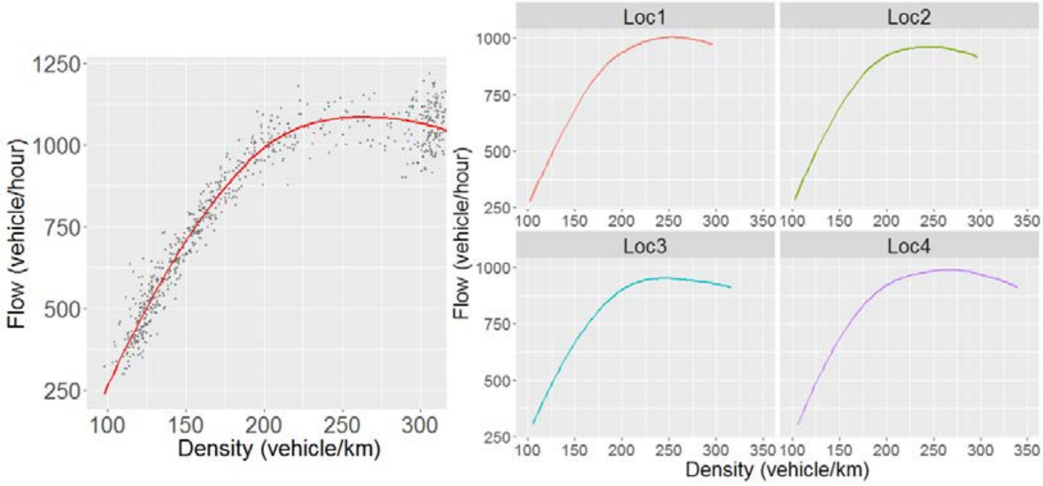

Figure 6. (a) Estimated MFDs with Case Loc0; (b) Estimated MFDs with Case Loc1, Loc2, Loc3, Loc4

Different MFD shapes are also observed for these four cases: after the peaks, MFD figures end at different densities in four cases. In Case Loc4, the MFD line drops until the density almost reaches 350 vehicles/hour, while in Case Loc1, the MFD line drops until a density of about 300 vehicles/hour. This is because after the corridor reaches its capacity, congestion occurs, resulting in a formation of a local queue. This queue exists upstream of the double parking delivery location. Downstream of the truck, traffic remains in un-congested flow conditions. Different queue lengths were detected in the four cases. For Location 4, which is located at the far end of the corridor, the queue can extend the full length of the Lexington Avenue study area; for the locations closer to the network entry point, only a truncated queue ending at the network extent is observed. As a result, only lower weighted densities are observed in congested conditions for these cases.

5.2 Scenario 2- Delay Scenario Results

Figure 7 describes the distributions of individual vehicle delays for each of the seven sensitivity analysis cases. Regardless of parking duration, there appears to be little change in the median and 25th percentile vehicle delays. However, for the mean, 75th percentile, and especially 95th percentile observations, there appears to be an upward slope, with total vehicle delay increasing as a function of average double parking duration. These results suggest that in these moderate traffic conditions, while many vehicles will not experience a noticeable change in total delay due to increased duration of double parking, a few vehicles will experience longer delays.

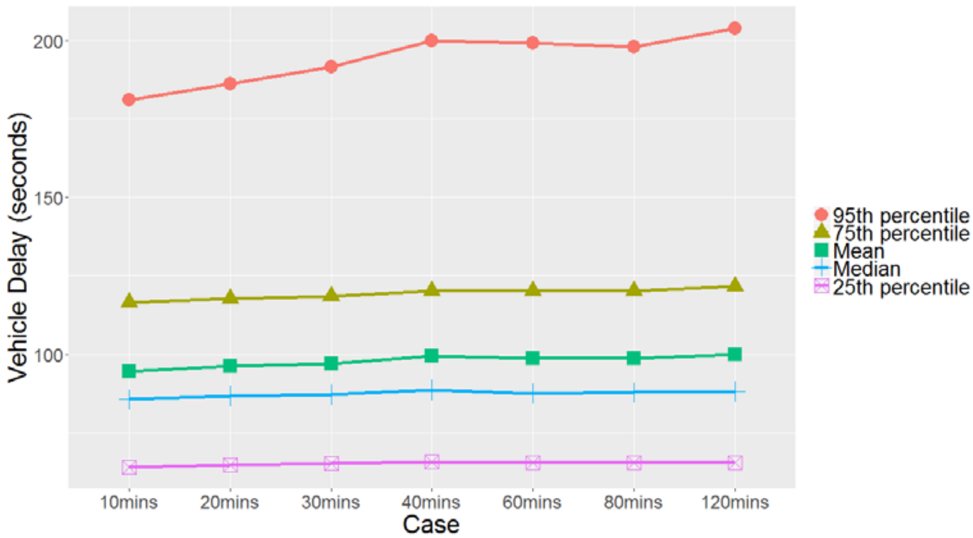

Figure 7. Vehicle Delay Statistics

To further investigate this relationship, p-values for bootstrapping paired median, mean, and 95th percentile tests are provided in Table 1. A significant difference in medians is only observed between very short (< 20 min) and very long (120 min) parking durations. However, a significant difference in means occurs for parking durations of 40 minutes and greater compared to parking durations of 30 minutes or less. Results for tests comparing 95th percentile observed values for each case produce similar results; parking durations of 40 minutes or more results in significant increases in delay compared to shorter parking durations. These results suggest that while many vehicles traveling in these moderately dense traffic conditions will not experience any significant change in delay, a small number of vehicles will experience significantly more delay, resulting in a significantly higher mean delay per traveler.

Table 1. P-value for paired bootstrapping hypothesis test

	Case 20mins	Case 30 mins	Case 40 mins	Case 60 mins	Case 80 mins	Case 120 mins
			Median			
Case 10 mins	0.468	0.256	0.192	0.169	0.104	**0.081**‘ ’
Case 20 mins		0.267	0.177	0.167	0.116	**0.054**‘ ’
Case 30 mins			0.255	0.371	0.26	0.161
Case 40 mins				0.86	0.776	0.65
Case 60 mins					0.378	0.235
Case 80 mins						0.329
			Mean			
Case 10 mins	0.525	0.211	**0.012** ‘.’	**0.013** ‘.’	**0.016**‘.’	**0.000 ‘***’**
Case 20 mins		0.198	**0.007**‘*’	**0.008** ‘*’	**0.005 ‘*’**	**0.000 ‘***’**
Case 30 mins			**0.043‘.’**	**0.050‘.’**	**0.060**‘ ’	**0.009‘*’**
Case 40 mins				0.734	0.736	0.38
Case 60 mins					0.484	0.167
Case 80 mins						0.148
			95th percentile			
Case 10 mins	0.748	0.254	**0.002‘*’**	**0.004‘*’**	**0.004‘*’**	**0.000 ‘***’**
Case 20 mins		0.102	**0.003 ‘*’**	**0.002‘*’**	**0.003‘*’**	**0.000 ‘***’**
Case 30 mins			**0.047‘.’**	**0.042‘.’**	**0.062**‘ ’	**0.001‘**’**
Case 40 mins				0.668	0.736	0.235
Case 60 mins					0.565	0.12
Case 80 mins						0.093

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

5. Data Limitations

The results obtained in this study are relevant to a very small study area. The number of vehicles and traffic characteristics observed in this study were limited by available time and labor resources. Although patterns of parcel delivery activities observed in this study were found to be consistent with results from a previous study, data were collected for only one day. A larger dataset collected over a larger scale area and longer time period is needed to provide more broadly representative results given the variability of delivery types and related parking behavior characteristics. More innovative data collection methods – such as video analytics and machine learning – are needed to collect detailed curbside behavioral data at a large scale.

Given the small network size, this study investigated the capacity and delay impacts only from isolated double parking events. Once data collection at a large scale is conducted, the traffic and emissions simulation models can be extended to investigate more complicated double parking events, such as simultaneous obstructions in multiple locations along a corridor.

6. Conclusions and Policy Implications

Major policy relevant conclusions from the field observation and micro-simulation analysis conducted in this case study area are:

- Deliveries to residential buildings occurred throughout the day, with the highest peak observed during afternoon hours;
- Carriers typically operated according to one of three models: (1) most parcel delivery vehicles parked for a short duration, making deliveries to a single location; (2) some parcel delivery vehicles parked for much longer durations, making deliveries from a parked vehicle to multiple destinations; (3) One grocery operator continuously occupied a legal curbside space, from which delivery personnel made multiple deliveries;
- Corridor capacity is reduced by truck double parking; impacts are greatest when double parking obstructs intersection turning movements; and
- Travel delays for some drivers will increase significantly when the average duration of individual double parking events increases, even if the total double parking remains constant.

As residential freight trips are expected to continue to rise in the future, improvements should be made to better manage street and curb space to accommodate this new demand. Continued reliance on current double parking behavior will result in increased negative traffic and environmental impacts. Results from this study suggest that a number of policy alternatives can be employed to reduce the impacts of truck double parking on traffic delay. First, in developing policies for shared space between freight and other modes in areas with mixed activity, planners should explicitly consider the temporal distribution of expected freight demand, recognizing that residential deliveries occur throughout the day. On Lexington Avenue, many commercial designated spaces that do exist are in effect only until 10 AM; later in the afternoon when residential delivery activity peaks, with no designated curbside space available, commercial vehicles frequently have to double park. Extending the timeframe for commercial dedicated spaces could help to accommodate commercial vehicles currently double parking later in the day. Potential reallocation of unrestricted parking on side streets (e.g. E. 80th St) to commercial dedicated space should also be considered to limit the demand for sparse commercial vehicle parking on higher volume, already crowded avenue corridors.

In addition to, or instead of, providing additional curbside space, roadway managers may also consider managing the locations where and the durations for which double-parking is legally allowed. Corridor capacity estimations based on the MFD method suggest that double parking should be limited or even eliminated in locations that restrict an intersection turning movement. Trucks frequently double park at corners where they can easily access a curb with a rolling cart. In areas where double parking at a corner can create a problematic condition, additional curb access such as a mid-block curb cut could help to enable mid-block double parking and alleviate some traffic impacts from corner parking. Field observation found that delivery vehicles operated by a single driver who is solely responsible for a large volume of deliveries will likely park for a long duration. Microsimulation results suggest that vehicles double parked for 40 or more minutes even in moderately dense travel conditions will significantly increase delay to some travelers compared to vehicles parked for a shorter duration. Together, these results suggest that limiting the duration of individual double parking events through enforcement could be effective to reduce traffic impacts. However, doing so may have broader supply chain implications for the operators currently employing this delivery model; for example, parcel delivery companies currently conducting deliveries from a centrally parked vehicle might need to move the vehicle between multiple parking spaces or to operate multiple vehicles to serve the same delivery area, with associated impacts on staff requirements, distances traveled, etc. The net traffic and environmental impacts of such a change require further investigation in future research.

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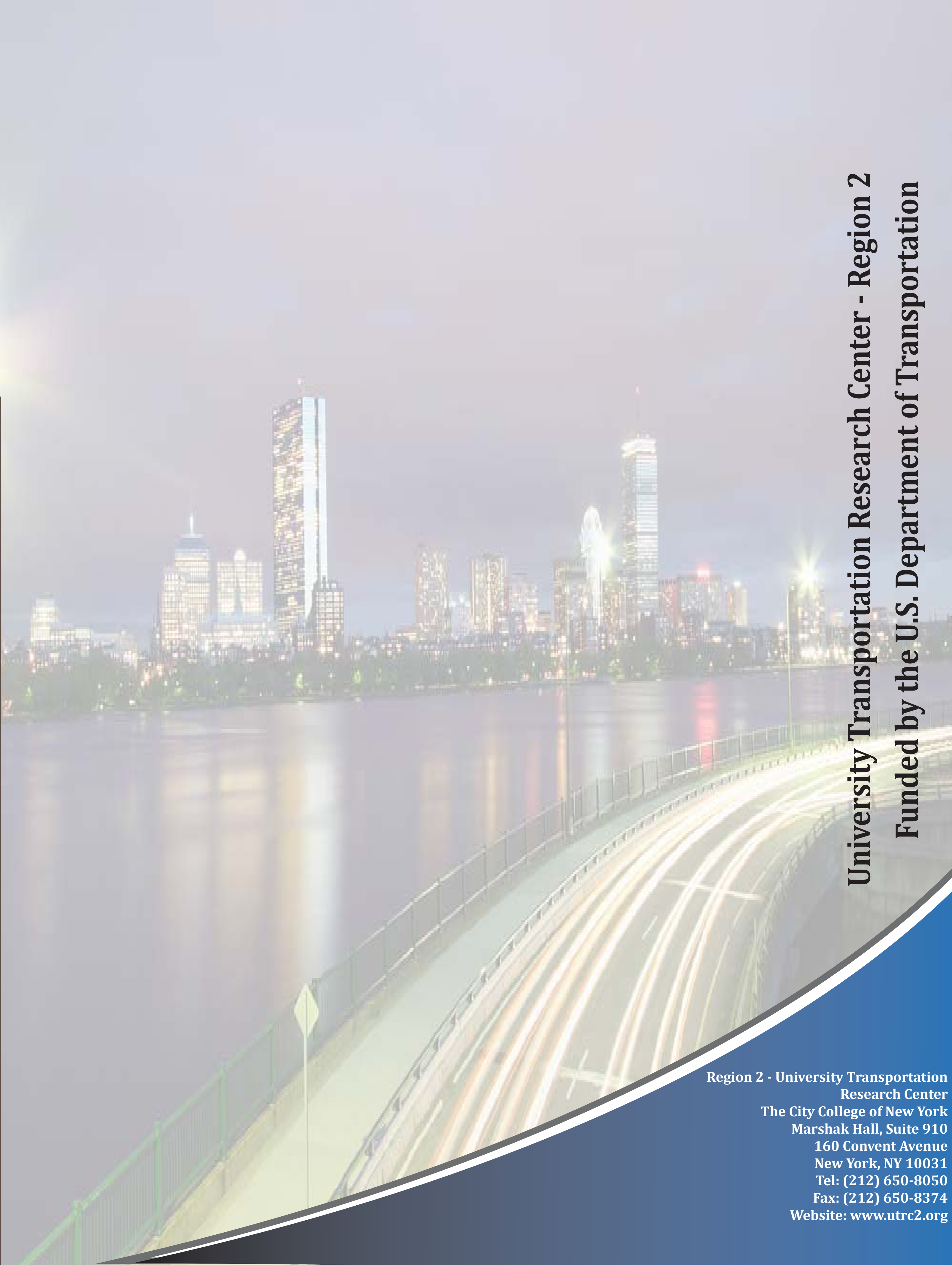

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