MODELING DOUBLE PARKING IMPACTS ON URBAN STREET

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Abstract

Double parking (DP) is one of the key contributors to traffic congestion on urban streets. Double parking violations of commercial vehicles while they load and unload at delivery locations with insufficient curbside space can have significant negative impact on traffic. Motivated by the need to study such impact in urban cities, this paper utilizes parking violation records for New York City along with field data collected using video recording, and adopts a comprehensive modeling approach that combines available data with two types of models. The first is an M/M/∞ queueing model used to estimate double parking effect on the average travel time. The second is a micro-simulation model developed and calibrated to study individual and combined effects of various explanatory variables. Both models account for different effects of general vehicles and commercial trucks. Via case studies in Midtown Manhattan and Downtown Brooklyn (New York, US), double parking activities and driver behaviors are investigated and used for comparative analysis. The M/M/∞ queueing model has been empirically validated using field data collected as part of this study. Comparison results show a good fit for uncongested traffic conditions. Micro-simulation results indicate different impact levels for 21 scenarios in four categories namely, travel demand, double parking locations, frequency, and durations. This study can provide traffic agencies a potential approach to quantify the impact of double parking in a large-scale network and insights into the management and alleviation of on-street parking problems including incentives for encouraging off-hour deliveries and more effective enforcement during peak hours.

INTRODUCTION

In urban areas, obstructions of traffic such as double parking, commercial vehicle deliveries, pedestrian jaywalking, taxi pick-ups and drop-offs, are potential impediments to road capacity and vehicular speed, and causes traffic delay and safety risks. New York City Department of Finance (NYCDOF) defines "double parking" as "standing or parking a vehicle on the roadway side of a vehicle already stopped, standing or parked at the curb" *(1)*. It is mainly due to the lack of available on-street parking spaces and sometimes makes the street impassable, especially in one-way single-lane situations. According to New York City Department of Transportation (NYCDOT) parking regulations, double parking of passenger vehicles is illegal at all times in New York City (NYC), regardless of location, purpose or duration *(2)*. In most cases, a double parked vehicle will block part of the street and a bus or a bicycle lane, if one is present. Double parking can become a serious problem especially in congested urban areas since it is both obstructive and irritating.

Most cities rely on fines when dealing with double parking *(3)*. In 2014, double parking violation had 502,082 ticketed cases and was ranked seventh among all the parking violations in New York City according to NYCDOF records. In reality, the total number of double parking violations is highly underestimated as most of such activities may not even be recorded or ticketed. Notably, it becomes more complex in mixed-used or commercial zones while double-parked commercial vehicle can lead to further reduction in capacity and increase in travel time (TT) and delay.

There are several other strategies to reduce double parking of commercial vehicles, especially during the peak hours. A recent study that focused on Off-Hour Delivery (OHD) strategies emphasizes the importance of promoting these strategies to reduce congestion caused by double parking delivery trucks. On the one hand, driving on an OHD route saves about $9,000/year/OHD-tour in parking fines since it is easier for truck drivers to find legal parking spaces near their delivery destination during the off-hours *(4)*. On the other hand, increased enforcement of parking fines for double parking during the regular hours could encourage more carriers to participate in OHD *(5)*.

One of the challenges in quantifying the effects of double parking is the lack of reliable analytical approaches dealing with this important problem. There's a need to identify a robust analytical methodology so that a large number of sites can be studied efficiently to quantify the impact of double parking as well as various long and short term parking enforcement and management strategies in a large urban network such as New York City. The use of a very detailed microscopic simulation tool for this purpose might not be feasible due to time and budget constraints.

As an alternative approach, a stochastic queuing model proposed in Gursoy-Baykal *et al. (6)* to estimate incident induced delays is adopted to estimate average delayed travel time, given the amount and duration of double parking activities. This kind of queuing model applicable to transportation systems, can be applied at the macroscopic level, consists of multiple road segments modeled as 'individual servers' that provide service to vehicles that join the queue. It has a set of simplifying assumptions about vehicle arrival distribution, service distribution, and number of servers to derive equations to predict the queue lengths and waiting times. It can be magnitude of order inexpensive and faster to develop and implement such models compared with microscopic simulation models. However, accuracy of such macroscopic models for various spatial-temporal characteristics of a highly complex urban transportation network has to be validated carefully. This paper describes such two models and discusses pros and cons of each approach along with suggestions for improving both models.

LITERATURE REVIEW

Various studies have been taken into consideration for on-street parking and traffic congestion. In 2009, Portilla *et al.* *(7)* extended a model developed by Baykal-Gürsoy *et al.* *(6)* to quantify the influence of parking maneuvers and badly parked cars on average link journey times. Baykal-Gürsoy *et al.*'s model *(6)* was a M/M/∞ queueing model subjects to random interruptions of exponentially distributed durations that was originally developed to simulate the effects incidents have on delays that she had proposed in a previous article *(8)*. It describes a queuing system where arrival and service processes of the vehicles are all Poisson processes with infinite number of servers. In Portilla *et al.'s* study, badly parked cars are introduced as time events while parking maneuvers are introduced as high-frequency short duration event. The results showed a 15%-199% increase in average journey time and a 6%-55% reduction in capacity. Guo *et al.* *(9)* evaluated influence factors of on-street parking by using a proportional hazard-based duration model. Narrow lanes, frequent turnover rates, and parking occupancy show a negative effect on travel time.

However, only a few studies focus on the occurrence of double parking. Recent efforts have primarily concentrated on the price strategies or applying microsimulation models to explore on-street parking impact on traffic. Millard-Ball *et al.* *(10)* evaluated the first two-year performance of SF*park* *(11)* – a demand-responsive rate adjustment parking system embarked by San Francisco Municipal Transportation Agency. Rate changes have helped achieve the city's occupancy goal (60%~80%) and reduced cruising by 50%. Another pilot called "PARK Smart" *(12)* was implemented in New York City by NYCDOT. Schaller *et al.* *(13)* summarized that pricing can be effective in achieving the goals of commercial loading availability, increasing turnover, and parking availability. Morillo and Campos *(14)* showed that the economic cost differs depending on the DP location and the type of typology.

Besides pricing strategies and economic impact, Kladeftiras and Antoniou *(15)* conducted a research project using microsimulation to estimate the impact of average speed, delay and stopped time, as well as environmental impact caused by double parking. An auxiliary lane is created in the model for one-lane roadways for the vehicles to overtake the double-parked vehicle. Results showed that by eliminating double-parking activities, it can increase 10% - 15% in average speed and reduce 15% and 20% in delay and stopped time. Researchers in Italy also studied illegal parking impact in a high-density urban area in Palermo, Italy *(16)*. Results showed that parking durations over 5 minutes would have significant negative impacts.

To sum up, most studies in the literature only provide insights into policy and economic aspects of double parking. Only a few micro-simulation models are used to simulate double parking impacts, but these are mainly outside the US and usually shown to be time-consuming and labor intensive for network-wide implementation. Therefore, there is a need to identify a more efficient macroscopic approach such as the queueing based model described in Gursoy-Baykal *et al.* *(6)* to study the impact of double parking activities. Moreover, such macroscopic methods have to be validated using real-world data and/or microscopic simulations. The feasibility of using microscopic simulation for modeling double parking under various street configurations has to be established since none of the major simulation tools has a default functionality for modeling double parking. This paper attempts to address both these needs by collecting and analyzing field data and validating a queueing based macroscopic model, as well as demonstrating a Paramics based microscopic simulation model extended through a special application program interface (API) developed by the research team to realistically modeling of double parking on urban streets.

DATA DESCRIPTION

NYCDOF's parking violation records in 2014 are summarized to investigate the frequency of double parking activities in NYC. As shown in the following table (TABLE 1), double parking ranked as the seventh highest parking violation in NYC, which represents 5.0% of the total NYCDOF's parking violation records in 2014. Since most of the double parking events are difficult to record, this number can be assumed to be significantly less than the real number of such violations.

TABLE 1 Top 10 NYC Parking Violations in 2014

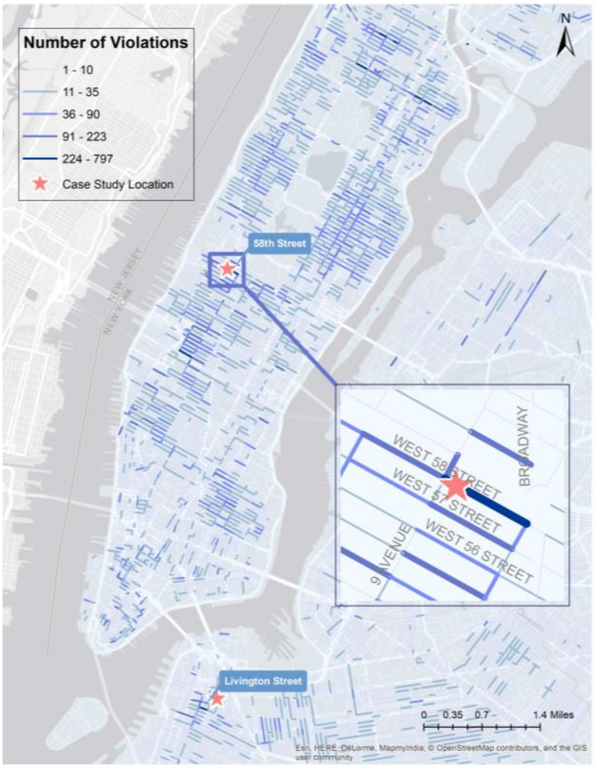
Rank	Violation Code	Tickets	Percentage	Violation Description
1	21	1,337,993	13.4%	Stand or park during street cleaning
2	38	1,302,810	13.1%	Muni meter: failing to show a receipt
3	14	884,828	8.9%	General no standing
4	37	745,096	7.5%	Muni Meter: excess of allowed time
5	20	584,334	5.9%	General no parking
6	71	556,677	5.6%	No Inspection Sticker
7	46	502,082	5.0%	Double parking
8	7	482,051	4.8%	Not stop at red light
9	40	479,191	4.8%	Stand or park beside a fire hydrant
10	36	457,141	4.6%	Exceeding speed limit in school zone

An automatic geocoding program is developed by the research team based on Google Geocoding API *(17)* to convert the original address information into geographic coordinates that can be employed to geolocate each event on a map.

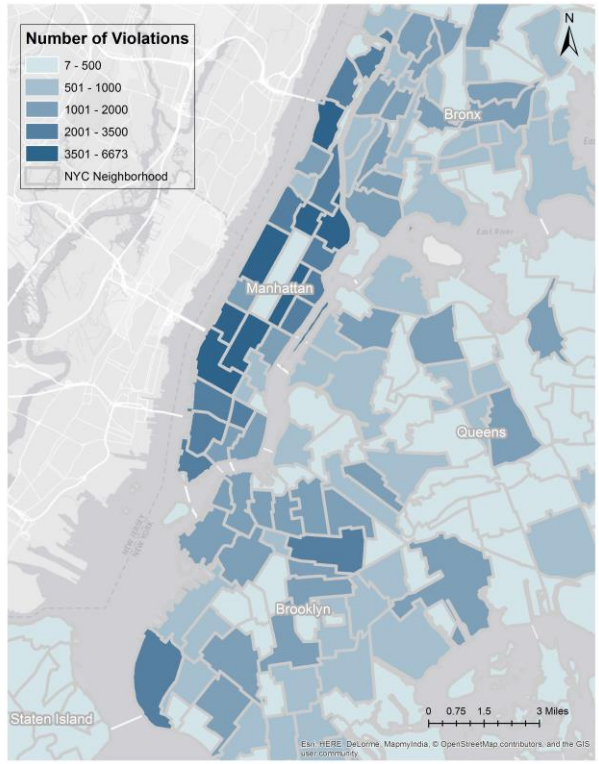
Violation records are also visualized onto streets and neighborhoods to identify DP "hotspots". The goal of the geocoding and visualization is to understand the spatial-temporal nature of double parking violations in New York City.

FIGURE 1 shows the results of four-month data from July to October in 2014. On the neighborhood level, the neighborhood of Upper East Side, Upper West Side, and Midtown Manhattan have the highest double parking violation records for all type of vehicles. The neighborhood of Upper East Side, Upper West Side, and Hudson Yards-Chelsea-Flatiron-Union Square ranked top three of double parking violation records for commercial vehicles. Double parking has more violation records in commercial districts or mixed commercial/residential districts, while commercial DP has less records compare to total DP in boroughs other than Manhattan that are mainly residential. It must also be noted that Police enforcement is a crucial factor to the number of summons for passenger cars. However, this may not necessarily reduce the occurrence of commercial vehicle double parking in large and highly congested urban areas such as NYC, since their loading and unloading activities are often along a short distance at multiple destinations with not many opportunities of legal parking during a given time frame.

On the street level, 58th Street and Livingston Street ranked the first in Manhattan and Brooklyn. The highest number is up to 797 total violations and 420 commercial violations on a single street block in July to October in 2014.

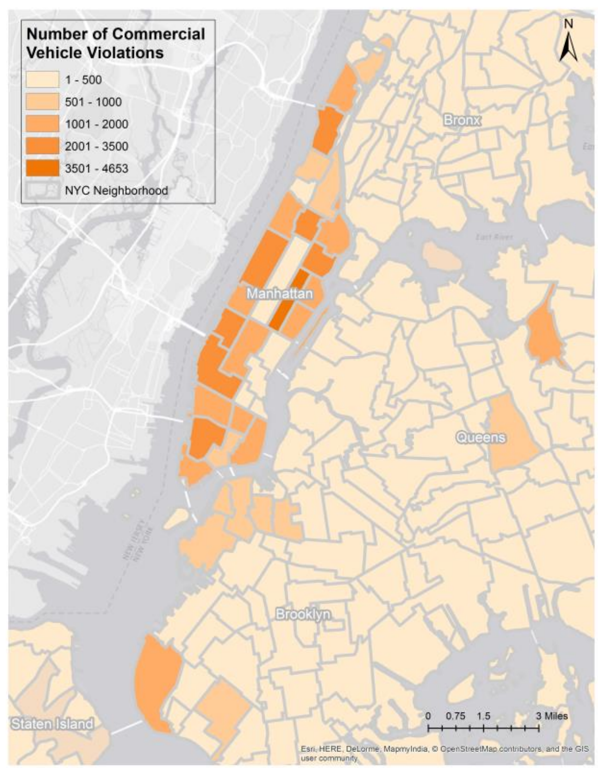


(a) Total DP by street



(b) Total DP by neighborhood

(c) Commercial DP by street



(d) Commercial DP by neighborhood

FIGURE 1 NYC double parking violation tickets, 2014 July to October.

Case Study Sites

After identifying the hotspots, two case study sites, where the occurrence of double parking is found to be significant from the above analysis, were chosen specifically (FIGURE 2).

1. Manhattan: 58th Street between 8th Avenue and 9th Avenue (highest number of records)
2. Brooklyn: Jay Street between Myrtle Avenue and Metrotech Center (observation of high DP occurrence)

FIGURE 2 Double parking activities in study sites.

Traffic movements were recorded in April, July and November in 2015 during AM (8-9AM), Midday (12-1PM), and PM (5-6PM) time periods for both sites to obtain traffic flow, speed, queue length, DP information, and driver behaviors. The following observations are found from the recorded videos:

- Double parked trucks have more impact than general cars (e.g. further reduction on the effective lane width).
- Manhattan site has a shorter duration of DP events compared to the Brooklyn site.
- The passing speed is generally higher than the default Paramics incident passing speed (10MPH) which indicates that double parked events should not be treated same as incidents.
- Speed reduction is subject to multiple factors such as the location of DP.
- For both sites, AM and Midday have noticeable number of DP events (20-30/hour), while PM has very few DP events (1-2/hour). The regular curbside parking is not fully occupied and the turnover rate is high during PM period.

Double parking information includes location, arrival time, departure time, vehicle type and duration. A sample count sheet is shown in TABLE 2. The location of the DP events is according to the nth ($n = 1, 2, 3 \ldots$) regular curb-parked vehicle measured from the upstream end of the link. So the "location" shown in TABLE 2 stands for the double parking location parallel to the regular curb parking. AM period is used for both study sites to better distinguish the delay caused by double parking from the delay caused by midblock jaywalking pedestrians, which occurs a lot during Midday.

TABLE 2 Sample DP Events

Site	Location	Arrival Time	Departure Time	Duration	Vehicle Type
Brooklyn	5	8:41:18	8:41:52	0:00:34	Car
Brooklyn	5	8:46:45	8:49:15	0:02:30	Car
Brooklyn	6	8:50:11	8:52:08	0:01:57	Truck
Brooklyn	2	8:51:15	8:51:55	0:00:40	Car
Brooklyn	5	8:52:52	8:56:53	0:04:01	Car
Brooklyn	2	8:57:09	9:04:17	0:07:08	Car
Manhattan	4	8:02:30	8:02:53	0:00:23	Taxi
Manhattan	1	8:04:40	8:06:16	0:01:36	Car
Manhattan	1	8:34:20	8:35:10	0:00:50	Truck
Manhattan	5	8:45:10	8:46:25	0:01:15	Car

Traffic information is collected and summarized for every 15 minutes (TABLE 3). One important observation for the Brooklyn site is that the traffic was experiencing severe downstream blocking during the last 15 minutes of the observed AM hour.

TABLE 3 Traffic Information for Case Studies

Location	Time	Volume	HV%	# DP	Status	Avg.TT(s)	Standard deviation(s)
Brooklyn	8:00-8:15 AM	66	12.1%	6	DP	5.52	1.19
					w/o DP	5.26	0.93
	8:15-8:30 AM	58	19.0%	3	DP	5.47	0.98
					w/o DP	5.07	0.91
	8:30-8:45 AM	59	18.6%	4	DP	6.01	1.83
					w/o DP	6.00	0.82
	8:45-9:00 AM	65	12.3%	8	DP	14.03	15.49
					w/o DP	4.61	0.02
Manhattan	8:00-8:15 AM	114	17.5%	8	DP	7.86	2.54
					w/o DP	6.74	1.43
	8:15-8:30 AM	108	13.0%	6	DP	8.09	1.27
					w/o DP	7.77	0.12
	8:30-8:45 AM	107	15.9%	6	DP	8.15	1.40
					w/o DP	6.93	0.98
	8:45-9:00 AM	127	29.9%	7	DP	8.57	0.63
					w/o DP	6.74	1.14

METHODOLOGY

M/M/∞ queueing model

A queueing model assumes that the space occupied by an vehicle on the roadway link represents one queueing "server", which starts its service once a vehicle joins the link and carries the "service" until the end of the link is reached *(18)*. The notation of queueing models is classified by arrival distribution, service distribution and the number of servers. A queueing model that has a Markovian arrival rate, a Markov modulated service rates, and an infinite number of servers in the system is called M/M/∞ queueing model. A Markov process defines discrete states and the transition probability from one state to another. One of the key features is that it solely depends on the current state. The M/M/∞ model is a stochastic process that has the following features:

- Arrivals process is a Poisson process at rate λ.
- Exponential service times with parameter μ. There are always sufficient servers in the system that every vehicle is served immediately after arriving.
- When a vehicle arrives or departs, the system moves to an adjacent state.

When double parking occurs, it indicates the high occupancy of the curbside parking lane. This is also observed in the video with a turnover rate of only one or two vehicles per hour for regular curbside parking. Thus, the regular curbside parking impact is negligible in this case study. Adopted from *(6, 7, 18)*, the system is designed with two server states "Failure (F)" or "Normal (N)" to represent the conditions with or without double parking events. Let r denote the rate of DP clearance time and f the frequency of DP events. The system will be in state (i, F) if there are i vehicles in the system that are interrupted by double-parked vehicles, while the system will be in state (i, N) if there are i vehicles in the system that are travelling without interruption. The depiction of the modified M/M/∞ queueing model on a two-lane link is shown in FIGURE 3. The servers in the systems will work at a low service rate μ' when a double parking event happens (FIGURE 4).

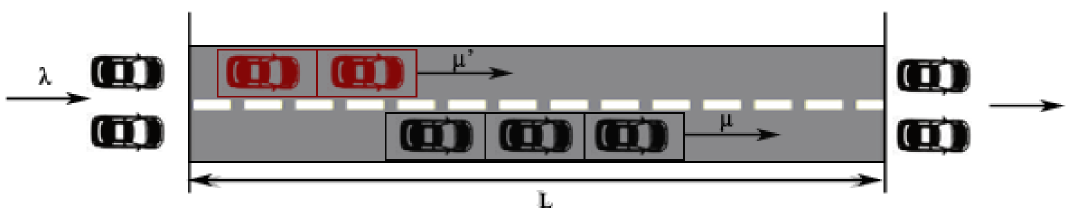


FIGURE 3 Modified M/M/∞ queueing model on a two-lane link (based on *(6)*).

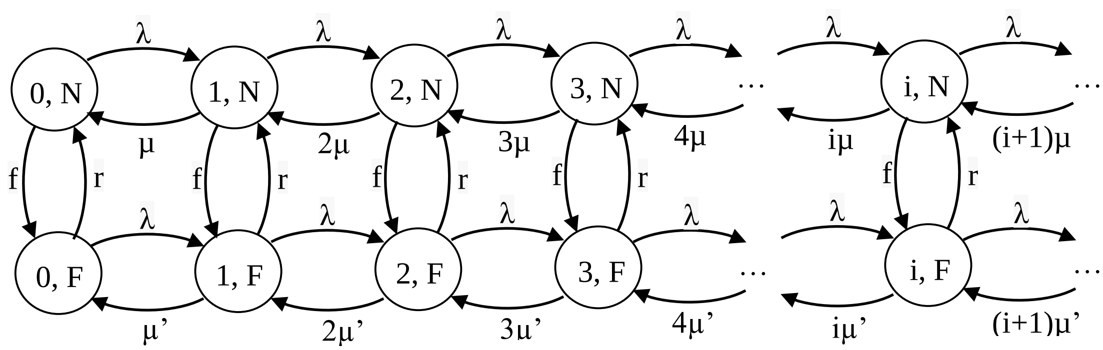


FIGURE 4 State transitions for M/M/∞ model with two server states (based on*(18)*).

One important result from Baykal-Gursoy and Xiao *(8)* showed that the expected number of vehicles on the link can be represented as below when the M/M/∞ queueing system is experiencing service interruptions:

$$\mathrm{E(X)} = \frac{\lambda}{\mu} + \frac{\lambda f(\mu - \mu')}{\mu^2 (r+f)}\left(1 + \frac{(f+\mu)(\mu-\mu')}{(r\mu + f\mu' + \mu\mu')}\right) \quad (1)$$

Average travel time on the link is:

$$W = \frac{E(X)}{\lambda} = \frac{1}{\mu} + \frac{f(\mu - \mu')}{\mu^2 (r+f)} (1 + \frac{(f+\mu)(\mu - \mu')}{(r\mu + f\mu' + \mu\mu')}) \tag{2}$$

To reflect road segment characteristics, Equation (2) is reformatted by Portilla *et al. (7)* to compute average travel time t:

$$t = \frac{L}{v}[1 + \frac{f(1-\frac{v'}{v})}{\frac{1}{d} + f}(1 + \frac{(f + \frac{v}{L})(v - v')}{(\frac{v}{d} + fv' + \frac{v - v'}{L})})] \tag{3}$$

Where *L=length of the link (mile); D=λ=traffic demand (veh/h); f=frequency of double parking (events/hour), d=1/r=average duration time of double parking (h); v=μL=average speed without double parking (mph); and v'= μ′L=average speed with double parking (mph).*

With the intention of accommodating commercial vehicle violations, a double parked commercial vehicle is treated as two double parking events in this study. Moreover, double parking impact can vary among different street segments due to traffic volume, number of lanes, gross leasable area (GLA) of commercial properties and so on. To capture these effects, equation (3) is modified by adjusting a correction factor C_f as follows:

$$t = C_f \frac{L}{v}[1 + \frac{f(1-\frac{v'}{v})}{\frac{1}{d} + f}(1 + \frac{(f + \frac{v}{L})(v - v')}{(\frac{v}{d} + fv' + \frac{v - v'}{L})})] \tag{4}$$

And,

$$C_f = \frac{1}{N}\sum_{i=1}^{N} \frac{\text{Real TT}}{\text{Model TT}} \tag{5}$$

Where *Real TT = field travel time (s), Model TT = queueing model travel time (s), N = number of observations.*

We propose a correction factor of C_f = 1.07 for Manhattan site and C_f =1.02 for Brooklyn site based on the observed data. However, since the observed data is limited, we are not capable of generalizing C_f for all possible influencing factors. This will be the focus of future study where automated data collection methods can be deployed.

Microsimulation Model

A Paramics *(19)* micro-simulation (FIGURE 5) is developed for the Brooklyn site to simulate complex conditions especially when downstream blocking happens. The model is bounded by Jay Street to the West, Flatbush Avenue Extension to the East, Tillary Street to the North, and Willoughby Street to the South. The particular interest of this study focuses on the road segment between Myrtle Avenue and Metrotech Center on Jay Street where DP data is available. It's a two-way segment has one 10-ft travel lane, one 4-ft bike lane and one 10-ft curbside parking lane in each direction and is referred as the reference link in this study.

Paramics is a high-performance software that model the movement and behavior of individual vehicles *(19)*. To simulate double parking activities, an "incident" file coded in C programming language is used to specify where, when and how long the "double parking event" should occur. Double parking is programmed as a special incident type that has the event duration, lane specification and overspills. The occurrence can be defined as either random or fixed on each link. In order to test the location impact of DP event, this case study uses fixed incident with defined distance and time.

Since the incident feature does not work well for single-lane situations while the vehicle behind the double-parked event will not move until the event is cleared, a narrow auxiliary lane is used along with a customized API plug-in to allow vehicles to overtake the DP vehicle. The API plug-in is developed to slow down vehicle on a certain distance of the road link to simulate driver behaviors when passing a DP vehicle. The location, length, and speed of the slow-down area can be customized. The micro-simulation model is calibrated based on field traffic counts, average link travel time and observed behaviors collected in April, 2015. It is also validated with Novemeber's data in the same year to demonstrate reasonable prediction capability. Validation results shows a GEH *(20)* of traffic volume less than 0.20 and a root mean square error (RMSE) of travel time less than 1.20 for all time intervals.

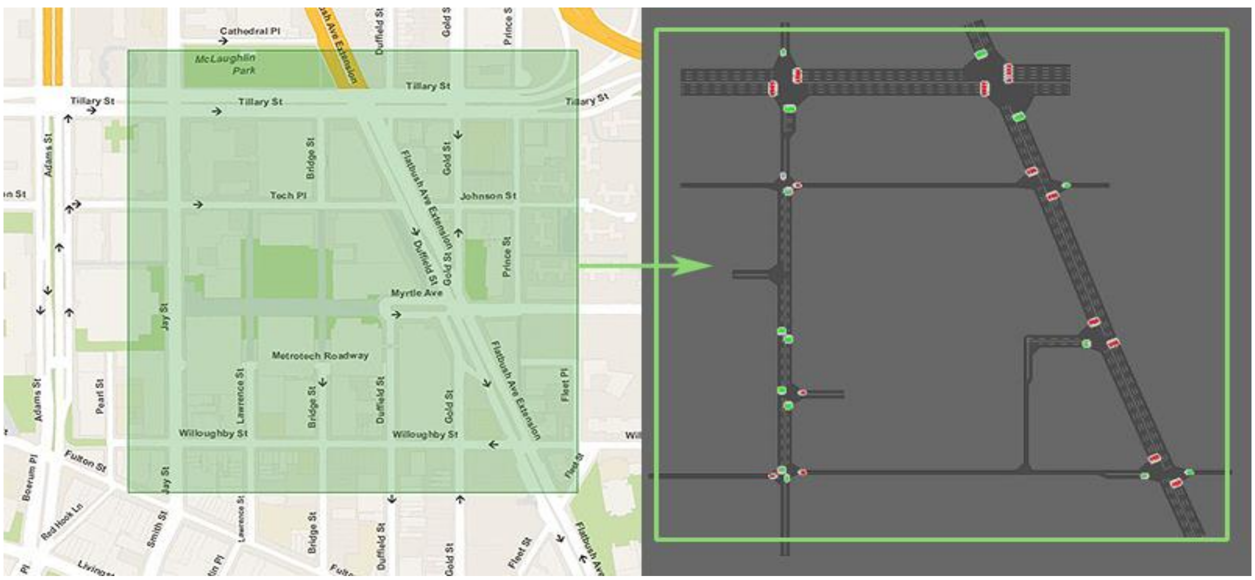


FIGURE 5 Case study area in Downtown Brooklyn and Paramics network.

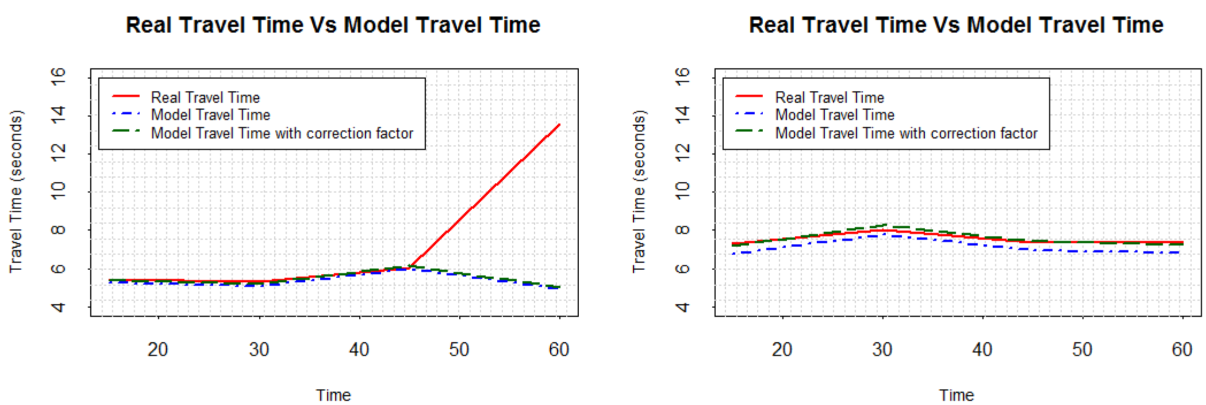
The Traffic Engineering Handbook *(21)*, along with other publications *(7, 22)*, have addressed the effect of curb parking, mainly caused by the lack of a curb lane plus the parking activity next to a moving traffic stream. To estimate the impact on the average travel time due to different factors under DP condition, 21 different scenarios were designed into four categories:

<u>Category 1: Location of Double Parking Events Scenarios</u>
Scenario 1-3: Double parking events happen at the beginning of the block, midblock, and the end of the block
<u>Category 2: Demand Scenarios</u>
Scenario 4-7: 110%, 120%, 130%, 140% of morning peak demand
<u>Category 3: Frequency of Double Parking Events Scenarios</u>
Scenario 8-11: Increase one, two, three, and four double parking event every 15 minutes
<u>Category 4: Duration of Double Parking Events Scenarios</u>
Scenario 12-21: Average duration of the events is increased by one minute in each scenario (e.g. Scenario 12 has one-minute average duration, Scenario 21 has 10-minute average duration).

RESULTS AND DISCUSSION

First, M/M/∞ queueing model is applied to estimate average travel time with a 15 minute time interval. FIGURE 6 and TABLE 4 provide a summary of the results. The result implies that the M/M/∞ queueing model has a percentage difference of less than 8% for both sites in terms of average travel times compared with the actual field travel times when no downstream queueing exists. While applying correction factors to the queueing model, the percentage difference is further reduced to less than 4%. In this study, the correction factor is tied to site-specific conditions. However, by introducing it, we intend to introduce the idea of a general factor that will help modelers to capture the impact of factors on traffic as a result of double parking. Many parameters such as traffic volume, number of lanes, GLA of commercial properties may have an effect on the correction factor. Further study and data collections are needed to define it as a general function in terms of all these different characteristics of city streets as part of ongoing efforts.

Average field travel time significantly increased due to the downstream blocking of the Brooklyn site in the last 15 minutes of the observed hour (FIGURE 6(a)). Under this circumstance, M/M/∞ queueing model is found to be incapable of capturing certain spillover conditions which resulted in the difference between the field data and the queueing model output. The reason for this, is that M/M/∞ queueing model assumes independence of different queues, as well as the independence of the arrival of double parking events, and does not account for spatial queue or queue capacity.



(a) Brooklyn Site (Congested) (b) Manhattan Site (Uncongested)

FIGURE 6 M/M/∞ queueing model results.

TABLE 4 Summary of Field, Queueing Model, and Microsimulation Result

Site	Time	Field TT	Model TT	Model TT with C_f	Microsimulation TT
Brooklyn	8:00-8:15 AM	5.41	5.27	5.39	5.54
	8:15-8:30 AM	5.30	5.08	5.20	5.83
	8:30-8:45 AM	6.01	6.00	6.14	6.21
	8:45-9:00 AM	13.60	4.95	5.07	12.91
Manhattan	8:00-8:15 AM	7.32	6.77	7.21	-
	8:15-8:30 AM	8.03	7.78	8.29	-
	8:30-8:45 AM	7.38	6.98	7.43	-
	8:45-9:00 AM	7.40	6.82	7.26	-

The micro-simulation model is then used to quantify complex characteristics of double parking events such as DP location. Travel time results are shown in the following heat maps (FIGURE 7) for the four scenarios described in the previous section.

The first category tested the impact due to different DP locations. DP events at the end of the block and midblock have similar mild effects on the average TT. Events occurring at the beginning of the block have a 5.15% higher impact in terms of the average TT increase over the AM peak hour. This matches the field observation that once a vehicle is double-parked near the beginning of the block (close to the upstream end of the road in the direction of traffic flow), drivers are more likely to slow down. DP vehicle under this condition usually reduces the effective lane width and causes potential conflicts with other activities at the intersection such as pedestrian crossing.

The second category of simulation scenarios examined the impact on the travel time of applying 110%, 120%, 130% and 140% of morning peak demand. Generally, higher demand resulted in higher travel time, as expected. The increase of the average travel time is 7.3%, 18.5% and 18.6% for 20%, 30% and 40% increase in the traffic demand, respectively, while 10% increase in demand does not cause a significant change in average travel time.

The third category of simulation scenarios accounted for the travel time effect if the frequency of DP event increased. The hourly average travel time increased by 3.1%, 13.6%, 20.5%, and 27.6% when there is an increase of DP event frequency by 1, 2, 3, and 4 vehicles per 15 minutes, respectively.

The fourth category of scenarios specifies various duration time for DP events from 1 minute to 10 minutes. As shown in FIGURE 7, the longer the event goes on, the greater the increase in the average travel time. Average travel time can be more than two times higher in the worst-case scenario where the average duration of DP event is 10 minutes.

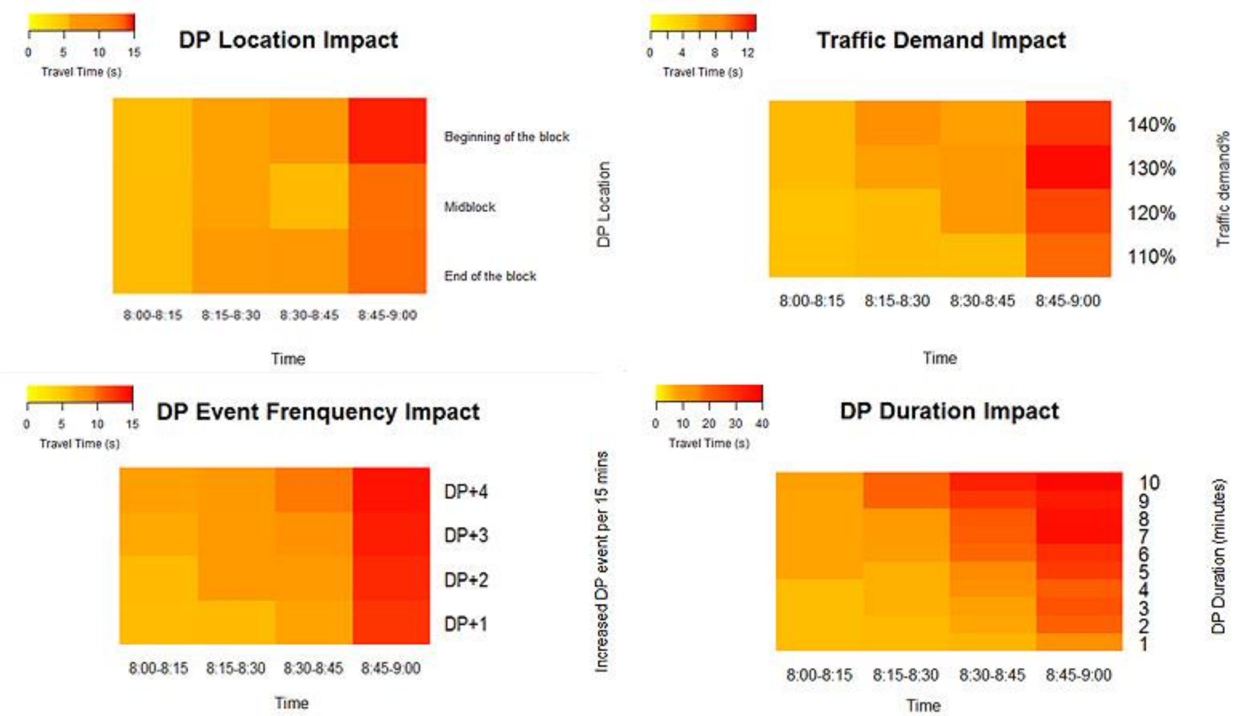


FIGURE 7 Microsimulation results.

CONCLUSIONS AND FUTURE WORK

This study examined a macroscopic M/M/∞ queueing model and micro-simulation for estimating average travel time in the presence of double parking activities. Under uncongested traffic conditions without downstream blocking, applying the M/M/∞ queueing model produced a good fit with the field data. The observations obtained from video recording were used to develop and calibrate a microsimulation model for one of the two case study areas namely, Downtown Brooklyn. Simulation output shows that the location, frequency, and duration of the double parking event and overall traffic demand have a certain impact on the average travel time.

Overall, M/M/∞ queueing model is an effective approach to compute average travel time for unsaturated traffic flows under double parking conditions. For a large urban network, it has the potential to be implemented instead of micro-simulation models mainly due to its computational efficiency, if it can be combined with an appropriate correction factor. Effect of commercial vehicles is also estimated in the model where one double-parked truck is assumed to account for two DP events. However, when downstream blocking happens, the traffic condition does not completely depend on what is hapenning on the current road segment. Micro-simulation is a more powerful tool than the M/M/∞ queueing model for evaluating such congested scenarios and can be used to examine individual and combined effects of various explanatory variables.

Future research will focus on collecting more field data using automated image processing techniques, investigating specific impacts of double-parked commercial vehicles, exploration of the accurate estimation of the correction factor function, correction factor for various spatio-temporal characteristics of the transportation network, and developing new APIs to improve the micro-simulation model for more challenging geometric and traffic conditions.

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