University Transportation Research Center - Region 2

# Final Report

## Quantitative Analysis of Residential Parking Intrusions by Passenger Vehicles in New York City



Performing Organization: New York University (NYU)

May 2017

Sponsor:
University Transportation Research Center - Region 2

## University Transportation Research Center - Region 2

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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ABSTRACT

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# Quantitative Analysis of Residential Parking Intrusions by Passenger Vehicles in New York City

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## 1 Introduction

Parking intrusion refers to the spillover impacts when non-residents park on neighborhood streets free of charge in order to access nearby attractive opportunities (e.g., stadiums, schools, supermarkets, or train stations). It becomes a contentious political issue when a large number of intruders compete with local residents for limited free street parking. Opponents believe that such intrusion should be prohibited for two reasons. One is a possible violation of property right. Residents believe that they should have the priority over non-residents for the public street parking in front of their home. The other is the generation of negative externalities for the public. Parking intrusion encourages driving to areas with convenient transit services and worst traffic congestion (Marsden, 2006), causing further congestion and extra Greenhouse Gas emissions. Without guaranteed supply of parking, the excessive parking cruise for a free on-street parking space in the neighborhood often endangers local pedestrians, cyclists and children as parkers do not always focus on driving (AASHTO, 2011).

Some disagree. They often defy the "privilege" of residents over public streets, regardless of the location. If people pay for public streets, they should all have the equal access for parking regardless of their home location. Some also support parking intrusion on the ground of economic development—intruders might be visitors who bring jobs and money to the local neighborhoods. Without free parking, those people may not be able to come, particularly for those from areas without convenient public transit.

Among opponents, people also disagree with each other regarding the solution to parking intrusion. Local residents often prefer a Residential Parking Permit (RPP) program that prohibits non-residents from parking on neighborhood streets. Almost all major cities in the United States adopt RPP programs in certain areas. However, RPP programs are quite complex to design, particularly in old, dense urban areas with stiff competition for street parking. Local governments normally approve RPP programs if they meet three criteria: the petition from a high percentage of local residents (e.g., 65% as in Chicago), a high occupancy rate of street parking (e.g., 85% as in Chicago), and a high share of intruders among parked cars (e.g., 45% as in Chicago). The last two rates may vary significantly by time and block, so it is always tricky to set up these criteria such as the size of a RPP zone. It is also quite time consuming to verify them through field surveys.

Alternatively, some government officials argue that meter reform on commercial streets might be a better solution to parking intrusion to nearby residential neighborhoods. If meter price is set to reflect its market value, parkers will not over-consume these spaces, and parking should be easier to find on commercial streets, albeit at a higher price. In that case, drivers might be less likely to park in nearby neighborhoods. However, the twist of that argument is that the higher meter price may push more drivers to search for free parking in nearby neighborhoods. The net outcome may depend on the specific location.

Although the above arguments are all reasonable in certain ways, they remain largely conceptual without solid empirical evidences. Which neighborhoods in New York City are experiencing the most intrusions? What are their spatial patterns and possible reasons? How can we tackle or do we need to address these intrusions? It is safe to say that policy makers and transportation professionals still know little about the intrusion patterns, its reasons, consequences, and effective solutions. The scope of this research is the intrusion of on-street parking by passenger vehicles in residential neighborhoods in a dense urban setting. The research is to improve our understanding of parking intrusion in New York City, focusing specifically on the spatial patterns of intrusion density, exploration of its determinants, the calculation and spatial patterns of induced excessive vehicle miles traveled (VMT), and possible policy recommendations.

## 2 Literature Review

The present knowledge on parking intrusion is scarce. Even RPP programs are not well documented in the transportation literature. Some of our previous studies did not fully focus on parking intrusion but might provide some findings. One indicated that parking intrusion could result from the provision of free and abundant on-street parking in residential neighborhoods (Guo, 2013c). The other study concluded that the launch of a RPP program that charges residential on-street parking to reflect residents' willingness to pay while ensuring the local benefits from the program revenues could potentially mitigate many current parking problems, including the parking intrusion (Guo and McDonnell, 2013). However, though an RPP program may reduce both residential parking intrusion and parking cruise, our earlier study on home parking convenience suggested that an RPP program may increase the parking certainty for local residents and therefore encourage car usage (Guo, 2013b) and neutralize the positive effect of the program on dealing with parking intrusions.

Other important information sources are actually newspapers, online forums or blogs, and government documents. Nevertheless, most of these sources describe attitudes, preferences, or perceptions from various stakeholders around a controversial policy or project instead of solid empirical evidences. It seems that the discussion or debate is based more on fantasies and fears instead of facts. The most comprehensive studies on parking intrusion were conducted by New York City Department of Transportation (NYC DOT) for the new Yankee Stadium in Bronx (NYC DOT, 2012) and the Barclay Center in Brooklyn (NYC DOT, 2013).

In the Yankee Stadium study area, DOT first surveyed in August 2011 the street parking occupancy at the same time on game and non-game days to check if occupancy increased significantly on game days. They found an average small increase of 7.5 percentage point. Second, DOT surveyed plate numbers of cars parked overnight in the study area, assuming they are from local residents. They then matched the plate numbers with the DMV database and found that 45% of vehicles parked overnight were registered outside the study area. Third, they did the same plate matching for vehicles parked at game times on both game and non-game days, and calculated the share of "intruded vehicles" using 45% as an adjustment factor. The result showed that game goers accounted about 17% of parked vehicles in the study area. DOT concluded that the new Yankee Stadium did not cause severe parking intrusion to the neighboring area. DOT conducted a similar study for the Barclay Center in April 2013 after it opened in September 2012. The study also found an average 17 percentage point increase of parking occupancy on game days, but the share of non-resident vehicles remained the same between game and non-game days (which actually contradicts to the 17 percentage point increase).

The two studies offer the most detailed, empirical evidence on parking intrusion in New York City. They both recommend a better management of metered parking space (e.g., higher price or extended hours) not RPP as the solution. However, their method has two potential flaws: the plate-matching method and the sampling method. First, both studies do not explain why a significantly high portion of vehicles parked overnight (45%) is registered outside the study area. Are they local residents or intruders? This portion may capture residents who moved to the neighborhood but have not updated their vehicle registration. Second, the Barclay Center study monitored street parking over a consecutive eight days (April 6 to 13, 2013) while the game days and non-game days compared are not the same day of week. Game days are Saturday and Tuesday while the non-game days are Monday, Wednesday and Friday that often possess different travel patterns. Both study only sampled parking at one time spot (e.g., 1pm, 4pm, 5pm, and 7pm in the Yankee Stadium study) or a narrow time window (7-8pm in the Barclay Center study) for selected street segments. This leads to the critique on the representativeness of the results.

The two DOT studies are limited in answering some of the fundamental questions on parking intrusion: where are they concentrated? What are the key determinants of parking intrusion that could help policy makers understand and manage such behavior? How much is the excessive driving (avoidable VMT) associated with parking intrusion? This research aims to overcome the methodological flaws of the DOT studies and answer these questions utilizing a new type of data source—parking violations/tickets.

## 3 Parking Intrusions in New York City

New York City (NYC) has the worst residential parking intrusion problem in the United States because of fierce competition for street parking spaces, counter-productive parking pricing, lack of RPP programs, and the alternate-side parking (ASP) regulation.

The competition for street parking in NYC neighborhoods is stiff and brutal. About 4 million New Yorkers (47%) do not have off-street parking spaces on their property and residential streets are their only options (Guo, 2013a). As journalist Calvin Trillin put it: "You can park your car on the streets of New York, or you can have a full time job, but you can't possibly do both." (Guo and Schloeter, 2013).

It is counter-productive to assign so much City's public space to automobiles without having vehicle owners to pay for it. In the high-density City of New York, commercial metered parking only occupies approximately 2% of the street-parking stock while residential parking accounts for most of the rest (Guo and McDonnell, 2013). Nevertheless, the residential street parking in NYC residential neighborhoods is provided free of charge. Our earlier research (Guo, 2013c) demonstrated significant behavioral consequences of providing free and sufficient on-street parking spaces in residential neighborhoods: they increase private car ownership by approximately 9%, which means that the provision of free street parking explains 1 out of 11 cars owned by households. The higher car ownership and consequent greater car usage could potentially increase parking intrusions in other neighborhoods.

However, New York City does not have a RPP program, the only exception of major cities in the U.S., so anyone from anywhere is able to legally park on any City streets. The efforts so far to implement a RPP program in New York have also failed. When the Bloomberg administration proposed the congestion pricing scheme in 2007, many neighborhoods right outside the pricing zone worried about parking intrusion. The scheme eventually included a RPP program in those areas to ease the concern (Neuman, 2008). In the Atlantic Yards development in Brooklyn, one of the most controversial issues is the basketball stadium (now Barclay Center for Brooklyn Nets) with 18,000 seats but only 1,100 parking spaces. Parking intrusion was at the center of the political battle, "blurring political allegiances and pitting former allies against each other" (Witt, 2011). The surrounding neighborhoods proposed an RPP program but it was rejected by the NYC DOT on the ground of lack of severe intrusion by game goers, even DOT found severe parking intrusion by non-game goers on non-game days (NYC DOT, 2012). The debate climbed to a new high level in 2011, when the City Council, pressured by so many neighborhoods, passed a bill (40: 8) to allow RPP programs in qualified neighborhoods. However, RPP is the State authority and the State Assembly refused to give the permission to New York City. In 2013, over half of survey respondents (52.5%) said they would be willing to pay for an average $408 per year for an on-street parking permit if the city offered them, even though the revenue would not necessarily benefit the neighborhoods (Zhan and McDonnell, 2013). The battle over parking intrusion and RPP programs will continue in the foreseeable future, and reshape major policy and investment decisions in New York City.

The NYC ASP regulation for street cleaning has considerable influences on the residential on-street parking as well. The on-street parking, compared to off-street parking, is more subject to a variety of parking regulations. Those no parking, no standing, limited parking, metered parking regulations and bus stops exert larger impacts on parking in commercial areas or commercial overlays of residential areas. The ASP regulation, in contrast, significantly affects the residential areas at large—our main study area of parking intrusions. In New York City, over 70% of city streets are cleaned two or more days per week, and 40% are cleaned at least four days per week. According to our study in 2012, street cleaning and ASP regulation force residents without off-street parking spaces to use their vehicles when they otherwise would not due to the fear of losing their parking space (Guo and Xu, 2012). An increasing car usage and decreasing supply of parking spaces will further the competition for street parking spaces including the free ones in residential areas and thus potentially exacerbate the parking intrusion problem.

Not surprisingly, parking intrusion has become one of the most difficult and politically explosive issues in many NYC residential neighborhoods. The design of an efficient, effective, and equitable parking policy in New York City would be incomplete if parking intrusions are not properly addressed.

## 4 Data and Method

### 4.1 Data Sources

The major datasets used for analysis are the March 2010 NYC Parking Violations Issued from New York City Department of Finance and driver registration demographic data from New York State Department of Motor Vehicles (NYS DMV). We select parking violation data in March 2010 because it is a time when traveling and parking patterns are comparatively normal, with the least variations introduced by seasonal changes or big-event peaks.

The driver registration demographic data was acquired through a FOIL request in July 2012. The vehicle-registered zip code was up-to-date because NYS DMV requires New York State residents to report a change of residence address on registration within 10 days (NYS DMV, 2016b) and people who recently moved to New York State to register within 30 days (NYS DMV, 2016d). The time gap between parking ticket data and driver registration data may have some but limited impact on the accuracy of intrusion determination. For out-of-state vehicles that received a ticket in March 2010 but had not yet registered then, the driver registration data acquired two years later would be very likely to include the correct registered zip code. There might be some number of vehicle owners who moved within New York State between March 2010 and July 2012, which might influence the accuracy of intrusion determination. However, the moving might cause both the inaccurate determination of real intrusions in March 2010 as non-intrusions and real non-intrusions as intrusions, the two un-captured scenarios would neutralize each other. Since the registration of vehicles in New York State is typically updated every two years, a further data check was performed on the subgroup of passenger vehicles in the July 2012 registration data that still have registration year of 2010. The result shows very similar patterns of hot spot clusters (see Fig. 6 in Appendix) and origin-destination lines (see Fig. 9 in Appendix), and exactly the same signs with similar significance level for each regression coefficient (see Fig. 7 and Fig. 8 in Appendix). Other scenarios like registration of a leased car (NYS DMV, 2016c) or transfer of car ownership (NYS DMV, 2016a) would not contribute to additional inaccuracy because the vehicle plate and the registration are not permitted being transferred between vehicle owners. Without a change in registered residence address between March 2010 and July 2012, the plate and its registration information remain accurate in intrusion determination.

Different NYC administrative and political boundaries, zoning district data, street lines, and geocoding package are acquired from NYC Department of City Planning[1] (NYC DCP). The NYC neighborhood boundaries from NYCPedia are applied to descripting the locations of spatial patterns in later analyses. This study also employs census data[2] from United States Census Bureau, NYC zip code boundaries, subway stations, and municipal parking facilities from NYC Open Data, and commuter railroad station data[3] from the Newman Library of Baruch College, CUNY.

### 4.2 Methodologies

| Step | Filtering Standard | Pre-step tickets # | Post-step tickets # | % |
|---|---|---|---|---|
| Geocoding of parking violations/tickets using Geosupport Desktop Edition (16B) | Tickets that are successfully geocoded | 872,370 | 708,445 | 81.21% |
| Joining parking violations/tickets with driver registration demographic data of requested plates (with a size of 293,714 records) | Tickets that are successfully joined | 708,445 | 427,285 | 60.31% |
| Determination of potential intrusion | Tickets issued at a zip code different from the zip code the vehicle was registered | 427,285 | 361,246 | 84.54% |

[1] The datasets or tools used are NYC Zoning Districts (nyzd), MapPLUTO 11v2, Selected Facilities and Program Sites (Facilities_2015_shp), Borough Boundaries (Clipped to Shoreline) (nybb_16b), Census tracts 2010 (Clipped to Shoreline) (nyct2010_16a), NYC Commercial Overlay District (nyco), LION Single Line Street Base Map (16a), and Geosupport Desktop Edition (16B).
[2] The datasets used are total Population (ACS_10_5YR_B01003), Household Size by Vehicles Available (ACS_10_5YR_B08201), Median Year Structure Built (ACS_10_5YR_B25035), and Means of Transportation to Work (ACS_10_5YR_B08301).
[3] The datasets used are LIRR Stops (stops_lirr_nov2015) and Metro-North Stops (stops_metro_north_nov2015).

| | | | | |
|---|---|---|---|---|
| | Tickets issued in select residential areas (excluding commercial overlays) | 361,246 | 119,092 | 32.97% |
| Further screening of potential intrusion | Tickets that are spatially intersected by tickets with meter-related reason | 119,092 | 94,427 | 79.29% |
| Screening of plate type | Tickets that has "PAS" plate type (in "Type" column) | 94,427 | 60,541 | 64.11% |
| Screening of zip code that vehicles were registered | Tickets that are successfully joined with New York State zip codes | 60,541 | 59,235 | 97.84% |
| | Tickets that are successfully joined with New York City zip codes | 59,235 | 40,695 | 68.70% |
| | Registration Year in 2010 | 60541 | 17697 | |

### *4.2.1 Geocoding of parking tickets*

Parking tickets were geocoded using NYC DCP's Geosupport Desktop Edition[4] based on house number, street name, and county fields. Geosupport Desktop Edition is a highly customized geocoding package that support geographic processing needs for New York City. For each address of a ticket, the geocoding generated new fields including its X and Y coordinates, Neighborhood Tabulation Areas, zip code, and 2010 census tract. Out of 872,370 parking tickets, 708,445 (81.21%) were successfully geocoded.

### *4.2.2 Join of parking tickets and driver registration demographic data*

The geocoded parking tickets were inner joined with NYS DMV's driver registration demographic data of 293,714 requested plates based on the shared plate field; that is, new fields of age, gender, and vehicle-registered zip code were added to each joined ticket if there is a match between the "Plate" column in both datasets. Out of 708,445 parking tickets, 427,285 (60.31%) were successfully inner joined.

### *4.2.3 Determination of potential intrusion*

Potential residential parking intrusions were determined by selecting parking tickets issued at a zip code different from a vehicle-registered zip code and issued at free residential parking spaces as opposed to metered parking spaces. The determination of a free residential parking includes choosing tickets only in select residential areas (residential zoning districts excluding buffered commercial overlays) and further excluding tickets with meter-related reasons.

Primarily, a difference check was performed on ticket-issued zip code and vehicle-registered zip code as a basic detection of potential parking intrusions. Out of 427,285 parking tickets, 361,246 (84.54%) were detected.

After that, the select residential area boundary was generated to help detect tickets issued on free residential parking rather than metered parking. Therefore, buffered commercial overlays where metered parking was provided were excluded from NYC residential zoning districts. Table 2 in Appendix listed 10 random distances picked between the street centerline and the lot line of a commercial overlay. A 50-percentile distance (46.47 ft) was used for the choice of overlay buffer to generate the select residential areas[5]. Out of 361,246 parking tickets, 119,092 (32.97%) were selected in the select residential area.

A sampling data check (Table 3 in Appendix) was then conducted on tickets with meter-related reasons[6]. We searched their addresses in Google map and checked if they do have a meter or meters in Google street view so as to evaluate the accuracy of previous geocoding, join, and intrusion determination. The result shows a comparatively high accuracy of geocoding because at most of the sampling addresses with meter-related reasons we did find a meter or meters. However, it also indicated a necessity for further screening of potential parking intrusions because there were still a plenty of accurately geocoded parking tickets with meter-related reasons that should have been excluded.

Parking tickets with meter-related reasons were exported as a separate shapefile. For all 119,092 tickets, those spatially intersected with that shapefile were excluded and the rest of 94,427 tickets (79.29%) were kept; that is, the more tickets with meter-related reasons left on a street, the larger possibility that the street has metered parking and all the tickets on this street should have been excluded.

### *4.2.4 Screening of plate type and vehicle-registered zip code*

[4] Geosupport Desktop Edition (16B) Function 1A was used.

[5] A 46.47-ft buffer was created around commercial overlays and was then erased from residential areas to get a select residential area.

[6] Having "32-Overtime PKG-Missing Meter", "32A Overtime PKG-Broken Meter", "33-Feeding Meter", "34-Expired Meter" or "37-Expired Muni Meter" in "V_DESCRIPT" field.

Parking tickets were screened by selecting only passenger vehicles (NYS DMV standard issue plates)[7]. All other registration classes including personalized plates, commercial vehicles, taxi, and etc. were excluded because the focus of our study is the residential parking intrusions by passenger vehicles. Out of 94,427 parking tickets, 60,541 (64.11%) were selected and later utilized for the hot spot and regression analyses.

Parking tickets were further screened for calculation and visualization of avoidable VMT by selecting vehicles registered in New York City zip codes only[8]. Those tickets issued on vehicles registerd in non-NYC zip codes were excluded because we are detecting those intrusions in an area that might be influenced by a citywide parking policy in the near future. Meanwhile, the exclusion would not make a large difference on calculation of avoidable VMT since an intrusion trip with longer distance is less avoidable due to limited availability of the public trasportation[9] and an advantage of gauranteed traveling certainty and flexibility by driving. Out of 60,541 parking tickets, 40,695 (67.11%) were selected and used for the VMT calculation.

## 5 Analyses and Results

### *5.1 Hot Spot Analysis of Parking Intrusions*

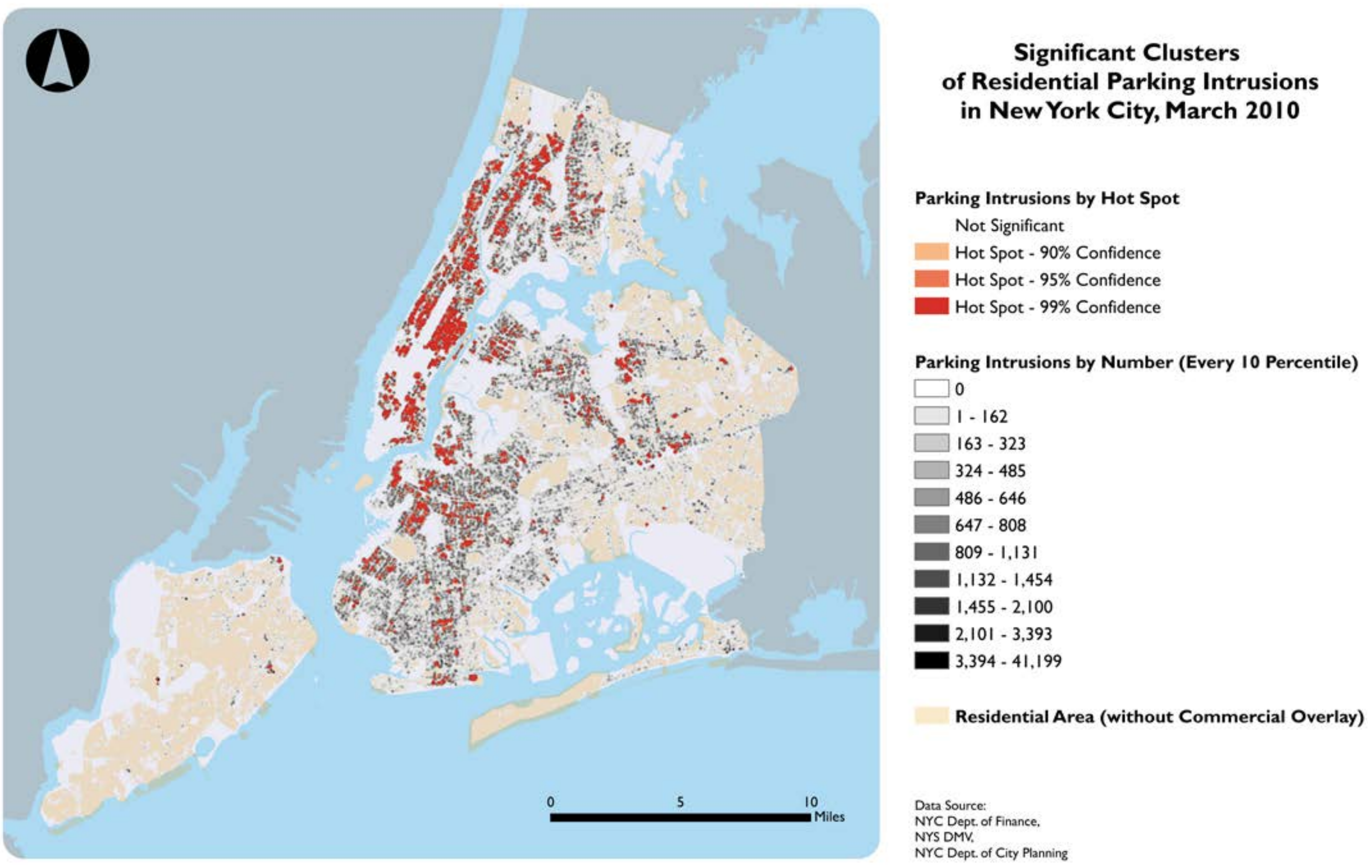


**Fig. 1.** Significant clusters of residential parking intrusions in New York City (March 2010) *Note:* The parking intrusions by number was generated using ArcGIS Kernel Density tool. Rasters use 200 by 200 foot resolution with 400-foot search radius to reflect average distance of a block (square root of a typical 200 ft by 800 ft block area). The parking intrusions by hot spot was generated utilizing ArcGIS Create Fishnet tool and Hot Spot Analysis (Getis-Ord Gi) tool. Hot spot analysis uses 200 by 200 foot resolution with 400 foot distance band to correspond with Kernel Density parameters and reflect block area as cell size. The choices of distance band ensure an inclusion of eight nearby cells in the calculations of statistical significance for each target cell. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning.

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[7] Parking violations/tickets that have “PAS” in the “Type” field.

[8] Parking violations/tickets that were successfully joined by New York City Zip Code shapefile.

[9] Public transportation ratio was used for calculation of avoidable VMT. This will be specified in the next section.

Significant clusters of residential parking intrusion in New York City was generated (see Fig. 1 above) from hot spot analysis to help understand the city-wide geographical patterns of intrusions.

In Manhattan, significant clusters of residential parking intrusions are mainly located in almost all its residential areas, including most parts of Upper East Side, Upper West Side, Hell's Kitchen, Chelsea, West Village, Greenwich Village, East Village, Lower East Side, Two Bridges, Gramercy, Kips Bay, Morning Side Heights, Washington Heights, East Harlem, Harlem, Inwood, east part of Midtown, and west part of Murray Hill.

In Brooklyn, significant clusters are primarily concentrated at northern neighborhoods, such as Brooklyn Heights, Cobble Hill, Boerun Hill, Fort Greene, Clinton Hill, Park Slope, South Slope, Prospect Heights, Crown Heights, Williamsburg, and Bedford-Stuyvesant, but also in Sunset Park. There are smaller clusters in other neighborhoods as well—Bushwick, Ridgewood, Flatbush, East Flatbush, East New York, Borough Park, Bay Ridge, Midwood, Bensonhurst, Sheepshead Bay, Brighten Beach, and Manhattan Beach.

In Bronx, most intrusions are located along Grand Concourse in Norwood, Fordham, Mount Hope, Mount Eden, Claremont Village, Concourse, Concourse Village, and also in some areas of Riverdale, Tremont, Belmont, Parkchester, Morris Heights, University Heights, Kingsbridge, Mott Haven, Wakefield, Allerton, Bronxdale, Morris Park, Westchester Square, Soundview, Union Port, and Longwood.

Clusters of intrusions in Queens are mostly located in Flushing, Forest Hills, Kew Gardens, Jackson Heights, Astoria, Jamaica, Rego Park, Elmhurst, some areas of Long Island City, Briarwood, Jamaica Estates, and Bayside, intersections of Rockaway Boulevard, Liberty Avenue, and Woodhaven Boulevard in Ozone Park.

Staten Island has the least number and size of intrusion clusters—they are in St. George, South Beach, and along Richmond Avenue.

### *5.2 Regression Analysis of Parking Intrusion Density*

To further undertand vital factors that contribute to the patterns of residential parking intrusion, a regression analysis was carried out on geographical unit of census tract. The description of regression variables were specified below in Table 1.

Ordinary least squares (OLS) regressions were conducted on both full New York City group and non-Manhattan subgroup of intrusion density of passenger vehicles by census tract as an effort to understand citywide patterns of residential parking intrusions. The results were displayed respectively in Fig. 2 and Fig. 3. A visualization of correlation of regression variables was graphed in Fig. 4.

The dependent variable intrusion density is the total number of residential parking intrusion with only passenger vehicles registered in New York City zip codes normalized by the total length of street (representing total supply of on-street parking spaces) in each census tract.

The regression has ten independent variables: percentage of select residential areas in census tract areas, number of elementary school, number of subway stops, car ownership (per household), and vehicle density (per square mile) in each census tract, total office areas (million square feet), total retail areas (million square feet), and number of commuter rail (LIRR and Metro-North) stations within 1/3 mile (1,760 feet) search distance from each census tract, whether or not each census tract has at least one garage, and whether or not the median year of built in each census tract is later than 1961. In both full group and non-Manhattan subgroup, the ten variables in total explain approximately 39% of the total variance in intrusion density of passenger vehicles across different census tracts. Among the variables, the number of commuter rail stations and the number of subway stops are not statistically significant in both groups because the p-value for them is greater than the common alpha level of 0.05. The total office areas and whether or not each census tract has at least one garage are not statistically significant in non-Manhattan subgroup.

**Table 1**

Description of Regression Variables

| Name (Data Type) | Definition | Calculation | Mean | Standard Deviation | Minimum | Median | Maximum |
|---|---|---|---|---|---|---|---|
| PASintruKL (Double) | NYC passenger vehicle intrusion density - number of tickets per 1,000 feet of total street length in each census tract for trips of | Calculate by dividing 1,000 times of total number of passenger vehicle tickets in March 2010 identified as potential residential parking intrusions by total length of street | 1.50 | 1.60 | 0 | 1.02 | 14.35 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | potential parking intrusions with passenger vehicles registered in New York City zip codes only | segments in each census tract | | | | | |
| SltRsiRtio (Double) | Percentage of select residential areas in total areas of each census tract | Calculate by dividing select residential areas (residential areas without a buffered commercial overlays) by total areas (square mile) of each census tract | 0.68 | 0.26 | 0 | 0.74 | 1.00 |
| SchoolEl (Double) | Number of elementary school in each census tract | Spatial join New York City census tract shapefile (Target Features) and elementary school shapefile (Join Features) if the former contains (Match Option) the latter | 0.61 | 0.84 | 0 | 0 | 6.00 |
| SbwyStp (Double) | Number of subway stops in each census tract | Spatial join New York City census tract shapefile (Target Features) and NYC subway station shapefile (Join Features) if the former contains (Match Option) the latter | 0.22 | 0.54 | 0 | 0 | 6.00 |
| Vhcl_Hshld (Double) | Car ownership per household in each census tract | Calculate by dividing total number of vehicles by total number of households in each census tract | 0.72 | 0.46 | 0 | 0.60 | 2.29 |
| VhclDen_sm (Double) | Vehicle density in each census tract (per square mile) | Calculate by dividing total number of vehicles by total areas (square mile) of each census tract | 9510.11 | 5104.96 | 0 | 9227.06 | 47979.90 |
| OfficeAreaM (Double) | Total office areas within 1/3 mile (1,760 feet) search distance from each census tract (million square feet) | Spatial join New York City census tract shapefile (Target Features) and MapPLUTO shapefile (Join Features) if the former intersects (Match Option) the latter within 1760 feet search radius, with sum (Merge Rule) of Office Areas and Retail Areas in MapPLUTO | 3.33 | 13.03 | 0 | 0.66 | 164.41 |
| RetailAreaM (Double) | Total retail areas within 1/3 mile (1,760 feet) search distance from each census tract (million square feet) | | 1.27 | 1.80 | 0 | 0.82 | 18.87 |
| CmtrlRIB (Double) | Number of commuter rail (LIRR, Metro-North) stations within 1/3 mile (1,760 feet) search distance from each census tract | Spatial join New York City census tract shapefile (Target Features) and commuter rail station shapefile (Join Features) if the former intersects (Match Option) the latter within 1760 feet search radius | 0.16 | 0.41 | 0 | 0 | 3.00 |
| GarageD (Double, Dummy Variable) | Whether or not each census tract has at least one garage | Spatial join New York City census tract shapefile (Target Features) and NYC Parking Facilities shapefile (Join Features) if the former contains (Match Option) the latter, then replace non-zero records with 1 | 0.24 | 0.43 | 0 | 0 | 1.00 |
| MdnYr1961A (Double, Dummy Variable) | Whether or not the median year of built in each census tract is later than 1961 | For records that are not null, calculate by subtracting 1961 from median year of built, then replace positive records with 1 and negative records with 0 | 0.15 | 0.35 | 0 | 0 | 1.00 |

*Note:* The first variable "PASintruKL" is the dependent variable while the rest of ten variables are independent variables. A descriptive analysis was conducted on each variable to generate its mean, standard deviation, minimum, median, and maximum utilizing Python with GeoPandas and NumPy packages. The elementary school shapefile used for calculation of "SchoolEl" variable includes three sub-categories (1001, Elementary School - Public; 1011, Elementary School - Public Charter; 1101, Elementary School - Private/Parochial) under Schools in Facilities_2015_shp from NYC Department of City Planning. *Source:* United States Census Bureau, CUNY, NYC Department of Fiance, NYS DMV, NYC Open Data, and NYC Department of City Planning,.

**OLS Regression Results**

| | | | |
|---|---|---|---|
| Dep. Variable: | PASintruKL | R-squared: | 0.395 |
| Model: | OLS | Adj. R-squared: | 0.392 |
| Method: | Least Squares | F-statistic: | 140.6 |
| Date: | Thu, 08 Sep 2016 | Prob (F-statistic): | 1.26e-226 |
| Time: | 00:12:18 | Log-Likelihood: | -3546.3 |
| No. Observations: | 2166 | AIC: | 7115. |
| Df Residuals: | 2155 | BIC: | 7177. |
| Df Model: | 10 | | |
| Covariance Type: | nonrobust | | |

| | coef | std err | t | P>\|t\| | [95.0% Conf. Int.] | |
|---|---|---|---|---|---|---|
| Intercept | 0.5365 | 0.116 | 4.637 | 0.000 | 0.310 | 0.763 |
| SltRsiRtio | 1.2348 | 0.146 | 8.473 | 0.000 | 0.949 | 1.521 |
| SchoolEl | 0.2137 | 0.033 | 6.541 | 0.000 | 0.150 | 0.278 |
| SbwyStp | -0.0984 | 0.055 | -1.791 | 0.073 | -0.206 | 0.009 |
| Vhcl_Hshld | -1.5976 | 0.071 | -22.567 | 0.000 | -1.736 | -1.459 |
| VhclDen_sm | 0.0001 | 5.92e-06 | 17.456 | 0.000 | 9.18e-05 | 0.000 |
| OfficeAreaM | -0.0194 | 0.004 | -5.086 | 0.000 | -0.027 | -0.012 |
| RetailAreaM | 0.1744 | 0.030 | 5.834 | 0.000 | 0.116 | 0.233 |
| CmtrRlB | 0.1006 | 0.066 | 1.525 | 0.127 | -0.029 | 0.230 |
| GarageD | 0.2479 | 0.074 | 3.350 | 0.001 | 0.103 | 0.393 |
| MdnYr1961A | -0.3821 | 0.078 | -4.873 | 0.000 | -0.536 | -0.228 |

| | | | |
|---|---|---|---|
| Omnibus: | 904.280 | Durbin-Watson: | 1.704 |
| Prob(Omnibus): | 0.000 | Jarque-Bera (JB): | 5860.235 |
| Skew: | 1.844 | Prob(JB): | 0.00 |
| Kurtosis: | 10.164 | Cond. No. | 6.92e+04 |

**Fig. 2.** Regression result of NYC intrusion density of passenger vehicles by census tract. *Note:* The Ordinary least squares (OLS) regression analysis was performed utilizing Python with GeoPandas and NumPy packages. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning, NYC Open Data, and United States Census Bureau.

**OLS Regression Results**

| | | | |
|---|---|---|---|
| Dep. Variable: | PASintruKL | R-squared: | 0.396 |
| Model: | OLS | Adj. R-squared: | 0.393 |
| Method: | Least Squares | F-statistic: | 122.5 |
| Date: | Thu, 08 Sep 2016 | Prob (F-statistic): | 2.54e-196 |
| Time: | 00:23:41 | Log-Likelihood: | -2815.5 |
| No. Observations: | 1878 | AIC: | 5653. |
| Df Residuals: | 1867 | BIC: | 5714. |
| Df Model: | 10 | | |
| Covariance Type: | nonrobust | | |

| | coef | std err | t | P>\|t\| | [95.0% Conf. Int.] | |
|---|---|---|---|---|---|---|
| Intercept | 0.3377 | 0.120 | 2.813 | 0.005 | 0.102 | 0.573 |
| SltRsiRtio | 1.2980 | 0.142 | 9.117 | 0.000 | 1.019 | 1.577 |
| SchoolEl | 0.1754 | 0.032 | 5.518 | 0.000 | 0.113 | 0.238 |
| SbwyStp | -0.0715 | 0.061 | -1.170 | 0.242 | -0.191 | 0.048 |
| Vhcl_Hshld | -1.4270 | 0.067 | -21.331 | 0.000 | -1.558 | -1.296 |
| VhclDen_sm | 8.263e-05 | 6.29e-06 | 13.138 | 0.000 | 7.03e-05 | 9.5e-05 |
| OfficeAreaM | 0.0129 | 0.020 | 0.661 | 0.509 | -0.025 | 0.051 |
| RetailAreaM | 0.3907 | 0.053 | 7.375 | 0.000 | 0.287 | 0.495 |
| CmtrRlB | 0.1067 | 0.062 | 1.718 | 0.086 | -0.015 | 0.228 |
| GarageD | 0.1091 | 0.075 | 1.460 | 0.145 | -0.037 | 0.256 |
| MdnYr1961A | -0.2569 | 0.076 | -3.364 | 0.001 | -0.407 | -0.107 |

| | | | |
|---|---|---|---|
| Omnibus: | 655.228 | Durbin-Watson: | 1.724 |
| Prob(Omnibus): | 0.000 | Jarque-Bera (JB): | 3211.647 |
| Skew: | 1.583 | Prob(JB): | 0.00 |
| Kurtosis: | 8.569 | Cond. No. | 7.14e+04 |

**Fig. 3.** Regression result of non-Manhattan intrusion density of passenger vehicles by census tract. *Note:* The Ordinary least squares (OLS) regression analysis was performed utilizing Python with GeoPandas and NumPy packages. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning, NYC Open Data, and United States Census Bureau.

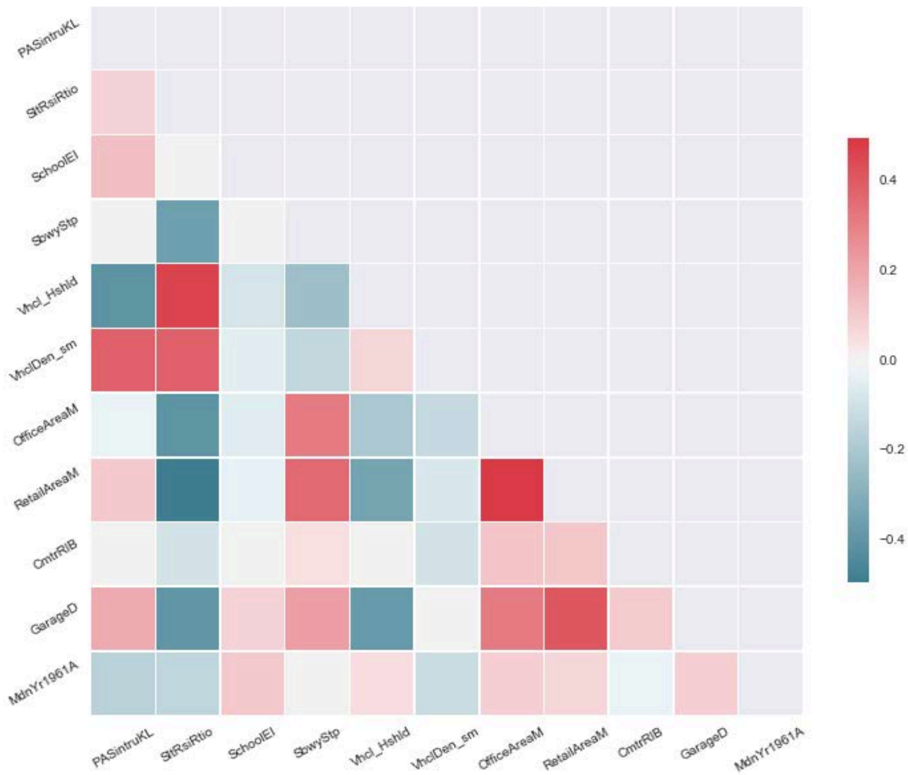


**Fig. 4.** Correlation of variables in regression analysis. *Note:* The visualization of correlation was performed utilizing Python with GeoPandas, NumPy, and matplotlib packages. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning, NYC Open Data, and United States Census Bureau.

Most of the ten variables behave as expected. Larger number of elementary schools and larger surrounding retail areas (permitted under commercial overlay zoning districts in residential areas) tend to encourage higher intrusion density because schools and retails are important amenities that local free residential parking spaces could easily access. Larger percentage of select residential areas in census tract areas also means higher intrusion density since higher percentage represents higher supply of parking spaces for potential intrusions normalized in calculation by the same total length of street in each census tract. Higher vehicle density and a census tract with at least one garage as opposed to one without also encourages intrusion density because they indicate a higher-density neighborhood with comparatively more nearby opportunities that impose fierce competitions for limited parking spaces and with tougher parking regulation enforcement. The stricter enforcement may result from more regulations that could be violated due to high density of bus stations, and more police officers issuing parking tickets.

In comparison, a census tract with the median year of built later than 1961 as opposed to no later than 1961 tend to discourage the intrusion density due to more off-street parking spaces available in later-developed neighborhood and thus less competitions for on-street parking. Larger office areas also tend to deter intrusion density. This may result from limited office areas around select residential areas (office use is not permitted under commercial overlay zoning districts in residential areas) and that commuting to work place may have a stricter requirement on parking certainty (finding a parking space within acceptable search time and distance). Additionally, higher car ownership discourages intrusion density because places with a number of cars per household display people's heavy dependence on private vehicles and abundant parking spaces available in local neighborhood—they are more likely lower-density areas with limited nearby opportunities.

Though not statistically significant, larger number of subway stops discourages intrusion density as well possibly because the extensive coverage of subways can provide an alternative means of transportations to people from areas close to home directly to a destination and avoid driving. However, more commuter rail stations encourage intrusion density since the long inter-station distance and limited citywide coverage of the rail system facilitate more park-and-ride around stations rather than complete replacement of driving.

### *5.3 Calculation and Visualization of Avoidable VMT*

Both straight-line and avoidable Vehicle Miles Traveled (VMT) were calculated so as to display the potential level of negative externalities generated from residential parking intrusions and to visualize origin-destination line pairs with high intrusion trips.

For each pair of locations—the exact location where parking violations/tickets were issued and the centroid of a zip code where the vehicle were registered, a straight line was created and its length was calculated[10]. For 40,695 tickets identified as potential residential parking intrusions with passenger vehicles registered in New York City only, the total annual straight-line VMT is 1,604,714.59 miles (133,726.22 miles in March 2010 * 12 months).

The avoidable VMT is the straight-line VMT weighted by public transportation ratio and network distance factor. The public transportation ratio was calculated by dividing number of population using public transportation (bus, streetcar, subway, railroad, or ferryboat) by total population in each census tract[11]. The ratio is used because the larger the portion of population using public transportations (bus, streetcar, subway, railroad, or ferryboat) as opposed to private and other transportation (car, truck, van, taxicab, or motorcycle, walking, bicycling, or others), the more VMT that could have been avoided if there is no residential parking intrusions and the trip is inevitable. The network distance factor 1.417 was acquired from a nationwide study that proves the straight-line distance, after multiplied by a detour index of 1.417, an appropriate proxy for driving distance. (Boscoe and Henry, 2012). To sum up, the avoidable VMT is calculated by applying the equation (1) below:

$$AVMT = SVMT * PTR * NF \quad (1)$$

Where in (1):

AVMT □Avoidable VMT

SVMT □Straight-line VMT

PTR □Public transportation ratio

NF = Network distance factor (1.417)

The total weighted annual network VMT (VMT that could have been avoided if there is no parking intrusion) is 2,273,880.58 miles (189,490.05 miles in March 2010 * 12 months)—more than 91 times the Earth's Equator. Since the calculation has only considered vehicles that received parking tickets, the overall annual avoidable VMT could be a lot more than 2 million miles.

[10] Based on a pair of X and Y coordinates "XY to Line" tool in ArcGIS was used (with "SUMMONS" field as unique ID, and GEODESIC as line type) and the distance was acquired utilizing Calculate Geometry (length in feet). This new shapefile was joined back to the potential parking intrusion shapefile based on "SUMMONS" to add a new VMT field (in feet).

[11] The two fields the number of population using public transportation and total population were calculated on census tract level from the ACS 2006-2010 table Means of Transportation to Work and aggregated onto zip code level using ArcGIS spatial join tool. The public transportation ratio was then calculated on zip code level. For zip codes 10173, 10175, 10176, and 10177, the ratio equal to that of the zip code 10017.They were then joined to the potential parking intrusion shapefile based on vehicle-registered zip code.

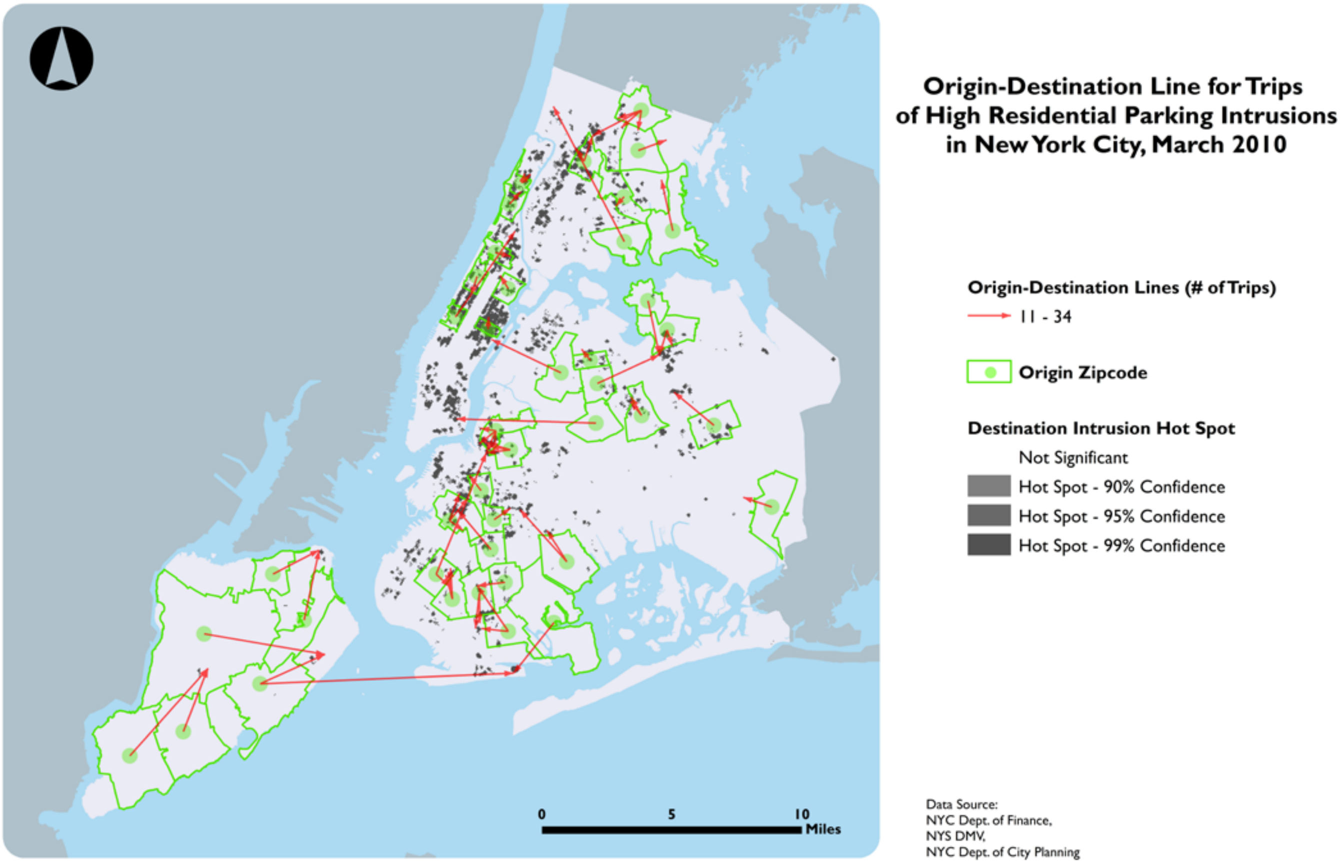


**Fig. 5.** Origin-destination line for trips of high residential parking intrusions in New Yor City (March 2010). *Note:* For each pair of locations—the centroid of a census tract where parking violations/tickets were issued and the centroid of a zip code where the vehicle were registered, a straight line was created based on a pair of X and Y coordinates using "XY to Line" tool (with "SUMMONS" field as unique ID, and GEODESIC as line type) and the VMT distance, census tract code, and zip code registered were acquired by joining the updated NYC census tract shapefile to this new shapefile based on "SUMMONS". The line shapefile was then dissolved to get lines pointing from zip code centroid to census tract centroid, with census tract code and zip code registered as dissolve_field and count of VMT field as a new field. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning.

The Fig. 5 graphs 62 origin (zip code)-destination (census tract) line pairs with high intrusion trips. Each origin-destination pair has an origin of the New York City zip code centroid where vehicle were registered and a destination of census tract centroid where the tickets were issued. For clear display of origin-destination line pairs and better understanding of determining patterns, only lines with over 10 trips are selected for visualization.

Most of the origin-destination pairs are within its own borough, except that one traveled from Staten Island (Oakwood and New Dorp) to Brooklyn (Manhattan Beach) and two started from Queens and ended in Manhattan (from Middle Village to Lower East Side and from Woodside to Upper East Side).

Additionally, most of the origin-destination pairs that originated from non-Manhattan boroughs either headed towards Manhattan or ended in places closer to Manhattan. However, exceptions existed in places far from Manhattan in Bronx, Queens, and Brooklyn where Riverdale, Norwood, Pelham Bay, Co-op City, Flushing, and Sheepshead Bay, Manhattan Beach became popular destinations for high intrusion trips.

The other noticeable pattern is a plenty of short-distance origin-destination pairs. Since one step of intrusion determination is to identify tickets with different ticketed zip code and register zip code, some may argue that some short-distance intrusion may result from parking search right across the zip code boundary but totally within vehicle owners' acceptable search time and distance. However, considering the comparative large area of a zip code, the opposite might be true as well—a lot of long-distance parking intrusions within the same zip code might not be captured. The two un-captured scenarios would neutralize each other and the short-distance intrusion should still be considered as a significant pattern in NYC residential parking intrusion.

# 6 Discussion

*6.1 Recommendations*

It takes time and efforts to tackle residential parking intrusions. The research may offer some instructions on which neighborhood should have a prior consideration for the development of a new RPP program in New York City. Reviewing both intrusion hot spots and popular destinations for high intrusions trips, Upper East Side, Upper West Side, Lower East Side, Washington Heights, Norwood, Flushing, Williamsburg, Fort Greene, and Park Slope are the neighborhoods that should be first considered for the implementation of a RPP program. The surrounding neighborhoods that might have already experienced a certain level of parking intrusions may receive additional spillover intrusions after an application of the program in those prior neighborhoods. As a result, a buffered area is recommended in the initial program implementation to include more nearby neighborhoods: Fordham, Gramercy, Morning Side, Harlem, South Slope, and Crown Heights.

Besides, additional metered parking spaces should be provided in neighborhoods with high intrusions. The provision of additional metered parking spaces should not reduce the existing residential parking stock (both on-street and off-street), but should increase the total parking stock by taking the advantage of areas that new residential parking spaces could not easily be generated from.

*6.2 Limitations*

This study still has limitations. The tools and datasets used—Geosupport Desktop Edition (2016), MapPLUTO (2011), Selected Facilities and Program Sites (2015), NYC Parking Violations Issued (2010), and etc.—are from different years and may thus influence the accuracy of this study. Additionally, the analysis fails to exclude the scenario that people might register their vehicles in a place different from their home zip code because of intentional vehicle registration outside New Yor City for lower insurance costs and change of registered residence address during the time gap between parking ticket data (March 2010) and driver registration data (July 2012). The intentional registration might result into an overestimation of residential parking intrusions while the change of registered addres might lead to both an overestimation and a underestimation.

This study can hopefully inform New York City's efforts to deal with existing residential parking intrusions—both implementing a RPP program with prior considerations in certain neighborhoods and offering additional metered parking spaces. With good and effective strategies designed, the drivers could enjoy a more efficient traveling and parking, the residents could have a cleaner and safer living environment, and the city government could have more alternatives to improve the quality of life utilizing the same or fewer resources.


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## Appendix

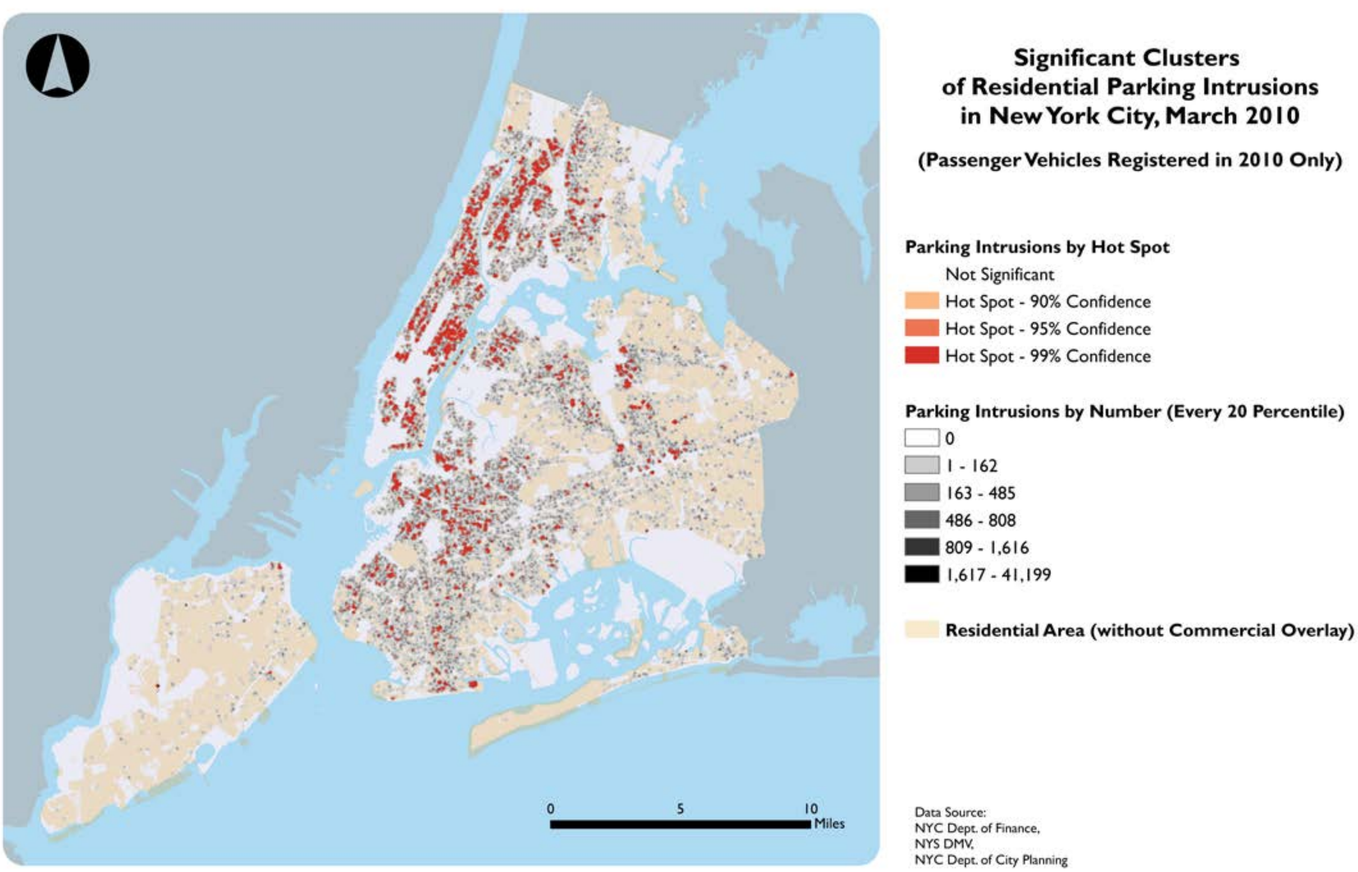


**Fig. 6.** Significant clusters of residential parking intrusions in New York City (March 2010) (Passenger vehicles registered in 2010 only) *Note:* The parking intrusions by number was generated using ArcGIS Kernel Density tool. Rasters use 200 by 200 foot resolution with 400-foot search radius to reflect average distance of a block (square root of a typical 200 ft by 800 ft block area). The parking intrusions by hot spot was generated utilizing ArcGIS Create Fishnet tool and Hot Spot Analysis (Getis-Ord Gi) tool. Hot spot analysis uses 200 by 200 foot resolution with 400 foot distance band to

correspond with Kernel Density parameters and reflect block area as cell size. The choices of distance band ensure an inclusion of eight nearby cells in the calculations of statistical significance for each target cell. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning.

```
                            OLS Regression Results
==============================================================================
Dep. Variable:              PASintruKL   R-squared:                       0.395
Model:                             OLS   Adj. R-squared:                  0.392
Method:                  Least Squares   F-statistic:                     140.6
Date:                 Thu, 08 Sep 2016   Prob (F-statistic):         1.26e-226
Time:                         00:12:18   Log-Likelihood:               -3546.3
No. Observations:                 2166   AIC:                             7115.
Df Residuals:                     2155   BIC:                             7177.
Df Model:                           10
Covariance Type:             nonrobust
================================================================================
                  coef    std err          t      P>|t|      [95.0% Conf. Int.]
--------------------------------------------------------------------------------
Intercept       0.5365      0.116      4.637      0.000         0.310     0.763
SltRsiRtio      1.2348      0.146      8.473      0.000         0.949     1.521
SchoolEl        0.2137      0.033      6.541      0.000         0.150     0.278
SbwyStp        -0.0984      0.055     -1.791      0.073        -0.206     0.009
Vhcl_Hshld     -1.5976      0.071    -22.567      0.000        -1.736    -1.459
VhclDen_sm      0.0001   5.92e-06     17.456      0.000      9.18e-05     0.000
OfficeAreaM    -0.0194      0.004     -5.086      0.000        -0.027    -0.012
RetailAreaM     0.1744      0.030      5.834      0.000         0.116     0.233
CmtrRlB         0.1006      0.066      1.525      0.127        -0.029     0.230
GarageD         0.2479      0.074      3.350      0.001         0.103     0.393
MdnYr1961A     -0.3821      0.078     -4.873      0.000        -0.536    -0.228
==============================================================================
Omnibus:                       904.280   Durbin-Watson:                   1.704
Prob(Omnibus):                   0.000   Jarque-Bera (JB):             5860.235
Skew:                            1.844   Prob(JB):                         0.00
Kurtosis:                       10.164   Cond. No.                     6.92e+04
==============================================================================
```

**Fig. 7.** Regression result of NYC intrusion density of passenger vehicles registered in 2010 (by census tract). *Note:* The Ordinary least squares (OLS) regression analysis was performed utilizing Python with GeoPandas and NumPy packages. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning, NYC Open Data, and United States Census Bureau.

```
                            OLS Regression Results
==============================================================================
Dep. Variable:              PASintruKL   R-squared:                       0.396
Model:                             OLS   Adj. R-squared:                  0.393
Method:                  Least Squares   F-statistic:                     122.5
Date:                 Thu, 08 Sep 2016   Prob (F-statistic):         2.54e-196
Time:                         00:23:41   Log-Likelihood:               -2815.5
No. Observations:                 1878   AIC:                             5653.
Df Residuals:                     1867   BIC:                             5714.
Df Model:                           10
Covariance Type:             nonrobust
================================================================================
                  coef    std err          t      P>|t|      [95.0% Conf. Int.]
--------------------------------------------------------------------------------
Intercept       0.3377      0.120      2.813      0.005         0.102     0.573
SltRsiRtio      1.2980      0.142      9.117      0.000         1.019     1.577
SchoolEl        0.1754      0.032      5.518      0.000         0.113     0.238
SbwyStp        -0.0715      0.061     -1.170      0.242        -0.191     0.048
Vhcl_Hshld     -1.4270      0.067    -21.331      0.000        -1.558    -1.296
VhclDen_sm   8.263e-05   6.29e-06     13.138      0.000      7.03e-05   9.5e-05
OfficeAreaM     0.0129      0.020      0.661      0.509        -0.025     0.051
RetailAreaM     0.3907      0.053      7.375      0.000         0.287     0.495
CmtrRlB         0.1067      0.062      1.718      0.086        -0.015     0.228
GarageD         0.1091      0.075      1.460      0.145        -0.037     0.256
MdnYr1961A     -0.2569      0.076     -3.364      0.001        -0.407    -0.107
==============================================================================
Omnibus:                       655.228   Durbin-Watson:                   1.724
Prob(Omnibus):                   0.000   Jarque-Bera (JB):             3211.647
Skew:                            1.583   Prob(JB):                         0.00
Kurtosis:                        8.569   Cond. No.                     7.14e+04
==============================================================================
```

**Fig. 8.** Regression result of non-Manhattan intrusion density of passenger vehicles registered in 2010 (by census tract). *Note:* The Ordinary least squares (OLS) regression analysis was performed utilizing Python with GeoPandas and NumPy packages. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning, NYC Open Data, and United States Census Bureau.

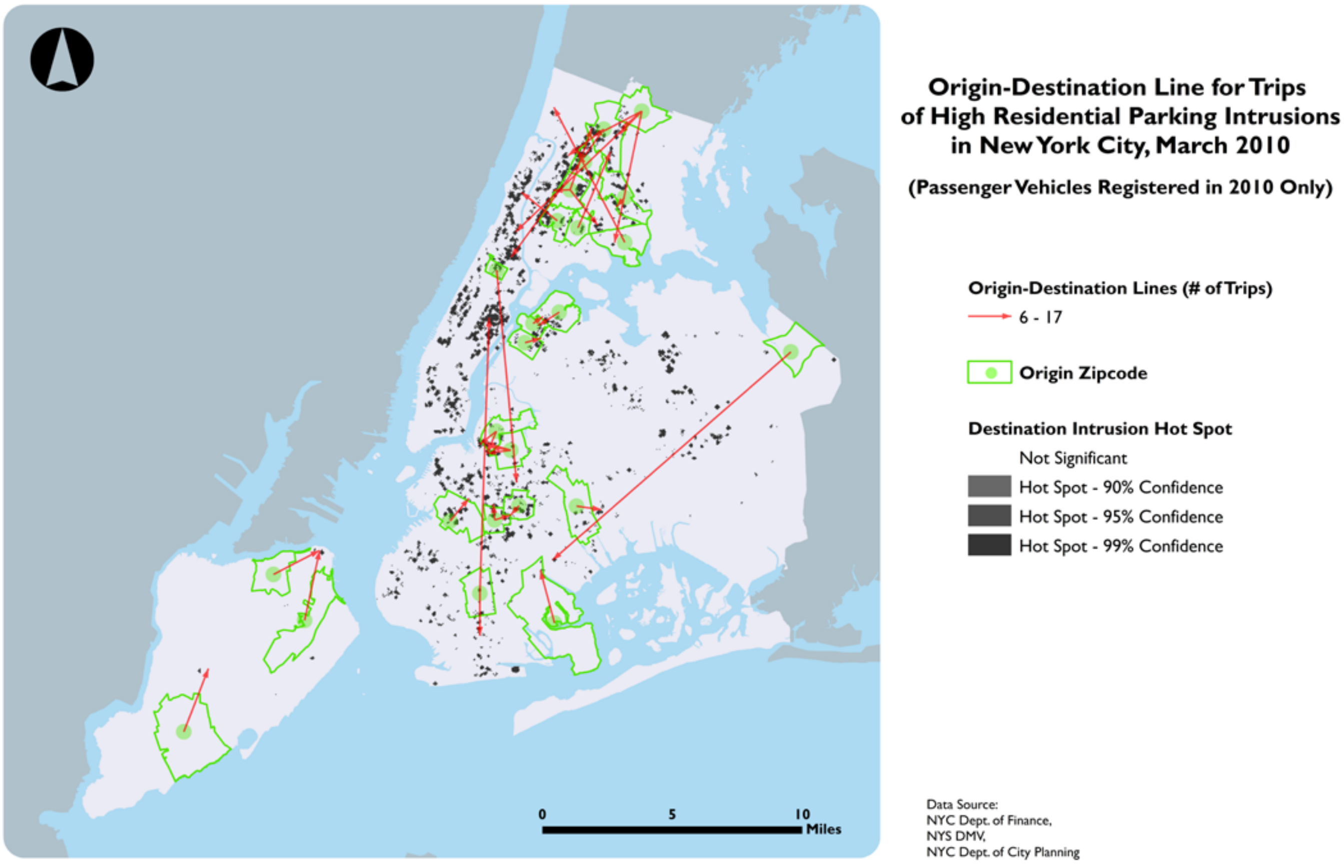


**Fig. 9.** Origin-destination line for trips of high residential parking intrusions in New Yor City (March 2010) (Passenger vehicles registered in 2010 only). *Note:* For each pair of locations—the centroid of a census tract where parking violations/tickets were issued and the centroid of a zip code where the vehicle were registered, a straight line was created based on a pair of X and Y coordinates using "XY to Line" tool (with "SUMMONS" field as unique ID, and GEODESIC as line type) and the VMT distance, census tract code, and zip code registered were acquired by joining the updated NYC census tract shapefile to this new shapefile based on "SUMMONS". The line shapefile was then dissolved to get lines pointing from zip code centroid to census tract centroid, with census tract code and zip code registered as dissolve_field and count of VMT field as a new field. *Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning.

**Table 2**

Sample Distance for Commercial Overlay Buffer Calculation

| Address | Borough | Zip | Commercial Overlay-Centerline Distance (ft) | |
|---|---|---|---|---|
| 150-15 Northern Blvd | Queens | 11354 | 46 | 51.85 |
| 64-04 Queens Blvd | Queens | 11377 | 84.42 | 109.79 |
| 924 Westchester Ave | Bronx | 10459 | 47.24 | 48.36 |
| 3756 White Plains Rd | Bronx | 10467 | 43.58 | 48.86 |
| 965 Amsterdam Ave | Manhattan | 10025 | 47.35 | 46.93 |
| 140 1st Ave | Manhattan | 10009 | 42.93 | 52.88 |
| 1023 Fulton St | Brooklyn | 11238 | 37.14 | 38.68 |
| 4622 New Utrecht Ave | Brooklyn | 11219 | 36.62 | 36.28 |
| 98 Victory Blvd | Staten Island | 10301 | 28.44 | 36.74 |
| 1778 Hylan Blvd | Staten Island | 10305 | 55.89 | 40.76 |

*Source:* NYC Department of Fiance, NYS DMV, and NYC Department of City Planning,.

**Table 3**

Sampling Data Check For Evaluating The Accuracy Of Geocoding And Intrusion Determination

| Address with meter-related reason | Borough | Google map meter check |
|---|---|---|
| 249-06 Hillside Avenue, Queens, NY | | Yes |
| 69-36 215th St, Queens, New York, NY | | Yes |
| 149-44 12th Rd, Queens, NY 11357 | | Yes |
| 78-33 Springfield Blvd, Oakland Gardens, NY | | Yes |
| 89-40 134th Street, Queens, NY | | Yes |
| 11406 Lefferts Blvd, South Ozone Park, NY | | Yes |
| 35-64 79th Street, Jackson Heights, NY | Queens | Yes |
| 86-27 115 Street, Queens, NY | | Yes |
| 99-17 97th St, Jamaica, NY | | Yes |
| 54-53 71st St, Maspeth, NY | | Yes |
| 28-55 36th Street, Astoria, NY | | Yes |
| 35-63 78th St, Flushing, NY | | Yes |
| 70-18 66th St, Glendale, New York 11385 | | No |
| 7119 20th Avenue, Brooklyn, NY | | Yes |
| 1566 72nd Street, Brooklyn, NY | | Yes |
| 481 83 Street, Brooklyn, NY | | Yes |
| 1275 43rd St, Brooklyn, NY | | Yes |
| 475 53rd Street, Brooklyn, NY | | Yes |
| 30 Schermerhorn Street, Brooklyn, NY | Brooklyn | Yes |
| 1276 71st Street, Brooklyn, NY | | Yes |
| 1713 65th Street, Brooklyn, NY | | Yes |
| 1111 Carroll St, Brooklyn, NY | | Yes |
| 107 Moore Street, Brooklyn, NY | | Yes |
| 1590 Rockaway Parkway, Brooklyn, NY | | Yes |
| 148 8th Street, Staten Island, NY | | No |
| 488 Pelton Avenue, Staten Island, NY | | Yes |
| 16 Burnside Avenue, Staten Island, NY | | Yes |
| 134 New Street, Staten Island, NY | Staten Island | Yes |
| 38 Winthrop Place, Staten Island, NY | | Yes |
| 525A Targee Street, Staten Island, NY | | Yes |
| 134 New Street, Staten Island, NY | | Yes |
| 1601 Williamsbridge Road, Bronx, NY | | Yes |
| 250 Bedford Park Boulevard, Bronx, NY | | Yes |
| 2505 Lorillard Place, Bronx, NY | | Yes |
| 3071 Perry Ave, Bronx, NY | Bronx | Yes |
| 111 East 210th Street, Bronx, NY | | Yes |
| 556 W 239th St, Bronx, NY | | No |
| 558 E 235th St, Bronx, NY | | No |
| 567 West 170 Street, New York, NY | | Yes |
| 80 W 132nd St, New York, NY | | Yes |
| 348 E 9th St, New York, NY | | Yes |
| 251 East 32nd Street, New York, NY | Manhattan | Yes |
| 552 W 112th St, New York, NY | | No |
| 217 East 66th Street, New York, NY | | Yes |
| 238 East 6th Street, New York, NY | | No |

*Source:* NYC Department of Fiance, NYS DMV, NYC Open Data, Google Street View, and NYC Department of City Planning,.

**Table 4**

Description of the census tract Shapefile Columns including Regression Variables

| Feature Name | Feature Description | Data Type | Calculation | Source | Source Link |
|---|---|---|---|---|---|
| CTLabel | census tract Label | String | Existing features in nyct2010_16a | nyct2010_16a from NYC Department of City Planning | http://www1.nyc.gov/site/planning/data- |

| | | | | | |
|---|---|---|---|---|---|
| BoroCode | 1 - Manhattan (New York County)<br>2 - Bronx (Bronx County)<br>3- Brooklyn (Kings County)<br>4 - Queens (Queens County)<br>5- Staten Island (Richmond County) | String | | | maps/open-data/districts-download-metadata.page |
| BoroCT2010 | Boro code and census tract code | String | | | |
| CDEligibil | | String | | | |
| NTACode | Neighborhood Tabulation Area code | String | | | |
| NTAName | Neighborhood Tabulation Area name | String | | | |
| PUMA | | String | | | |
| BoroCTJoin | Boro code and census tract code | Double | Equal to BoroCT2010 | N/A | N/A |
| realIntrus | Number of tickets in March 2010 identified as potential residential parking intrusions in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) shapefile D (Join Features) | shapefile D | N/A |
| total_tick | Total number of valid tickets (427,285) in March 2010 in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) shapefile B (Join Features) | shapefile B | N/A |
| PASintrus | Number of passenger vehicle tickets in March 2010 identified as potential residential parking intrusions in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) shapefile F (Join Features) | shapefile F | N/A |
| total_stre | Number of street segments in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) LION (Join Features), sum (Merge Rule) of length of Join Feature as street_Len | LION Single Line Street Base Map (16a) from NYC Department of City Planning | http://www1.nyc.gov/site/planning/data-maps/open-data/dwn-lion.page |
| street_Len | Sum of total length of street segments in each census tract (Feet) | Double | | | |
| Intrs_KStL | Intrusion density - number of tickets in March 2010 identified as potential residential parking intrusions per 1,000 feet of total street length in each census tract | Double | Calculate by applying realIntrus / (street_Len / 1,000) | N/A | N/A |
| SchoolEl | Number of elementary school in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) elementary schools (Join Features) from Facilities_2015_shp (1001, Elementary School - Public; 1011, Elementary School - Public Charter; 1101, Elementary School - Private/Parochial) | Facilities_2015_shp from NYC Department of City Planning | http://www1.nyc.gov/site/planning/data-maps/open-data/dwn-selfac.page |
| Non_MN | Whether or not each census tract is outside Manhattan | Double, Dummy Variable | Replace records of 1 with 0, and records of 2, 3, 4, 5 in BoroCode with 1 | N/A | N/A |
| CmtrlRIB | Number of commuter rail (LIRR, Metro-North) stations within 1/3 mile (1,760 feet) search distance from each census tract | Double | Spatial Join: nyct2010_16a (Target Features) intersects (Match Option) merged commuter rail stations (Join Features) from LIRR and Metro-North shapefiles, with 1760 feet search radius | stops_lirr_nov2015, stops_metro_north_nov2015 | https://www.baruch.cuny.edu/confluence/display/geoportal/NYC+Mass+Transit+Spatial+Layers |
| Non_MN_CmtrlRIB | Number of commuter rail (LIRR, Metro-North) stations within 1/3 mile (1,760 feet) search distance from each non-Manhattan census tract | Double | Calculate by applying CmtrlRIB * Non_MN | N/A | N/A |
| SbwyEntrc | Number of subway entrances in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) subway entrances (Join Features) | subway entrances from NYC Open Data | https://data.cityofnewyork.us/Transportation/Subway-Entrances/drex-xx56 |
| SbwyEntrcD | Whether or not each census tract has at least one subway entrance | Double, Dummy Variable | Replace non-zero records of SbwyEntrc with 1 | | |

| | | | | | |
|---|---|---|---|---|---|
| SbwyStp | Number of subway stops in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) subway stations (Join Features) | subway stations from NYC Open Data | https://data.cityofnewyork.us/Transportation/Subway-Stations/arq3-7z49 |
| Non_MN_SbwyStp | Number of subway stops in each non-Manhattan census tract | Double | Calculate by applying SbwyStp * Non_MN | N/A | N/A |
| Ppltion | 2010 Total population in each census tract | Double | Join nyct2010_16a with total population table based on BoroCTJoin | ACS_10_5YR_B01003 from United States Census Bureau | http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t |
| Household | Number of households in each census tract | Double | Existing features in HOUSEHOLD SIZE BY VEHICLES table | ACS_10_5YR_B08201 from United States Census Bureau | http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t |
| Hshd_0v | Number of households with no vehicles in each census tract | Double | | | |
| Hshd_1v | Number of households with 1 vehicle in each census tract | Double | | | |
| Hshd_2v | Number of households with 2 vehicles in each census tract | Double | | | |
| Hshd_3v | Number of households with 3 vehicles in each census tract | Double | | | |
| Hshd_4vm | Number of households with 4 vehicles or more in each census tract | Double | | | |
| TtlVehicle | Total number of vehicles in each census tract | Double | Calculate by applying 0 * Hshd_0v + 1 * Hshd_1v + 2 * Hshd_2v + 3 * Hshd_3v + 4 * Hshd_4vm | N/A | N/A |
| TctArea_sm | Area of each census tract (square miles) | Double | Calculate geometry of nyct2010_16a | N/A | N/A |
| PopDen_sm | Population density in each census tract (per square mile) | Double | Calculate by applying Ppltion / TctArea_sm | N/A | N/A |
| VhclDen_sm | Vehicle density in each census tract (per square mile) | Double | Calculate by applying TtlVehicle / TctArea_sm | N/A | N/A |
| Garage | Number of garages in each census tract | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) NYC Parking Facilities (Join Features) | NYC Parking Facilities | https://nycopendata.socrata.com/Transportation/Municipal-Parking-Facilities-Manhattan-/i8d5-5ciu/data |
| GarageD | Whether or not each census tract has at least one garage | Double, Dummy Variable | Replace non-zero records of Garage with 1 | | |
| MdnYrBlt | Year difference between median year of built and 1961 in each census tract | Double | For records that are not null, calculate by applying median year of built minus 1961 | ACS_10_5YR_B25035 from United States Census Bureau | http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t |
| MdnYr1961A | Whether or not the median year of built in each census tract is later than 1961 | Double, Dummy Variable | Replace positive records of Garage with 1, and negative records of Garage with 0 | | |
| BldgAreaB | Total building areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | Spatial Join: nyct2010_16a (Target Features) intersects (Match Option) MapPLUTO (Join Features), sum (Merge Rule) of ComArea, ResArea, OfficeArea, RetailArea, GarageArea, StrgeArea, FactryArea, OtherArea in MapPLUTO, with 1,760 feet search radius | MapPLUTO 11v2(the closest one using CT 2010 ) from NYC Department of City Planning | http://www1.nyc.gov/site/planning/data-maps/open-data/pluto-mappluto-archive.page |
| ComAreaB | Total commercial areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |
| ResAreaB | Total residential areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |
| OfficeArB | Total office areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |

| | | | | | |
|---|---|---|---|---|---|
| GarageArB | Total garage areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |
| StrgeAreaB | Total storage areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |
| FactryArB | Total factory areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |
| OtherAreaB | Total other areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |
| RetailArB | Total retail areas within 1/3 mile (1,760 feet) search distance from each census tract (square feet) | Double | | | |
| Vhcl_Hshld | Car ownership per household in each census tract | Double | Calculate by applying TtlVehicle / Household | N/A | N/A |
| VMTtripNYC | Number of tickets in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) shapefile F2 (Join Features), sum (Merge Rule) of VMTv as VMTvNYC, WVMTv as WVMTvNYC, and WNVMTv as WNVMTvNYC. | shapefile F2 | N/A |
| VMTvNYC | Total number of straight-line Vehicle Miles Traveled (VMT) in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only (feet) | Double | | | |
| WVMTvNYC | Total number of weighted straight-line Vehicle Miles Traveled (VMT) in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only (feet) | Double | | | |
| WNVMTvNYC | Total number of weighted network Vehicle Miles Traveled (VMT) in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only (feet) | Double | | | |
| VMTvNYCa | Average number of straight-line Vehicle Miles Traveled (VMT) per trip in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only | Double | Calculate by applying VMTvNYC / VMTtripNYC | N/A | N/A |
| WVMTvNYCa | Average number of weighted straight-line network Vehicle Miles Traveled (VMT) per trip in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only | Double | Calculate by applying WVMTvNYC / VMTtripNYC | N/A | N/A |
| WNVMTvNYC a | Average number of weighted network Vehicle Miles Traveled (VMT) per trip in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only | Double | Calculate by applying WNVMTvNYC / VMTtripNYC | N/A | N/A |
| SltRsiArea | Select residential areas in total areas of each census tract (square miles) | Double | Spatial Join: nyct2010_16a (Target Features) contains (Match Option) shapefile C2 (Join Features), sum (Merge Rule) of area (in square miles) which was acquired from Calculate Geometry | shapefile C2 | N/A |
| SltRsiRtio | Percentage of select residential areas in total areas of each census tract | Double | Calculate by applying SltRsiArea / TctArea_sm | N/A | N/A |
| IntrusRtio | Percentage of number of tickets identified as parking intrusions in total number of tickets | Double | Calculate by applying realIntrus / total_tick | N/A | N/A |
| TickPerPop | Total number of valid tickets (427,285) per population in March 2010 in each census tract | Double | Calculate by applying total_tick / Ppltion | N/A | N/A |
| IntrsKLNYC | NYC intrusion density - number of tickets per 1,000 feet of total street length in each census tract for trips of potential parking intrusions with vehicles registered in New York City zip codes only | Double | Calculate by applying VMTtripNYC / (street_Len / 1,000) | N/A | N/A |

| | | | | | |
|---|---|---|---|---|---|
| PASintruKL | NYC passenger vehicle intrusion density - number of tickets per 1,000 feet of total street length in each census tract for trips of potential parking intrusions with passenger vehicles registered in New York City zip codes only | Double | Calculate by applying PASintrus / (street_Len / 1,000) | N/A | N/A |

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