Estimating Parking Utilization in Multi-Family Residential Buildings in Washington, D.C.

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ABSTRACT

The District Department of Transportation and the District of Columbia Office of Planning recently led a research effort to understand how parking utilization in multi-family residential buildings is related to neighborhood and building characteristics. Prior research has shown that overbuilding of residential parking leads to increased automobile ownership, vehicle miles traveled, and congestion. Parking availability can affect travel mode choices and decrease the use of transportation alternatives. In addition, zoning regulations requiring parking supplies that exceed demand can increase housing costs and inhibit the development of mixed-use, mixed-income, pedestrian-friendly neighborhoods. The primary research goal is to develop an empirical model for parking utilization in Washington, D.C. and to apply the model to an interactive, web-based tool, named ParkRight DC, to support and guide parking supply decisions. A transparent, data driven process for parking supply decisions may help relieve problems associated with over- or under-supply of parking. This paper outlines the data collection, model development process, functionality of the resulting tool, and findings on key relationships and policy implications. The model and associated tool relies on local information reflecting residential development and auto ownership patterns drawn from a survey of multi-family residential parking use at 115 buildings covering approximately 20,000 dwelling units in the District. The resulting model achieved an R-square of 0.835, which is a very strong model given the complexity of the relationship being researched.

INTRODUCTION: WHY PARKING MATTERS

Prior research has shown that overbuilding of residential parking leads to increased automobile ownership, vehicle miles traveled, and congestion. Parking availability can affect travel mode choices, increasing single-occupancy vehicle use and decreasing the use of transportation alternatives. In addition, zoning regulations requiring parking supplies that exceed demand can increase housing costs and inhibit the development of mixed-use, mixed-income, pedestrian-friendly neighborhoods. Evidence-based information to guide the development review process and help planners and developers optimize the number and price of parking spaces provided could help avoid problems associated with over- or under-supply of parking.

Residential parking demand has long been a contentious issue in Washington, D.C., with development proposals often generating passionate arguments by citizens concerned about parking spillover that would reduce the availability of on-street parking (as well as traffic impacts, generally). Residents often do not understand the potential societal cost of providing over-parked developments, including increased housing costs and traffic impacts. Quite simply, one of the most effective transportation demand management (TDM) measures is providing appropriate supply for vehicle storage.

This issue is not unique to D.C. In many cities, concerns regarding new development impacts are often focused on impacts to residential parking availability and parking cost *(1, 2, 3)*. Discussions of parking are particularly passionate and divisive. Various stakeholders come to the discussion armed with assumptions and biases and are rarely informed by empirical parking data due to the lack of available parking utilization resources. By providing a robust, data-driven parking utilization model and publicly-accessible web-tool, this research promises to generate better-informed discussions of parking. This study focuses on researching and developing relationships between parking utilization and other factors, in support of efforts to use scarce resources more efficiently and minimize the over-provision of parking.

The Impacts of Space Devoted to Parking

Parked cars require a substantial amount of space. An on-street parking space may require between 144 and 200 square feet (sf). Off-street surface parking requires access lanes and ramps. Thus each space in a surface parking lot consumes between 300 and 350 sf. Structured above- and below-ground parking requires additional space for structural supports, stairs, and possibly elevators *(4)*.

Parking regulations shape development so that walking, cycling, and transit are less convenient when space devoted to surface parking spreads out destinations. This amplifies auto ownership, driving, and parking needs. An oversupply of parking can damage natural landscapes through urban sprawl, increase impervious surfaces, and add to greenhouse gas emissions *(5)*. In an urban context, where land prices are sufficiently high, the surface space required for parking is reduced through the creation of above- or below-ground parking garages. This has price implications that are discussed below.

The Impacts of Parking Cost

Growing demand for residences and commercial space in some cities is running up against requirements for on-site parking. To the extent that parking is not needed as much by new residents and employees, parking requirements needlessly add to the expense of urban development *(6)*. The cost of constructing parking, exclusive of land costs, may be around $10,000 per space for surface parking lots and up to $30,000 per space for underground structured parking *(7)*. To this must be added the cost of land, the cost of operations, maintenance, rehabilitation and replacement, and the foregone net revenues from alternative uses of the land devoted to parking. JBG, a District-area developer, estimates the cost of un-leased parking spaces in a below ground garage to be $480 per space per month (for a $50,000 space). At the same time, the market rent for a space in the U Street area is $221 per space per month. Thus, even market-rate parking fails to cover costs and appears to be subsidized by others (*8*). Unless parking costs are separated from the cost of housing – “unbundled” – households are forced to pay for parking regardless of their needs. Even when parking costs are unbundled, developers often cannot charge the full cost recovery price for parking in a competitive housing market *(9)*.

HOW DO WE KNOW HOW MUCH PARKING TO PROVIDE?

Existing resources for guiding parking provision decisions are incomplete or unsuited for application to urban areas such as D.C. Typically, decisions about how much parking to provide rely on the Institute of Transportation Engineers’ (ITE) informational report, *Parking Generation (10)*. The information gathered from ITE tends to be from auto-dependent suburban locations that do not apply well to a vibrant urban area with many modal options.

The ITE report emphasizes it is intended as an informational report and not as a manual, recommended practice, or standard; and that local conditions need to be carefully considered. The Urban Land Institute’s (ULI) book, *Shared Parking*, is a complementary, commonly cited resource for mixed use development parking supply setting, and includes a solid set of principles for considering parking needs of mixed use developments *(11)*. However, as with the ITE report, development context needs to be carefully considered, and the case studies in the ULI book primarily are oriented around town-center-style suburban developments.

Evidence From Literature

Several recent studies have highlighted the oversupply of parking in multifamily residential developments. Most of these studies have assessed parking supply and demand in transit-oriented developments (TODs) or different types of development centers to help ascertain the relationship between development density and multimodal access with parking utilization.

To build evidence that TODs are over-parked, Cervero et. al. looked at 31 multi-family residential housing complexes within 2/3 of a mile of rail transit in Metropolitan Portland and in the East Bay of the San Francisco region. The research uncovered that the average amount of parking built for all projects was 1.57 spaces per unit, notably above the ITE’s rate of 1.2 as well as the average observed demand of 1.15 *(5)*. Further research into the mismatch between parking supply and demand at TODs in the Bay Area found that on average, only 1.3 spaces per unit were occupied during the period of peak demand while 1.7 spaces were supplied *(11)*. A comparison of multifamily buildings at an urban and suburban center in King County, WA found an oversupply of parking at both locations, with greater excess at the suburban location (0.58 spaces/unit) than the urban one (0.22 spaces/unit). Additionally, demand was less than the ITE rates at both types of centers, but the difference was more dramatic in the urban center where observed demand was about half of the ITE rate *(12)*.

Additional research in King County as part of the Right Size Parking Project confirmed these findings. The results of the data collection indicated that in the central business district, parking supply averaged 0.8 spaces per residential unit, while utilization averaged 0.6 vehicles per occupied residential unit. This pattern repeated itself in urban and suburban settings resulting in a countywide average supply of 1.4 spaces per residential unit, while utilization averaged 1.0 vehicles per occupied residential unit *(13)*.

Even with this compelling research, a lack of consensus remains on factors that drive demand for parking and account for the variation in auto ownership in multifamily buildings particularly in urban locations. Thus, a need remains to develop context appropriate information for the development types and unique urban form found in D.C.

Evidence From Practice

Parking minimums associated with zoning became commonplace as zoning spread across the country in the first half of the 20th Century. The first parking requirements in the District were established in 1942 through the “District of Columbia Motor Vehicle Parking Facility Act” adopted by the U.S. Congress. Less than a month later, D.C. adopted an amendment to its zoning regulations calling for compulsory off-street parking. In 1956, Harold Lewis, a New York planning and zoning consultant, recommended a major zoning overhaul, including stricter parking requirements to better meet current and future demand *(14)*. For example, the Lewis Plan cited the need to require off-street parking for all new development hoping for “…the eventual removal of curb parking and the subsequent freeing of the traffic arteries” and anticipating a deficit of tens of thousands of parking spaces throughout the District *(15)*. The Zoning Regulations that went into effect in May 1958 adopted most of Lewis’ recommendations. The basic structure of the regulations has been in place since then, with some significant amendments over the last five decades. More recent amendments include parking requirements being relaxed for redevelopment of historic properties, development near Metrorail stations, and for developments that employ various TDM strategies. These requirements still remain higher than many advocates claim is necessary. Existing off-street parking requirements can be found in the D.C. Municipal Regulations (DCMR), Title 11, Chapter 21.

Changing demographics and behaviors make it difficult to predict how much parking is truly required today. Although the District’s population is rising, vehicle miles traveled per capita has been declining since 1996. Additionally, between 2010 and 2012, the number of car-free households in D.C. grew by 12,612 - representing 88% of new households citywide. During that time, the share of car-free households in D.C. increased from 35% to 38%, second only to New York City *(16)*. These trends indicate less parking may be needed. For developers, the “right” amount of parking has to do with the tradeoffs of the marketability of units based on how much parking a renter or buyer wants to lease or buy, the cost of building the parking, and the potential of a non-car owning market. In costly urban sites that are walkable and well served by transit, developers tend to want to build only enough underground parking to satisfy a demand for parking even where demand is low.

In practice, developers and their bankers and prospective retail tenants provide much direction on parking decisions. Since the 2008 recession, there is some evidence that developers are increasingly scrutinizing the size of their parking facilities as a way to cut costs and that bankers have become less insistent on ample parking when making financing decisions. There are many recent local examples in both the commercial and residential markets that certainly help justify the need for a better understanding of parking utilization.

Bankers, developers, and retailers who have experience in suburban settings may find it difficult to estimate parking requirements in a transit-friendly and pedestrian-friendly urban environment. For example, a development in Columbia Heights in D.C. included some larger stores that had not yet typically established urban locations. Although parking requirements for this location were set at about half of suburban requirements, actual parking utilization has been about one quarter of those requirements. Though vehicular travel to this shopping complex is light, patronage has been robust, with higher-than-expected sales tax revenue allowing municipal bonds that financed the parking garage to be retired 15 years ahead of schedule (*17*). Excess parking has been constructed in some new residential buildings as well. For instance, apartments in a new rental building near Union Station, are fully leased but only 60% of the parking spaces are leased *(17)*.

A NEW APPROACH – THE RIGHT SIZE PARKING MODEL

Innovation Leader: King County, Washington

Noting the negative impacts caused by over-parking and the lack of resources to better inform parking provision decisions, King County Metro Transit undertook the Right Size Parking project to address this gap. The project developed models and a website to estimate parking demand and associated impacts in multifamily residential developments in urban and suburban infill environments.

The project collected data from multifamily residential building in areas where multifamily residential development is likely and zoned for. These areas include downtown areas, TODs, and more suburban locations with all-day transit service *(18)*. These areas encompass approximately 270 square miles of the 2,115 square miles in King County.

A total of 223 buildings surveyed. Place-based statistics such as residential density and block size were tracked to ensure adequate diversity. The survey collected information about the building and parking facilities were visited within the designated time period (12am-5am) in order to count the number of occupied stalls.

208 buildings were used in the final regression. Many variables were tested in the regression analysis both from and urban form perspective as well as building characteristics. The final regression equation (having an R-square of 81%) used seven independent variables to estimate parking utilization *(9)*. These are in order of decreasing significance:

- Gravity Measure of Transit Service Frequency,
- Percent of Units Designated Affordable,
- Average Number of Bedrooms per Unit,
- Gravity Measure of Jobs plus Population in the Surrounding Neighborhoods,
- Unit Size,
- Average Rent, and
- The Price Charged for Parking.

Using this robust model as the engine for the website calculator allows users to estimate parking utilization for a given building on any parcel in the developed part of King County.

Why Washington, D.C. Requires a Revised Approach

There are many lessons learned and applicable outcomes of the King County approach that translate to the D.C. context. Seeing the value of the tool, DDOT and OP assembled a team including many of the same technical experts involved in the King County project to research the local context and customize the tool. Early in the development of the D.C. approach, the team recognized that the D.C. context required a rethinking of the research approach and anticipated use of the tool. Critical context considerations included:

1. Smaller geographic area and much higher development density. D.C. is only 61 square miles compared to 2,115 square miles for King County. Population and housing unit density are both over 10 times higher in D.C. compared to King County (9,865 persons per square mile compared to 913 persons per square mile).
2. Parking demand in D.C. is significantly lower than King County, in part a result of higher density, greater mix of uses throughout D.C., and an expansive transit system.
3. D.C. is more uniformly urban than King County. As such, the data collection process would show less diversity on neighborhood context related variables. Sensitivity to these types of variables within the model and ultimately the tool was expected to be more subtle.
4. Curbside parking is a scarce resource and a recurring political issue throughout much of D.C. The balance between the use of private, developer provided parking, and on-street parking managed through D.C.'s residential parking permit program is a unique variable for consideration in this model.
5. Stakeholders who will utilize the tool represent a broader audience. Unique to the District are the Advisory Neighborhood Commissions (ANCs). ANCs are the body of local government with the closest official ties to the people in a neighborhood and are directly involved in the development review process. ANCs consider a wide range of policies and programs affecting each neighborhood, including traffic, parking, and zoning, and ANC positions on parking relief requests are given "great weight" by the District's zoning bodies.

THE IMPORTANCE OF THE LOCAL DATA COLLECTION PROCESS

Development of a model reflecting the unique characteristics of multifamily housing in D.C. required a robust data collection and survey process. The project's initial goal was to collect data at 100 to 120 multifamily residential buildings. Because of the District's compact geography and relatively homogeneous levels of transit access, fewer sites than King County were needed to establish a representative sample.

Site Identification and Screening

The project first identified properties controlled by major developers and property management companies to maximize the outreach efficiency. These sites were screened for a variety of factors, including: (1) the presence of off-street parking; (2) the sufficiency of the off-street parking supply, to remove sites with a high potential for spillover to on-street spaces; and (3) development size, with a cutoff of ten occupied units. Building occupancy was not considered as a separate factor, although newer buildings were given several months to lease up so parking demand stabilized.

The resulting sites were compiled in a database and mapped. Underrepresented neighborhoods and corridors were scrutinized using field visits and online mapping services to identify additional properties. The database was updated throughout the process to ensure the collected sample contained sufficient geographic breadth across the District and compositional depth of the different sizes and types of residential buildings found in those neighborhoods.

Approval and Data Collection

The team contacted each property's ownership for approval to conduct the count and receive contact information for the properties' managers. Responses to these requests were mixed but over time enough willing participants were found to fill out a representative sample of properties.

Once corporate approval and property manager contact information were received, the count team scheduled a time to collect building information. This interview covered basic parameters for use as potential independent variables in the model (Figure 1). The interview also was used to arrange site access for the overnight parking occupancy count, conducted at a later date between midnight and 5:00 AM on a typical weekday.

The resulting sample included 115 buildings collected during spring and summer of 2014 and 2015, of which 13 had no parking. These zero parking sites were collected in order to gain an understanding of building parameters, relative to sites with parking. The 115 buildings covered 20,541 dwelling units, 19,223 of which were occupied (94%), representing approximately 18% of the District's apartment stock *(19)*. Condominium buildings were less likely to participate, meaning the sample consisted largely of apartments.

District of Columbia **Residential Parking Study** — Field Data Form

<u>Property Managers</u>: The first phase of the DC RPS consists of an on-site interview to collect information about your building and its parking policies, covering the questions in Sections 2-5 below. To streamline the process, please have any relevant information handy during the interview. The project team will collect the data covered in Section 6 during a subsequent overnight count.

Site and Contact Information (to be completed by project team)

1.1. Building Name		1.5. Management Corp.	
1.2. Street Address		1.6. Site Contact Name	
1.3. Parcel ID Square:	Lot:	1.7. Site Contact Title	
1.4. Parking Study Site ID		1.8. Site Contact Email	
		1.9. Site Contact Phone	

Building Information

2.1. Year Constructed		
2.2. Total Residential Square Footage	sf	*including common areas, storage, mechanical rooms, etc.*
2.3. Number of Building Floors		*including occupied basements but not below-grade garages or storage*
2.4. Non-Residential Uses in Building		
2.5. Are any Transportation Demand Management strategies used on site?		
Bicycle Facilities	yes / no	If yes, list:
Transit Information	yes / no	If yes, list:
Transit Benefits	yes / no	If yes, list:
Carshare or Bikeshare Subsidies	yes / no	If yes, list:
Other	yes / no	If yes, list:

Unit Information

3.1. Unit Occupancy Total Units:	Occupied:	Vacant:
3.2. Unit Designation	Condo Units (owner- or renter-occupied):	Apartment Units:
	# of Affordable Units (breakout below):	# for Senior Housing:
3.3. Classification of Affordable Units *Based on DC Housing Production Trust Fund (HPTF) designations*	# Low Income (51-80% AMI):	
	# Very Low Income (31-50% AMI):	
	# Extremely Low Income (0-30% AMI):	

Unit Classification and Cost	Total	Studio/Eff	1 BR	2 BR	3+ BR
3.4. Number of Owner-Occupied Condo Units					
3.5. Average Size of Condo Units (square feet)	--				
3.6. Average Sale Price of Condo Units (current going rate)	--	$	$	$	$
3.7. Number of Apartment or Renter-Occupied Condo Units					
3.8. Average Size of Rental Units (square feet)	--				
3.9. Average Monthly Cost of Rental Units (current going rate)	--	$	$	$	$
3.10. Number of Vacant Units					

FIGURE 1 Interview form used in study, showing collected data for each site.

District of Columbia **Residential Parking Study** — Field Data Form

Parking Information

4.1. Total Number of On-Site Vehicle Parking Spaces ______ *not including loading berths*

# of spaces designated for residential use	On-Site: ______	Off-Site: ______
# of spaces designated for other users (on-site only)	Visitors: ______	Service Vehicles: ______
# of spaces designated for small vehicles	Compact Vehicles: ______	Motorcycles/Scooters: ______
# of spaces designated for cooperative vehicles	Carpool or Vanpool: ______	Carshare Vehicles: ______
# of spaces designated for nonresidential uses	Exclusive Use: ______	Shared with Residential: ______

4.2. Number of Bicycle Parking Spaces Private (bike room/pen in lot/garage): ______ Public (on-street): ______

Note that the capacity of different rack types varies: a) inverted-U or ring-and-post racks hold 2 bikes, b) wave/ladder racks vary by length, c) bike room systems like vertical mounts hold 1 bike each. Do not count trees, signposts, parking meters, etc.

4.3. Are tenants observed or known to park on-street overnight? yes / no If yes, estimate how many cars: ______

Parking Costs

5.1. How do residents pay for vehicle parking? A: parking is free or bundled with rent or condo fee / B: separately deeded (condos) or unbundled (rentals), provide cost below

5.2. Cost per residential parking space Monthly Cost (apt.): $ ______ Deeded Cost (condo): $ ______

5.3. How is residential parking enforced? unrestricted / pass or sticker / license plate checks / gate-controlled

5.4. Monthly cost per parking space for non-residents Hourly Rate: $ ______ Monthly Permit: $ ______

5.5. Where do non-residents or visitors park? ______

5.6. Other Comments ______

List special practices like perks (offering free or discounted parking for the first year, giving out extra visitor passes, etc) or special pricing schemes (higher price for a second parking space, higher price for parking within a garage/under cover, etc)

Field Data Collection (to be completed by project team)

6.1. On-Site Interview Conducted By: ______ Date: ______ Time: ______

6.2. Overnight Count Conducted By: ______ Date: ______ Time: ______

Count Results: Residential Vehicles Parked On-Site: ______ Residential Spaces: ______

Parking Configuration: Surface Lot: yes / no Structured (circle ABOVE or BELOW ground floor): yes / no

6.3. Quality Control Count Conducted By: ______ Date: ______ Time: ______

Count Results: Residential Vehicles Parked On-Site: ______ Residential Spaces: ______

Parking Configuration: Surface Lot: yes / no Structured (circle ABOVE or BELOW ground floor): yes / no

6.4. On-Street Parking on Adjacent Blockface(s) *estimated occupancy to be determined during overnight count*

	Road (or n/a)	**Residential Entrance?**	**Type of Parking**	**Estimated Occupancy**
North Side		yes / no	unrestricted / ___-hr Limit / metered / RPP / enhanced RPP	____%
West Side		yes / no	unrestricted / ___-hr Limit / metered / RPP / enhanced RPP	____%
South Side		yes / no	unrestricted / ___-hr Limit / metered / RPP / enhanced RPP	____%
East Side		yes / no	unrestricted / ___-hr Limit / metered / RPP / enhanced RPP	____%

(Figure 1 continued) Interview form used in study showing collected data for each site.

CRUNCHING THE DATA – WHAT THE MODEL SHOWS

The data collected on the 115 buildings were used to develop a similar model of parking utilization as in King County. Sites that were condominiums, or had owner occupied units mixed with rental, zero parking buildings, and buildings which have incomplete data from the survey were left out of the regression analysis for this paper. This leaves 92 apartment buildings which have complete data and are in the model. Figure 2 is a map of all 115 sites surveyed overlaid with the modeled value for parking utilization.

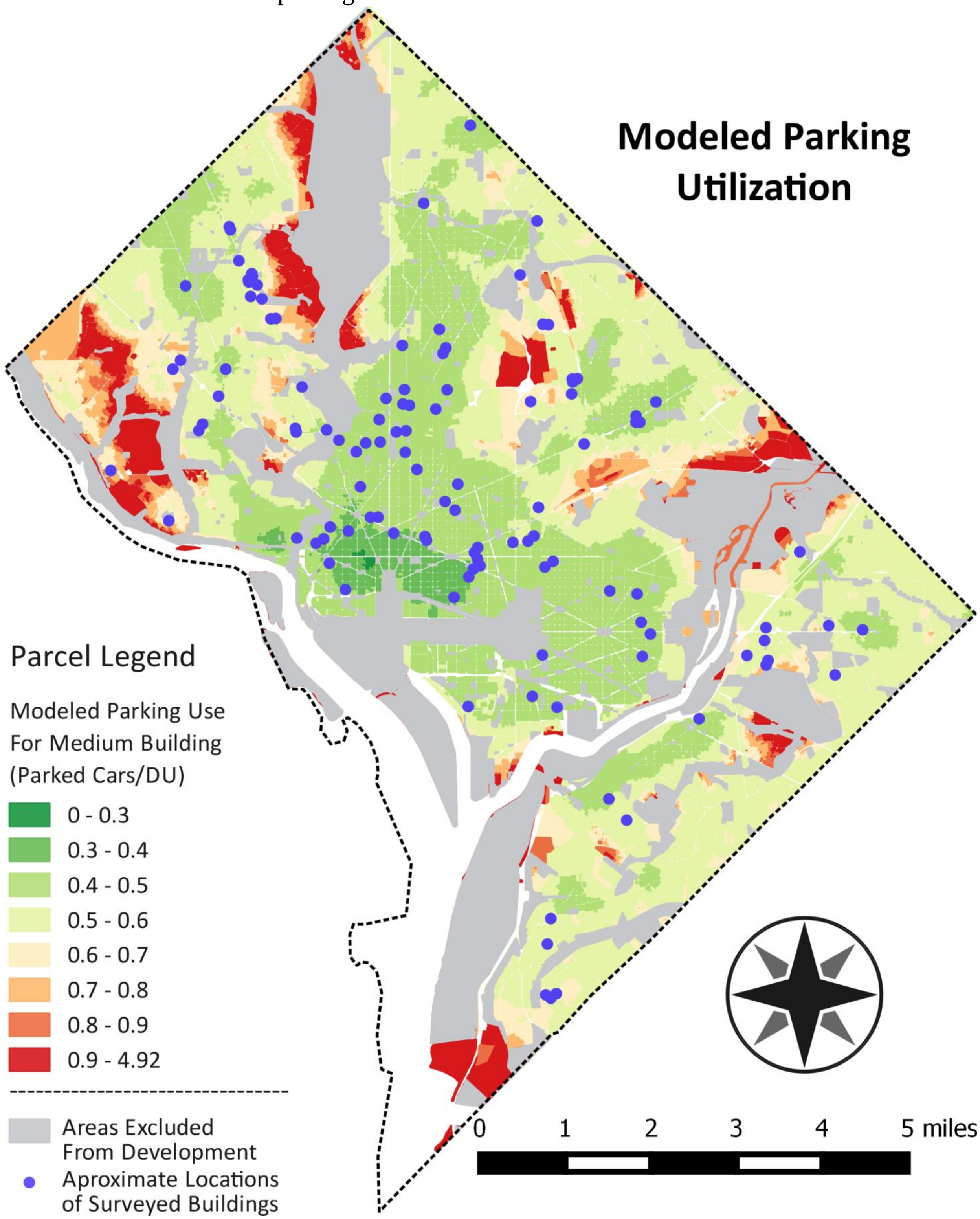

Figure 2 Approximate locations of surveyed buildings.

Across the surveyed sites, only 60% of the stalls are being used on average. Figure 3 shows an abundance of parking in these buildings, plotting observed parked cars vs. provided stalls. Data collection thus confirms that buildings appear to be oversupplied with parking.

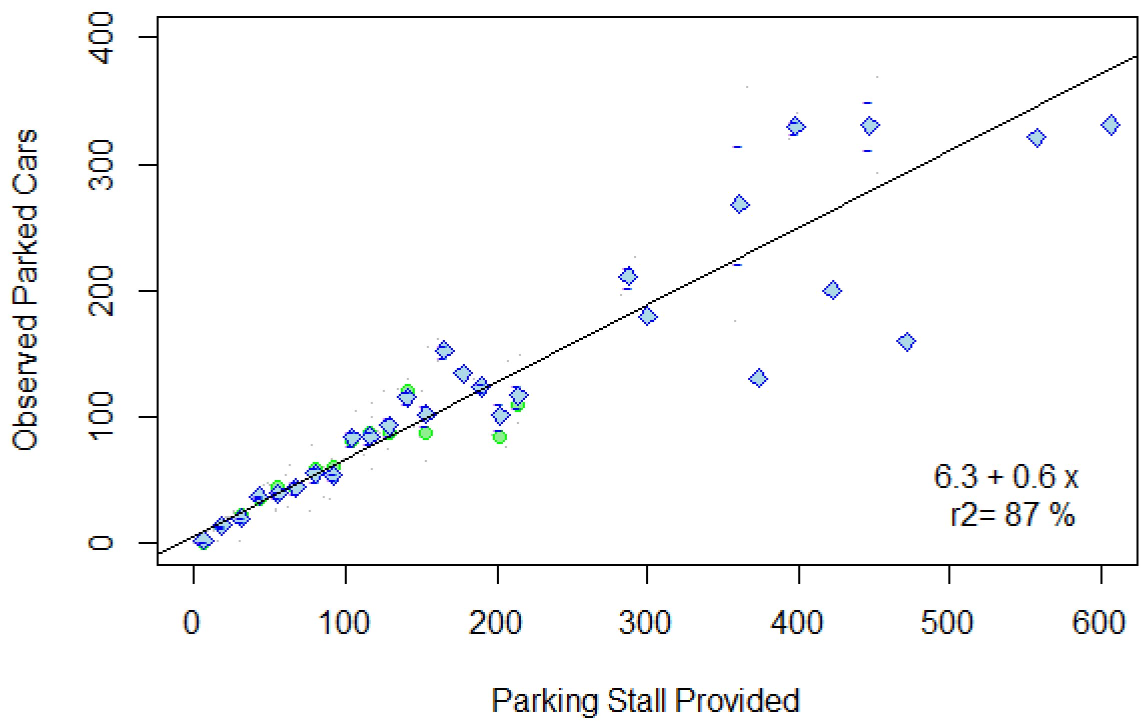

Figure 3 Parked cars versus parking stalls.

Table 1 lists the final variables used in the model and shows summary statistics of these variables for the 92 buildings used in the regression. The dependent variable for this regression is the observed parked cars per occupied housing unit in the building, or *parking utilization*. The independent variables were chosen to optimize both goodness of fit and predictability. The tested variables were grouped into two major categories, variables that describe the building and those that describe the surrounding neighborhood.

Table 1 Summary of Variables

Variable	Symbol	Description	Data Source	Transform Function	Min.	Avg.	Max.
Dependent Variable							
Parking Utilization	P_{use}	Observed parked cars per occupied housing unit in the building.	Survey and Site Visit	None x	0.166	0.44	1.125
Building Independent Variables							
Parking Supply per Unit	P_{supply}	Number of stalls provided divided by the total number of units in the building.	Survey	Inverse of Variable + 1 1/(1+x)	0.017	0.641	3.750
Transit Information	T_{inf}	Dummy variable set to 1 if there is transit information available.	Survey	None x	0	0.30	1

Variable	**Symbol**	**Description**	**Data Source**	**Transform Function**	**Min.**	**Avg.**	**Max.**
Fraction Affordable	F_{affd}	Fraction of units set aside for affordable housing.	Survey	None x	0	0.20	1
Average Unit Size	U_{size}	Average unit size (Sq. Feet) for all units in the building occupied or vacant.	Survey	Inverse 1/x	436.9 Sq. Ft.	758 Sq. Ft.	1113.0 Sq. Ft.
Parking Price	P_{price}	The average price charged for parking one car in the buildings parking facilities.	Survey	None x	$0.00	$123.88	$300.00
Average Bedroom per Unit	$U_{bedrooms}$	Average Bedrooms per unit reported for all units in the building occupied or vacant. Studio units we counted as one bedroom and units with three or more were counted as three.	Survey	Inverse 1/x	1.0	1.4	2.4
Average Rent	U_{rent}	Average Rent for all units in the building occupied or vacant.	Survey	Inverse 1/x	$639	$1,815	$3,345
Surrounding Neighborhood Independent Variables							
Block Size	B_{size}	Average size of all blocks that intersect a ¼ mile buffer around each parcel	Parcel GIS file from DCOP; US Census TIGER shape file.	None x	2.2 Acres	5.6 Acres	14.5 Acres
Retail/Service Job Density	J_{retail}	The number of employees working in these establishments was totaled for establishments within ¼ mile of the parcel. This total is then divided by the land area within this the ¼ mile area.	Employment location and number of employees from DCOP.	None x	0 Retail Jobs per Acre	6.8 Retail Jobs per Acre	45.2 Retail Jobs per Acre
Transit Trips per Hour per Acre	T_{walk}	Number of trips available within a ¼ mile for buses and ½ mile for rail using network distances, divided by the area (in acres) within a ¼ mile of the parcel.	CNT GTFS data for D.C. transit agencies, and Open Trip Planer.	Inverse of Variable + 1 1/(1+x)	3.63	16.75	62.56
Jobs by 45 Minute Transit	J_{45}	The transit commute time is determined from every block in DC to every Transportation Analysis Zone (TAZ). The numbers of jobs in the TAZs that are within a 45 transit trip are totaled to create this measure.	Parcel GIS file from DCOP, jobs in TAZs from the Metropolitan Washington Council of Governments, GTFS data for all transit providers in D.C. metro area, and Open Trip Planner.	Natural Log of 1 + Variable ln(1+x)	134,783	936,303	1,313,670 Jobs

The variables tested for building characteristics included bedrooms per unit, square feet of units, rents, parking supply, parking charges, and various amenities such as bike facilities, and access to car-share vehicles. In contrast to the King County model, the use of parking supply was employed in the model, and was found to be the variable that correlates most with parking utilization. Other building-related variables were found to be statistically significant as well, including average rent, average unit square feet, fraction of units dedicated for affordable housing, parking price, and if the building management provides information on the availability of public transportation.

The variables tested to describe the building's neighborhood included distance to transit amenities (both Euclidean and network), distance to car and bike sharing facilities, several walkability measures such as block size, intersection density, link to node ratio, population and employment intensity, transit frequency and connectivity, and adjacency to residential permit parking (as a surrogate for on street parking availability – this was not significant). The most significant neighborhood variable was walkability as measured by block size. Also included in the final model was the total number of jobs available by transit with a 45 minute transit commute, the number of retail and service sector jobs within close proximity and transit available in a walking distance.

Since all of the buildings surveyed were in an urban setting, the model testing approach was more nuanced than in King County. This quantitative research combines the building data with the neighborhood data to estimate an ordinary least squares (OLS) regression model of parking utilization. This approach considers all interactions between the independent variables. For example the transit trips per hour variable was correlated with parking utilization, but once walkability (measured by block size) and all the other variables were introduced into the regression it was found that the statistical significance was reduced to a level that would not include it in the final model. However, if transit trips per hour and block size were interacted then the interaction variable was found to meet the significance criteria of Pr(<|t|) greater than 15% (raised from the usual 5% to include this important interaction). All variables were interacted with other variables and the final model form was chosen so that all interacting variables meet the significance criteria. Equation 1 is the final regression equation; the colored backdrop on the map in Figure 1 show how this modeled parking utilization varies, by parcel, across D.C.

$$P_{use} = 1.47 - \frac{1.4}{\left(1 + P_{supply}\right)} - \frac{25 \times \ln(1 + J_{45})}{U_{size}} - 0.00006 \times P_{price} \times J_{retail} - \frac{20 \times J_{retail}}{U_{rent}} + \frac{0.028 \times J_{retail}}{\left(1 + P_{supply}\right)} - 0.008 \times F_{affd} \times \ln(1 + J_{45}) + \frac{323}{U_{bedrooms} \times U_{size}} + 0.06 \times B_{size} - \frac{0.08 \times B_{size}}{U_{bedrooms}} - \frac{0.9 \times T_{inf}}{T_{walk}} + \frac{0.08 \times B_{size}}{T_{walk}}$$

Equation 1 Regression Equation (See Table 1 for symbol definition)

Table 2 lists the variables in combination as well as the value of the regression coefficients and their standard errors. Using this flexible form has the advantage of finding significant combinations of independent variables; however, it does make the model somewhat more complicated to interpret. No longer are all the independent variables unrelated to one another. In order to understand the relationship of any single independent variable with parking utilization the other variables must be examined. Table 3 shows how the parking utilization estimate changes with a small change in each independent variable when the other independent variables are at their average value (from the surveyed buildings). This model gives an R-square of 83.5% and thus represents a very robust model, which is then used as the engine for the web-tool calculator.

Table 2 Final Fit Coefficients in Order of Decreasing Statistical Significance
(Increasing Pr(>|t|))

Variable 1	Variable 2	Coefficient Value	Coefficient Error	Pr(>|t|)
Intercept		1.47	.09	0.00%
Parking Supply per Unit	--	-1.4	.1	0.00%
Average Unit Size	Jobs by 45 Minute Transit	-25	7	0.08%
Parking Price	Retail/Service Job Density	-.00006	.00002	0.11%
Average Rent	Retail/Service Job Density	-20	6	0.13%
Retail/Service Job Density	Parking Supply per Unit	.028	.009	0.19%
Fraction Affordable Units	Jobs by 45 Minute Transit	-.008	.003	0.20%
Average Bedroom/Unit	Average Unit Size	323	104	0.25%
Block Size	--	.06	.02	0.27%
Average Bedroom/Unit	Block Size	-.08	.03	0.32%
Transit Information	Walkable Transit Trips/Day	-.9	.3	0.41%
Block Size	Walkable Transit Trips/Day	.08	.05	14.24%

Table 3 Derivatives and Point Elasticities by Independent Variable at Average Value for all Independent Variables

Variable	Avg. Value	Derivative*	Elasticity+
Building Independent Variables			
Parking Supply per Unit	0.641	0.44	0.59%
Transit Information	0.30	-0.052	-0.0339%
Fraction Affordable	0.20	-0.12	-0.048%
Average Unit Size	758 Sq. Ft.	0.00019	0.29%
Parking Price	$123.88	-0.00040	-0.10%
Average Bedroom per Unit	1.4	0.015	0.044%
Average Rent	$1,815	4.2×10^{-5}	0.16%
Surrounding Neighborhood Independent Variables			
Block Size	5.6 Acres	0.0077	0.090%
Retail/Service Job Density	6.8 Retail Jobs per Acre	-0.0016	-0.023%
Transit Trips per Hour per Acre	16.75	-0.00053	-0.019%
Jobs by 45 Minute Transit	936,303	-3.7×10^{-8}	-0.072%
*The **derivative** represents the chance in modeled parking utilization with one unit of change in the independent variable.			
+The point **elasticity** represents the percent change in parking utilization for a one percent change in the independent variable.			

MODEL APPLICATION: THE WEB-BASED TOOL

A primary goal in this study was to provide a tool to estimate parking utilization on a dynamic website to support and guide parking supply and management decisions. Given the relative complexity of the model, the tool allows end-users to view the model results in a simpler, easier to understand form. Tool development focused on displaying expected parking utilization throughout the District and considers the unique perspectives, experience, and concerns of three audiences typically involved in the process: the general public, zoning bodies, and the development community (including developers and real estate finance professionals).

Online Tool Functionality and Intended Use

The draft web-tool is shown as a screenshot in Figure 4 and is branded ParkRight DC. The research is condensed into a simple map where parking utilization for all developable parcels in D.C. is illustrated. The tool allows users to view estimated parking utilization for multi-family developments throughout D.C. The tool should not be viewed as a definitive answer. Rather, it should be seen as a resource to inform discussions, weigh the factors impacting parking demand, and help consider the proper provision of parking.

For any location selected, users are able to develop scenarios and view the influence on parking utilization by adjusting the model inputs. Unique aspects of the building and location specifications tab of the D.C. tool include options to:

- Develop a building scenario based on typical large, medium, and small buildings in the District and their parking specifications. Parking use for each typical building scenario are estimated based on study data. A custom option is also available allowing the user to enter unique building and parking specifications.
- Lock the building scenario to optimize supply. This case will return the optimal number of parking stalls needed to meet estimated utilization for the scenario.
- Lock the building scenario to the market parking price. This case will return the suggested parking price based on the scenario.
- Allow the user to note the presence of TDM information within the building, which when checked automatically adjusts estimated utilization downward based on data collected in the study.

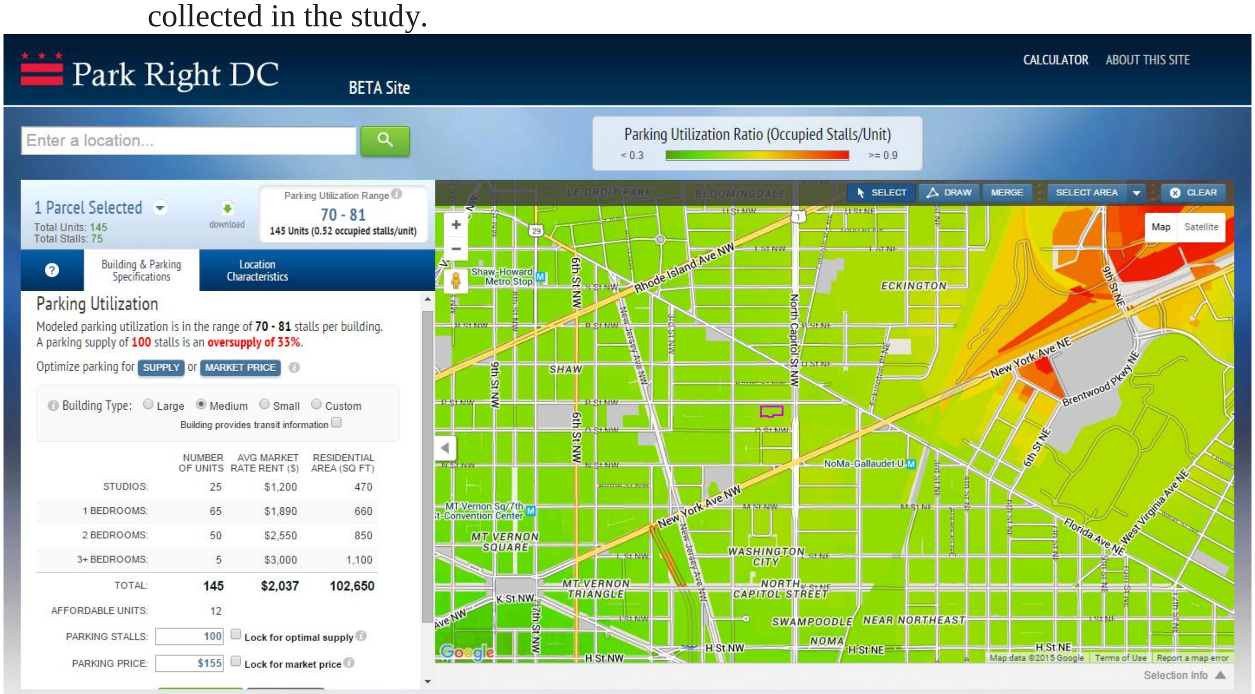

Figure 4 Screenshot of the ParkRight DC tool.

CONCLUSION

This effort provided valuable insight to DDOT and OP on factors driving parking supply decisions. Important findings include:

- On average, only 60% of parking stalls are being used.
- Parking supply was found to be the variable that correlates most with parking utilization, accounting for 66% of the variation in observed parking utilization. Other building variables were found to be statistically significant as well, including parking price, average rent, and unit size.
- The most significant neighborhood variable was a combination of walkability (measured by block size) and frequency of transit service within walking distance. As walkability and transit frequency increased, parking utilization decreased.
- The model achieved an R-square of 0.835 – indicating that the variables used in the model on average predict about 83.5 percent of the variance in parking utilization. This is a very strong model given the complexity of the relationship being researched.

Limitations

ParkRight DC intended to be a decision-support tool, not a decision-making tool. It can serve as a resource to inform discussions while users weigh the factors affecting parking use and consider how much parking to provide, but it cannot provide definitive answers about specific future policies or developments.

Real world parking use can and will vary from estimates produced by models. Several elements can affect parking utilization above or below the levels predicted by this model, including TDM and market segmentation. TDM plans can help reduce parking utilization by encouraging the use of non-auto travel and discouraging auto ownership. Additionally, a particular market target may have different parking utilization characteristics than the "average" resident the model and tool assume.

The model used in the web-tool is statistically very strong, but like all models, there exists error in estimates (the standard error for this model's estimates is 0.11). Data collection limitations also affect the model's accuracy. Observed parking mostly included supply that was off-street and on the same property, unless additional parking provided for residents was noted by property managers, and thus on-street parking supplies may not fully be taken into account. On-street parking utilization could not be accounted for in model development at this stage due to the lack of reliable on-street parking utilization information. However, the sites selected for the study were screened based on available parking supply in order to control for potential undersupplied parking that could result in spillover. The result was sites studied whose predominant parking could be measured through parking counts, rather than those where undefined off-site parking would have resulted in an underrepresentation of parking use.

To ensure confidence in the model estimates, only properties in DC are covered by this model. The data sample utilized covered a wide range of neighborhoods, but data collection was restricted based on a variety of factors. Some of these factors made data collection in certain parts of the District challenging, therefore the data collected is not necessarily a perfect representation of multi-family residential buildings in the District. Furthermore, because the model relies on data from existing buildings, it may not be representative of future buildings whose characteristics may differ or which may be located in new areas where few existing multi-family buildings are.

Applications

Together, the model results coupled with the web-tool can be used to better tie District policy and planning efforts to current trends in parking utilization. With this innovation there is now quantitative data to speak to calibrating the parking need with current demographic trends in the District.

This research will help improve the transparency with which DDOT is able to analyze potential parking demand from a development, which is often an area of concern among existing communities during the development review process. The research also facilitates understanding among the zoning bodies, community stakeholders, and the development community about parking assumptions to help all parties reach conclusions that best support community development and transportation goals.

The District has been updating the parking requirements in its zoning regulations. This subject has been controversial, and questions have been raised regarding the consistency of the requirements with actual levels of demand. DCOP's draft recommendations include eliminating, reducing, and/or providing greater flexibility in parking requirements in different parts of the District, and specifically near transit. This study will provide information needed to test and calibrate the new parking requirements as they are adopted and implemented, and may inform future policy changes regarding parking. A challenge is that parking utilization calculates *average* occupied parking spaces, which is different from zoning regulations that establish parking *minimums*. Accordingly, parking utilization rates cannot be directly applied to zoning regulations, but can still provide valuable guidance to inform future parking policy discussions.

Next Steps

While this research has contributed to the understanding of local parking utilization, future improvements will help further this research question. Refinements to the research include additional data collection, incorporating curbside parking utilization into the model, exploration of correlations with vehicular trip generation, refreshing the data used in model development on a regular basis, analyzing condominium buildings, and undertaking deeper comparisons to existing parking provision resources.

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