CHAPTER 3

How DDOT Did It

Creating the cost-saving asset-lite approach

3 How DDOT Did It

Developing a cost-saving 'asset-lite' approach to demand-based pricing took careful planning. Here is how DDOT streamlined the approach other agencies have taken to measure real-time occupancy, share real-time information with the public, and appropriately price parking.

3.1 PARKING OCCUPANCY DETECTION: STATE OF THE PRACTICE

Parking occupancy is the fundamental building block for implementing a demand-based pricing program. Jurisdictions around the U.S. (Chapter 1) have used a range of data sources to measure parking occupancy, including parking meter payments and in-ground sensor data. Based on lessons learned about the limitations and benefits of different parking occupancy data sources and collection methods, DDOT pursued an asset-lite approach that blended occupancy data derived from a limited deployment of sensors with data elements from various sources. To increase the likelihood of the asset-lite strategy being effective, DDOT changed to a pay-by-space on-street parking configuration and developed a modified user interface for the parking availability app.

Before developing the asset-lite approach, DDOT assessed the benefits and drawbacks of two key sources of occupancy data used by other jurisdictions: meter payments and sensors. To date, most jurisdictions have used one data source to the exclusion of the other. The results of the assessment revealed the benefits and drawbacks of this approach.

3.1.1 Payment Data

Parking meter payments may provide a useful source of parking occupancy data. However, they do not necessarily paint an accurate picture of occupancy. Payment compliance rates vary significantly from city to city—often due to varying levels of disabled placard use and abuse, parkers exempt from payment (like police and government vehicles), and poor compliance because of inconsistent parking enforcement. Within a city, payment compliance can be highly variable from block to block, within a block, or by time of day.

3.1.2 Sensor Data

Cities across the U.S. have experimented with on-street sensors to measure parking occupancy. There are many benefits from such installations, including the potential to guide vehicles quickly to available parking, to direct enforcement, and, most importantly, to enable informed decisions about meter rates and time limits. Key limitations of sensor hardware include the high costs, increased maintenance needs, and rapid turnover of sensor technologies.

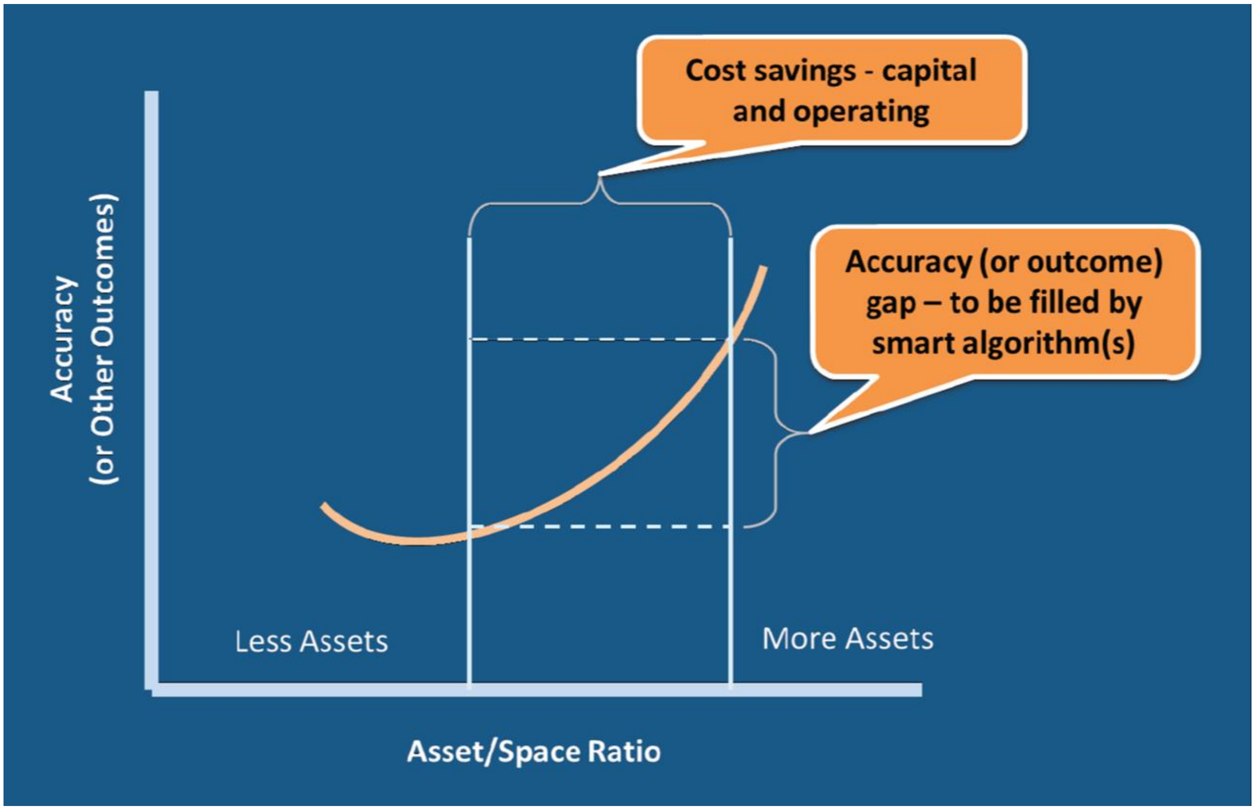
3.2 THE ASSET-LITE APPROACH

Rather than placing sensors in every parking stall or relying solely on meter payment data, DDOT tested the benefits of a blended approach of different data sources. DDOT posited that the pilot could reduce the number of sensors deployed by using meter payment data along with other data sources to extrapolate and fill gaps in the data, while also reducing the cost to operate the system. Reducing sensor coverage below 100% reduces data accuracy, but the effects can be mitigated through the following techniques:

- **Spatial sampling**, or observing only a fraction of the available spaces, and
- **Temporal sampling**, or observing blocks during different periods.

By fusing these sampling methods with payment data and other data from the parking ecosystem, like citations for metered parking, DDOT aimed to make accurate occupancy predictions in the pilot area and informed decisions about pricing (Figure 3-1).

Figure 3-1. The asset-lite approach aims to achieve the desired level of specificity in occupancy detection using fewer assets.



DDOT used a step-down method to identify the minimum viable product to meet the pilot's core needs, namely accurate parking occupancy predictions. The three steps are:

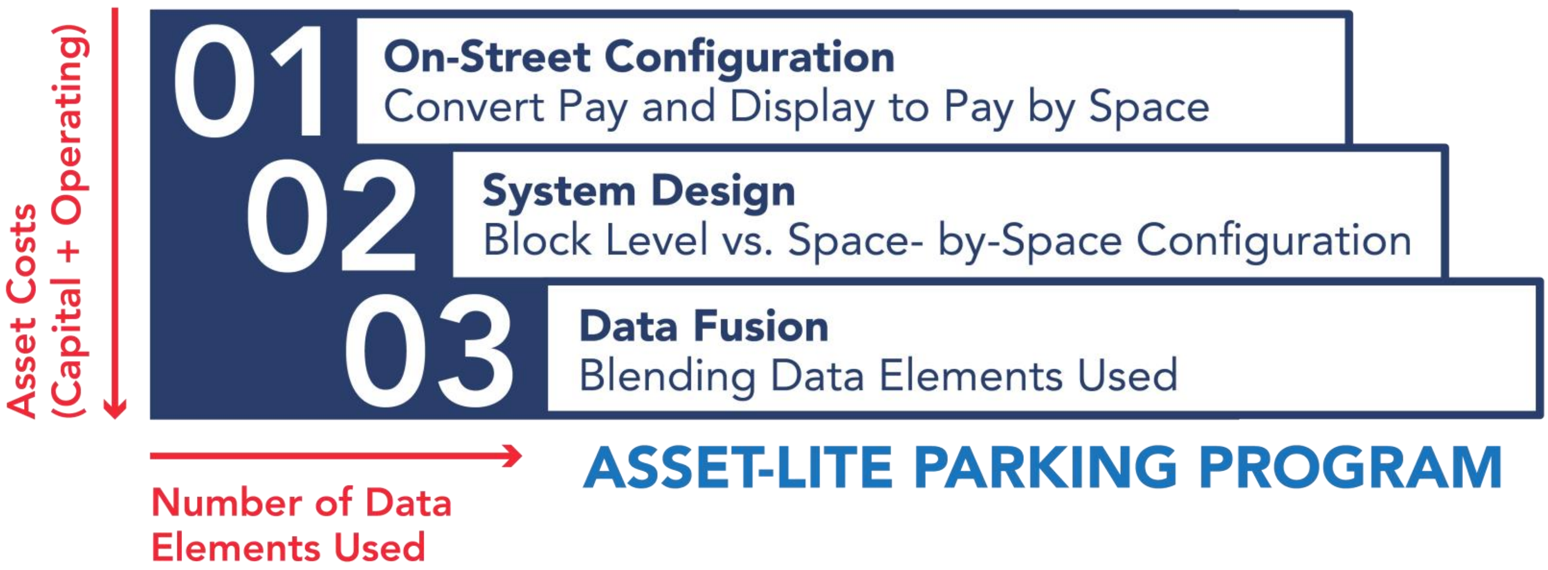
1. **On-street configuration**

2. **System design**

3. **Data fusion**

These three steps, shown in Figure 3-2, are discussed in more detail in the next three sections.

Figure 3-2. DDOT's step-down approach to monitoring and analyzing parking occupancy



3.3 STEP 1: ON-STREET CONFIGURATION

Since curbside parking is a finite resource it is imperative to design a system that informs the customer experience, promotes sustainability, and maximizes supply. With this in mind, DDOT chose to convert to a demarcated parking arrangement. Demarcated parking defines the parking stalls along the block with paint, poles, or single-space meters. Demarcating parking spaces fixes the location of vehicles along the curb and fixes the parking supply. These changes improve the accuracy and usefulness of occupancy data collected by sensors and meter payments.

DDOT converted the on-street parking configuration in the pilot area to demarcated parking using poles with space numbers on the sidewalk (Figure 3-3). The conversion to pay-by-space took place in May 2015 (Figure 3-4).

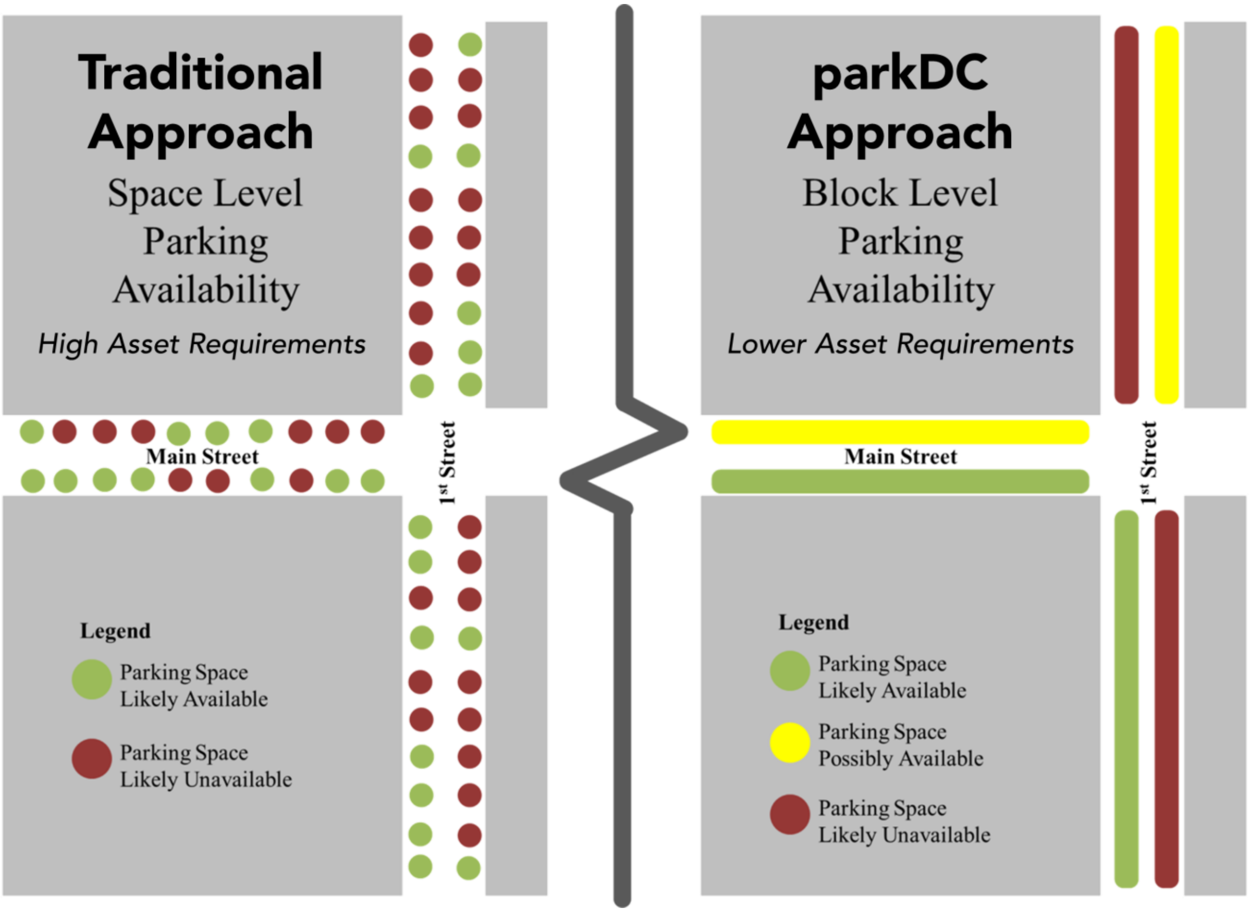
Figure 3-3 Space Demarcation Pole

Figure 3-4. Outreach materials for conversion to pay-by-space from pay-and-display

3.4 STEP 2: SYSTEM DESIGN

DDOT's asset-lite approach questions how thorough data needs to be to make reasonable predictions about occupancy. By understanding the purpose behind collecting occupancy information, DDOT could adjust the level of detail needed, resulting in a more cost-efficient, flexible system. To this end, DDOT decided to report parking availability by block rather than by space. By providing data on the likelihood of finding a space at the block level—which is good enough for a driver searching for an available parking space—DDOT reduced the accuracy requirement and consequently the number of assets needed. Figure 3-5 illustrates this concept.

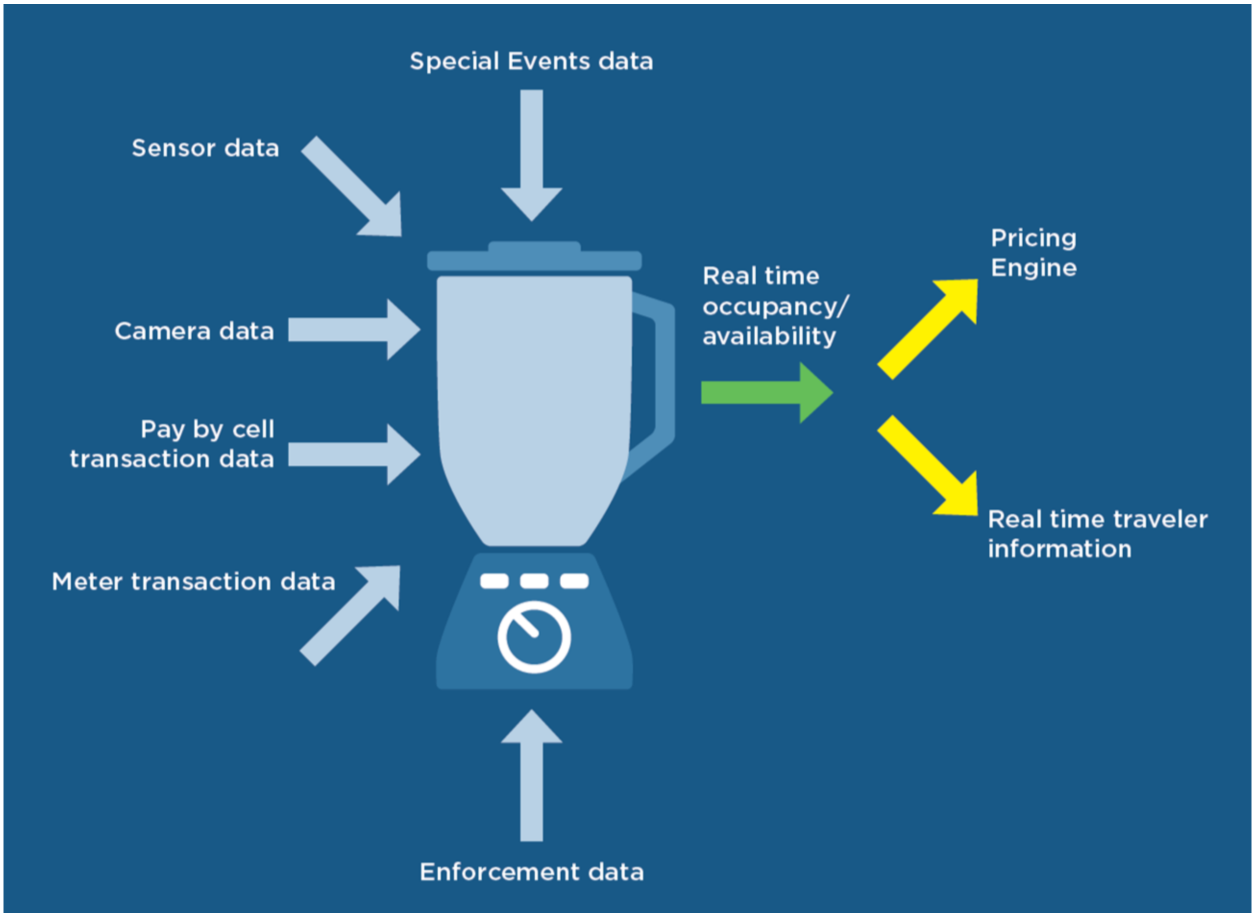
Figure 3-5. Block-level probabilities compared to space-level availability



3.5 STEP 3: DATA FUSION

The final step in the step-down approach helps DDOT meet the goal of the asset-lite approach: reducing the number of data collection devices that must be deployed by combining data from multiple sources. DDOT tested a variety of data sources to determine the optimal mix to predict real-time parking occupancy and inform both the pricing engine and real-time traveler information system for the pilot (Figure 3-6). By establishing which technologies performed best under various conditions and blending data from a variety of sources, DDOT was able to develop relationships and proxies, lowering costs and improving accuracy. More information on occupancy data and the data fusion methodology are found in the next two sections.

Figure 3-6. DDOT's mix of real-time and historic data sources



3.5.1 Data Fusion Approach

DDOT has worked to develop reliable occupancy data from multiple components of the parking ecosystem, including payments at networked parking meters, pay-by-cell transactions, temporal and spatial occupancy sampling, and parking citations. By leveraging a variety of data sources, DDOT can either supplement or supplant meter payment and sensor data to paint a picture of occupancy that allows for accurate rate recommendations and helps motorists find parking.

The data fusion approach relies on other data sources as stand-ins (data proxies) for the spaces without in-ground sensors and data analytics to predict occupancy. Here is how it works:

Phase I: Strategic Sensor Deployment

Temporal data collected using portable closed-circuit television (CCTV) cameras, time-lapse cameras, meter transactions and pay-by-cell transactions helped identify occupancy characteristics of on-street parking spaces by time of day and day of week. This information was used to develop a sensor deployment strategy that can provide highly-accurate real-time occupancy information about the whole study area. The pilot started with an assumed 50% sensor coverage.

Phase II: Refining Occupancy Information Derived from Sensors Using Data Fusion

DDOT's pay-by-space configuration paved the way to improve data collection and accuracy, making data fusion possible. The occupancy estimates from Phase I were combined with real-time data from other parts of the parking ecosystem to derive more refined and accurate occupancy estimates. The predictions were fine-tuned through an iterative, continuous process.

Phase III: Finding the Minimal Viable Sensor Coverage

During Phase III, DDOT ignored certain components of data to determine if they could accurately predict occupancy without them. DDOT found that the 50% sensor coverage established in Phase I provided the minimum viable coverage for the pilot area. No changes were made to the original pilot sensor deployment.

The results of the data fusion approach are discussed below.

3.5.1.1 Phase I - Strategic Sensor Deployment

Strategic sensor placement was key to the success of parkDC's asset-lite approach. DDOT used the following guidelines to ensure the best possible placement for the pilot sensors:

- **Determine the acceptable level of detail.** The occupancy estimates are utilized for two purposes:
    - Developing the pricing strategy
    - Informing the real-time parking availability app

  Of the two uses, traveler information requires a higher level of data accuracy because if the public does not trust that they will receive good information, they could potentially lose faith in the information provided. If travelers do not use the information provided, it cannot help alter behavior.

  As highlighted in Step 2 of the asset-lite approach, the requirements for accurate traveler information can be reduced by efficient interface design. Providing customers with block-level probabilities reduces the need for data about every individual parking stall.

- **Apply spatial and temporal sampling to gather high-quality occupancy data at reduced cost.** In spatial sampling, sensors or other detection devices are installed in only a fraction of the available spaces. Using models of spatial dependence (the tendency for nearby locations to influence each other and to possess similar attributes) at different locations, DDOT can calculate the expected error in occupancy predictions for any given sensor arrangement. DDOT used an algorithm to pick the sensor arrangement that best minimizes errors.

- **Test multiple sensor vendors to ascertain the best vendor for the District.** DDOT performed a technology assessment of two different sensor vendors. After determining both were acceptable, the study area parking spaces were divided between the two vendors using clustering algorithms to minimize communications infrastructure duplication.

The rest of this section provides more details of how DDOT used the guidance above to deploy the sensors using the following three steps:

Initial Sensor Testing → **Temporal Sampling** → **Sensor Deployment Algorithm**

3.5.1.1.1 Initial Sensor Testing

The study began by gathering data from seven block faces in the study area with 100% in-ground sensor coverage to test the sensors and to model and evaluate the effectiveness of sampling methods (Figure 3-7). A total of 50 in-ground sensors from two different vendors were assessed. Dome mounted sensors were also tested on five block faces in the study area. Outliers, such as known holidays, street closures, and special events, were removed and occupancy estimated using a fraction of the data. Those estimates were then compared to actual occupancy collected from portable CCTV cameras to determine accuracy. Through this process, DDOT verified that:

- Parking use in two spaces on the same side of a block is more likely to be similar than two spaces across the street from each other
- Occupancy in two spaces across the street from each other correlate more than two spaces on different block faces, despite the spaces being the same distance from each other

This finding is demonstrated in Figure 3-8 below. Because of this assessment, DDOT assumed that occupancy should be determined by block using data from that block. Space-level patterns helped DDOT identify strategic “indicator spaces” that provided a stronger indication of block-level occupancy than other spaces on their associated block faces.

Figure 3-7. Sensor installation locations for early sensor test

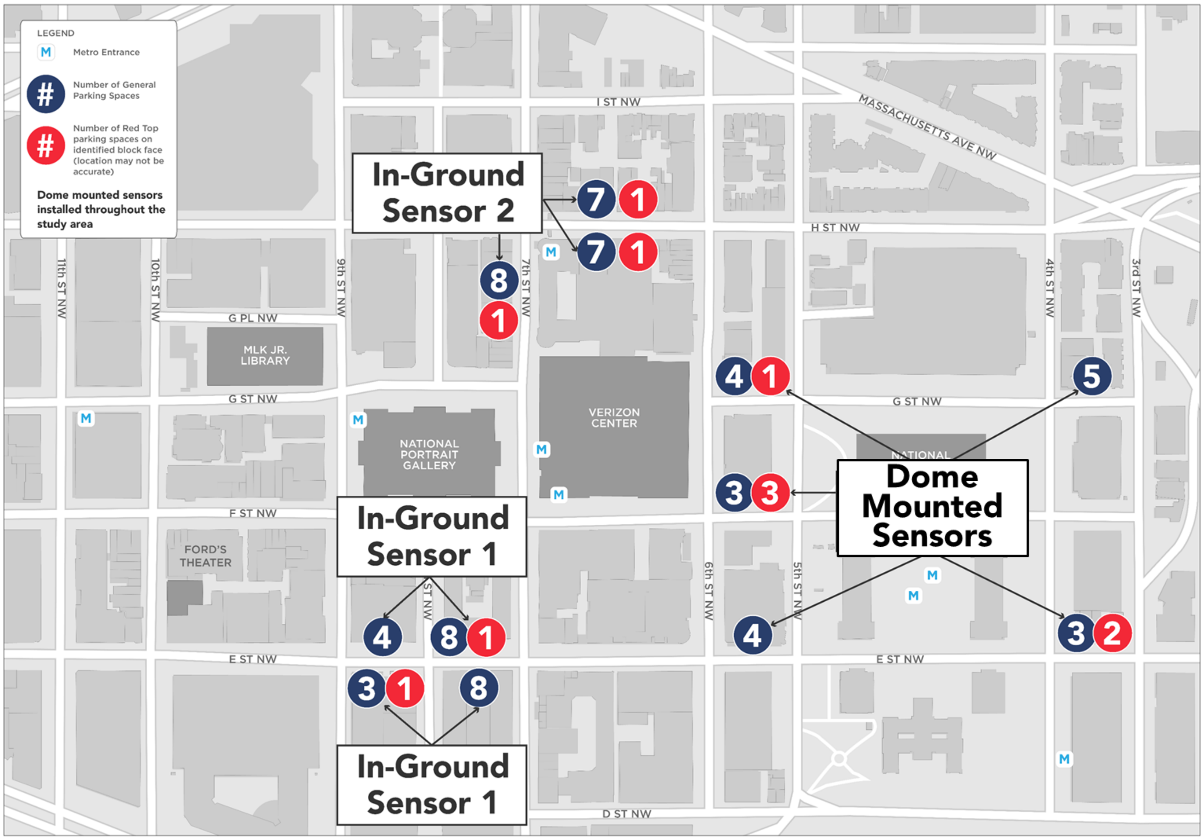
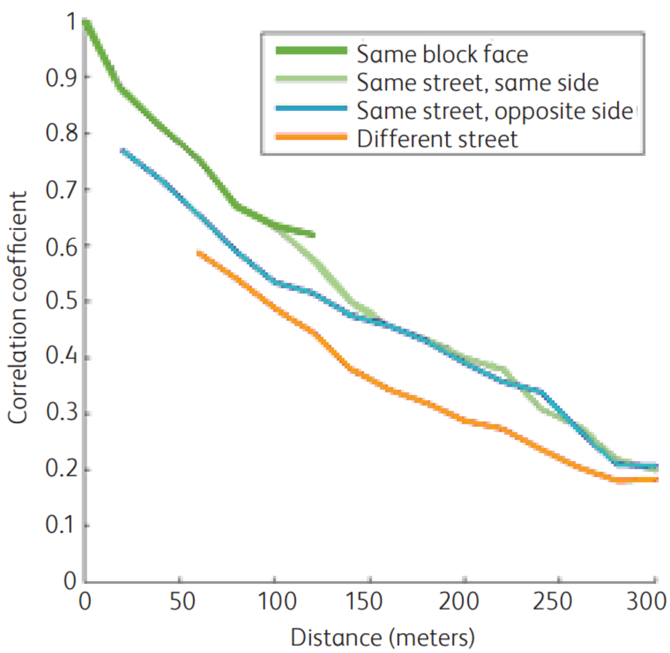


Figure 3-8. The spatial correlation between occupancy for pairs of stalls at different distances and with different relationships

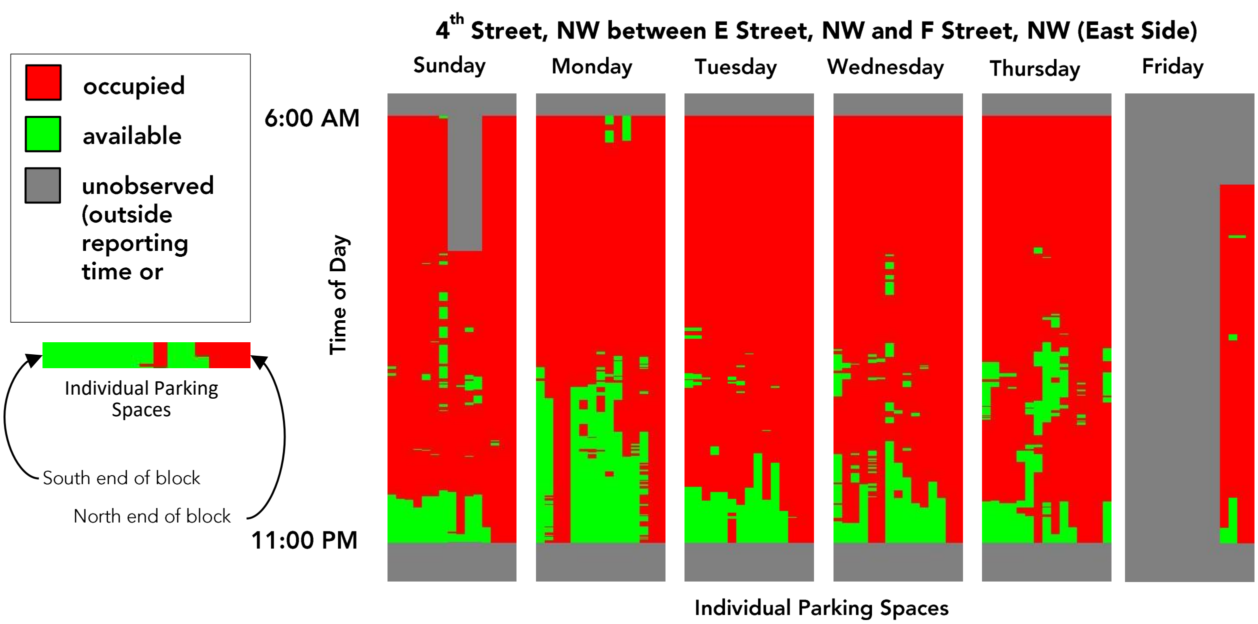


3.5.1.1.2 Temporal Sampling

To help determine the right location for each sensor, DDOT used temporal sampling from portable CCTV cameras analyzed with computer vision algorithms. Temporal sampling, or observing blocks during different periods, assumes that a block's past performance can help accurately predict future performance. 58 blocks were observed for a week each over 13 weeks using six mobile camera trailers. Data collection was prioritized on blocks at both the low and high extremes of paid usage, and blocks with large variations of paid usage. An example of the results of these observations are shown in Figure 3-9. As shown, red indicates spaces that are occupied, green indicates spaces that are available, and gray indicates unobserved usage, either due to being outside data reporting times (between 11:00 p.m. and 6:00 a.m.), or due to sensor communication issues.

Based on the assumption that occupancy can be determined by block using data from that block or immediately adjacent blocks, the CCTV data collection helped determine occupancy values for every parking stall in the study area. Groups of spaces on each block were examined to verify those that best represented the average occupancy on the block. This study led to the conclusion that DDOT could accurately predict occupancy on a block by placing fewer sensors on larger blocks with more curbside parking spaces and more sensors on blocks with fewer spaces.

Figure 3-9. CCTV results at a sample block face (right)

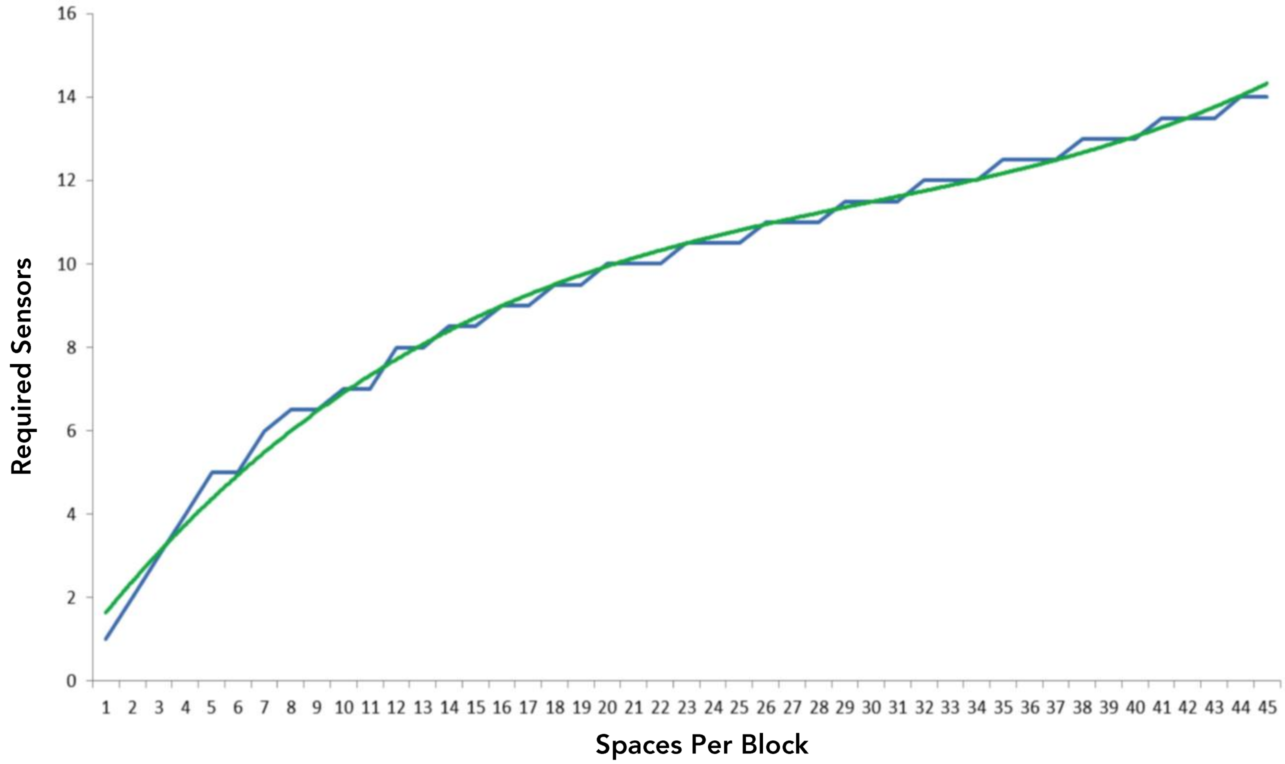


3.5.1.1.3 Sensor Deployment Algorithm

DDOT's sensor deployment algorithm ensured that the appropriate number of sensors was allocated on each block face to ensure the needed level of accuracy (Figure 3-10). DDOT also compared the fraction of occupancy during periods of high demand (greater than 90%) to low demand (less than 70%) and allocated additional sensors to those blocks where the difference was highest. The number of stalls requiring sensors were generally reduced when payments closely correlated to occupancy. In addition, sensors were also allocated to cover all eighteen Red Top Meters (meters reserved for persons with disabilities) in the pilot area.

> *There are 252 different ways to install five sensors in 10 stalls, and a huge number (close to a centillion) ways to install 450 sensors in 900 spaces.*

Figure 3-10. Sensor deployment algorithm



General business rules for the sensor deployment included:

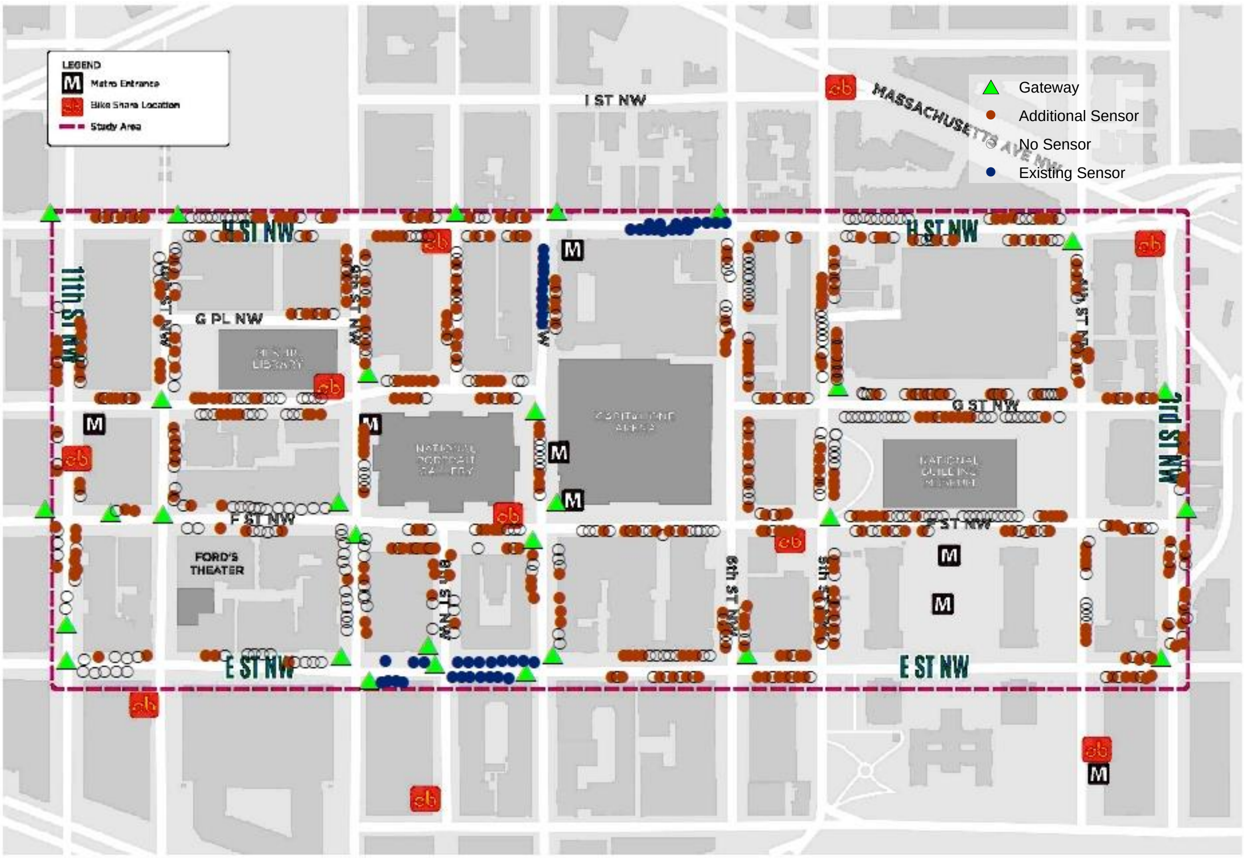
- Blocks with fewer spaces require a higher percentage of sensors
- Blocks with greater congestion require more sensors than blocks with fewer parkers
- Sensors are placed to maximize spatial coverage
- Percentage of coverage on a block depends on variability between spaces and on variability from day to day

After initially testing 50 sensors, DDOT procured another 450 sensors for an overall 50% sensor coverage in the pilot area.

DDOT sought to reduce the need for communications infrastructure and the related costs associated with the 450 new sensors and allocated sensors using clustering algorithms which grouped sensors from each individual vendor together. This methodology effectively minimized the distances between existing and new sensor installations. By accounting for existing sensors as well as the locations of wireless communications infrastructure in the final deployment strategy, DDOT required fewer antennae and reduced costs.

DDOT produced mapping files for the installation as represented in Figure 3-11 below and made minor changes during the installation process as required by construction and the occasional parking meter relocation.

Figure 3-11 Sensor Installation Map for Pilot Area



3.5.1.2 Phase II: Refining Occupancy Information Derived from Sensors Using Data Fusion

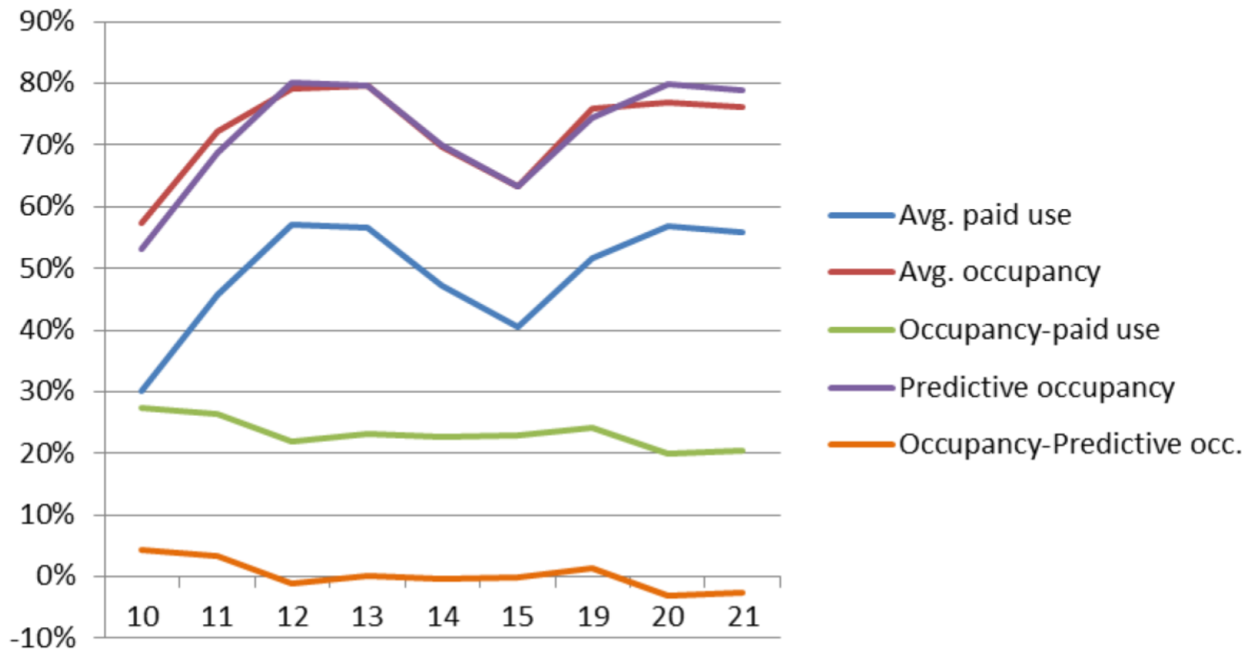
Spatial sampling on blocks with partial sensor coverage and temporal sampling at locations with minimum or no sensor coverage provide opportunities to further enhance predictive algorithms with the goal of fusing different data sources to estimate occupancy distributions. There are challenges associated with fusing data with different levels of coverage, speed of transmittal, and detail. However, when successfully done, it can improve occupancy estimates.

3.5.1.2.1 Increasing Accuracy of Predictions through Data Fusion

Figure 3-12 represents just how disparate data sources can be on a sample block. Paid use (the blue line), or the fraction of total time available for purchase across all spaces on a block that has been purchased, does not line up with actual occupancy captured via full sensor coverage and/or Portable CCTV cameras (the red line). By studying the difference between these values, DDOT was able to create a predictive factor (green line) that could be added back to real-time payments to predict occupancy (purple line). Using this technique DDOT found that the error in estimating the average occupancy at a given time-of-the-week is relatively low at 6.3% across the pilot area, and even lower (5.7%) on the block in question.

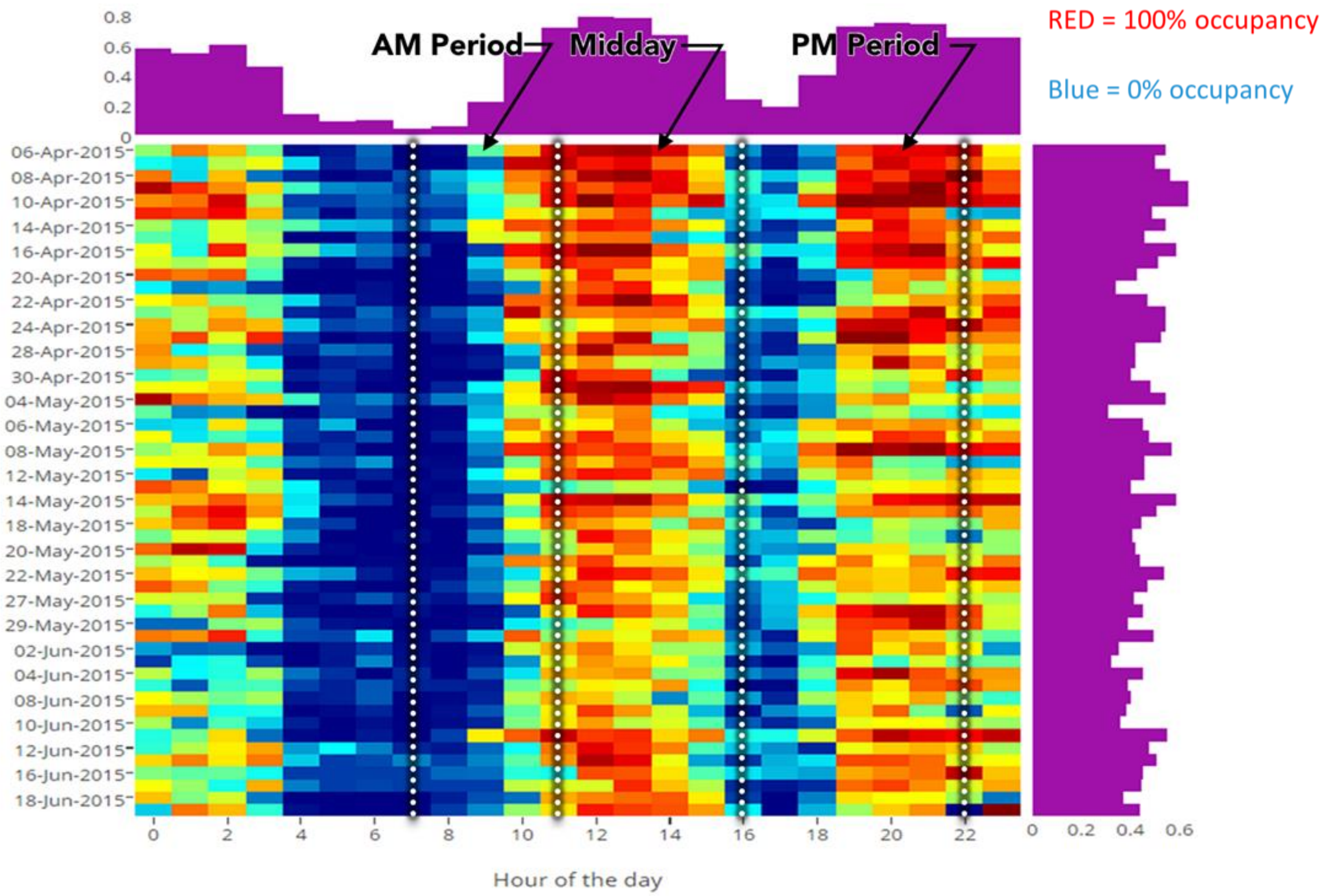
This analysis, however, fails to capture the true impact of illegal (unpaid) parking. Motorists illegally parking without paying negatively impact the relationship between paid use and occupancy. Historical parking citation data can help round out the picture. Each time a parking enforcement officer issues a citation for an expired meter, that citation represents an unpaid parker. By factoring illegal parkers into average paid use, DDOT achieved an even lower error of only 5.8% in the entire pilot area.

Figure 3-12. Predicting occupancy using historical payments



With the addition of sampled sensor data to payment and camera data, DDOT can make precise predictions for each block every minute of the day, every day of the week. Output from the sensors and cameras uncovers trends by space and by block, providing real data instead of anecdotes about parking and space use. Figure 3-13 provides an example of the analysis output, revealing critical information about hourly and daily use. Hourly use is demonstrated by the purple histogram on the top of the figure. Daily use is documented in the purple histogram at the right side of the figure.

Figure 3-13. Sample occupancy output from data fusion approach for one block face



3.5.1.3 Phase III: Finding the Minimal Viable Sensor Coverage

Building on Phases I and II, DDOT further merged spatial and temporal data to see if even greater reductions in sensor coverage would yield comparable results in the pilot area. For this study, the original 50% sensor coverage was deemed appropriate. DDOT plans to regularly revisit this Phase III assessment for this area and before deployment in other areas of the District. The constantly changing parking landscape requires ongoing refinement of occupancy predictions. Businesses come and go, sensors fail or are removed, events change parking patterns, and new technologies arise. Phase III bookends an iterative, nimble approach to evolving technology deployment, improving user-friendliness for system users and policymakers.

3.5.2 Technologies Used to Collect Occupancy Data

As part of the third step in the step-down approach, DDOT attempted to work out the best methodology for capturing high-quality occupancy data in the study area. The traditional method of collecting parking occupancy information is to count the number of vehicles parked on a block manually. Data collected in this manner is labor intensive, unreliable, not timely or scalable, and can require significant postprocessing data reduction. While DDOT has used manual data collection via mobile devices in neighborhood parking studies, this approach was deemed insufficient for the pilot. Instead, DDOT used manual data collection only for periodic validation of other methods and of the results of the data fusion process.

In searching for a better occupancy detection and prediction solution, DDOT conducted a thorough and wide-ranging technology assessment for on-street parking occupancy sensing. The technology assessment evaluated the feasibility of each technology in the District environment. The on-street occupancy detection technologies known to be available to DDOT at the outset are summarized in Table 3-1. *Further details on DDOT's hunt for the best occupancy detection technologies can be found in the Data Book.*

Table 3-1. Summary of Occupancy Detection Technology

Type of Methods to Detect Parking Occupancy	Advantages	Disadvantages	Deployed in parkDC Pilot?
In-Ground Sensors	▪ Can accurately detect vehicles ▪ Data available in real time	▪ High installation and maintenance costs ▪ Coordination needed with capital and maintenance projects, development projects, and snow removal operations ▪ Detection algorithms need to be adjusted to account for urban noise such as underground utilities, subways, and buses on curb lanes ▪ May not detect vehicles accurately in poor weather conditions (standing water, snow cover) ▪ Not portable; must be permanently installed in the ground ▪ Require demarcated spaces. Pilots in undemarcated areas have been unsuccessful	▪ Yes – 500 sensors were deployed over 1,000 metered spaces on 92 block faces, and 18 sensors were deployed at Red Top parking meters (reserved for persons with disabilities)
Dome-Mounted Sensors	▪ Can accurately detect vehicles ▪ Can be networked using same system as networked meters ▪ Can leverage assets	▪ May impact meter battery life ▪ May require changes to infrastructure (yoke redesign) ▪ Not portable; must be	▪ Yes – dome mounted sensors were installed to test technology but not ultimately used in the pilot

Type of Methods to Detect Parking Occupancy	Advantages	Disadvantages	Deployed in parkDC Pilot?
	already in place ▪ Data available in real time	installed within existing single-space meters ▪ Requires installation and maintenance costs ▪ Only work with single-space meter deployments; cannot use with multi-space meters	
Portable CCTV	▪ Measures space between cars and vehicle lengths ▪ Portable ▪ Potential to also provide vehicle classification and data from proximate travel lanes, including vehicle counts, vehicle speeds, bicycle, and pedestrian counts ▪ Spaces do not need to be demarcated	▪ High installation and maintenance costs ▪ May be prone to vandalism ▪ Moving and placing cameras can be difficult ▪ Privacy concerns ▪ Data reduction required, via algorithms that can detect cars or staff to review video. ▪ Shorter battery life than sensors ▪ Data may not be available in real time if data is stored locally	▪ Yes – six portable trailers featuring up to four cameras each provided data for 58 blocks at the outset of the pilot
Time-Lapse Cameras	▪ Cheaper, commercially available product Long battery life ▪ Portable ▪ Relatively small size ▪ Potential to also provide vehicle classification and double parking in nearby travel lanes	▪ Data is not available in real time ▪ Moving cameras can be difficult and require location for mounting ▪ Privacy concerns ▪ Data reduction required via algorithms that can detect cars or staff to review video.	▪ Yes – 15 time-lapse cameras deployed at loading zones in the pilot area for periodic monitoring
Fixed Camera	▪ Automated data reduction ▪ Measures space between cars and vehicle lengths ▪ Potential to also provide vehicle classification and data from proximate travel lanes, including vehicle counts, vehicle speeds, bicycle, and pedestrian counts	▪ Not portable ▪ Privacy concerns ▪ Requires accurate computer vision algorithms ▪ Requires data management, installation and maintenance costs	▪ Yes – Fixed cameras on 2 block faces to test technology

Type of Methods to Detect Parking Occupancy	Advantages	Disadvantages	Deployed in parkDC Pilot?
	▪ Spaces do not need to be demarcated		
Cameras with GPS	▪ Cheaper, commercially available product easily installed on a motor vehicle	▪ Data is not available in real time ▪ Privacy concerns ▪ Requires staff time to review, set up driving routes, and review video ▪ Urban canyon effect can hinder GPS data, GPS accuracy	▪ No
Manual Counts	▪ No need to invest in technology	▪ Accuracy is hard to verify ▪ Data is not available in real time ▪ Requires significant labor; generally, requires more labor costs than any other method	▪ Yes – manual counts conducted on 14 block faces in the pilot area and 10 block faces in a control area before and after pilot implementation
Payment and Citation Data	▪ Data available in real time	▪ Does not account for turnover, length of stay, exempt parkers, or illegal parkers ▪ Payment and citation data not always a good proxy for occupancy ▪ Requires data management costs	▪ Yes – payments from networked multi-space meters, single-space meters, and pay-by-cell mobile application specific to 900 spaces, including 92 Red Top meters

Type of Methods to Detect Parking Occupancy	Advantages	Disadvantages	Deployed in parkDC Pilot?
License Plate Recognition Technology	▪ Automated data reduction ▪ Can detect vehicle plate numbers and be used for enforcement purposes	▪ Cameras are not able to differentiate between vehicles that are parked versus in transit ▪ Data is not available in real time ▪ Requires data management, installation and maintenance costs ▪ Requires staff to either drive vehicles or needs to be mounted on fleet vehicles that circulate regularly ▪ The cameras do not distinguish areas of the block where curbside regulations change. Routes need to be constructed to address this. ▪ Urban canyon effect can hinder GPS data, GPS accuracy	▪ No
Crowdsourcing Applications (e.g. ratings of available parking on a block or in a zone)	▪ No or minimal assets (e.g. signage) to install in the field ▪ Data available in real time	▪ Data may be incomplete ▪ May require contracts and some staffing for data integration ▪ Need to engage with various app developers to either develop a crowdsourcing application or use their data to integrate with other data the agency obtains. ▪ Users must agree to share their location information to get complete data	▪ No

The following sections describe the data collection technologies selected for use in the pilot. They introduce the technology, explain how it works, and outline how the technology was used in the pilot.

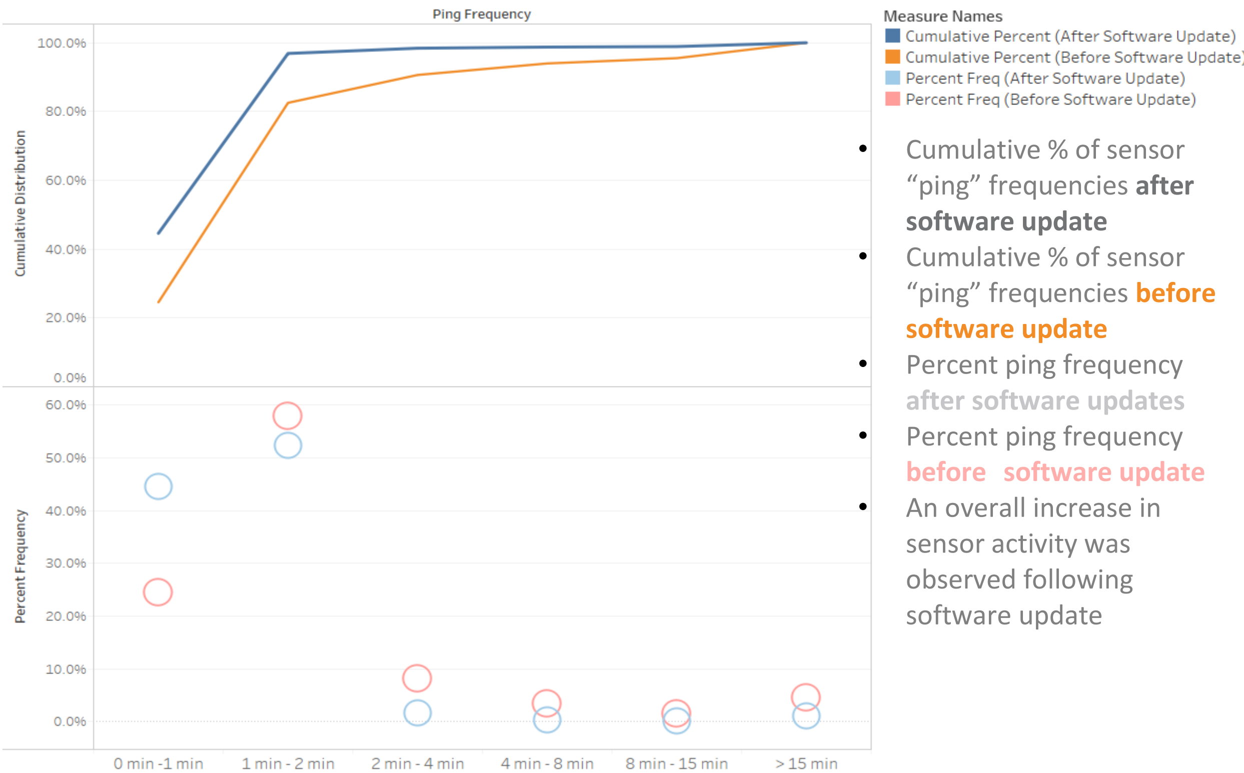
3.5.2.1 In-Ground Sensors

Parking sensors about the size and shape of a hockey puck are placed in the pavement to automatically collect parking occupancy data using magnetometers, radar, and/or optical readers. These sensors wirelessly transmit data to nearby networked communication equipment. DDOT initially selected two sensor vendors to provide occupancy data for the pilot. Two vendors allowed DDOT to test multiple iterations of the same technology and find the best product for the pilot.

In an urban environment, fixed objects such as utility boxes and signal cabinets, as well as moving items such as underground heavy rail transit vehicles, cause interference with the sensors' magnetometers. This can reduce their ability to accurately detect occupancy. While vendors have developed strategies to counter this interference, the varying nature of blocks in urban environments still poses challenges for sensors. The use of cameras and manual field verification can help test the accuracy of the parking sensors.

Early in the process, DDOT worked with sensor vendors to identify sensor communication issues. The sensor vendors used a "heartbeat" report which showed the number of times a sensor pinged a back-office connection. The sensors with the lower number of pings were troubleshot until their ping frequency rose. Figure 3-14 shows how the number of sensors pinging at an acceptable level rose sharply after a software update.

Figure 3-14. Sensor ping frequency and cumulative number of sensors reporting at acceptable frequency intervals



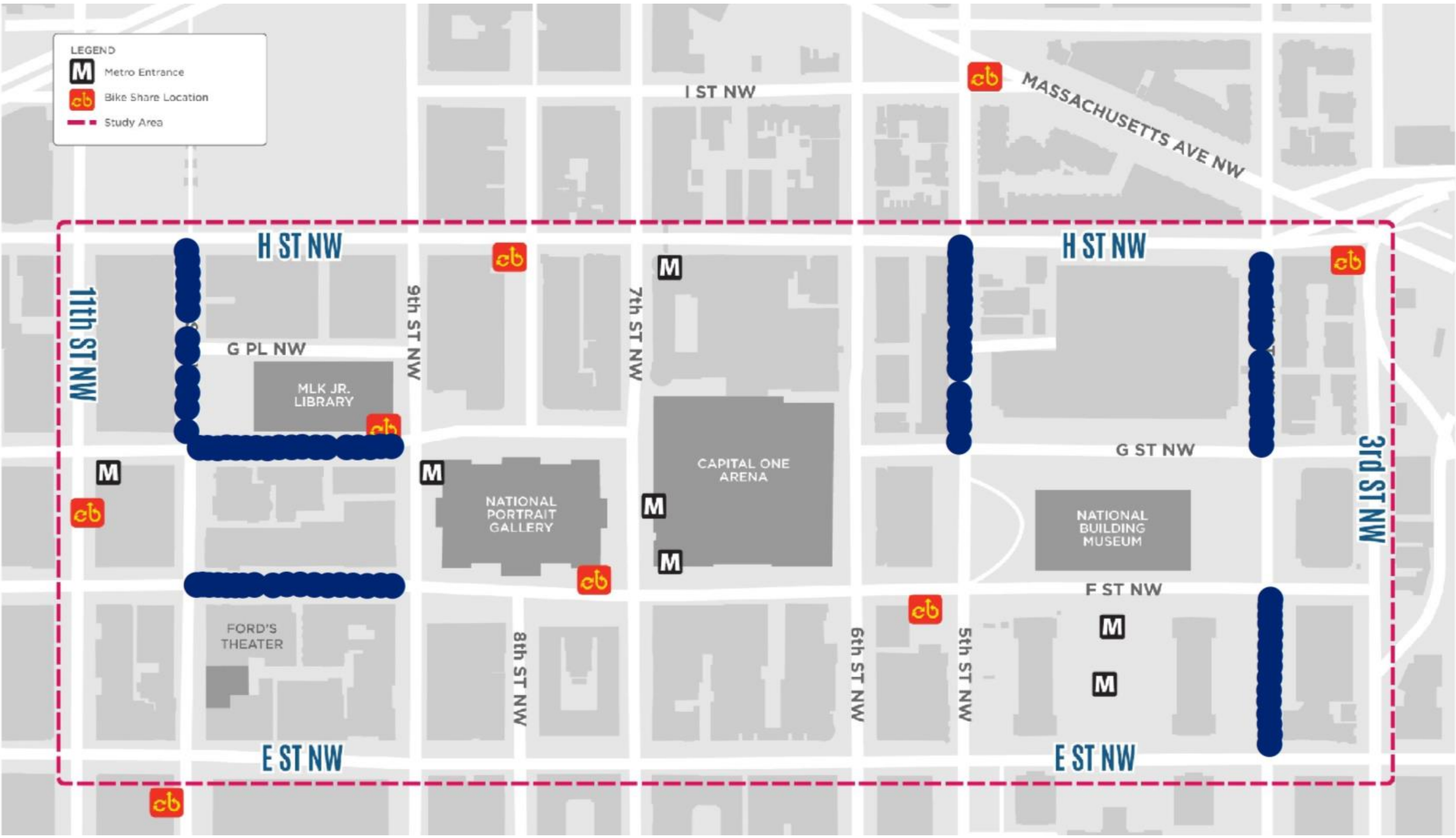
3.5.2.2 Portable CCTV Cameras

Portable CCTV cameras gather detailed camera footage that can measure space between cars and vehicle lengths and provide vehicle counts, vehicle speeds, vehicle classification, and bicycle and pedestrian counts. CCTV cameras are transported on trailers and accrue high installation and maintenance costs. Technicians can process video footage in two ways: manually (requires staff time) or automatically (requires automation using algorithms that can detect cars).

DDOT used portable CCTV cameras with automatic data processing in the pilot to lay the foundation for in-ground sensor deployment. A block-by-block review of the pilot area was completed to identify blocks appropriate and inappropriate for portable cameras. Six trailers with cameras were moved on a weekly basis throughout the pilot area (four weeks of coverage shown in Figure 3-15), capturing information from 58 blocks. Because single cameras did not cover many spaces, up to four cameras were mounted on each trailer. Unlike in-ground sensors, the CCTV disrupted curbside space in the pilot area. Each trailer was about the size of a compact car (12.5 ft long, 7 ft wide, and 8-30 ft high depending on whether cameras were extended or retracted). Moving the trailers was extremely labor intensive, requiring several hours a week per trailer.

DDOT developed a methodology to guide installation of mobile CCTV trailers to optimize accuracy. It was imperative for operators to set up the cameras properly per vendor guidelines to ensure data capture and analysis using computer vision. Obstructions, like large vehicles and trees, can impact the accuracy of the counts and were factored into the analysis. During installation, DDOT attempted to minimize these obstructions. The computer vision algorithms were modified to address potential camera shake due to wind or the passage of large vehicles. This required the algorithms to be individually fine-tuned for each installation. Each installation also required setup and output generation reviews as well as algorithm testing and processing.

Figure 3-15. One week of portable CCTV coverage



Data was infrequently captured outside of operable meter hours to preserve battery life, and the trailers required frequent data transfers locally using flash drives. Because of law enforcement concerns, there were several blocks where cameras were off limits.

The occupancy analysis used minute-by-minute images run through an automated software system. While that painted an accurate picture of use, it did not provide enough detail about turnover, as vehicles leaving and arriving at a space in the same minute were not necessarily captured. Furthermore, the arrival or departure of two vehicles was interpreted as a single, large vehicle event on a couple of occasions. To assess accuracy, the camera images were manually reviewed at set five-minute intervals to ensure the analytic software used to measure occupancy and turnover was accurately estimating both.

3.5.2.3 Time-Lapse Cameras

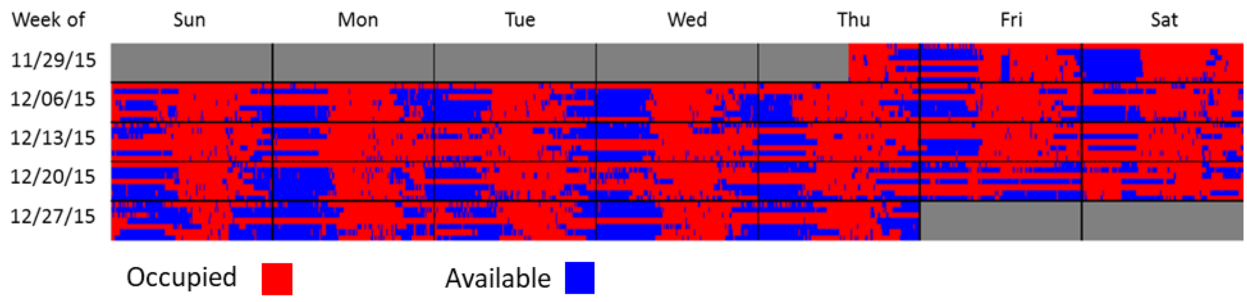
DDOT used time-lapse photography to monitor parking, occupancy, and turnover. This approach uses readily available off-the-shelf technology, shown in (Figure 3-16) and provides more robust and detailed data over a longer duration than portable CCTV cameras. Time-lapse cameras can be mounted on city assets, such as streetlight or signal poles by a technician. When set to take photos every five minutes, these cameras can remain in the field for over a month with two AA batteries.

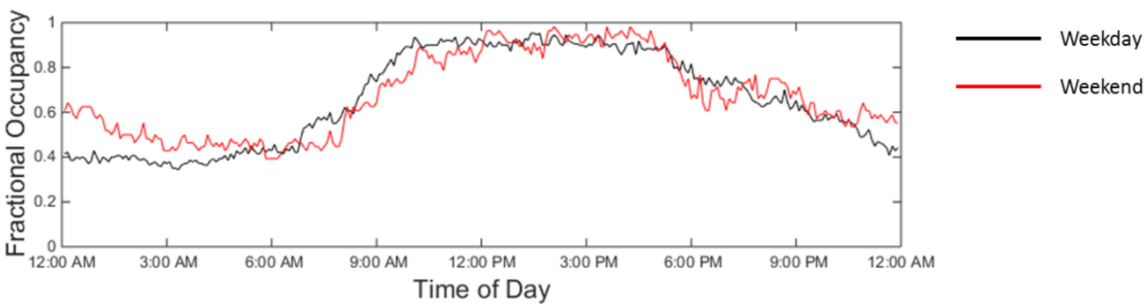
Figure 3-16. Time-Lapse Camera

There are two generally accepted techniques for analyzing time-lapse photography footage. The first is to review the footage manually, which is time consuming and potentially expensive depending on labor rates. The second is to review it using computer vision. Video analytics, as demonstrated in Figure 3-17, provide insights regarding space occupancy and availability.

DDOT has used time-lapse cameras for a range of parking studies, but in the pilot used them specifically for observing loading zone activity. DDOT charted occupancy patterns by vehicle type on weekdays and weekends and used time-lapse photography to hone in on loading zone use and misuse in the pilot area.

Figure 3-17. Screenshot of time-lapse footage set up for data analysis (top), parking occupancy measured from time-lapse camera (middle), parking occupancy by time of day measured from time-lapse camera (bottom)





3.5.2.4 Fixed Cameras

DDOT tested fixed cameras as another potential source of real-time occupancy data. Fixed cameras were mounted on existing light poles in the pilot area to detect and classify parked on-street vehicles in real time. The parking event data was then sent over a Wi-Fi network, aggregated in the cloud, and made available through a set of secured APIs.

DDOT tested cameras on two block faces in the pilot area. The biggest challenges to the use of the fixed cameras were identifying and setting up a Wi-Fi network for the selected area and performing parking detection from a lower mounting angle than is typical (~15 ft) due to the use of shorter ornamental light poles in the pilot area. The Wi-Fi network was provided by the Office of the Chief Technology Officer (OCTO) of the District of Columbia. Due to several mounting and location challenges, installation took significantly longer than planned. These challenges, however, led to two key product improvements:

1. The video sensors and lighting control nodes can now operate over cellular as well as Wi-Fi networks, so if Wi-Fi is not available, communication can continue.
2. The parking detection algorithms were modified to support a low pole mount and continue to detect parking even when occluded by passing vehicles.

The project also inspired a new API that supports aggregating spot-by-spot data to the block face level, so it can easily be displayed on parking navigation maps for citizens and visitors.

Due to the installation delays, the cameras were evaluated against other technologies in the final assessment, but their data did not directly inform the pilot's occupancy and pricing models.

3.5.2.5 Payment and Citation Data

Along with active occupancy data collection from sensors and cameras, DDOT incorporated additional passive data that could serve as a proxy for occupancy data: payment and citation data. DDOT used these passive sources to supplement parking occupancy detection technology and minimize the number of assets deployed in the field. DDOT collected space-level payment information by moving to the demarcated, pay-by-space environment, as described above.

Due to relatively low correlations between payment data and occupancy, District payment transaction data alone would be an insufficient proxy for occupancy on most blocks. Placard usage and free parking for government vehicles contribute to the poor correlation between payment data and real-time occupancy. Also, payment data may not truly reflect the duration of a stay or turnover. This is because payment at District meters, customers pay when they park for the planned duration of their stay. If a customer vacates a space before their payment window ends, then reported payment data loses its accuracy. Consequently, while payment data can reduce the demand for parking occupancy technology, it is currently unable to fully offset the need for parking occupancy technology.

In the District, the Department of Public Works (DPW) is primarily responsible for parking enforcement and manages citations issued. DPW enforcement officers issue citations to non-compliant vehicles via networked handhelds, which upload citation details to a central location. The transition to demarcated parking in the pilot area allowed DPW officers to link citations with specific parking spaces. Like payment data, citation data serves as a proxy for occupancy data. Historical citation issuance, along with payment data, was used to supplement occupancy predictions using temporal and spatial sampling.

3.5.2.6 Manual Counts

DDOT also conducted manual parking occupancy counts. Surveyors collected weekday parking occupancy data on 14 block faces in the pilot area and 10 block faces in a nearby control area before the first price change and after the fourth price change. Table 3-2 shows the manual occupancy data collection time bands. This data was primarily used to understand issues related to double parking and placard use in the study area, discussed in sections 3.9.1.1.3 and 3.9.1.2.1, respectively.

Table 3-2. Manual parking occupancy survey time bands

Morning Period 1	Morning Period 2	Midday Period 1	Midday Period 2	Evening Period 1	Evening Period 2
8:15–9:15 AM	9:45–10:45 AM	11:15 AM–12:15 PM	2:00–3:00 PM	4:30–5:30 PM	6:30–7:30 PM

3.6 THE PRICING ENGINE

DDOT used data collected through the asset-lite approach to inform the pricing engine and develop price change recommendations. The data fusion process was used to inform each of the five price changes that were implemented throughout the pilot period.

Noted economists such as Dr. Donald Shoup advise that 15% of the spaces on a block should always be available to ensure there is adequate turnover and to avoid discouraging parkers. That goal (85% or 90% occupancy), however, does not necessarily tell a complete story. While 85% or 90% could represent an even distribution of demand over the course of an hour or day, it likely does not. Using average demand to guide pricing decisions fails to recognize nuanced yet critical parking trends.

A better methodology, like the one undertaken by the District, is to compare periods when use is too high to periods when use is too low. DDOT used technique to compare the fraction of high use (> 90% occupancy) to the fraction of low use (< 70% occupancy). If the fraction of high use less the fraction of low equaled:

- Greater than 38%, then DDOT recommended rate increases
- Between 38% and -38%, then the DDOT recommended no change in the rate
- Less than -38%, then the DDOT recommended rate reductions

DDOT prioritized simplicity and local conditions when developing the initial rate structure, building on the District-wide base price for on-street parking ($2.30/hr.) and limiting the total number of initial prices to three price bands: $2.00/hr., $2.30/hr., and $2.75/hr. A more aggressive rate structure was considered (five price bands with $1.75/hr. on the low end and $3.00/hr. on the high end) and discarded for the initial price change to systematically determine the impacts of incremental change and avoid the perception of price gouging. In addition to developing the preliminary rate structure, DDOT developed business rules for the pilot to set clear limits on the rate structure adjustment and communication processes.

Since the implementation of the first change in October 2016, the number of price bands has increased incrementally in accordance with the business rules. Rates increased more aggressively during later rounds as the amount of a rate increase or decrease needed to be sizeable enough to impact behavior. Five price changes were implemented during the pilot. As of the fifth price change, the rate structure has grown to encompass nine price bands, ranging from $1.00/hr. to $5.50/hr. Table 3-3 shows how the pilot rate structure has evolved since the first price change.

Table 3-3. Penn Quarter/Chinatown Pricing Pilot rate structures

Price Change	Rate Structure (hourly rates)								
Baseline				$2.30					
Round 1 ***October 2016***			$2.00	$2.30	$2.75				
Round 2 ***February 2017***		$1.50	$2.00	$2.30	$2.75	$3.25			
Round 3 ***May 2017***	$1.00	$1.50	$2.00	$2.30	$2.75	$3.25	$4.00		
Round 4 ***August 2017***	$1.00	$1.50	$2.00	$2.30	$2.75	$3.25	$4.00	$4.75	
Round 5 ***November 2017***	$1.00	$1.50	$2.00	$2.30	$2.75	$3.25	$4.00	$4.75	$5.50

While data has served as the foundation for the time bands and price changes developed for the parkDC pilot, institutional knowledge of and sensitivity to the effects of the pilot on customers have also been taken into consideration. DDOT's conservative, data-driven approach to implementing rate changes in the study area serves as a model for expanding the pilot to other neighborhoods within the District.

3.6.1 Segmentation

Rates were partitioned across the hours of a day to optimize demand. DDOT's goal was to reduce the likelihood of pricing errors while keeping the structure simple. Rates need to be both easy to understand and to communicate to customers in order for drivers to incorporate pricing into their decision-making. When motorists do not know what to expect in terms of rates, they cannot effectively respond to pricing signals. When they arrive at a meter they will pay whatever is required to park to avoid the hassle of finding another spot and the rates will fail to impact driver behavior. DDOT wanted to avoid this scenario.

DDOT sought to implement just three or four partitions per day and, whenever possible, began and ended the partitions on the hour to avoid confusion. Partitions were also influenced by rush hour restrictions that impact parts of the pilot area (7 AM-9:30 AM and 4 PM-6:30 PM). It is much easier for customers to plan their trips when they know rates will increase at noon as opposed to, say, 12:13 PM. Further, DDOT treated weekdays and weekends separately to simplify messaging.

Occupancy data was used to assess parking patterns in the study area and determine time of day segments when different price changes could go into effect. Three weekday time of day segments (7 AM–11 AM, 11 AM–4 PM, 4 PM–10 PM) and one Saturday time of day segment (7 AM–10 PM) were identified based on observed parking behavior in the study area. The meters operating on Saturday needed just a single segment based on reduced weekend utilization.

3.6.2 Increments

The amount of an hourly rate increase or decrease must be sizeable enough to impact behavior. The business rules for the parking pilot stipulated that all rate adjustments would be made in increments of no less than 50 cents up or down. Smaller increments implemented in precedent demand-based parking pricing studies did not have large impacts on changes in parking behavior. The business rules also specified that rate changes would be in increments of no more than $1.50 up or down, in accordance with District policy.

3.6.3 Frequency

Typically, fewer, well-communicated rate changes carry more weight than frequent modifications. Customers can suffer from communication fatigue if rate changes occur more than four to six times per year. Per the pilot business rules, price changes were implemented in the pilot area on a quarterly basis (every three months).

3.6.4 Thresholds

DDOT established low-and high-end pricing thresholds in the pilot business rules. The low-end threshold was 50 percent of the prevailing District rate ($2.30/hr.) rounded down to the nearest 50 cent increment ($1.00/hr.). The high-end threshold, established by District Council, was $8.00/hr.

3.7 TIME LIMIT ADJUSTMENTS

DDOT also explored time limit increases on block faces where parking spaces were consistently underused, and rate decreases did not encourage drivers to use the spaces. Per the pilot business rules, time limit increases were explored on block phases when on-street prices had been reduced to the prevailing price floor ($1.00). After the third price change was implemented, DDOT identified block faces in the eastern third of the pilot area that exhibited the potential for time limit changes. Following an assessment of block face proximity to local businesses and rush hour restricted corridors, DDOT implemented time limit changes on the eligible blocks in the eastern third of the pilot area. The parking window was increased from two to four hours on weekday evenings after 4 pm and all day on Saturdays.

3.8 LOADING ZONES

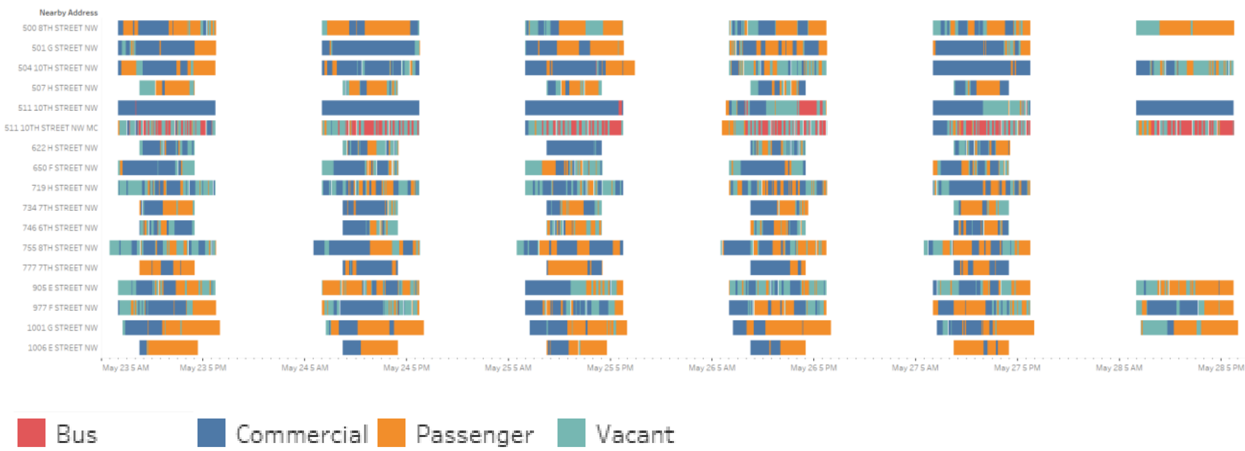
DDOT studied loading zone activity to understand how demand-based pricing could also serve commercial vehicles. When parking demand outweighs supply, drivers may resort to parking illegally, including encroaching on loading zones. Thriving businesses in downtown districts must receive deliveries and delivery truck parking and idling can block travel lanes if loading zones are already occupied and off-street loading bays are not available (Figure 3-18). Recognizing that most commercial vehicles do not want to park illegally but will do so when no reasonable alternative is available, DDOT sought to improve the availability of loading zone spaces by analyzing who was using the zones and developing pricing and enforcement strategies from that baseline.

Figure 3-18. Delivery vehicle activity in the study area

DDOT conducted surveys of loading zone activity in 2016 before the first demand-based price change and after the fifth price change was implemented in 2017. Time lapse cameras were used to gather one week of occupancy data at each loading zone in the study area. DDOT collected information about the types of vehicles that used each loading zone (passenger, commercial, or bus), and the duration of all vehicle parking sessions. DDOT also collected vehicle type and session duration information for double parking events.

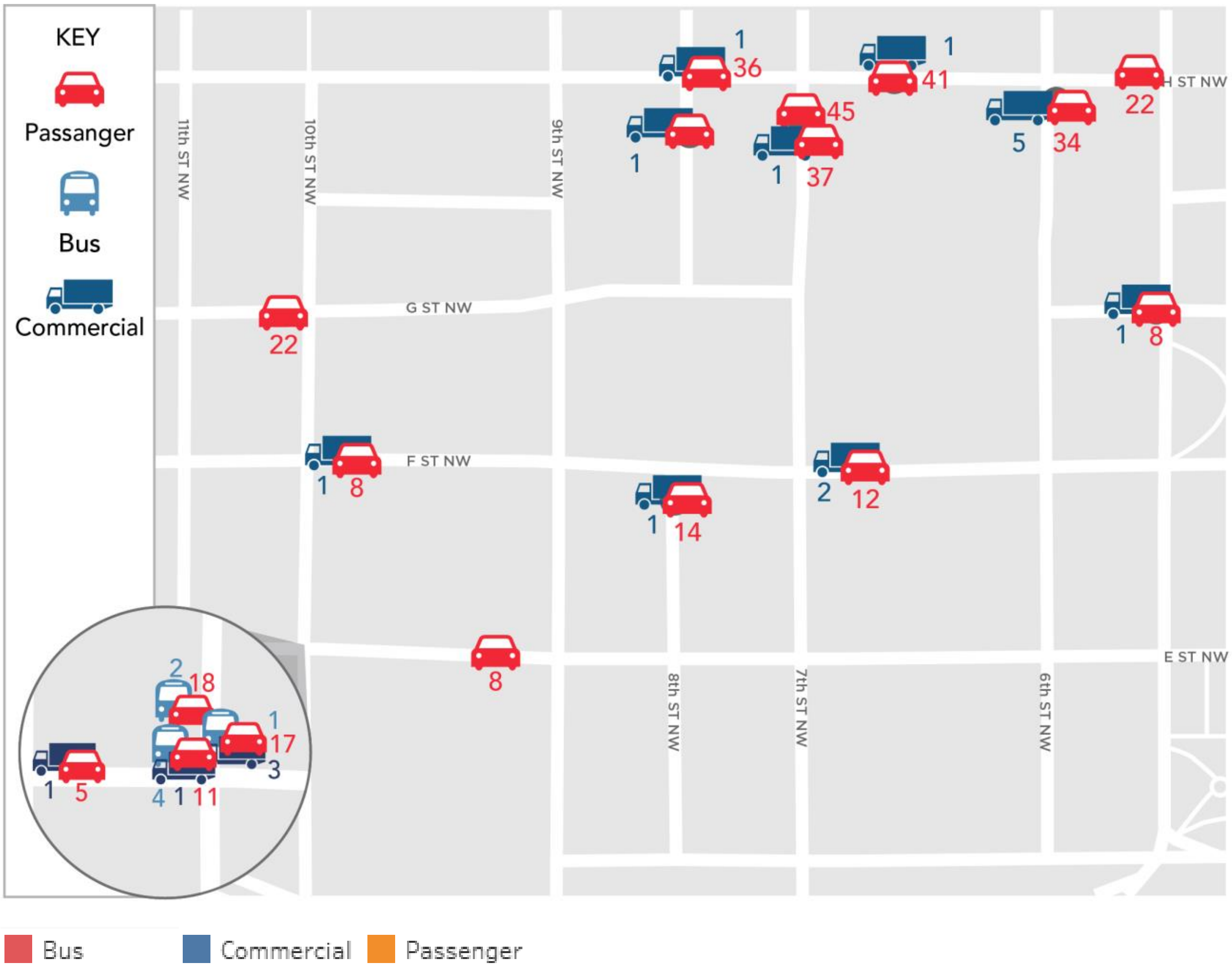
Loading zones were priced at the prevailing rate of $2.30 per hour when the 2016 video survey was conducted and were in operation until 7 PM. DDOT compared the vehicle type and duration of all parking events in each loading zone to determine whether certain loading zones were experiencing high volumes of unauthorized use. As shown in Figure 3-19, many of the loading zones in the pilot area experienced unauthorized passenger vehicle activity throughout the weekday. Eight of the 16 loading zones observed in the before conditions assessment were occupied by passenger vehicles more than 50% of the time they were in operation. Thirteen of the 16 loading zones experienced a greater number of unique passenger vehicle parking sessions than all other vehicle types.

Figure 3-19. Loading zone activity by zone and vehicle type (2016)



Upon further investigation, the pattern of passenger vehicle encroachment into loading zones continued into the evening, after the spaces were no longer reserved for commercial vehicles. Most vehicles observed using loading zones after 7 PM were passenger vehicles (Figure 3-20). Thirteen of the 16 loading zones experienced nearby double parking throughout the week with double parking sessions ranging in length from five minutes to eight hours.

Figure 3-20. Vehicles parked after 7 PM by vehicle type (2016)



DDOT determined that proactive measures were necessary to discourage the improper use of loading zones in the pilot area. DDOT extended loading zone hours of operation until 10 PM and raised the hourly parking rate at all loading zones to match the highest prevailing on-street parking rate on their associated block faces. If the highest prevailing on-street rate on a given block face was $4.50 during midday, then the loading zone on that block would be priced at $4.50 per hour for all three weekday and Saturday time periods. This higher price was intended to serve as a disincentive to passenger vehicles and other unauthorized users, and the extended hours of operation were intended to improve accessibility for delivery vehicles attempting to access the study area during off-peak hours.

3.9 EVALUATION METHODS

This section describes the methodology used to evaluate the effects of the pilot. The evaluation methods are divided into two areas of evaluation:

1. **The system user experience**, which is further divided into three levels:
   - **Level 1: Curbside effects.** DDOT has direct control over these areas, and metrics include the pilot's influence on customer ability to find parking, customer ability to pay for parking, and instances of illegal parking.
   - **Level 2: Pilot area network effects.** The pilot would be expected to impact the surrounding transportation system, and metrics include the availability of parking information, placard use and abuse, and safety.
   - **Level 3: Broader transportation and land-use activity.** This level addresses the wider transportation ecosystem that includes the parkDC pilot. Metrics include broader transportation and land use activity include impacts on multimodal mobility and economic vitality.

2. **The agency perspective** provides the metrics for outcomes desired by DDOT, the managing agency of the parkDC Penn Quarter/Chinatown pilot.

3.9.1 The system user experience

> *The system user experience discusses the impacts felt by people parking in the area (level 1), those traveling in or through the area (level 2), and area's businesses and wider transportation ecosystem (level 3).*

3.9.1.1 Level 1: Curbside Effects

DDOT has direct control over these areas, and outcomes include the pilot's influence on customer ability to find parking, customer ability to pay for parking, and instances of illegal parking.

3.9.1.1.1 Cruising for Parking Detection

To support the pilot evaluation, DDOT also deployed a network of automated vehicle identification (AVI) sensors to collect data related to vehicles cruising (or circling) for parking. By comparing changes in parking occupancy throughout the pilot to changes in the number of vehicles cruising for parking and how long those vehicles circled for parking, DDOT had another data-driven measure with which to measure the success of the pilot. The analysis methods described here were used for metrics under both curbside effects (level 1) and pilot area network effects (level 2).

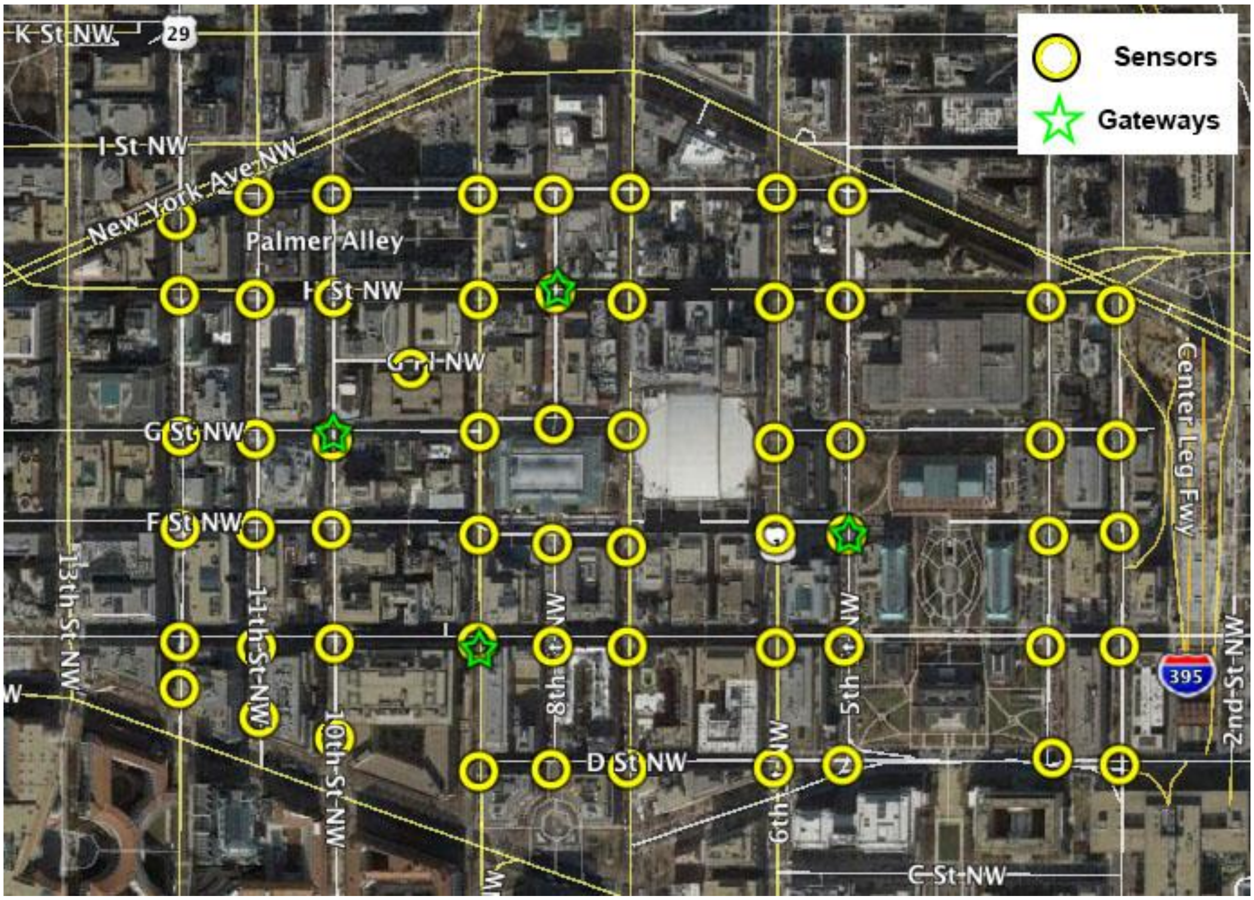
Automatic Vehicle Identification Sensors

Traditionally, travel times have been studied indirectly from field-based observations of counts and occupancy transformed into spot speeds or observed snippets via license plate surveys and other techniques. The advent of automatic vehicle identification (AVI) and automatic vehicle location (AVL) technologies has made it possible to observe travel times directly for individual vehicles. AVI data collection sources, which include Bluetooth readers, detect a passing vehicle at one sensor, then re-identify the vehicle at a second sensor, allowing the vehicle's trip time between two points to be directly computed. AVL data (such as GPS or cellular data) provides a vehicle trace updated within some period. AVI sensors are now widely used by public agencies to measure travel in transportation networks, particularly travel times.

Although AVL technology may provide higher fidelity data than AVI technology, AVI data have several advantages over AVL data. AVL data are not generally available, often requiring commercial purchase or access to restricted datasets. GPS traces produced from navigation devices and apps may include only part of a route (usually while navigation assistance was needed), with biased samples that can exclude regular commuters and the portion of a route that would include cruising. AVI data give cities the ability to own the raw travel data for areas of interest. AVI data is generally unbiased, capturing a cross-section of trip types. In tests leading to this work, Bluetooth penetration rates of 10-20% of vehicles were seen.

In an ideal case, one could collect AVI travel time data continually on every link in the network to improve the accuracy of travel time prediction. However, the cost of installing a single commercial Bluetooth reader is about $10,000. For this reason, current Bluetooth AVI deployments focus almost exclusively on freeway or arterial settings with sparse sensor deployment, rather than dense, urban deployment. However, with the commodification of hardware necessary to construct such readers, readers may be built at much lower cost, opening new possibilities for deployments – including observing circling for parking.

Figure 3-21. AVI sensor network deployment



Sensor Network Deployment

To best measure cruising related to the Penn Quarter/Chinatown Pricing Pilot DDOT chose to deploy a dense network of Bluetooth AVI sensors. DDOT determined that capturing routes that might exit and re-enter the study area would improve the quality of measurement. The sensor network extended one block north, west, and south of the study area. Interstate 395 forms a natural barrier at the eastern edge of the study area, so it was not necessary to extend the network to the east.

DDOT deployed a network of 59 sensors, shown in Figure 3-21, from 3rd to 12th Streets NW and D to I Streets NW. Since DDOT wanted to measure cruising over multiple years, sensors needed to be permanently mounted and connected to an available power supply. A new sensor prototype and new software were developed to ensure the success of the remote data collection effort.

In almost all cases, sensors were located at an intersection, but in a few cases, it was necessary to install them closer to the middle of a block. Rather than install a sensor at each end of G Place NW, it was only necessary to install a single sensor in the middle of the block, since the street is only one block long. The three sensors located near intersections on Pennsylvania Avenue NW (10th, 11th, and 12th) were installed away from the intersection toward E Street, since most of the poles at intersections on Pennsylvania Avenue are designed to be removable for events on Pennsylvania Avenue, like presidential inaugurations. Though installation at the intersection is generally more desirable, these location adjustments were expected to have little to no effect on data quality.

The sensor network was deployed during the summer of 2016, with complete operation in place by September 2016. Four gateways for remote data collection were also installed. The automated cruising for parking data used the same time bands as the DDOT time-of-day pricing bands, with further segmentation for rush hours (Table 3-4).

Table 3-4. Cruising for parking analysis time bands

Morning Peak 1	Morning Peak 2	Mid-day	Afternoon Peak	Evening
7:00–9:30 AM	9:30–11:00 AM	11:00 AM–4:00 PM	4:00–6:30 PM	6:30–10:00 PM

3.9.1.1.2 Time to Find Parking Manual Surveys

DDOT conducted manual parking search time surveys to supplement cruising data collected by AVI sensors. To collect the data, DDOT used a technique also used by SFpark[1] which assumed that drivers searching for parking travel at approximately the same speed as bicyclists. The manual surveys were conducted via bicycle in the pilot area and in a control area on both weekdays and Saturdays. Surveyors bicycled through the pilot and control areas along pre-defined routes in search of parking spaces. The number of bicycle search runs, elapsed time between the start of each search and location of a suitable parking space, and the number of laps of the survey route run during each search were recorded.

These manual surveys were conducted twice: once before the first price change was implemented and once following implementation of the fourth price change. Figure 3-22 outlines the time to find parking manual survey process.

[1] http://sfpark.org/resources/survey-deployment/

Figure 3-22. Parking Search Time Survey Process

The time to find parking survey process used slightly different time bands than the DDOT time-of-day pricing bands (Table 3-5).

Table 3-5. Time to find parking manual survey time bands

Weekday AM 8:30 – 10:30 AM	**Weekday Midday** 12:00 – 2:00 PM	**Weekday PM** 5:00 – 7:00 PM
Saturday Midday **12:00 – 2:00 PM**	**Saturday PM** **4:00 – 8:00 PM**	
Sunday Afternoon **1:00 – 5:00 PM**		

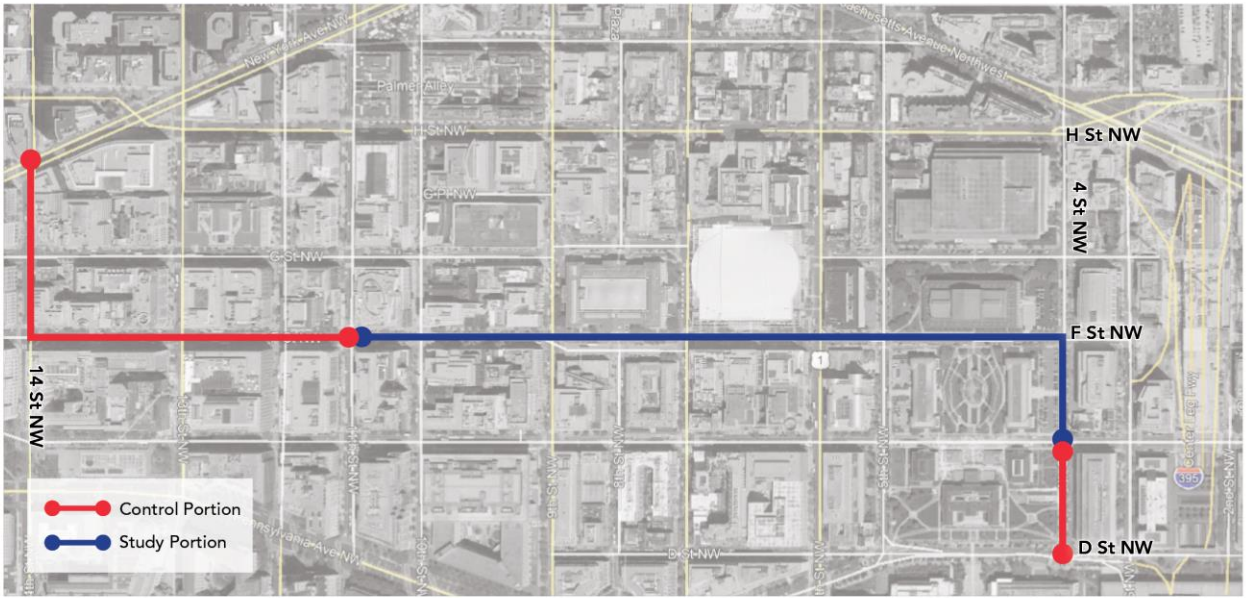
3.9.1.1.3 Parking Enforcement and Compliance

Parking enforcement is necessary for ensuring greater parking availability and turnover. It is a key consideration in implementing parking management strategies. At a broad level, other jurisdictions found that when parking management strategies are properly implemented, enforcement revenue typically decreases, despite increases in the amount of enforcement conducted. When parking spaces are easier to find and more available, drivers are less likely to park illegally. DDOT sought to improve compliance both by increasing parking availability and by improving traveler information, notably with a highly visible parking decal on each multi-space meter that detailed prices and parking restrictions by time of day (further detailed in Chapter 4). To evaluate compliance and enforcement, DDOT looked at both placard use and citation issuance.

Double Parking

Since double parking contributes to downtown congestion and can result from an imbalance in parking supply and demand, DDOT sought understand how the parkDC pilot may have affected double parking. Data was collected on two weekdays along a study route located within the pilot area and a control route located in close vicinity to the pilot area (Figure 3-23). Both routes included over 70 parking spaces, a large enough number to produce a statistically significant result in a before and after comparison. In both the before and after conditions, data was collected in six time bands between 8:00 AM and 7:30 PM.

Figure 3-23 Double Parking Survey Map



The analysis of loading zones (discussed in section 3.8, above) using time-lapse cameras also allowed DDOT to assess changes in double parking associated with loading zones and motorcoach zones.

Citations

Within the District, parking enforcement is under the jurisdiction of DPW. During the conversion to pay-by-space, DDOT worked with DPW to develop enforcement procedures and update software to allow for integration software used by enforcement officers' handheld enforcement devices and DDOT's system. This coordination also included training sessions with all enforcement officers who work in the study area. However, enforcement in the study area was inconsistent following these changes due to a mix of improper enforcement or enforcement officers avoiding the pilot area. Consequently, DDOT is unable to determine whether compliance was improved in the study area. For informational purposes, citation data was still analyzed (Chapter 5) but with the caveat that conclusions cannot be drawn from the data. For each price change, the data includes two full months of citation data within the study area, for the period shown in Table 3-6. In time periods with more than two months in between price changes, DDOT chose months that align with months from other price changes to control for seasonality.

Table 3-6. Citation data analysis time periods

Period	Start Date	First Month	Second Month
Before Changes	N/A	June 2016	July 2016
Price Change 1	10/17/2016	December 2016	January 2017
Price Change 2	2/20/2017	March 2017	April 2017
Price Change 3	5/30/2017	June 2017	July 2017
Price Change 4	8/28/2017	September 2017	October 2017
Price Change 5	11/6/2017	December 2017	January 2018

3.9.1.2 Level 2: Pilot Area Network Effects

This part of the evaluation addresses impacts to the surrounding transportation system, including the availability of parking information, placard use and abuse, and safety.

3.9.1.2.1 Placard Use

Placard usage can contribute to the poor correlation between payment data and real-time occupancy data in DDOT's data fusion process. DDOT measured placard use in the pilot area before and after pilot implementation to determine whether parking availability for paying customers increased, decreased, or stayed the same during the pilot. DDOT conducted a survey of placard use before the first price change was implemented in October 2015 and after the fifth price change was implemented in November 2017.

DDOT conducted surveys of placard use in concert with surveys of double parking in 2015 and 2017 (see section 3.9.1.1.3 for more on the double-parking survey).

3.9.1.3 Level 3: Broader Transportation and Land-Use Activity

This is the wider transportation ecosystem that included the parkDC pilot. Metrics include broader transportation and land use activity and impacts on multimodal mobility and economic vitality.

3.9.1.3.1 Districtwide Trends

Changes to the District's population, employment, travel demand, economic activity, and multimodal transportation network can influence parking demand in the District, including the areas studied in the parkDC pilot. DDOT reviewed U.S. Census data from 2015 to 2017 to identify trends potentially impacting parking demand.

3.9.1.3.2 Congestion

Major roads in the pilot area traditionally experience high levels of congestion and low travel time reliability. The parkDC pilot sought to alleviate this congestion through improved access to parking. Improved access to parking was expected to reduce circling for parking and double parking, both of which contribute to congestion. DDOT attempted to measure the effect of demand-based pricing on traffic congestion and double parking.

To evaluate the effects the pilot had on traffic congestion, changes in the Travel Time Index (TTI) and Planning Time Index (PTI) were calculated for 2015, 2016, and 2017. TTI is the ratio of average or median travel time to the time required to make the same trip at free-flow speeds. For example, with a TTI of 1.2, a trip that takes 20 minutes at free-flow speeds would have an average or median travel time of 24 minutes. PTI is the ratio of travel time during the worst conditions (95^{th} percentile travel time) to the time required to make the same trip at uncongested speeds. For example, with a PTI of 1.2, a trip that typically takes 30 minutes in light traffic would require drivers to plan for 36 minutes to arrive on time.

3.9.1.3.3 Economic Analysis

Parking access directly relates to people's access to school, work, entertainment, food and shopping. DDOT reviewed business point data provided by a private entity for 2015, 2016 and 2017. This data was used to identify whether the pilot impacted economic activity in the Penn Quarter/Chinatown neighborhoods.

3.9.1.3.4 Multimodal Performance

In an urban area like the Penn Quarter and Chinatown neighborhoods, the relationships between various modes of travel make it likely that when operations for one mode changes, the other modes are affected. DDOT looked at performance for bus transit, rail transit, and bikeshare.

For transit, DDOT looked at data from the Washington Area Metropolitan Transit Authority (WMATA) Metrobus and Metrorail services. Multiple bus lines come through the pilot area and there are three Metrorail stops within the pilot area providing access to all rail lines. DDOT assessed annual trends in bus speeds and transit ridership to understand how the parkDC pilot may have impacted transit performance when compared to the District as a whole.

Founded in 2010, Capital Bikeshare is metropolitan Washington's bikeshare system. With over 4,000 bikes and 500 stations serving the District, Maryland, and Virginia, the service expands bicycling options for residents, commuters, and visitors. Within the pilot study area, several Capital Bikeshare stations are available in the Penn Quarter/Chinatown area. After the pilot was implemented, DC has expanded access to alternative modes through the introduction of dockless bikeshare and scooters. These dockless, inexpensive modes of transportation can be found Districtwide. DDOT reviewed ridership on the Capital Bikeshare system for stations in the pilot area compared to the system as a whole.

3.9.2 The agency perspective

This section provides the metrics for outcomes desired by DDOT, the managing agency of the parkDC Penn Quarter/Chinatown pilot.

3.9.2.1 Customer Experience

DDOT conducted a before and after survey to begin to understand how the parkDC pilot had affected stakeholder parking experiences. A QR code and web address were provided on the back of every receipt provided to customers after paying to park in the pilot area directing them to the survey. The survey asked responders about how often they drove or parked in the pilot area, how long it took to find a parking space, whether they thought about traveling by another mode, the clarity of the parking regulation information, and their experience finding an open parking space. More information on the customer experience is provided in Chapter 4.

3.9.2.1.1 Parking Information Accuracy

DDOT conducted five accuracy tests before and after both mobile applications were launched in December 2016. The tests aimed to understand how accurately the apps were predicting occupancy compared to what was observed on site. As part of each test, surveyors walked the pilot area and compared outputs from the mobile applications to observed real-time occupancy to see whether the mobile applications were reporting accurate information. After each test, results were scrutinized to identify accuracy issues and determine which component (app or algorithm) was causing errors.

3.9.2.2 Financial and Cost Effectiveness Analyses

DDOT assessed the affect that the parkDC pilot had on DDOT's parking-related revenues from meters and mobile payments. While improving the customer experience is the primary goal of parkDC: Penn Quarter/Chinatown, the project team has also considered the effects of demand-based pricing on revenue. A benefit-cost analysis assesses whether DDOT should expand the parkDC model to other neighborhoods in the District.