ASSET-LITE PARKING – USING BIG DATA ANALYTICS FOR DEVELOPING SUSTAINABLE SMART PARKING SOLUTIONS IN WASHINGTON, D.C.

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ABSTRACT

Real-time parking occupancy detection is often the missing piece as municipalities migrate up the "smart-parking" spectrum. Municipalities use occupancy detection for (a) providing real-time information to customers about parking availability, (b) making demand-based price adjustments for efficient use of curb space in a congested area, (c) establishing the right meter policies, like time limits, and (d) informing parking enforcement. The state-of-the-practice for occupancy detection has been using assets (such as sensors and cameras) for every parking space. However, given both the current pricing models and usage patterns, this approach is neither economically sustainable nor necessary. The parkDC: Penn Quarter/Chinatown pilot launched in Washington, D.C. seeks to develop reliable occupancy data using information from all parts of the parking ecosystem (such as networked meters, enforcement, and pay-by-cell transactions). Combined with a sampling of occupancy data collected through limited sensor deployment, mobile cameras, and fixed cameras, D.C. aims to develop a sustainable solution based on an optimal mix of assets and coverage. The cost, customer satisfaction, revenue, and operational implications of “asset-lite” solutions are discussed. This paper will enable jurisdictions to develop cost-efficient models for occupancy detection so they can strategically position themselves to implement real-time availability information and performance-based pricing.
INTRODUCTION AND LITERATURE REVIEW

The on-street parking industry has seen more innovations in the last eight years than it has in the eight decades since the installation of the first parking meter. “Smart parking,” the application of new technologies to parking, generally encapsulates the latest round of innovation in curbside management. Much of the current innovation mirrors and responds to what is happening in society more broadly. Technological components that are getting smaller, faster, and cheaper, coupled with broadly available mobile connectivity is driving change in how people interact with each other and how they interact with machines (1). At the same time, there has been a shift to cashless transactions; predictions are that by 2017 less than 25% of parking transactions will be by cash (2). And for cities, there are new challenges and expectation with both coming-of-age Millennials and retiring Baby Boomers both showing preferences for urban areas.

These trends have manifested themselves in three principal ways in the parking industry:

1. Migration to networked meters,
2. Introduction of alternative payment methods,
3. Infusion of occupancy data into curbside management.

The first two changes are well established among municipalities using current technology. The latter change is just beginning to see broader adoption with technology evolving to where it is cost-effective for municipalities.

Migration to Networked Meters

With falling technology costs, an increasing percentage of the five million parking meters in the United States are now networked (2). Networked meters have the ability to accept credit card payment and better uptime and enable proactive maintenance, both of which bring in more revenue and provide higher customer satisfaction. They also provide municipalities with real-time visibility into parking operations.

Introduction of Alternative Payment Methods

With a broader shift to cashless payment methods, carrying coins to pay meters is becoming obsolete. Widespread adoption of smartphones has enabled cities to add pay-by-cell options: 55 of the largest 100 U.S. cities offer some version of pay-by-cell (2). For parking agencies, the shift away from cash payments (both via pay-by-cell and at networked meters) increases the revenue per parking session (1).

Infusion of Occupancy Data into Curbside Management

The rise of the Internet of Things (3) and a robust cellular data network in cities are enabling new detection methods that open up new possibilities for real-time monitoring of parking space occupancy. Cities are now able to share real-time occupancy information for on-street spaces, reducing the need for drivers to circle for parking, and reducing congestion and pollution. The availability of this information brings parking on par with the rest of the travel experience: already, an urban traveler with a smartphone can (in real-time) see roadway congestion levels, track the arrival of nearby transit, and hail a cab digitally and monitor its approach.

Occupancy data also allows local governments to make demand-based price adjustments for efficient use of curbside space in congested areas, adjust meter policies like time limits based on traveler behavior and needs, and inform parking enforcement activities to support curbside management goals.

Evolutions in occupancy detection technology are beginning to allow for more cost-effective installations throughout cities, but real-time traveler information and performance parking pricing are still the exception rather than the norm (4). However, before these costs fall to the point that they can be broadly used, cities are seeking to use the full range of “big data” coming from the parking ecosystem to get occupancy data more cost-effectively. This paper focuses on a pilot project in Washington, D.C. seeking to do just this. After describing the state of the industry for real-time occupancy detection, we introduce the pilot project and how it is testing an asset-lite approach to occupancy detection.
Recent Efforts

Recent efforts to collect real-time parking occupancy data have emphasized the use of in-ground sensors, generally using at least one sensor per space (5). For instance, SFpark’s study of transactional parking sensor data for 8,200 on-street parking spaces used 11,917 sensors, 346 repeaters and 58 gateways for 8,200 parking spaces, a ratio of 1.45 sensors per space (6, 7). Parking occupancy studies in a west coast city, and a Midwestern city had similar sensor-to-space ratios, according to officials affiliated with these projects. New York City used two sensors per space, but unlike the other programs did not demarcate individual parking spaces (8).

SFpark also experimented with a no-sensor approach. Between August 2011 and the end of 2013, SFpark collected occupancy data through in-ground sensors. After implementing 13 demand-responsive rate adjustments using data from the in-ground sensors, SFMTA developed the Sensor Independent Rate Adjustment (SIRA) methodology to continue rate adjustments without the use of sensor technology (9). In developing the SIRA model, SFMTA chose to use a linear model which incorporated payment rate along with neighborhood type, and day of the week as variables. SFMTA did not use a log-log model with the same variables because of the “inherent uncertainty in estimating parking occupancy rates using a model rather than parking sensors…when it is wrong, [the linear model] is more likely to set rates that are too low rather too high” (9).

Use of the no-sensor SIRA model and the traditional use of in-ground sensors represent two extremes. A third asset-lite approach would use partial sensor coverage supplemented with a model similar to the SIRA model (5). While the reduction in the number of in-ground sensors would be expected to decrease the level of accuracy, a middle-ground likely exists between the two approaches used by SFpark.

PARKDC: PENN QUARTER/CHINATOWN

The District Department of Transportation (DDOT) is conducting a pilot study to implement demand-based pricing for on-street parking in the Penn Quarter and Chinatown neighborhoods in downtown Washington, D.C. As part of the study, DDOT is applying an “asset-lite” approach to occupancy detection that fuses data from multiple sources including in-ground parking sensors, fixed and mobile cameras, enforcement, and meter payment transactions. The parking occupancy and pricing data will be available to customers through a mobile application and to third-party app developers through an open-source portal.

The goals of the study are to improve the parking experience for customers, encourage the effective use of curbside space, and reduce downtown congestion associated with parking activity for personal vehicles, motorcoaches, and freight vehicles. The study will include a before-and-after evaluation including an analysis of parking occupancy, turnover, and transaction data; intercept surveys; and field-collected data such as parking search time. As an outcome of the project, DDOT plans to deploy the most effective technologies (the “minimum-viable solution”) citywide. This paper focuses on the asset-lite components of the overall project.

Study Area

The study area, shown in Figure 1, comprises three partially overlapping D.C. neighborhoods: Downtown, Chinatown, and Penn Quarter. The study area is located in the heart of D.C., between the National Mall to the south, the White House to the west, the Convention Center to the north and Union Station to the east. Within the study area are important destinations including the Verizon Center, National Portrait Gallery, Chinatown, and vibrant commercial areas, all creating a demand for parking and loading space that is consistently high.

From a transportation perspective, the study area includes 114 block faces, 1,000 metered spaces, 30 loading zones, six Capital Bikeshare stations, two on-street carsharing spaces, three Metrorail stations serving all regional Metrorail lines, many Metrobus stops, and freeway-arterial interactions to the east of the study area.
FIGURE 1  Study area.

ASSET-LITE APPROACH
The asset-lite approach aims to get to desired outcomes using fewer assets, as depicted in Figure 2. In the context of occupancy detection, one of the critical outcomes is accuracy. Using the state of the practice, it would take $A_2$ assets to get to an accuracy of $a_2\%$. The asset-lite solution will aim to get to $a_2\%$ accuracy using $A_1$ assets, which traditionally only gets a lower accuracy level of $a_1\%$. The accuracy gap ($a_2\%-a_1\%)$ is covered by data fusion/analytics – using data from other parts of the parking ecosystem. The cost savings from this approach is the capital and operating cost of $(A_2-A_1)$ assets.
Minimum-Viable Solution
Associated with the asset-lite approach is the concept of the minimum-viable solution. This approach ensures project goals are met by using a value engineering-type approach. As an example, some jurisdictions require a high degree of accuracy (upwards of 95%) from their sensors. The minimum-viable solution approach looks at the purpose for collecting occupancy information and adjusts the actual level of accuracy needed.

While traveler information requires a higher level of accuracy, the requirements can be reduced by efficient interface design. Figure 3 gives an example of this: showing block level probabilities (Concept B) rather than space level availability (Concept A) reduces required accuracy levels. Telling travelers their odds of finding a space rather than the precise number of spaces available provides the needed information with less precision and less accuracy needed from occupancy detection.
Another piece of the minimum-viable solution concept is the selection of an optimal mix of technologies to deploy, which could be a hybrid solution instead of a single technological solution. The minimum-viable solution is developed through a “step-down” approach shown in Figure 4. By adjusting the system design and fusing multiple data elements, the asset requirements and associated costs go down. In the case of parkDC: Penn Quarter/Chinatown, the cost is reduced through changes made to the on-street configuration, through the system design, and through a data fusion approach. Each of these elements are described in more detail in the next section.
FIGURE 4  Step down approach to reduce asset costs while obtaining a minimum-viable solution.

SYSTEM ELEMENTS FOR ASSET-LITE
The ultimate goal of the asset-lite approach is to reduce the number of data collection devices deployed by combining data from multiple sources. This requires testing a variety of devices and data sources in order to determine the optimum mix.

On Street Configuration
For this approach to work well, it is important to create the right environment for success. For this reason, DDOT made a strategic decision to transition to a pay-by-space environment on multispace meter blocks. Under the new configuration, where a vehicle parks on the block-space is designated by identified space markers, which fixes the number of spaces and where cars park along the block. This improves the accuracy of occupancy detection technologies and increases the granularity of transaction and enforcement data.

System Design
As shown in Figure 3, a user interface that shows block level probability of parking availability instead of space level availability further reduces accuracy requirement for occupancy. This has the potential to further reduce the number of deployed assets and reduce costs.
Data Fusion
The third element of this minimum-viable solution approach is to combine data from around the parking ecosystem, including a limited deployment of assets on the ground, to estimate occupancy. Less but more accurate sensing hardware will provide for better forecasts and decision-making. This asset-lite approach then “blends” a variety of sources of data. Paid usage and payment data are “blended” with sampled occupancy data, and sampled real-time occupancy data to determine the real-time occupancy of the system. This information is then used to inform the pricing engine and real-time traveler information system.

Technology Assessment
The parkDC: Penn Quarter/Chinatown pilot is conducting a thorough and wide-ranging technology assessment for on-street parking occupancy sensing. The technology assessment will determine the feasibility of each technology in the D.C. environment. By determining which technologies perform best under various conditions and pulling data from a variety of sources, relationships and proxies can be developed, thereby lowering costs while improving accuracy. The technologies include:

- In-ground sensors (3 vendors)
- Parking meter dome mounted sensors
- Movable cameras
- Fixed cameras

Testing has started on the first three technologies listed above, with the locations identified in Figure 5. The technologies will be evaluated using a range of evaluation criteria:

- Accuracy
- Latency
- Reliability
- Versatility
- Scalability
- Ease of installation
- Life cycle cost – capital, operating

![FIGURE 5 Technology assessment.](image)

Several factors will influence the final mix of devices deployed in the study area. Variations in street configuration and parking demand mean different devices may be necessary in different areas. For
example, a block lined with trees may create occlusions for overhead cameras and call for special sensor or camera configurations.

Similarly, while sensors and permanently mounted cameras provide highly accurate data, they are both expensive and difficult to maintain. Sensors are prone to interference, have only been shown to work effectively in demarcated parking environments, and often fall victim to street work (construction and snowplows). Permanently mounted cameras can run into issues when communication lines are disconnected for street work or for events, and the cameras must be maintained to ensure optimal performance. Reducing the number of sensors and cameras reduces exposure in addition to saving money.

**Payment Data**

Given the costs and exposure risks of relying solely on sensing devices, D.C.’s asset-lite solution will combine data from different sources to build a reasonably accurate picture of occupancy. Payment transactions are a good place to start, though the usefulness of the data source varies by city.

Pay-by-cell payments have grown in D.C. over the last four years and now represent 55% of all payments made. However, the penetration of pay-by-cell usage differs from block to block by as much as 40%, limiting the ability to use pay-by-cell alone as an occupancy proxy. As demonstrated in a Midwestern city (“City A”), the combination of pay-by-cell and meter payment data can offer a better window into parking utilization. In the city, the correlation between occupancy (established through sensors) and meter payments (transactions collected from smart meters and pay-by-cell) is nearly perfect at 0.982. However, the city is unique in that disabled drivers must pay to park at a meter, and the enforcement of meters is very proactive.

Figure 6 compares the relationship between payments in City A (left) to City B (middle), and to D.C. (right). The impact of lax enforcement and free parking for persons with disability and other placard users becomes readily apparent when comparing the almost one-to-one relationship between occupancy and paid use in City A on the left to City B where occupancy often exceeds payments. The poor correlation in City B (the correlation is just 0.60) is similar to most other cities. In the D.C. pilot area, for instance, seven blockfaces were compared, and the data is shown to the right of Figure 6, with the different dot colors representing different blockfaces. The correlation between payment and occupancy was calculated to be 0.31, with placard usage and free parking for D.C. government vehicles and other “official” vehicles contributing to the poor correlation. As a consequence, payment transaction data alone would be an insufficient proxy of occupancy on most blocks.

**FIGURE 6** A comparison of payments and occupancy in City A (left), City B (center), and a preliminary sample dataset in D.C. (right).

Further complicating matters, payment data may also not be determinative of the duration of a stay and turnover, especially in cities where metered spaces are not demarcated. Sensors in the pilot area were installed in demarcated spaces, ensuring binary reporting of “occupied” or “available” unlike
environments where spaces are not marked. Despite this, excluding outliers (events shorter than two minutes could denote a vehicle attempting to park), there was a significant disparity between paid time and the actual amount of time a vehicle parked. Cars parked from two to twenty minutes, for instance, were four times more likely to park without paying. Because of this disparity, we looked to temporal and spatial sampling using camera and sensors to supplement or supplant payment transactions to estimate occupancy.

Spatial and Temporal Sampling
Use trends are fairly static and indicate that occupancy can be extrapolated. While utilization may change significantly during a day, it may not change drastically from day to day or week to week. For instance, the standard deviation from week to week, Monday through Friday, was extremely small on blocks served by sensors in the pilot area, just 2.48% over an 11-week period. The standard deviation by day on the blocks was also acceptable, just 1.35%.

In addition to sensor data, D.C. used portable cameras to supplement payment data, and improve its understanding of parking trends. Six trailers equipped with up to four cameras each were moved throughout the pilot area on a weekly basis. Once positioned, they captured data on a particular block for several days before moving to the next scheduled block using the Whittle Index \((10)\) as guidance. The video was studied using algorithms and computer vision. The output revealed trends by space and block, providing real insights instead of anecdotes about parking and space use.

Some blocks have been reviewed multiple times to identify potential changes in parking demand and supply. Fewer visits on a particular block are required when payment transactions correlate to use, or when availability is high and occupancy rarely fluctuates hourly or daily. Still, challenges in applying spatial and temporal sampling must be addressed using advanced analytics.

Realizing this, D.C. will minimize the number of parking stalls observed, and the amount of time observations are collected. Spatial sampling provided information about where sensors should be installed, while temporal sampling assisted in determining how often occupancy should be measured and the order in which blocks are examined.

Sampling Challenges
Challenges remain in applying spatial and temporal sampling and must be addressed using advanced analytics. This section describes two particular challenges along with potential strategies for addressing them.

Challenge One – Occupancy on a Block May Not Be Evenly Distributed. Not only is it typical for there to be huge differences in occupancy from block to block, there can even be significant differences from stall to stall on a block face. A meter with high occupancy rates may sit right next to a meter with significant availability. Sampling models and decisions about the placement of hardware must account for these variations on a blockface level.

Excluding outliers, the standard deviation in occupancy between spaces on a block is very low. The average standard deviation across the seven blocks served by sensors was 5.45%. In the example noted in the top of Figure 7, the standard deviation excluding significant outliers is just 2.3% across all of the spaces on the west side of 700 7th Street, NW, with parking habits across the spaces being largely the same. But outliers matter. As the middle of Figure 7 shows, there are substantial differences between the utilization of proximate spaces on the 700 block of 7th Street, NW. There, for example, the occupancy of stall 7W002 is about 65%, in line with the use of stalls 7W004 through 7W010. But the average use of the first stall on the block, 7W001, is nearly 30% higher. Further, stall 7W002, a space reserved for persons with disabilities, is more than 50% less. Significant deviations may make it difficult for motorists using wayfinding apps to locate available parking and could negatively influence occupancy and the allocation of enforcement resources.

Sampling models and decisions about the placement of hardware must account for these variations on a blockface level.
Addressing Challenge One: Improving Occupancy Predictions with Sampling

We will work to place sensors in areas with significant fluctuations in occupancy, thereby improving our ability to accurately predict occupancy.
report use and turnover. In addition, we can reduce the impact of significant deviations by improving
occupancy predictions the entire block.

We applied occupancy data provided through spatial and temporal sampling to real-time paid use
to improve our occupancy predictions. We used historical occupancy data gathered by sensors and meter
and mobile payment transactions between April 6 and May 31, 2015, the seven blocks served by sensors
to determine the average daily and hourly deviation between occupancy and paid use. We then applied the
difference between these historical values (the “Factor,” as exemplified on the north side of 700 E. Street
at the bottom of Figure 7) to paid use (“Avg. Paid Use”), to estimate occupancy (“Predictive
Occupancy”). We compared the predicted value to actual occupancy during the period of June 1 to July
24, 2015, and we determined that the root mean square error (RMSE) was just 6.3% on these blocks (and
3.9% at 700 E. Street). We can, then, with some confidence, apply historical deviations between sampled
data to real-time payment data to very nearly calculate occupancy. This information can be communicated
to motorists via apps to help them find available parking and can help predict infractions.

**Challenge Two - While Some Blocks Demonstrate Few Deviations in a Space or on a Block from**
**Week to Week, Others Do Not.** The ability to predict occupancy with cameras is predicated on accurate
sampling. Towards this end, the sample size is important. If an area is studied for too few days, the data
may not be representative of true parking trends. A number of factors can influence occupancy and paid
use from week to week, including special events (like concerts or sporting events), street closures (due to
parades, motorcades, emergency response, etc.), and even seasonality.

On the north side of the 700 block of E Street, NW, as noted in Figure 8, there was a significant
deviation from normal use between April 20th and 25th. The paid use percentage dropped to single and
low-double digits between 10 AM and 5 PM. On other blocks, we sometimes witnessed significant
fluctuations in a single space, often on Saturdays. Paid use on those blocks could sometimes bounce
between 0% to 80% or more, resulting in a standard deviation of 35%.

To improve the predictive quality of the data further, D.C. tested whether meter payment
transactions could be combined with citation data to improve the average predicted occupancy on a block.

**Addressing Challenge Two: Improving Occupancy Predictions with Sampling and Citations** In addition to
ensuring a robust data sample to improve confidence in predictions, we can augment the sample by
estimating the percentage of spaces that should be paid in a given hour. We know how many vehicles are
paid at any given time, but that data alone doesn’t provide insights into motorists that have parked and
failed to pay.

Illegal parking can significantly influence variations in predicted occupancy. Motorists parking
illegally without paying parking meters negatively impact the relationship between paid use and
occupancy. We hypothesized that we could further improve our occupancy predictions by supplementing
the sampling Factor with real-time parking meter violation data. We again used historical sensor data
gathered and payment transactions from April 6 to May 31, 2015, and determined the average daily and
hourly deviations. Rather than applying this historical Factor to actual paid use for the period of June 1 to
July 24, 2015, we predicted what paid use should be (“Predicted Paid” as exemplified on the north side of
700 E. Street at the bottom of Figure 8) by adding a vehicle to the paid use calculation (“Avg. Paid”) when a citation was issued in a parking space for failing to pay a meter. When compared to the actual
occupancy (“Avg. Occupancy”) during the period of June 1 to July 24, 2015, the RMSE was reduced to
5.8% on the sensor blocks, an improvement of 8% (and an RMSE of 3.5% on 700 E. Street, a 12.8% improvement). We are confident that our ability to auger occupancy will only improve as resources are
better aligned to enforce meter violations.
FIGURE 8 Isolated deviations in a parking space (top) and the use of citations to help improve occupancy predictions (bottom).
NEXT STEPS

The D.C. pilot offers a unique opportunity to review a variety of data and determine its applicability and accuracy in reporting and predicting occupancy. Although significant work has been completed studying the relationships between a variety of sources, more study is required to identify patterns and determine how policies, street configurations, and parking habits influence occupancy. Towards that end, researchers shall:

- **Continue to collect and evaluate data.** As noted above, D.C. will continue to gather data from sensors and movable cameras and will expand its review to other data sources, including fixed cameras and vehicle mounted license plate recognition. The review will be expanded during the pilot to include occupancy determinations in loading zones and bus zones. Each week, data scientists study and enhance the computer vision algorithms to improve accuracy and address block-by-block and hour-by-hour peculiarities. That effort will be ongoing during the pilot.

- **Identify the optimal occupancy asset mix in the pilot area.** In doing so, D.C. will solicit customer feedback and will evaluate the accuracy, including quantitative and qualitative performance indicators, of the hardware and software solutions. We hope to select the right solutions for the right locations at the right times, measuring the impact of full and reduced sensor coverage (75%, 50%, and 25%) on accuracy. Ultimately, the goal is to select the optimal asset mix for occupancy detection, using sensing solutions for at least 50% of the system.

- **Establish demand-based pricing recommendations.** When hourly parking meter prices don’t keep up with demand, finding parking can be difficult. Artificial pricing structures ensure an uneven distribution of demand and create congestion as well as dangerous conditions. Performance-based pricing promotes alternatives, including parking a little further from one’s destination; taking mass transit, biking, or walking; or visiting a location when there is less congestion.

- **Manage demand by adjusting time limits.** In most cities, time limits, or the maximum time a customer can purchase and park at a meter, are fairly arbitrary. Most limits are set by ordinance and fail to recognize demand or the types of businesses being served by meters on a block. D.C. will work to improve the correlation between time limits and the pilot study’s goals.

- **Evaluate the effectiveness of wayfinding solutions.** Data fusion will provide a path forward to predict occupancy and provide data to app providers. These apps will communicate information to customers, providing them options and turn-by-turn navigation to blocks with available parking. We hope to learn about the customer experience and evaluate the effectiveness of such solutions.

CONCLUSIONS

This paper discusses an approach with the potential to become the state-of-the-practice for developing real-time availability for on-street parking in a sustainable and cost-effective fashion. It reduces the capital and operating expenditures of assets by leveraging data from other parts of the parking ecosystem. The data fusion and business analytics being tested in D.C. can enable the parking profession to mainstream the concept of demand-based curbside management and real-time parking availability information. This has implications beyond the immediate parking industry. It allows parking professionals to integrate this information with pricing information and real-time trip guidance information that are becoming part of the mainstream transportation sector, and provide a seamless set of information for customers.

Given that every vehicular trip ends with parking, a cost effective way of generating availability information opens up opportunities for combining this information with real-time trip-guidance systems. This “last-mile information” gives customers an idea about the entire end-to-end trip from their point of
origin to their destination including parking options. This visibility into the time and cost implications of
the entire trip enables a customer to make better-informed modal choices.

Real-time occupancy and demand also enables agencies to develop pricing and enforcement
strategies to more effectively manage curbside congestion. The relationship between curbside congestion
and roadway congestion is well recognized; but the toolbox currently available to agencies dealing with
curbside congestion is limited. The capability to apply performance-based parking pricing will enable the
transportation sector to address urban congestion in a more holistic fashion.

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