MATS UTC

FINAL REPORT

Quantifying the Impact of On-Street Parking Information on Congestion Mitigation

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16. Abstract

This study investigates the effects of different types of parking information on travelers' parking choice behavior and circulation time through a driving simulator and a stated preference survey. In the simulator-based driving experiments, a 3.47 mi^2 network was developed in the Chinatown area of Washington, D.C., with different traffic, driving condition, and information provision scenarios. The parking information was provided using a variable message sign (VMS) or a mobile application. In all scenarios, participants were able to choose among three parking options (one of two garages or on-street parking) with different prices and different walking distances to their final destination. A sample of 76 participants with diverse socioeconomic backgrounds completed 636 driving simulator scenarios. A multinomial logistic regression model, linear regression, and t-tests were applied to analyze the collected data. Results showed that types of information and age were important determinants of drivers' parking choice. Results also show that the availability of parking information decreases travelers' circulation time. In addition, the parking choice behavior revealed in the driving simulator was shown to be significantly different from the parking preference stated in the survey questionnaire.

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PROBLEM

Information plays an important role in travel. This extends to information about parking availability, which plays an important role as part of the travel process. Past studies have shown that, on average, 30% of cars need to cruise to find street parking during rush hours, increasing average travel time by as much as 8 minutes [1]. May jurisdictions have introduced innovative parking management strategies to address congestion in urban areas in order to reduce the congestion and emission levels associated with the time spent cruising for on-street parking. Mobile apps and sensing technologies containing varying levels of parking information are becoming increasingly available to drivers. On-street information provided by sensing technologies has an advantage over mobile apps in that it allows drivers to find available parking without taking their eyes off the road. On-street parking information has the added benefit of being more equitable, as it does not rely on the use of smartphone technology. However, smartphone apps are also beneficial for trip planning and in situations where drivers can rely on passengers to safely disseminate information or when the information is provided via audible prompts.

APPROACH

In this study, the research team proposed decoupling pricing and parking information and using an innovative method relying on-street signs as well as a smartphone app to provide accurate on-street parking availability information using parking meter data from a pilot study in the Penn Quarter/Chinatown area of Washington, D.C.

The effectiveness of the proposed method was tested for a range of parking information data using a driving simulator. Morgan State University's advanced, computer-based driving simulator was utilized to study drivers' parking behavior with and without parking availability information under varying traffic and parking conditions. The study focused on three cases: (1) no parking information provided, (2) parking information provided solely through a smartphone app, (3) parking information provided via on-street signage. The Virginia Tech Transportation Institute (VTTI) team also integrated these models into a microscopic traffic simulation environment to quantify the network-wide impacts for each of these cases.

This study can provide agencies with the tools necessary to incorporate parking information into curbside management best practices.

LITERATURE REVIEW

Like Advanced Traveler Information Systems (ATISs), which have been used widely to diminish congestion in urban areas, information about the availability of on-street parking is progressively significant, as congesting increases along with the additional time spent cruising for spaces. To address on-street parking issues and ease congestion, detailed and variable levels of parking information are becoming more freely available to consumers via smartphone apps and sensing technologies.

Following is a review of some works in the context of parking availability information in four primary areas: parking sign design, parking availability information and searching time, parking availability information and traffic congestion, and parking availability information and technology.

Parking Sign Design

Traditional signage guidelines are typically defined in the Manual on Uniform Traffic Control Devices (MUTCD). However, the MUTCD provides only limited regulations for parking signs, which must display constantly changing information based on parking locations and availability. Existing guidelines only define static parking sign designs. Related regulations in MUTCD include the following: parking signs (Sections 2B.46–2B.48), parking area signs (Section 2D.47), general no parking signs on low – volume roads (Section 5B.05), parking regulatory signs (Section 7B.17) [2].

The development of LED technology has allowed for the use of variable message signs (VMSs) as an effective way to deliver parking information. Three types of matrices are used in VMSs: modular, continuous line, and full matrices. According to a Federal Highway Administration (FHWA) report [3] the height of a character on a VMS can vary from 18 to 54 inches, and each character must be a minimum of five pixels wide by seven pixels high.

The design process for a VMS involves selection of the message, display format, display time, placement location (height and size), brightness, and other parameters. In general, the signs need to be visible, understandable, and unambiguous. Previous studies concluded that the following factors need to be considered when designing the signs:

- Search Time; pricing; area-wide traffic network and parking policy; individual characteristics (trip and personal); physical parking and built environment characteristics [4]

- Availability; distance from parking location to destination; safety; familiarity; price [5]

- Parking costs; distance between parking and the final destination; number of free spaces [6]

- Walking time; availability of parking spaces; parking fees; trip purpose [7]

Parking Availability Information and Searching Time

As the number of vehicles traveling to urban areas increases, so does the demand for parking spots, leading drivers to cruise the area in search of a parking space. A parking search begins when an individual reaches their destination, attempts to park, then drives around an area until finding a spot that meets their needs for that specific trip. Hence, a parking search translates to additional travel by drivers that occurs only upon reaching a destination [8]. Van Ommeren, Wentink, and Dekkers [9] estimated that time spent searching for parking increases commuting time by approximately 20%. Decreasing the time that vehicles spend searching for parking places alleviates not only traffic congestion but also the associated environmental impact. Studies by Waraich and Axhausen [10] and Shoup [1] found that at certain moments in the day, up to 50% of traffic is related to cruising for parking. A unique factor of the parking search is the length of time required by drivers to locate an empty parking space that efficaciously fulfills their requirements. Also, Arnott and Inci [11] investigated the parking search from an economic perspective and proposed an intelligent algorithm that allows drivers to choose a car park with the maximum probability of getting a space. Pullola, Atrey, and El Saddik [12] modeled the availability of a parking lot using a Poisson process and proposed an algorithm that helps in dynamically locating the best available parking lots nearest to the driver's destination.

Caicedo [8] advanced a demand assignment model to estimate the benefits of manipulating information with the objective of decreasing the time and distances involved in finding parking. The model allows for the evaluation of parking control measures and for quantification of information management's effect on parking. It analyzes real information to evaluate different possibilities for distributing information to influence the distance covered in reaching a parking space, the time spent searching, and the walking distance between the parking space and the destination. According to Rye et al. [13], if managing information about parking availability lessens the time spent circulating and seeking a free space, it may be possible to use information management to develop a comprehensive demand management tool. Guo et al. [14] provided numerous significant insights into the factors of disseminating travel time information on the impact of on-street parking. Arnott and Inci [11] recommended a simple model of parking congestion that focused on a driver's search for an available parking space in a spatially identical metropolis.

Several other studies in the literature have particularly focused on designing efficient pricing policies. For example, Tsamboulas [15] estimated how drivers' parking behavior changed based on a combination of increased/decreased walking time and higher/lower parking charges, and found that drivers would choose a costlier parking location if it was associated with reduced walking time. Gallo, D'Acierno, and Montella [16] developed a simulation-based parking assignment model with a hierarchical structure simulating parking location choice on a trip, including a cruising and a walking layer; studies indicated that between 8% to 74% of traffic congestion in urban areas is due to drivers looking for a place to park [1]. Chaniotakis and Pel [17] analyzed drivers' choice behavior among alternative parking locations under uncertain parking availability and search times. As parking probabilities are important determining factors in drivers' parking decisions, these studies indicate that parking guidance and reservation systems could be useful in reducing the time spent searching for parking, and indicate the value in further research into drivers' acceptance and willingness-to-pay towards such systems.

In a similar study targeted at reducing unnecessary travel time and its influence on traffic networks, Thompson, Takada, and Kobayakawa [18] developed a model to curtail parking queues, and hence waiting time, by dispensing extra demand across parking facilities with spare capacity and diverting drivers from centrally located parking toward parking facilities located closer to drivers' travel origins. It is apparent from the literature that well-designed and useful parking guidance information can help advance application and management of parking resources [8]. Moreover, guidance systems considerably improve the probability of finding an available parking space, alleviate obstruction of the drivers/visitors unfamiliar with the city center, decrease the queues in front of parking garages, reduce the total amount of vehicle-miles traveled (particularly in the city centers), and decrease the average trip time, energy consumption, and air pollution [19].

Intelligent Transport Systems (ITS) are giving traffic managers new opportunities to provide up-to-date information and guidance to drivers. Parking Guidance and Information (PGI) systems are among the most common forms of ITS presently in use. Most systems depend on VMSs to offer information about the accessibility of spaces at parking facilities [15], [18], [20]. Their overall purposes are to decrease the queue at parking facilities and to reduce parking search times. Dynamic PGI signs affect individuals' parking choices by offering drivers real-time information about parking situations with the goal of diverting motorists from congested parking amenities and encouraging the utilization of under-used parking facilities [18], [20]. An additional objective is to diminish parking search time and the related local traffic congestion resulting from vehicles circulating city centers to find vacant parking spaces [15]. Outcomes indicated that parking PGI services improved drivers' car park knowledge [21]. In conclusion, if PGI signs along main urban routes were used to transfer information about space availability within certain accommodations, this may have broader network implications for reducing unnecessary travel to already full parking facilities [22].

According to Axhausen and Polak [23], there are few before and after studies on the efficacy of PGI systems. This is in part due to the fact that studying drivers' behavior in relation to parking information is a new area of research; for example, behavioral models available for evaluating a PGI system are not yet well developed. To add to the body of work in this area, Axhausen and Polak [23] recently reported on the effectiveness of a PGI system in Frankfurt, which found that the system was effective in reducing time spent searching for parking.

Information related to the number of available parking spaces could be displayed on main roads, streets, and intersections, or could be distributed through the internet. Further, studies to date show that PGI systems usually do not change occupancy rates or average parking length, and that drivers become accustomed to the PGI systems, and the majority of them use, trust and appreciate the assistance and information they provide [23].

Parking Availability Information and Traffic Congestion

Network traffic flow and congestion increase when vehicles search for on-street parking, creating increased environmental and economic strains. The search for parking is an under-researched area that has been addressed only in recent years for the most part, despite the fact that it has tremendous adverse effects on individual drivers and society. Specifically, vehicles searching for parking are responsible for 14% of traffic density and generate a 50% growth in congestion-related time loss [22]. Likewise, in a review of 16 studies conducted in 11 cities in the U.S., an estimated average of 30% of traffic was searching for parking, with 8.1 minutes being the average search time [1].

In the same manner, according to Arnott and Inci [11], the number of cars cruising for parking increases traffic congestion in urban areas. Some researchers have considered the downtown parking model, which incorporates traffic congestion and saturated on-street parking, from an economic perspective. In a car-dominant era, parking policies and management are essential for managing traffic entering city centers, ensuring parking space availability and shifting passengers to other travel modes.

Several studies investigated the effect of parking policies on traffic flow and traffic demand management. Among those studies, Bolanowska and Hemily [24] and Willson [25] provided comprehensive reviews of transit supportive parking policies, while reviews of parking policies and management are given by [26]. Shiftan and Burd-Eden [20] attempted to model driver reaction to these policies. The effects of parking policies on traffic flow in central urban areas of developing countries are observed [27]. Petiot [28] studied the relationship between parking enforcement and travel demand management. A comparison of the effects of parking policies versus congestion pricing is provided by [29]. The elementary perceptions of the parking booking system and parking revenue management system are argued by [19]; the authors believe the objective purpose of their paper (maximization of income) can significantly impact traffic patterns, as well as make the spread of traffic flows more equal over time.

Parking Availability Information and Technology

Improvements in technology are influencing parking searches, with search time decreasing in urban areas as technological parking solutions are introduced. For example, the SFPark scheme in San Francisco uses embedded sensors in on-street parking spaces to specify real-time parking occupancy for each space, and employs dynamically flexible parking charges according to the demand for on-street metered parking spaces [30]–[32]. Internet websites, such as Parkopedia.co.uk, Car Parks 4U.com, and Confused.com give drivers information in advance as to the location of parking places around the desired destination, decreasing the need for parking search upon arrival.

Some systems claim to provide drivers with real-time information about vacant parking spaces, one such example being Fastprk [33]. Dynamic technological advances in the form of smartphone applications help motorists locate, and possibly reserve and pay for, an available parking space remotely by locating empty spaces in real-time, and consequently decreasing the time and effort needed for the parking search [34]. A 2014 scheme developed in Chicago, ParkChicago, allowed drivers to pay for parking via mobile phone without the need to locate a meter, show a valid ticket, or return to the meter to extend parking time. There are a number of other locations that generate smartphone applications to handle parking-meter payments, as ParkMobile does in the UK [35]. Each solution for mobile parking payment, from the first, such as Mobipay [36] to the latest smart parking applications like Central Parking Systems, required research activities focused on sensor deployments [37]. Mathew et al. [38] developed a smartphone app that reserved a parking space in an off-street lot. Drivers who had reserved a parking space beforehand decreased their search time by 40%, discovered an available space during peak times, decreased overall travel time, and reduced emissions since vehicles were no longer slowing down or accelerating to find a parking space. This type of smartphone application has the potential to achieve similar impacts for on-street parking searches. Grazioli et al. [39] demonstrated a modular, service-oriented smart parking system, which comprises web applications for parking operators and end-users, along with mobile apps for end-users and parking controllers.

To control its curbside and parking properties the D.C. Department of Transportation (DDOT) uses an app called ParkDC that reduces the Circulation Time for finding parking by providing real-time information about parking availability [40]. An advanced street parking system called PhonePark, using the GPS, accelerometer, and Bluetooth sensors on a traveler's mobile phone in conjunction with geospatial data, can automatically detect when and where the passenger parked their car, and when they left a parking slot [41]. Likewise, Shin and Jun [42] developed a smart parking algorithm that helps drivers find a parking facility based on features such as access time, walk time, parking charge, and traffic congestion with the potential to be applied to on-street parking. There are currently a number of efforts underway to develop systems to help drivers on the road, providing them with diverse types of pertinent information.

Almost all commercially available vehicles have substantial volumes of ferrous metals in their chassis and engine (e.g., iron, steel, nickel, cobalt, etc.), making Anisotropic Magneto-Resistive (AMR) sensors good candidates for detecting vehicles [43]. These sensors determine whether space is occupied or not by detecting the presence of a vehicle based on a change in the environment's magnetic field. Various researchers have proposed algorithms for vehicle parking detection by AMR sensor [37], [44].

Information related to the number of available parking spaces could be displayed on main roads, streets, and intersections, or could be distributed through the internet. To quantify the impact of on-street parking information on congestion mitigation, this study seeks to link information provision regarding parking availability and driving circulation time using a real-world network in downtown Washington, D.C., and parking availability information provided by the District Department of Transportation.

METHODOLOGY

Parking Information Signage Test

To evaluate the behavior of participants in the driving simulator, it was necessary to first code in a clearly designed and easy-to-understand sign providing parking information. The sign had to be easy to spot and straightforward in conveying the information to participants. In addition to being clearly designed, the optimal sign had to be easily understood by all age and gender groups and provide the parking information most needed by typical drivers. The goal of this part of the study was to identify which of the sample signs was the best-designed. Six parking sign designs with different information regarding parking rates, distances to destinations, directions, and other information were shown on the computer screen for a short period of time (Figure 1 through Figure 6). The length of the time period was approximately the same as the time a driver would have in the real world based on the speed limit when approaching and passing the sign. For each sign, the participants were asked to complete a questionnaire at the end of viewing period and describe the parking information they gathered from the sign (Appendix A). The questionnaire included specific questions in order to determine whether or not participants understood the signs. At the end of the questionnaire, each participant was asked to select up to two of the best signs, in their opinion.

Figure 1. Parking Sign 1

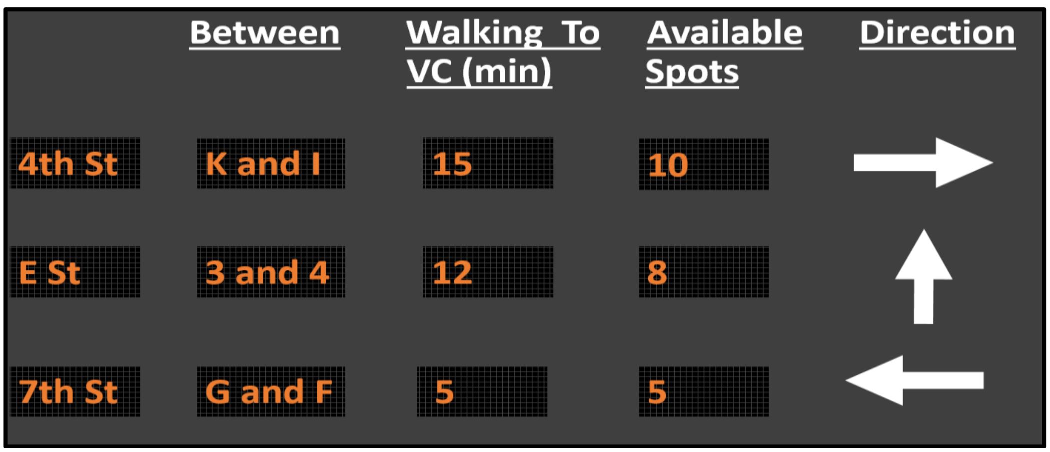

Figure 2. Parking Sign 2

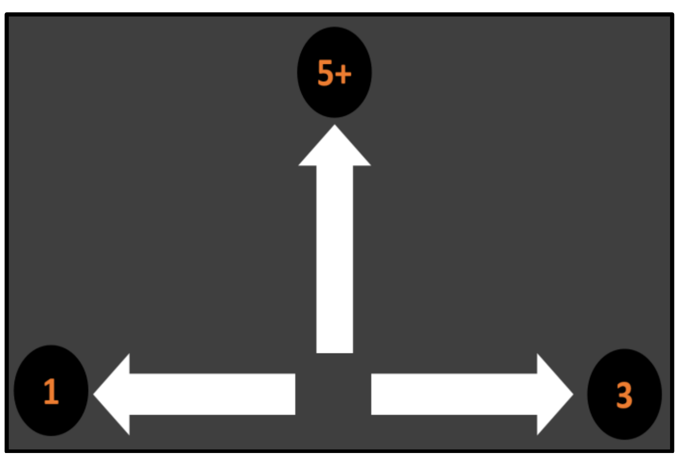

Figure 3. Parking Sign 3

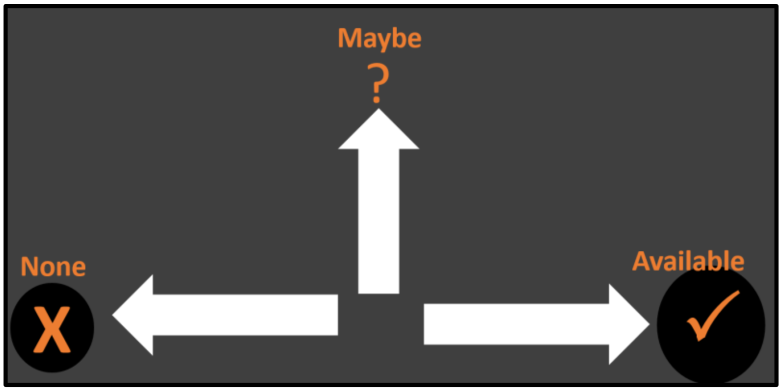

Figure 4. Parking Sign 4

Figure 5. Parking Sign 5

Figure 6. Parking Sign 6

Driving Simulator (DS)

This study used a driving simulator with VR-Design Studio software (formerly UC WinRoad) by Forum8 (Forum8) owned by Morgan State University. This computer-based simulator allowed researchers to simulate a real network and gather some useful parameters such as geographic positions, speed, distance traveled, offset by road's shoulder, acceleration, brake and yaw/pitch/roll angle, and accidents. The hardware is similar to a real car's and consists of the driver seat, cockpit, steering wheel, acceleration and brake pedals, ignition switch, gear stick, flash lights, and three surrounding monitors to provide a 3D view and rear view (Figure 7). The software can generate and edit network fundamentals including road markings, intersection design, traffic signals, cross sections, roadside signs, terrain setup and traffic generation. The software allows for the simulation of traffic flow, weather conditions, spatial environment, and static objects. Figure 8 shows a screenshot of the constructed environment in this study.

In this study, participants were asked to make a trip from one of two origins (the intersection of 14th St. and Pennsylvania St. or the intersection of K St. and 15th St.) to a final destination (Verizon Center) and find parking. The simulator recorded the useful parameters of the driving experience such as travel time, spot speed, lane changing, crashes, and location of chosen parking.

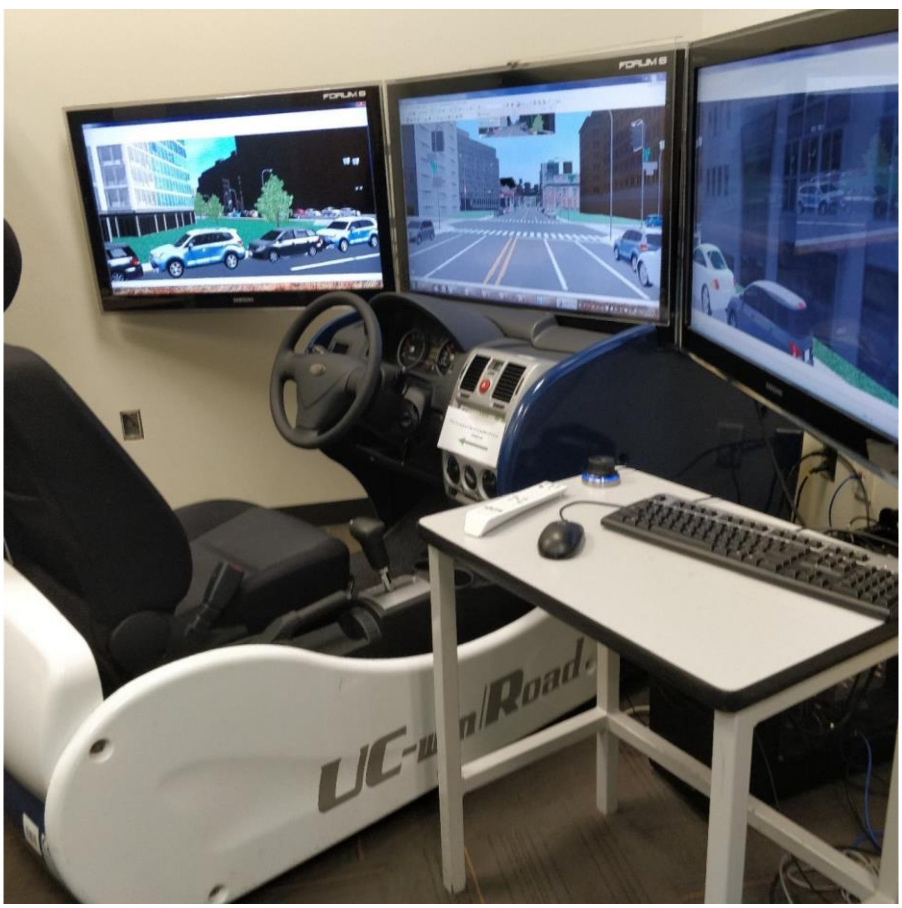

Figure 7. The Driving Simulator Owned by Morgan State University

Figure 8. A Snapshot of Network in Driving Simulator

Network Design

In the driving simulator, we developed a 3.45 mi^2 network of Chinatown in Washington D.C., including streets, signs, trees, vehicles, and buildings (Figure 9 and Figure 10). Then, using different scenarios, we asked participants to drive the route described in the Driving Simulator section above and find parking. Participants had three parking alternatives to choose from: 1) the Verizon Garage located at 6th St. between G St. and H St. with a walking distance time of 0 minutes to the destination; 2) the 11th St. Garage at F St. across 11th St. with a walking distance time of 7 minutes to the destination; and 3) On-Street Parking throughout the network with a walking distance time of between 0 and 20 minutes to the destination (Table 1).

Table 1. Parking Alternatives Information

Parking	Location	Walking distance time from parking to destination (Verizon Center)
Verizon Center Garage	6th St. between G St. and H St.	0 min
11th St. Garage	F St. across 11th St.	7 min
On-street lot	All the network	From 0-20 min

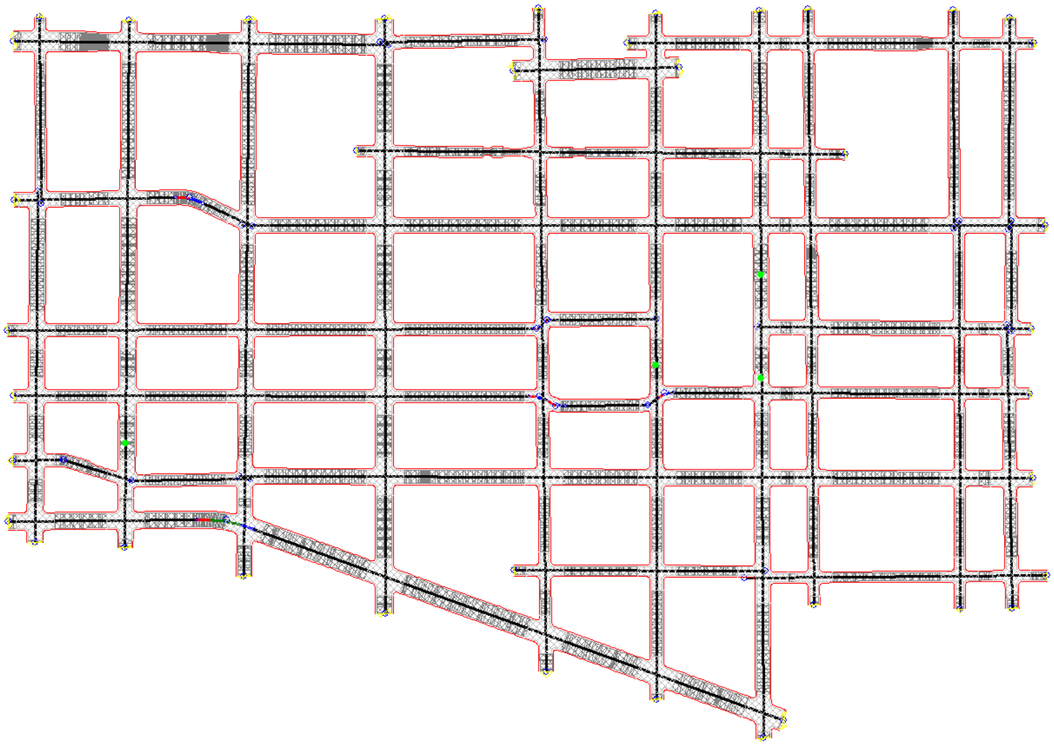

Figure 9. The Developed Network in the Driving Simulator

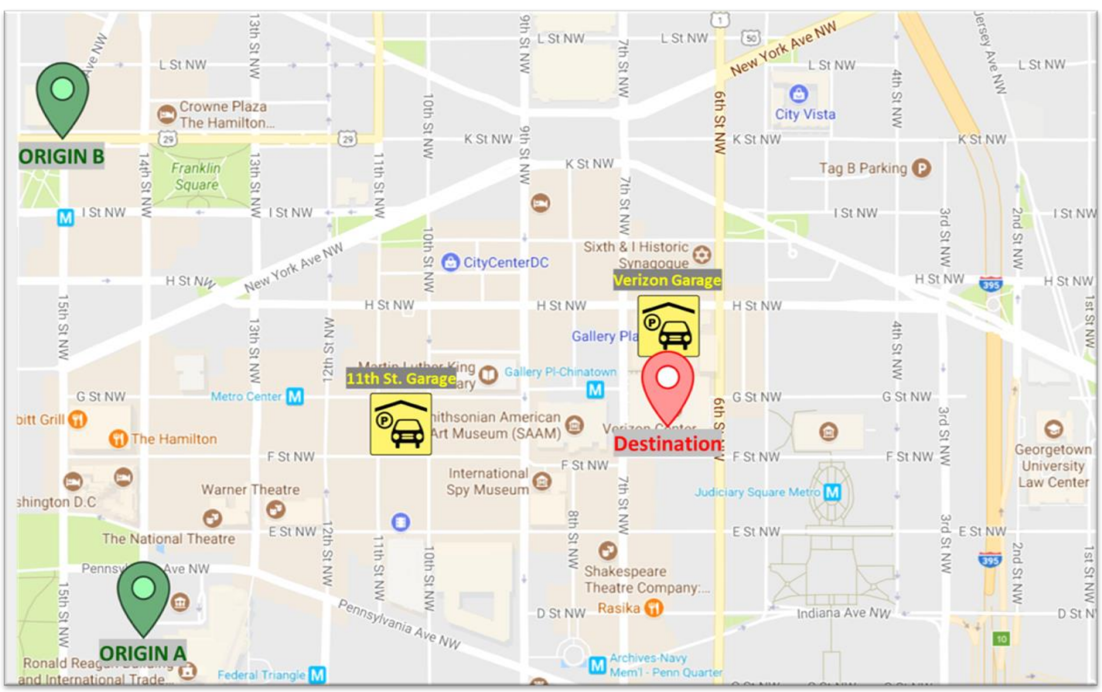

Figure 10. The Study Area

Scenario Design

Twenty-four scenarios were developed in this study to simulate:

- Different traffic conditions
    - AM peak
    - PM peak
    - Off-peak
    - Weekend
- Trip purposes
    - Purpose requires arrival at a set time
    - Purpose does not require arrival at a set time
- Different levels of parking availability information
    - No-information
    - VMS
    - Smartphone app

As shown in Table 2, Scenarios 1–4 and 13–16 were the base scenarios in which no information was provided to participants. These scenarios were used to benchmark participants' Circulation Time. Scenarios 5–8 and 17–20 included VMS-provided information for available on-street parking in each intersection (Figure 11). Scenarios 9–12 and 21–24 provided information via smartphone app (Figure 12). It should be noted here that the scenarios were not presented to participants sequentially in the driving simulator runs; all 24 scenarios were divided into four groups (A, B, C, and D) of six scenarios each and each participant chose to drive one to six scenarios.

Table 2 Description of Twenty-Four Scenarios in the Study

Scenarios	Origin	Information Type	Time Matters	Traffic Type	Parking price		
					Verizon Garage	11th St. Garage	On-street parking
1	K St. and 15th St.	No Information	Yes	PM-peak	$40	$20	$2
2	14th St. and Pennsylvania	No Information	No	AM-peak	$30	$20	$2
3	14th St. and Pennsylvania	No Information	No	Off-peak	$30	$20	$2
4	K St. and 15th St.	No Information	Yes	Weekend	$30	$20	$0
5	K St. and 15th St.	VMS	Yes	PM-peak	$40	$20	$2
6	14th St. and Pennsylvania	VMS	No	AM-peak	$30	$20	$2
7	14th St. and Pennsylvania	VMS	No	Off-peak	$30	$20	$2
8	K St. and 15th St.	VMS	Yes	Weekend	$30	$20	$0

9	K St. and 15th St.	App	Yes	PM-peak	$40	$20	$2
10	14th St. and Pennsylvania	App	No	AM-peak	$30	$20	$2
11	14th St. and Pennsylvania	App	No	Off-peak	$30	$20	$2
12	K St. and 15th St.	App	Yes	Weekend	$30	$20	$0
13	K St. and 15th St.	No Information	No	PM-peak	$40	$20	$2
14	14th St. and Pennsylvania	No Information	Yes	AM-peak	$30	$20	$2
15	14th St. and Pennsylvania	No Information	Yes	Off-peak	$30	$20	$2
16	K St. and 15th St.	No Information	No	Weekend	$30	$20	$0
17	K St. and 15th St.	VMS	No	PM-peak	$40	$20	$2
18	14th St. and Pennsylvania	VMS	Yes	AM-peak	$30	$20	$2
19	14th St. and Pennsylvania	VMS	Yes	Off-peak	$30	$20	$2
20	K St. and 15th St.	VMS	No	Weekend	$30	$20	$0
21	K St. and 15th St.	App	No	PM-peak	$40	$20	$2
22	14th St. and Pennsylvania	App	Yes	AM-peak	$30	$20	$2
23	14th St. and Pennsylvania	App	Yes	Off-peak	$30	$20	$2
24	K St. and 15th St.	App	No	Weekend	$30	$20	$0

Figure 11. Example of VMS in the Driving Simulator Network

Figure 12. Example of Mobile Application Displaying Parking Conditions (Green Indicates 5+ Parking Spots Available, Yellow 2–4 Spots Available, and Red up to 1 Spot Available)

Survey Questionnaires

In addition to participating in the simulator-based driving experiments, all driving simulator participants were asked to fill out three different survey questionnaires sequentially. The first two questionnaires were given before the driving simulator experience, and the third was given afterwards. The first questionnaire presented socioeconomic questions, including gender, age, education level, job status, driver's license type, income level, and household size. These characteristics were essential to accomplish a proper parking choice model in the next stage (Appendix B). In the second survey, for each specific study area, participants were shown a map similar to Figure 12, and were asked about their familiarity with this area. Participant attitudes toward different information types and parking choices were also elicited to determine their parking preference in each of the scenarios' conditions (Appendix C). The third survey (Appendix D) addressed the acceptance and usefulness of parking availability information provisions.

Driving Session Rules

To simulate real-world conditions, a set of rules was developed and explained to participants before the driving experiment. For example, for the parking alternative chosen in each scenario, a distinct amount of money (Verizon Garage: $1.50; 11th St. Garage: 75 cents; and on-street parking: 20 cents) was deducted as a parking fee from their participant payment of $4 per scenario driven. Although the real-life amount is $40 for the Verizon garage, $20 for the 11th St. garage and $2–$3 for on-street parking (on-street parking is free on Sundays), the costs were reduced to the amounts noted above so that participants were adequately compensated for their time. As noted earlier, some scenarios required the participant to be at the destination by a particular time. In these cases, there was a random deduction as a penalty if participants did not arrive on time. The deduction varied from $0–3 to simulate the risk of getting to the destination late. To ensure the most realistic scenarios, participants were also penalized for non-compliance with traffic signs (e.g., disobeying speed limit signs, running a red light), and for accidents and crashes. To make the study more realistic, after a participant found parking in each scenario, they were asked to leave the simulator and walk around the building for the time duration required to reach their destination. See Figure 13 for the GIS map containing walking time buffers to the different destinations.

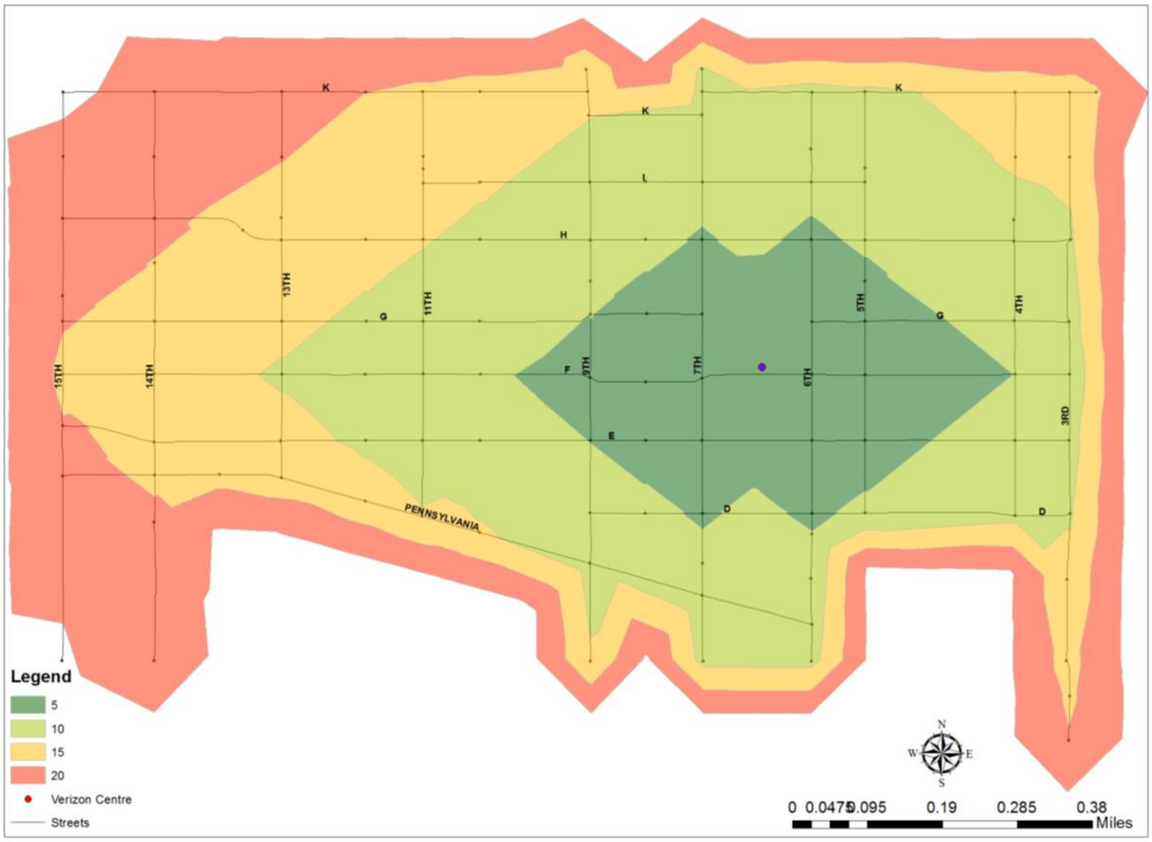

Figure 13. Walking Distance Time to Destination

Recruitment Process

Signage Computer Test

According to a preliminary statistical analysis, the minimum number of participants needed to complete the computer test with statistically significant results was 139. Participants were distributed among three age groups for both genders; this was determined to be the ideal distribution.

Participants were recruited by word of mouth and from the VTTI participant database. Participants who indicated interest in the project were asked to provide verbal consent prior to the researcher administering an eligibility screening over the phone. Eligible participants who wished to participate were scheduled to visit VTTI for the study. A consent form (Appendix E) was emailed to participants in advance so that they could read the form before coming to VTTI, and was then signed during their visit before the test session. Participants reviewed the signs and completed the questionnaire in a closed office/lab.

Driving Simulator Test

To obtain an unbiased sample, participants were solicited by distributing information related to the proposed simulator-based driving experiments on the Morgan State University campus and around the Baltimore Metro area. Recruitment information was also posted on advertising websites such as Craigslist and Facebook. In addition, some participants from past studies were contacted for participation. A subject number was provided to individual participants, and they were then scheduled to complete the first two questionnaires online before their driving experience. A friendly reminder was sent to participants a day before their driving simulator appointment.

Upon a participant’s arrival, a member of the research team presented a general outline of the study and explained the rules before requesting that the participant read and sign the consent form (Appendix F). The researcher also related the potential hazards of using the driving simulator (e.g., dizziness, nausea, and headache). Next, the participant was given a few minutes to practice driving the simulator.

DATA COLLECTION

To obtain an unbiased sample, participants were recruited according to the methods described above in the Recruitment Process

The 76 recruited participants completed 636 successful driving experiments, with an average of 8.3 scenarios per subject. Participants were asked to fill out the first two survey questionnaires before their driving session, and to fill out the third survey questionnaire immediately after completing the session. Participants’ socioeconomic characteristics are presented in Table 3.

To simulate real-world conditions, a set of rules (described above in the Driving Session Rules

section) were developed and explained to the participants before the driving experiment.

Descriptive and statistical analyses were performed using the collected data to understand travelers’ Circulation Time as well as their understanding of the parking sign information. A parking choice model was also developed.

Table 3. Participants' Socioeconomic Characteristics

Characteristics	Options	Percentages
Gender	Male	57.9%
	Female	42.1%
Age	18–25	44.7%
	26–35	35.5%
	36–45	10.5%
	46–55	2.6%
	56–65	6.6%
Education level	High school or less	31.6%
	Associate Degree	21.1%
	Bachelor degree	26.3%
	Post-graduate	21.1%
Work status	Unemployed	35.5%
	Work part-time	34.2%
	Work full-time	30.3%
Income level	< $20K	23.3%
	$20K–$30K	15%
	$30K–$50K	25%
	$50K–$75K	16.7%
	$75K–$100K	13.3%
	> $100K	6.7%
Household size	1	27%
	2	24.3%
	3	20.827%
	≥ 4	21.6%

FINDINGS

Computer-based Sign Test

To determine whether participants understood the parking sign information, a questionnaire asked each participant to select the types of information provided by each sign after the sign was shown briefly on the computer. Only answers from participants who correctly answered more than 50% of the questions were considered as valid answers and included in the final data analysis.

The distribution of participants as well as the sign that participants selected as “best” (up to two signs could be selected as best) are shown in Table 4 and Table 5, respectively.

Table 4. Participants’ Demographic Information

	Age Group 1 (≤30)	**Age Group 2 (31-59)**	**Age Group 3 (≥60)**
Male	24	24	24
Female	25	26	25

Table 5. Votes for the Best Signs

Sign Number	Vote Count
1	6
2	47
3	21
4	5
5	111
6	106
Total	296

For each sign i, the votes (X_i) follow a binomial distribution with population size 296 and probability p_i. The estimated distributions with mean (dashed line), 1% quantile, and 99% quantile for each sign are shown in Figure 14.

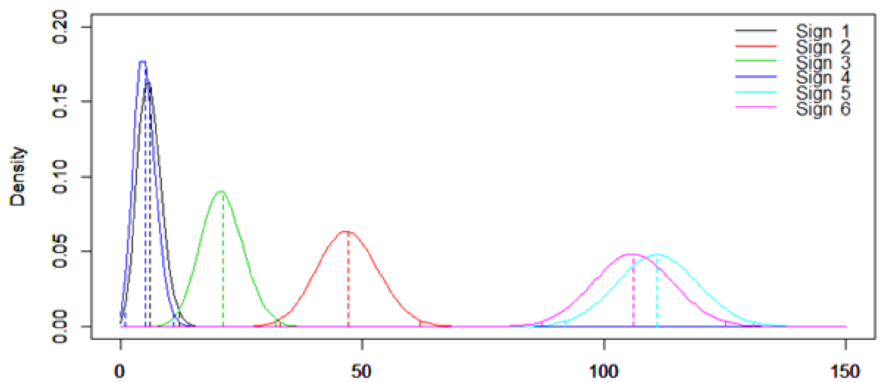

Figure 14. Distribution of Votes for the Best Signs

Wilcoxon Signed Test

Table 5 shows that sign 5 received the most votes for best sign. Thus, we can assume that the probability of choosing sign 5 is higher than the probability of choosing each of the other signs. Since the data do not follow a normal distribution, we chose the Wilcoxon signed-rank test instead of the t-test to compare sign 5 with the other signs. The results indicate that sign 5 is significantly better than signs 1, 2, 3, and 4 but not significantly better than sign 6.

Table 6. Wilcoxon Signed Test Results

Sign Number	Count	Estimated probability	Wilcoxon test P value	Critical P value *
1	6	0.0203	0.0000	0.01
2	47	0.1588	0.0000	0.01
3	21	0.0709	0.0000	0.01
4	5	0.0169	0.0000	0.01
5	111	0.3750	N/A	N/A
6	106	0.3581	0.3351	0.01

* Since five comparisons were conducted at the same time using the same dataset, the Bonferroni adjustment was applied to the critical P value: at significance level $\alpha = 0.05$, the critical value was adjusted to 0.05/5 = 0.01.

Driving Simulator Test

Parking Choice Analysis

According to the survey questionnaires, 56.45% of the participants were familiar with the study area and the other 43.55% were not. On-street parking was the stated preferred choice of 52.07% of participants, while 38.82% and 9.11% stated that the 11th St. Garage or Verizon Garage was their preferred choice, respectively.

The second questionnaire presented participants with scenarios similar to those designed for the driving simulator in order to analyze how these responses differed from their actual driving simulator choices.

Table 7 shows the parking choice indicated by participants in the surveys versus the parking choice selected in the driving simulator. As the table shows, these are significantly different. Only 48.98% of participants had identical stated and revealed parking choices. For example, a mere 0.37% of participants chose the Verizon Garage in the survey questionnaire and also chose this parking option in their driving simulator experience, while 0.92% of participants stated in the survey that they would choose the Verizon Garage but instead chose the 11th St. Garage in the simulator, and 7.82% stated they would choose the Verizon Garage but chose on-street parking in the simulator instead. Among the 4.09% of participants who chose the Verizon Garage in the driving simulator experience, 0.37% stated on the survey that they would choose it, while 1.59% stated they would choose the 11th St. Garage and 2.13% stated they would select on-street parking. Finally, while 52.07% of participants stated in the survey that they would choose on-street parking, only 44.70% actually chose it in the simulator. These parking choice differences could be attributed to the difference between the real price of parking (which was provided in the survey) and the much lower parking prices in the driving simulator scenarios.

Table 7. Stated Parking in Surveys vs. Selected Parking Choice in Driving Simulator

		Selected			
		Verizon Garage	11th St. Garage	On-street parking	Total
Stated	Verizon Garage	0.37%	0.92%	7.82%	9.11%
	11th St. Garage	1.59%	3.91%	33.33%	38.82%
	On-street parking	2.13%	5.24%	44.70%	52.07%
	Total	4.09%	10.06%	85.85%	100%

t-test Analysis

In order to find the Driving Travel Time, the start and end times of each scenario for each participant were extracted from the simulator's log files. The log files include different information, such as start time, end time, speed, road, crash, and other related information. The average Driving Travel Time by types of parking information was compared for all 24 scenarios using a t-test. Parking information was found to cause a significant reduction in Driving Travel Time. The result of the first t-test comparing No-Information Driving Travel Time versus VMS-Information Travel Time (Table 8) shows that the Driving Travel Time dropped from 11.25 min to 9.27 min when information was available via VMS. The result of the second t-test comparing Driving Travel Time between No-Information and App-Information Driving Travel Time (Table 8) shows that the Driving Travel Time dropped from 11.26 min to 7.90 min when information was available via the App.

In a subset of scenarios (scenarios 1, 4, 5, 8, 9, 12, 14, 15, 18, 19, 22, and 23), participants were told that they had to arrive at their destination by a set time (i.e., time mattered). The t-test comparison of No-Information Driving Travel Time to VMS-Information for these scenarios (Table 8) shows that the Driving Travel Time fell significantly from 11.21 min to 9.19 min when information was available via VMS. The results of the t-test comparing Driving Travel Time between No-Information and App-Information (Table 8) shows that the Driving Travel Time dropped from 11.21 min to 7.79 min when information was available via the App. Such a decrease in Driving Travel Time can be attributed to the participants consulting the App before starting their trip, finding a suitable parking space, and going directly to that space. The majority of participants did not pass by their final destination prior to parking when they had access to the App; however, when there was no information or information provided via VMS, participants went to the final destination first and then circulated to find parking.

A comparison between Driving Travel Time and Types of Information was also made for scenarios (scenarios 2, 3, 6, 7, 10, 11, 13, 16, 17, 20, 21, and 24) in which participants did not have to arrive at their destination by a set time (i.e., time did not matter). The results of the t-test comparing Driving Travel Time between No-Information and VMS-Information (Table 8) shows that the Driving Travel Time fell significantly from 11.30 min to 9.36 min when information was available via VMS. The results of the t-test comparing Driving Travel Time between No-Information and App-Information (Table 8) shows that the Driving Travel Time dropped from 11.30 min to 8.01 min when information was available via the App.

Table 8. t-test Results for Driving Travel Time Comparisons

Panel A. Between No-Information and VMS-Information (All Scenarios)					
Variable	N	Mean	Std. Dev.	t-statistic	Sig.
Driving Travel time with No Information	227	11.25	6.044	3.73	.000
Driving Travel time with VMS Information	214	9.27	5. 053	3.75	.000
Panel B. Between No-Information and App-Information (All Scenarios)					
Variable	N	Mean	Std. Dev.	t-statistic	Sig.
Driving Travel time with No Information	227	11.26	6.045	6.803	.000
Driving Travel time with App Information	195	7.90	3.569	7.058	.000

Panel C. Between No-Information and VMS-Information (Time Matters Only)					
Variable	N	Mean	Std. Dev.	t-statistic	Sig.
Driving Travel time with No Information	112	11.21	5.721	2.850	0.005
Driving Travel time with VMS Information	108	9.19	4.778	2.859	0.005

Panel D. Between No-Information and App-Information (Time Matters Only)					
Variable	N	Mean	Std. Dev.	t-statistic	Sig.
Driving Travel time with No Information	112	11.21	5.721	5.260	.000
Driving Travel time with App Information	96	7.79	3.036	5.493	.000

Panel E. Between No-Information and VMS-Information (Time Does Not Matter Only)					
Variable	N	Mean	Std. Dev.	t-statistic	Sig.
Driving Travel time with No Information	115	11.30	6.369	2.450	.015
Driving Travel time with VMS Information	106	9.36	5.342	2.467	.014

Panel F. Between No-Information and App-Information (Time Does Not Matter Only)					
Variable	N	Mean	Std. Dev.	t-statistic	Sig.
Driving Travel time with No Information	115	11.30	6.369	4.437	.000
Driving Travel time with App Information	99	8.01	4.032	4.582S	.000

Note: The reported significance is 2-tailed for all tests

The primary purpose of this study was to investigate the impact of parking information on Circulation Time. For this study, Circulation Time was defined as the time that a participant circulates to find parking after reaching their destination (the Verizon Center). As previously noted, Driving Travel Time was calculated using simulator log file data: the trip end time (i.e., time that the driver reaches the destination and finds parking) minus the trip start time (i.e., time that the driver starts driving). The time that a participant reached their destination was also extracted from the data files. Circulation Time was calculated by deducting the time that participants reached their final destination from their Driving Travel Time (end time minus start time). A negative Circulation Time indicated that the participant parked prior to reaching their final destination, which usually occurred when drivers had access to information or were familiar with the road network.

The comparison between Circulation Time and Types of Information is provided in Table 9 below. The results of the t-test comparing Circulation Time between No-Information (scenarios 1–4 and 13–16) and VMS-Information (scenarios 5–8 and 17–20) show that Circulation Time was reduced from 4.37 min to 4.33 min when information available via VMS; these results were not significant. The results of the t-test comparing Circulation Time between No-Information (scenarios 1–4, 13–16, and 21–24) and App-Information (scenarios 9–12) (Table 9) show that the Circulation Time was significantly reduced from 4.43 min to 2.42 min when information was available via the App.

Table 9. t-test Results for Circulation Time Comparisons

Panel A. Between No-Information and VMS-Information					
Variable	N	Mean	Std. Dev.	t-statistic	Sig. (2-tailed)
Circulation Time with No Information	227	4.37	4.628	.088	.930
Circulation Time with VMS Information	214	4.33	5.504	.087	.930
Panel B. Between No-Information and App -Information					
Variable	N	Mean	Std. Dev.	t-statistic	Sig. (2-tailed)
Circulation Time with No Information	227	4.38	4.628	4.902	.000
Circulation Time with App Information	195	2.42	3.387	5.016	.000

Regression Analysis

A linear regression analysis was performed to identify the relationship between Circulation Time as a dependent variable, Income Value of the Simulator (participants received $4.00 per completed driving scenario minus the parking fee), and types of information (No-Information and Information). The results (Table 10) show that there was a positive relationship between Circulation Time and Income Value of the Simulator—the more the participant circulates for parking, the more money they will receive. Previous tests showed a negative relationship between the Income Value of the Simulator and Annual Income of the Participant; thus, it makes sense that participants with less annual income prefer to circulate more in the simulator to earn more money. Furthermore, there was a significant negative relationship between Circulation Time and Types of Information; when participants have information related to parking space availability, they will circulate less than when they do not have any information.

Table 10. Results for the Regression of Circulation Time on Income Value of the Simulator and Types of Information

Variable	B	Sig. (2-tailed)
Intercept	-2.708	.000
Income Value of the Simulator	2.908	.000
Parking Information	-0.378	.000

Adjusted R Square: .770

Comparative Analysis

A comparison of stated and selected parking choice by scenario type is presented in Table 11. For the trips in which time did not matter (No Time) and parking space availability was provided via App, 1.02% of participants chose the Verizon Garage and 6.12% chose the 11th St. Garage. This was despite the fact that 6.19% of participants stated in the survey that they would choose the Verizon Garage and 26.24% stated that they would choose the 11th St. Garage. This is likely due to the No Time arrival condition and participant access to available parking spaces via the App. In the No Time arrival condition when participants did not have any information, 7.83% chose the Verizon Garage and 22.61% chose 11th St. Garage.

In all scenario conditions, the comparative rate of on-street parking was high. However, when there was information available and time mattered, percent of participants parking on-street increased to 94.85% in the simulator.

Table 11. Parking Choice Rate Comparative Analysis for Driving Simulator Experiments and Surveys

Scenario Condition	Parking Alternative	Revealed in Simulator	Stated in Survey
No Info _No Time	Verizon Garage	7.83%	6.92%

Scenario Condition	Parking Alternative	Revealed in Simulator	Stated in Survey
	11th St. Garage	22.61%	33.94%
	On-Street	69.57%	59.14%
No Info _Time	Verizon Garage	7.14%	12.47%
	11th St. Garage	14.29%	48.41%
	On-Street	78.57%	39.11%
App Info _No Time	Verizon Garage	1.02%	6.19%
	11th St. Garage	6.12%	26.24%
	On-Street	92.86%	67.57%
App Info _ Time	Verizon Garage	1.03%	11.39%
	11th St. Garage	4.12%	47.52%
	On-Street	94.85%	41.09%

Parking Choice Model

A multinomial logit regression analysis was performed to identify the most appropriate independent variables to describe the probability of choosing on-street parking. Among all socioeconomic characteristics and variables related to the scenarios, only Age and Type of Information had a significant impact on parking choice.

Table 12. Parking Choice Behavior Model

Parking Choice	Variable	β	Standard Error	Significance
Verizon Garage	**Constant**	2.38	0.888	0.01
	Age			
	18 to 25	-2.12	0.608	0.00
	26 to 35	-1.69	0.570	0.00
	36 to 45	-1.27	0.692	0.07
	More than 46		Reference Category	
	Types of Information			
	VMS Information	-1.08	0.490	0.03
	App Information	-2.35	0.771	0.00
	No Information		Reference Category	
	Travel Time Ratio	-1.41	0.383	0.00
11th St. Garage	**Constant**	-0.791	0.423	0.06
	Age			
	18 to 25	-1.62	0.419	0.00
	26 to 35	-1.49	0.422	0.00
	36 to 45	-1.11	0.519	0.03

More than 46	Reference Category		
Types of Information			
VMS Information	-1.62	0.364	0.00
App Information	-1.60	0.377	0.00
No Information	Reference Category		
Travel Time Ratio	0.264	0.0841	0.00

* On-Street Parking is reference category
Number of observations = 636
Adjusted R-square = 0.601

As discussed earlier, there were three parking choices: the Verizon Garage, the 11th St. Garage and on-street parking. On-street parking was the choice of the majority of participants, as it cost less than either garage. The results of the multinomial logistic regression are illustrated in Table 12, which shows that the probabilities of choosing the Verizon Garage and 11th St. Garage were lower than those of choosing on-street parking in all participant age groups. Younger participants were less likely to choose garage parking, which is reflective of their traditionally lower valuation of time. The Travel Time Ratio variable is the ratio of Total Travel Time (Driving Time + Walking Time) to the Travel Time from the origin directly to the Verizon Center. The Verizon Garage was costly but required no walking time. An individual who spent a significant amount of time traveling was less likely to have parked in the Verizon Garage compared to parking on-street. However, the reverse was true for the 11th Street garage; a longer travel time ratio indicated that a person was more likely to park in the 11th Street Garage compared to parking on-street. This result generally indicates that participants were cost aware and searched for, but were unable to find, cheaper on-street parking and thus settled on parking in the less expensive, more distant garage.

The Type of Information was found to be an important factor in this model. The probability of choosing the Verizon Garage or 11th St. Garage compared to on-street parking was less when there was available VMS or App information pertinent to parking space availability. This could be because the information helped participants find cheaper parking with less circulation, thereby affecting their parking choice. To test for independence from irrelevant alternatives, a nested logit model in which the first nest was the choice between on-street and garage parking was evaluated; however, this did not improve the model.

CONCLUSIONS AND RECOMMENDATIONS

This study used both a stated preference survey and driving simulator techniques to evaluate the effects of different types of parking space availability information on parking choice and circulation behavior.

Some 56% of the participants were familiar with the study area; among all participants 52.07 % stated that they preferred on-street parking, 38.82% that they preferred the 11th St. Garage, and only 9.11% chose the Verizon Garage.

The results illustrated that age and parking availability information affect parking choice behavior. Participants' choices were significantly different in the simulator experiment compared to the stated preference survey, which might be due to the real parking prices used in the survey versus the much lower prices used in the simulator experiments. Participants behaved differently when information existed and time mattered (i.e., they were penalized for being late). Very few participants opted for the Verizon Garage, which was the most expensive garage. However, when time mattered and there was no information available, they were willing to pay the Verizon Garage's parking price in order to be on time.

The comparative analysis reveals that when no information was provided, the probability of choosing the Verizon Garage was high in the driving simulator experiments. In the presence of information, a majority of participants chose on-street parking, as the information provided via the App showed the parking availability for the whole network, and on-street parking was the cheapest option. Furthermore, the results showed that there was a negative relationship between types of information and circulation time. We can therefore conclude that providing information decreases circulation time significantly. It was found that the App was more effective at decreasing circulation time than VMS. Future studies may examine the relationship between price sensitivity and traffic congestion on parking choice.

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APPENDIX A: PARKING SIGN SURVEY

VIRGINIA TECH TRANSPORTATION INSTITUTE

1. Please select information that you saw in **Sign 1** just shown. Select all that apply.

- ☐ Exact location of the parking spots
- ☐ Driving direction to the parking location
- ☐ Walking time to the destination
- ☐ Available parking spots

2. Please select information that you saw in **Sign 2** just shown. Select all that apply.

- ☐ Exact location of the parking spots
- ☐ Driving direction to the parking location
- ☐ Walking time to the destination
- ☐ Available parking spots

3. Please select information that you saw in **Sign 3** just shown. Select all that apply.

- ☐ Exact location of the parking spots
- ☐ Driving direction to the parking location
- ☐ Walking time to the destination
- ☐ Available parking spots

4. Please select information that you saw in **Sign 4** just shown. Select all that apply.

- ☐ Exact location of the parking spots
- ☐ Driving direction to the parking location
- ☐ Walking time to the destination
- ☐ Available parking spots

5. Please select information that you saw in **Sign 5** just shown. Select all that apply.

- ☐ Exact location of the parking spots
- ☐ Driving direction to the parking location
- ☐ Walking time to the destination
- ☐ Available parking spots

6. Please select information that you saw in **Sign 6** just shown. Select all that apply.

- ☐ Exact location of the parking spots
- ☐ Driving direction to the parking location
- ☐ Walking time to the destination
- ☐ Available parking spots

7. Please select (up to 2) parking sign(s) that you think is/are the best.

- ☐ Sign 1
- ☐ Sign 2
- ☐ Sign 3
- ☐ Sign 4
- ☐ Sign 5
- ☐ Sign 6

APPENDIX B. SURVEY QUESTIONNAIRE 1

Dear Participant,

We greatly appreciate your interest in our research. Your participation is of great importance to our studies. Please fill in the appropriate choice for each question.

Thank you.

1. **What is your gender?**
   - Male
   - Female
2. **What is your age group?**
   - 18 to 25
   - 26 to 35
   - 36 to 45
   - 46 to 55
   - 56 to 65
   - More than 65
3. **What is your highest level of education?**
   - High School or less
   - Associate's degree
   - Bachelor's degree
   - Post Graduate
4. **Do you work?**
   - No
   - Work Part-time
   - Work Full-time
5. **What type of driving license do you have?**
   - I don’t have a license/permit

- Learner’s Permit
- Permanent license for regular vehicles (class C)
- Permanent license for all types of vehicles (class A)

6. What is your household annual income? (Optional)

- Less than $20K
- $20 to $30K
- $30 to 50K
- $50 to $75K
- $75 to $100K
- More than $100K

7. What is your household size?

- 1
- 2
- 3
- 4 or more

8. How many young children (12 or younger) do you have in your household?

- None
- 1
- 2
- 3 or more

APPENDIX C: SURVEY QUESTIONNAIRE 2

Dear Participant,

Please fill this form. We greatly appreciate your interest, time and effort.

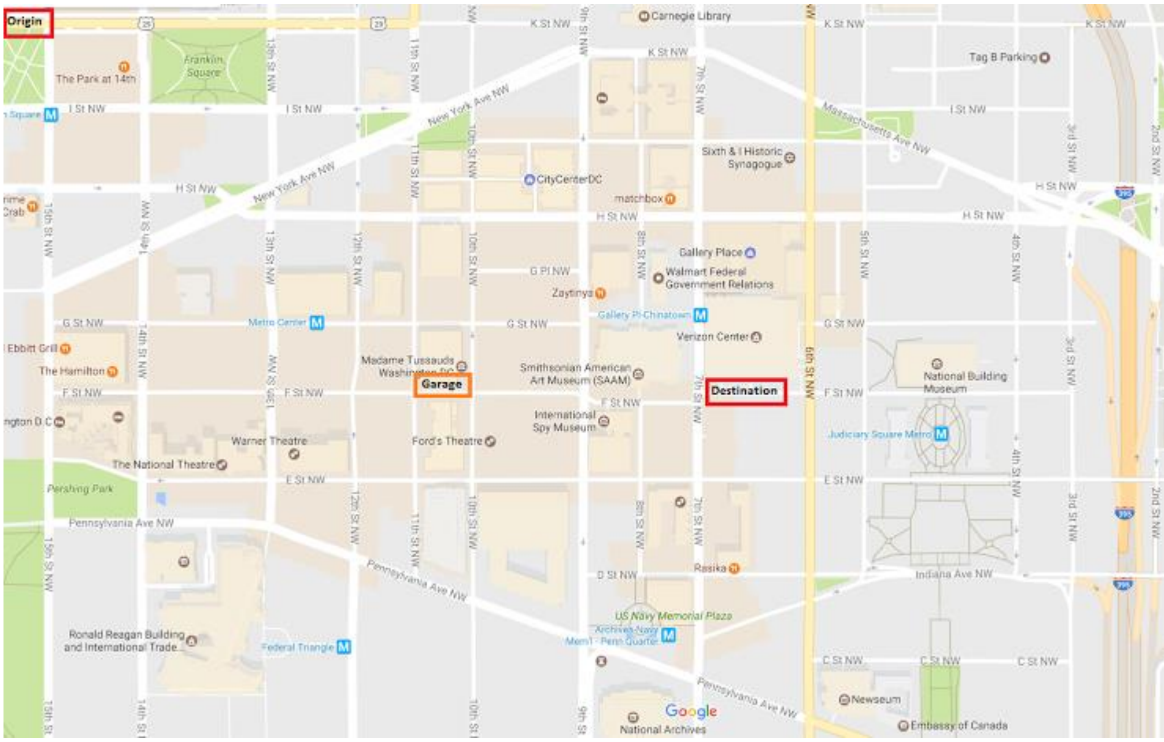
Thank you.

1. **When looking for parking what method(s) do you use?**

- o On-street location signs
- o Mobile parking apps
- o Websites/Google
- o GPS Navigation

2. **Which method do you believe is most effective to help you find a parking spot?**

- o On-street location signs
- o Mobile parking apps
- o Websites/Google
- o GPS Navigation



3. Are you familiar with the Chinatown area in Washington DC?

- o Yes
- o No
- o Somewhat

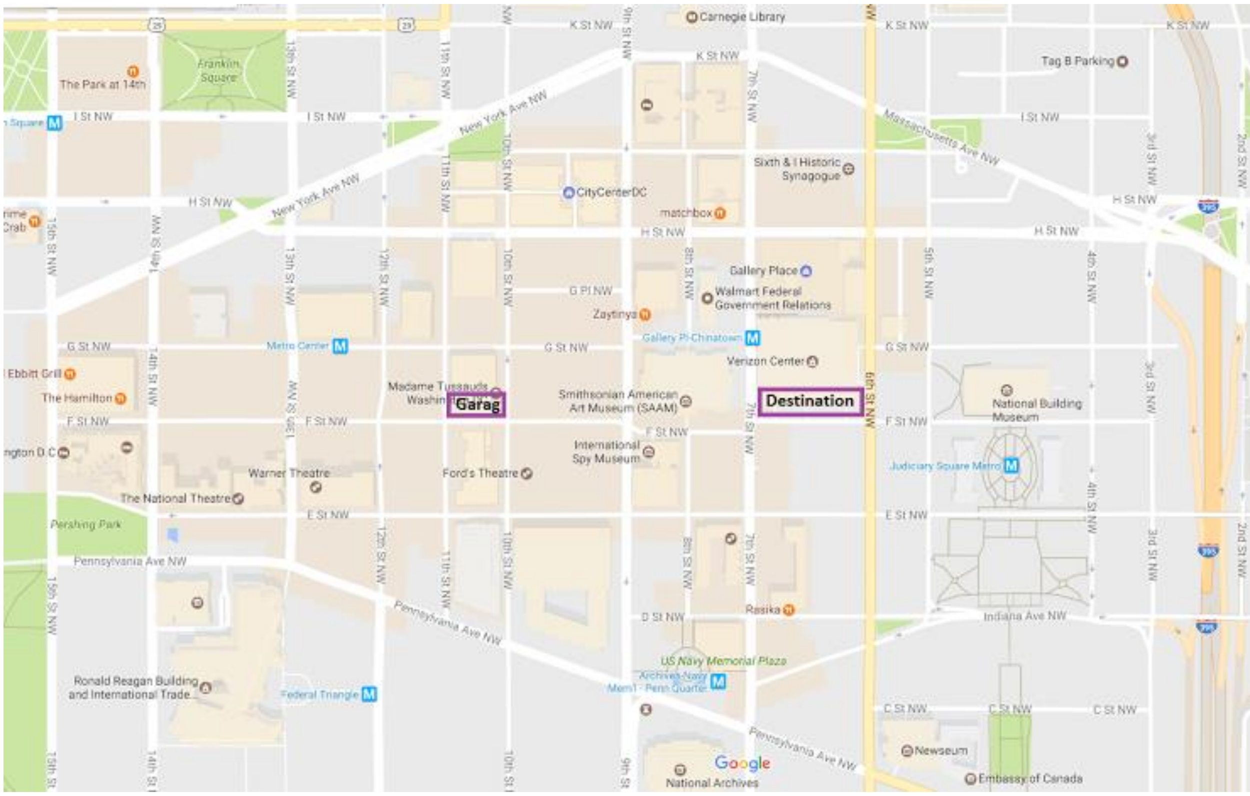
4. How often do you visit the Chinatown area?

- o Occasionally (l1-2 times a y ear)
- o Often (3 - 5 times a year)
- o Frequently (more than 5 times a year)

5. When visiting the Chinatown Area, where do you mostly likely park

- o On-street
- o Garage
- o I take transit

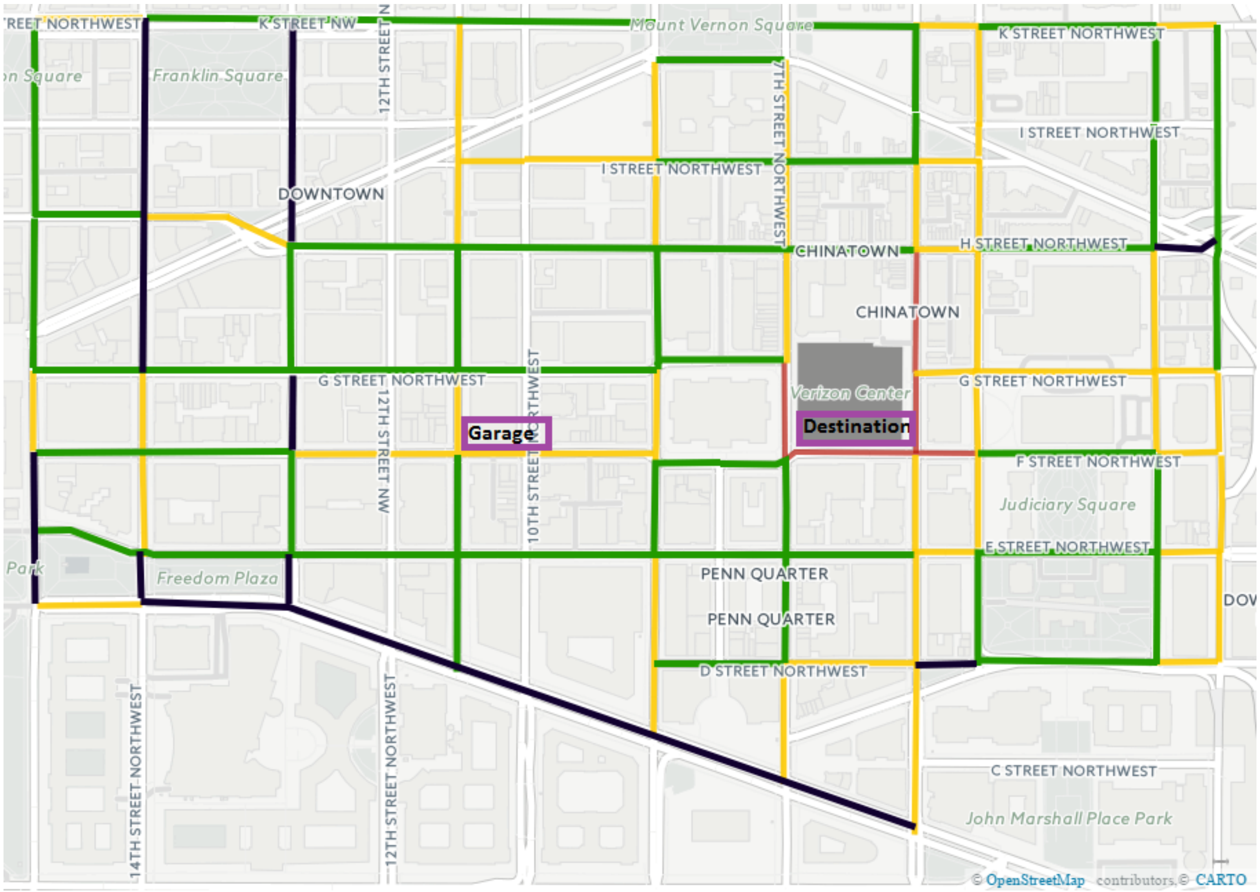
For each scenario below, your destination is the Verizon Center in the Penn Quarter/Chinatown area of Washington, D.C. Please read the questions carefully and choose your preferred parking location for each scenario.



6. **You plan to stay in the area for 2 hours or less. Choose your preferred parking location if you are:**

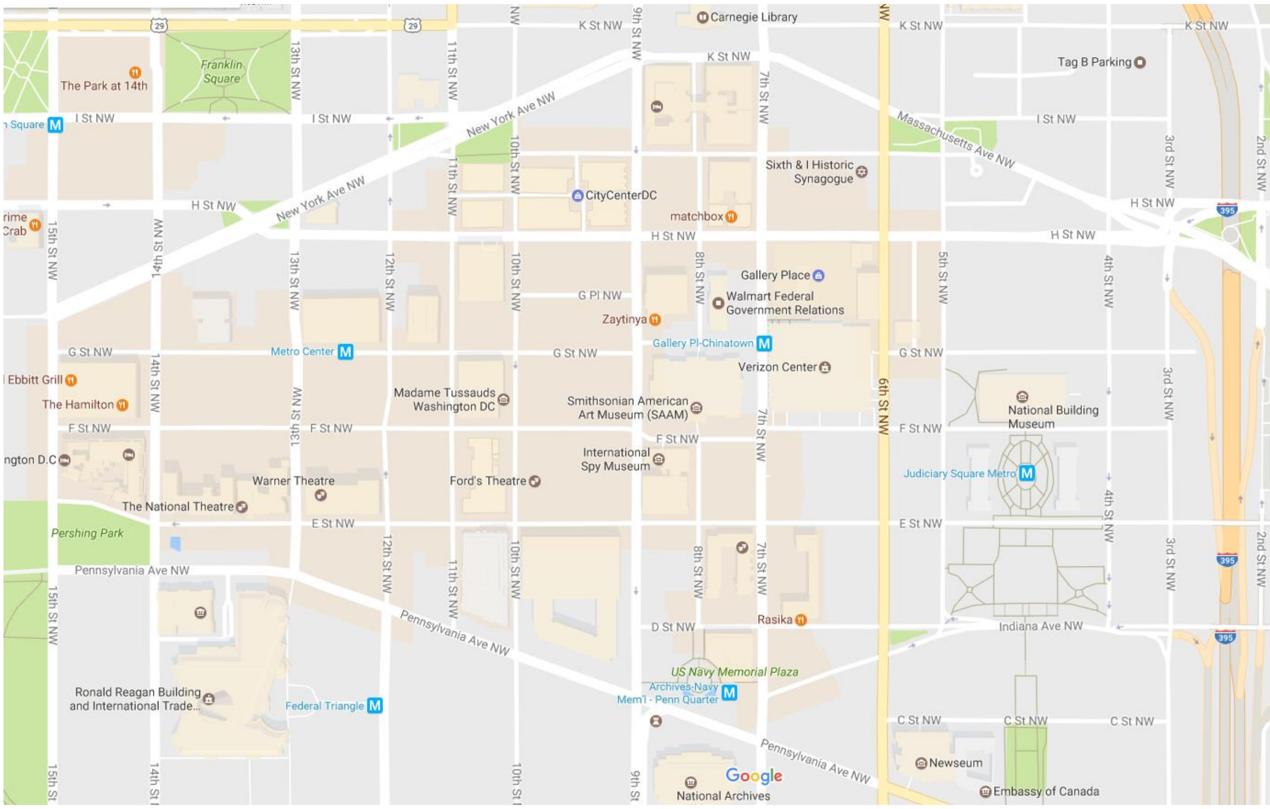
	On-Street; 0-20 min walk; \$2.3/hr (\$0 on Sunday)	Garage; 7 min walk; \$20	Garage at Verizon Center; 0 min walk; \$30
Going to a coffee shop on Thursday at 1pm	○	○	○
Going to an interview that starts at 2pm on Wednesday	○	○	○
Going to a coffee shop on Thursday at 1pm	○	○	○
Going to an interview that starts at 2pm on Wednesday	○	○	○

The map now shows the available parking around Verizon Center. Green indicates 5+ parking spots available, Yellow 2 - 4 spots available, and Red up to 1 spot available. No parking is allowed on Black streets.



7. **You plan to stay in the area for 2 hours or less. You can access above mobile app to acquire parking information before and during your trip. Choose your preferred location if you are:**

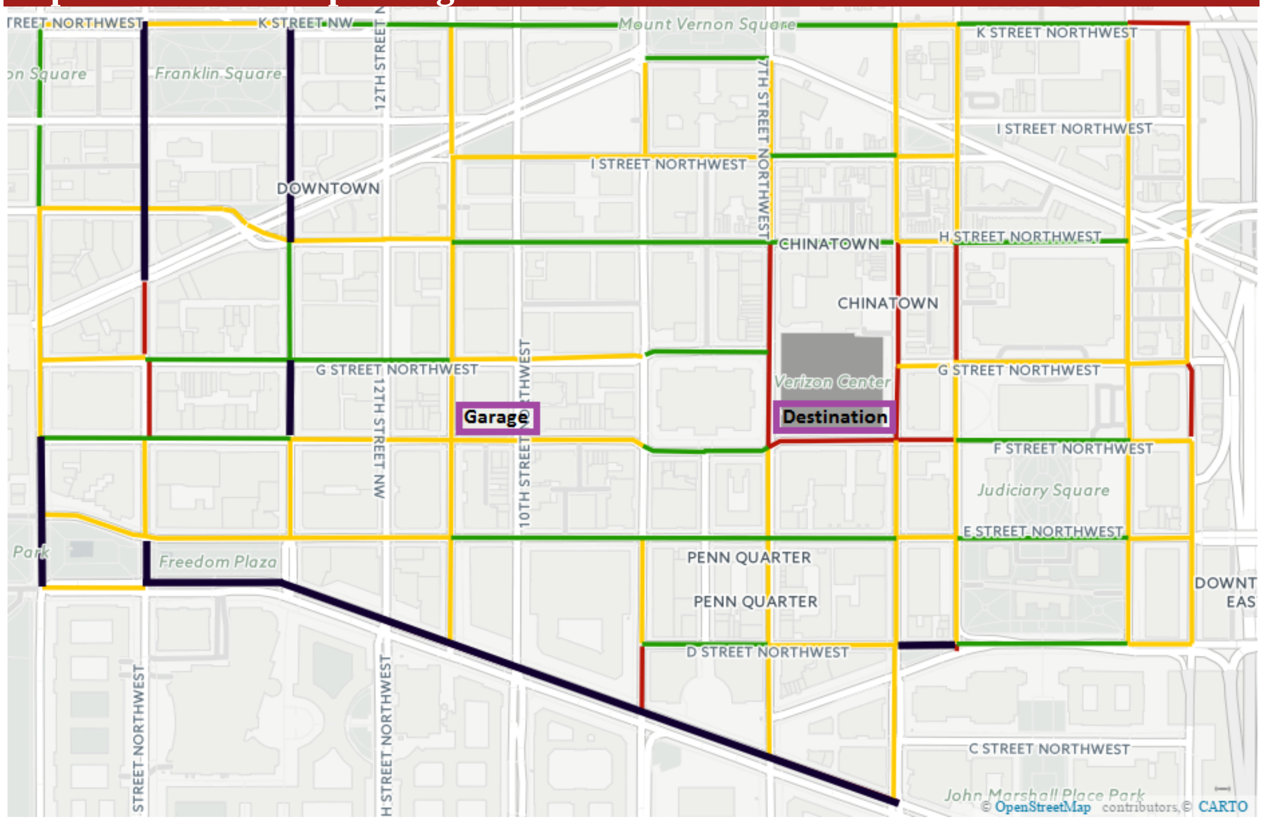
	On-Street; 0-20 min walk; \$2.3/hr (\$0 on Sunday)	Garage; 7 min walk; \$20	Garage at Verizon Center; 0 min walk; \$30
Going to a coffee shop on Thursday at 1pm	o	o	o
Going to an interview that starts at 2pm on Wednesday	o	o	o
Going to a coffee shop on Thursday at 1pm	o	o	o
Going to an interview that starts at 2pm on Wednesday	o	o	o



8. **You plan to stay in the area for 2 hours or less. Choose your preferred parking location if you are:**

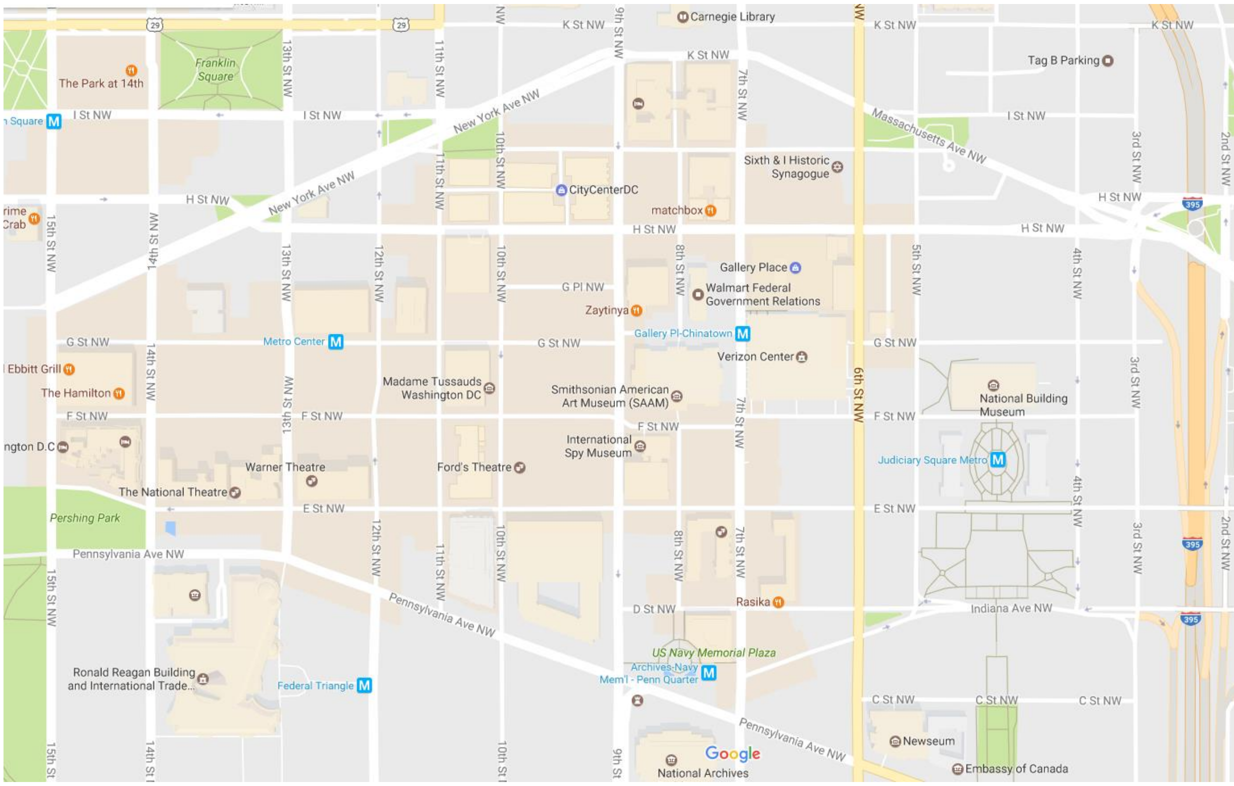
	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $30
Meeting your date on Tuesday at 6pm	○	○	○
Going to an interview that starts at 8am on Wednesday	○	○	○
Going to Cinema with your friend on Sunday	○	○	○
Meeting your date on Tuesday at 6pm	○	○	○
Going to an interview that starts at 8am on Wednesday	○	○	○
Going to Cinema with your friend on Sunday	○	○	○

The map now shows the available parking around Verizon Center. Green indicates 5+ parking spots available, Yellow 2 - 4 spots available, and Red up to 1 spot available. No parking is allowed on Black streets.



9. **You plan to stay in the area for 2 hours or less. You can access above mobile app to acquire parking information before and during your trip. Choose your preferred location if you are:**

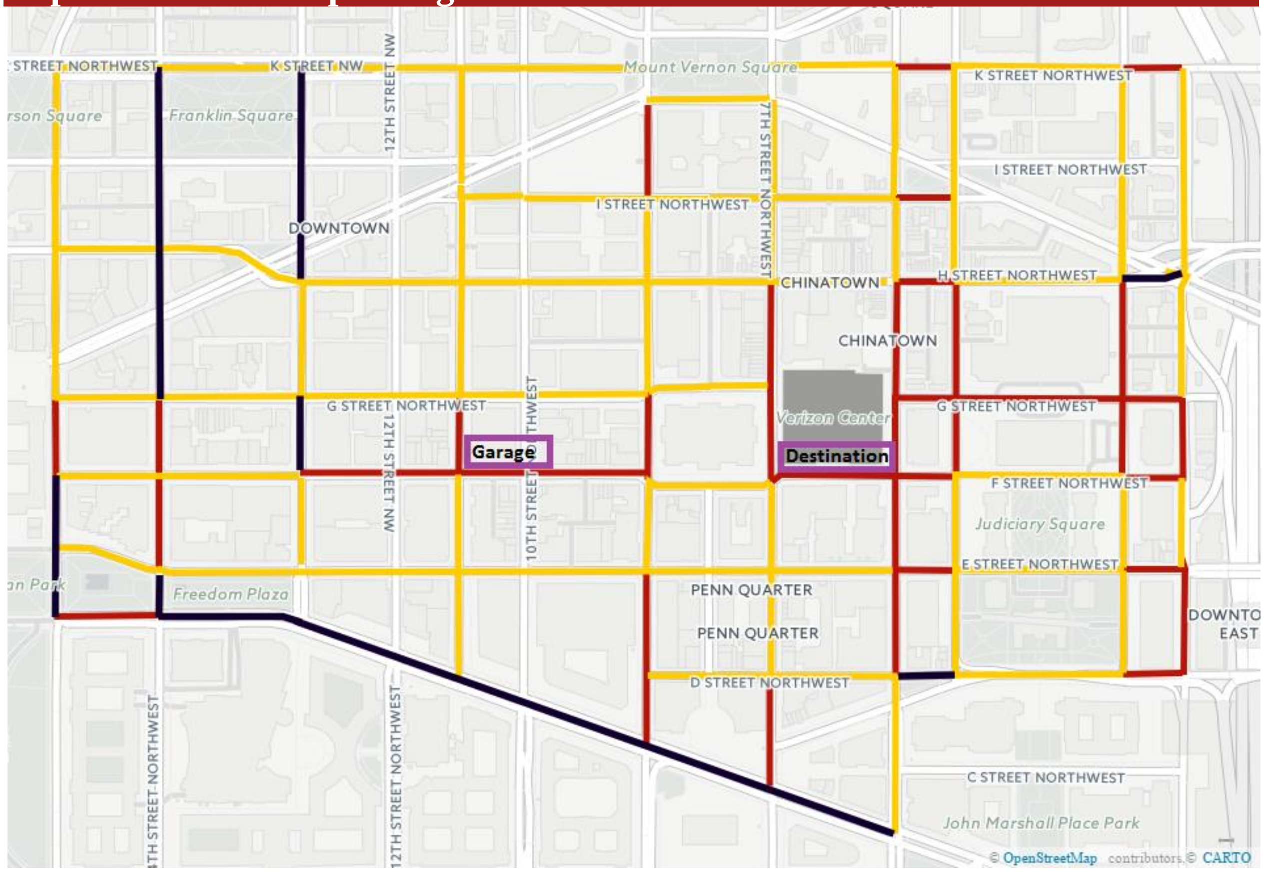
	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $30
Meeting your date on Tuesday at 6pm	o	o	o
Going to an interview that starts at 8am on Wednesday	o	o	o
Going to Cinema with your friend on Sunday	o	o	o
Meeting your date on Tuesday at 6pm	o	o	o
Going to an interview that starts at 8am on Wednesday			
Going to Cinema with your friend on Sunday			



10. You plan to stay in the area for 2 hours or less. Choose your preferred parking location if you are:

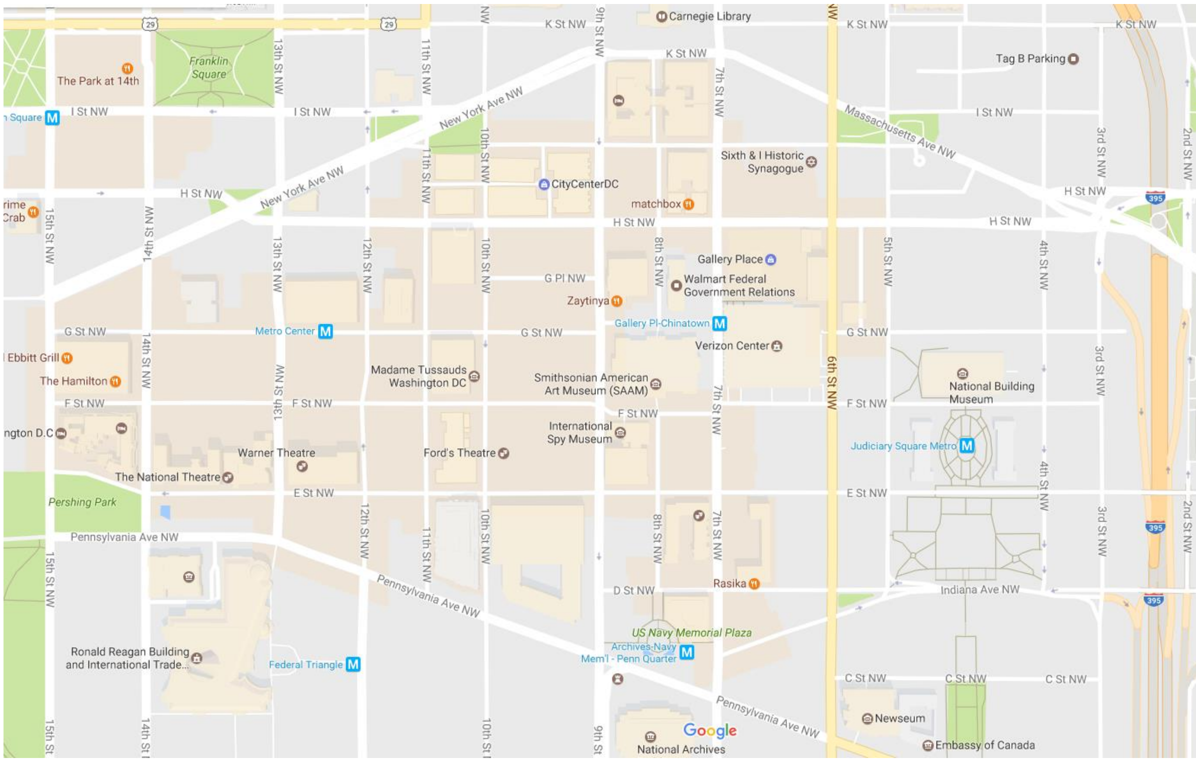
	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $40
Attending a work event that starts promptly at 5 pm on Friday when there is a concert at the Verizon Center	o	o	o
Getting dinner with your friends Saturday at 6 pm during a basketball game at the Verizon Center	o	o	o
Attending a work event that starts promptly at 5 pm on Friday when there is a concert at the Verizon Center	o	o	o
Getting dinner with your friends Saturday at 6 pm during a basketball game at the Verizon Center	o	o	o

The map now shows the available parking around Verizon Center. Green indicates 5+ parking spots available, Yellow 2 - 4 spots available, and Red up to 1 spot available. No parking is allowed on Black streets.



11. You plan to stay in the area for 2 hours or less. You can access above mobile app to acquire parking information before and during your trip. Choose your preferred location if you are:

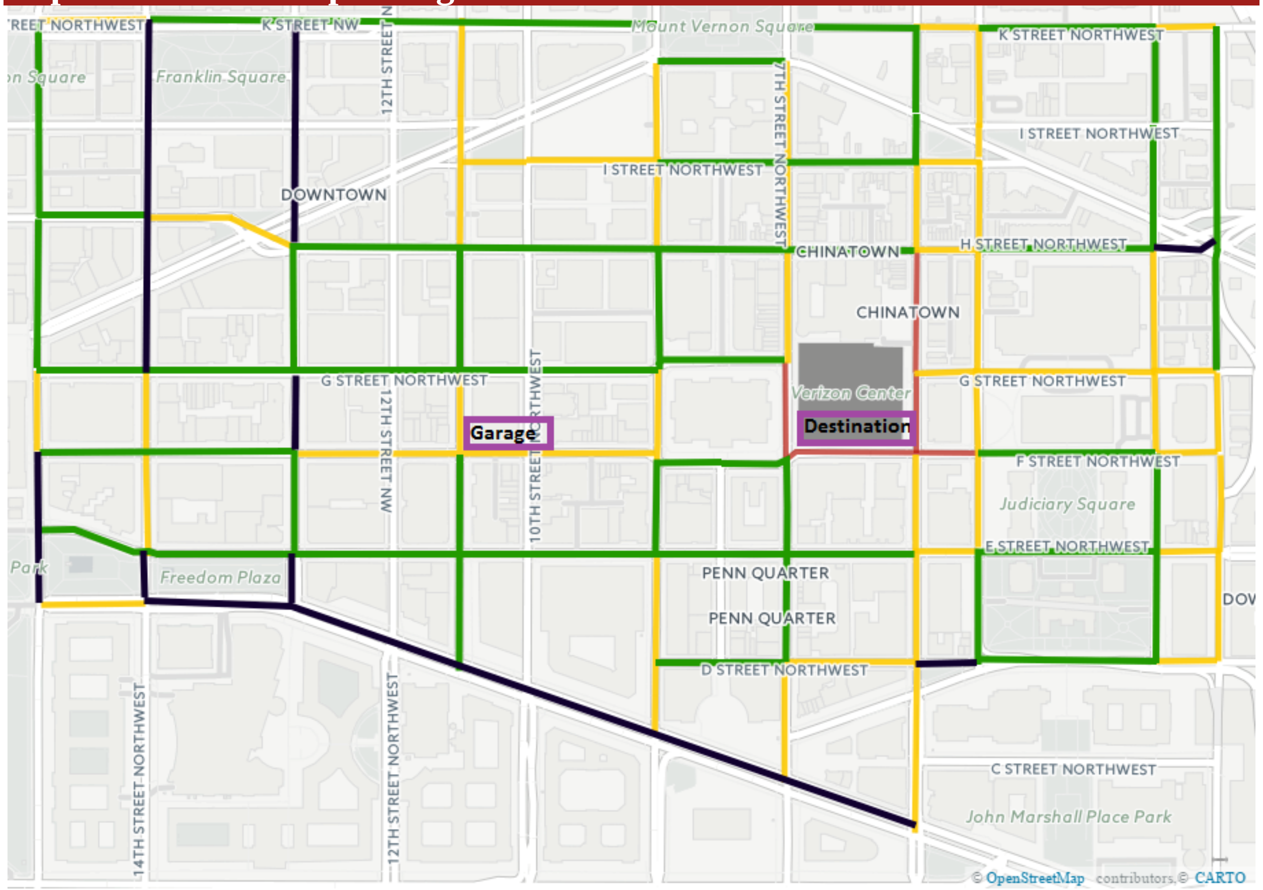
	On-Street; 0-20 min walk; \$2.3/hr (\$0 on Sunday)	Garage; 7 min walk; \$20	Garage at Verizon Center; 0 min walk; \$40
Attending a work event that starts promptly at 5 pm on Friday when there is a concert at the Verizon Center	o	o	o
Getting dinner with your friends Saturday at 6 pm during a basketball game at the Verizon Center	o	o	o
Attending a work event that starts promptly at 5 pm on Friday when there is a concert at the Verizon Center	o	o	o
Getting dinner with your friends Saturday at 6 pm during a basketball game at the Verizon Center	o	o	o



12. You plan to stay in the area for 5 hours or less. Choose your preferred parking location if you are:

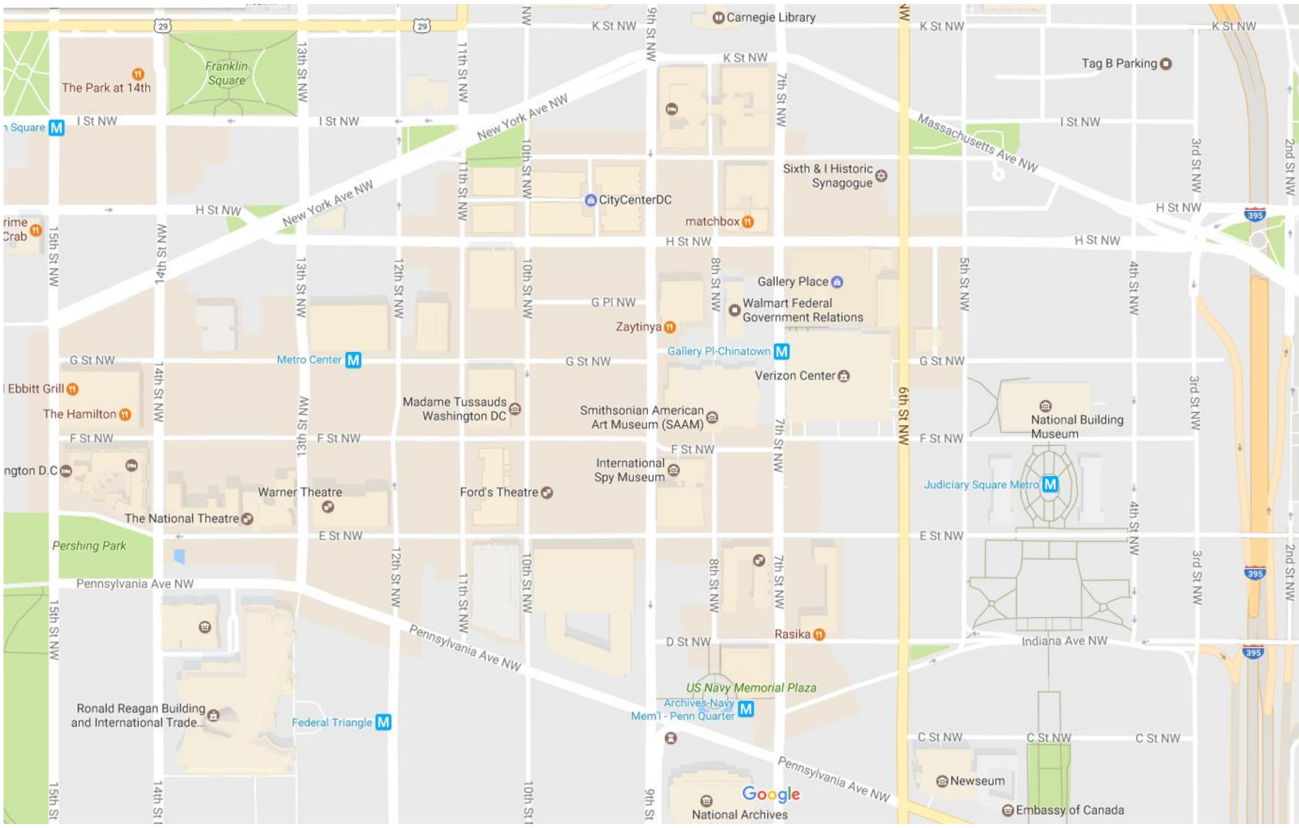
	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $30
Going to a Shopping Mall on Thursday at 1pm	o	o	o
Going to a conference that starts at 2pm on Wednesday	o	o	o
Going to a Shopping Mall on Thursday at 1pm	o	o	o
Going to a conference that starts at 2pm on Wednesday	o	o	o

The map now shows the available parking around Verizon Center. Green indicates 5+ parking spots available, Yellow 2 - 4 spots available, and Red up to 1 spot available. No parking is allowed on Black streets.



13. You plan to stay in the area for 5 hours or less. You can access above mobile app to acquire parking information before and during your trip. Choose your preferred location if you are:

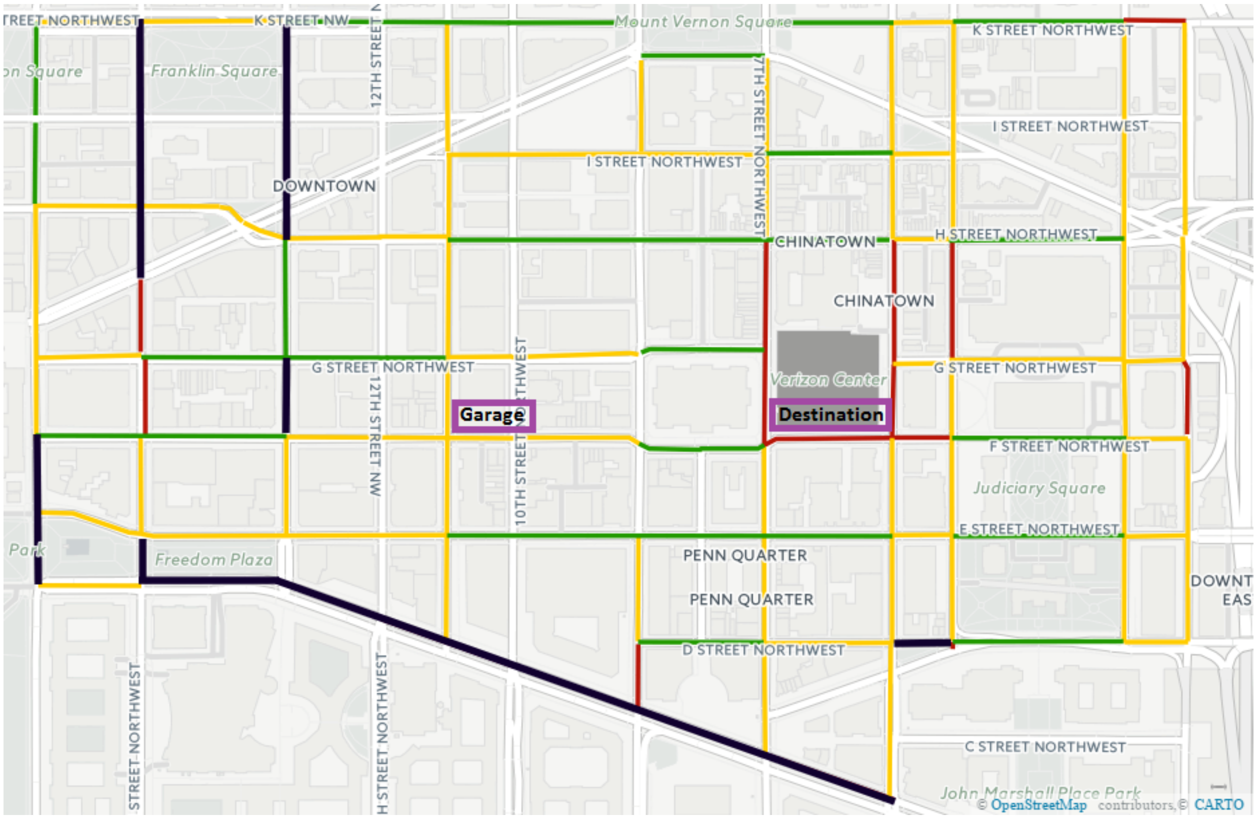
	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $30
Going to a Shopping Mall on Thursday at 1pm	o	o	o
Going to a conference that starts at 2pm on Wednesday	o	o	o
Going to a Shopping Mall on Thursday at 1pm	o	o	o
Going to a conference that starts at 2pm on Wednesday	o	o	o



14. You plan to stay in the area for 5 hours or less. Choose your preferred parking location if you are:

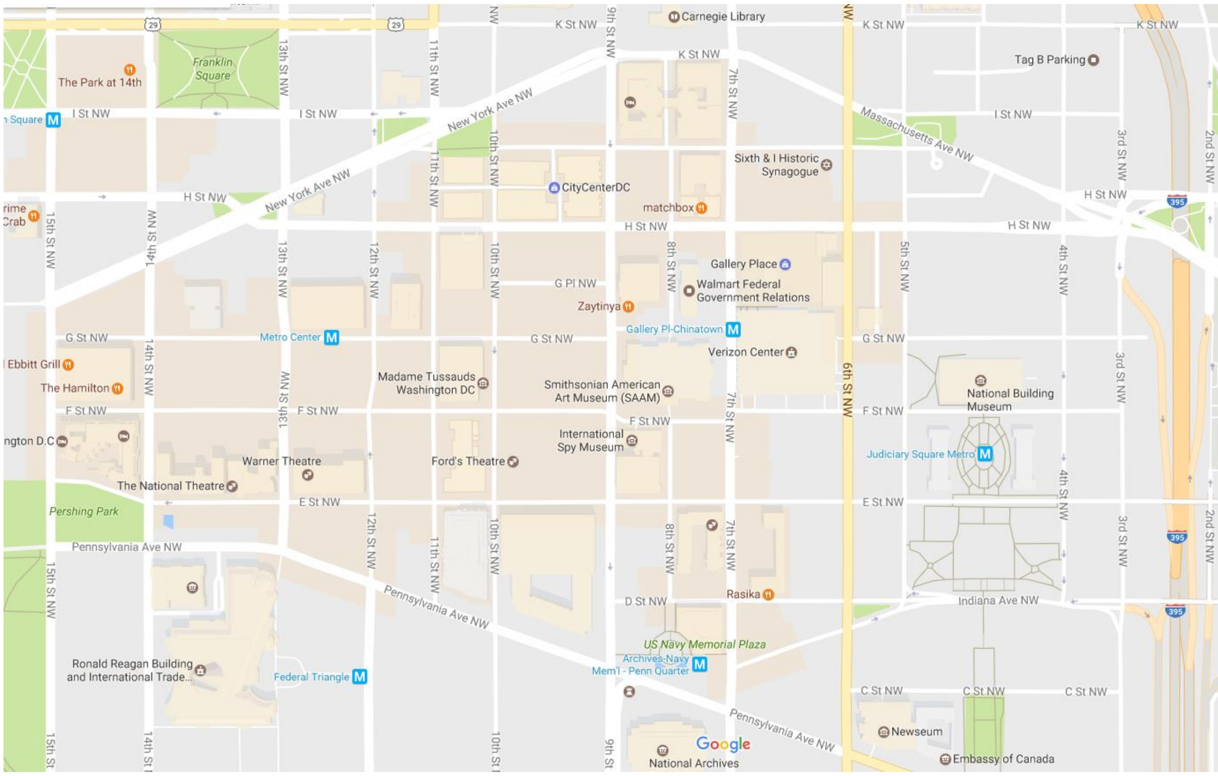
	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $30
Meeting your date on Tuesday at 6pm	o	o	o
Going to work and your shift starts at 8am on Wednesday	o	o	o
Going to Concert with your friend on Sunday	o	o	o
Meeting your date on Tuesday at 6pm	o	o	o
Going to work and your shift starts at 8am on Wednesday	o	o	o
Going to Concert with your friend on Sunday	o	o	o

The map now shows the available parking around Verizon Center. Green indicates 5+ parking spots available, Yellow 2 - 4 spots available, and Red up to 1 spot available. No parking is allowed on Black streets.



15. **You plan to stay in the area for 5 hours or less. You can access above mobile app to acquire parking information before and during your trip. Choose your preferred location if you are:**

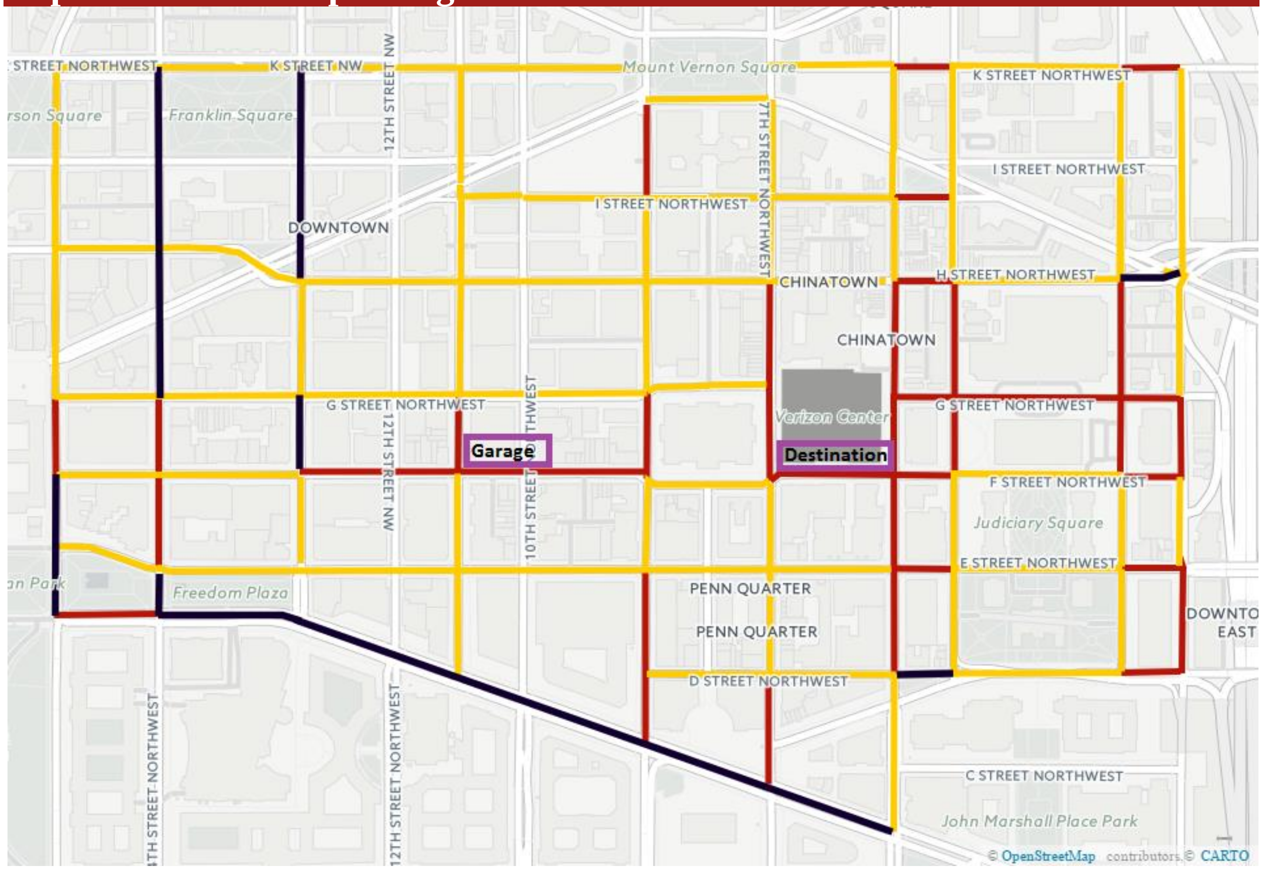
	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $30
Meeting your date on Tuesday at 6pm	○	○	○
Going to work and your shift starts at 8am on Wednesday	○	○	○
Going to Concert with your friend on Sunday	○	○	○
Meeting your date on Tuesday at 6pm	○	○	○
Going to work and your shift starts at 8am on Wednesday	○	○	○
Going to Concert with your friend on Sunday	○	○	○



16. You plan to stay in the area for 5 hours or less. Choose your preferred parking location if you are:

	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $40
Attending a festival which lasts all day on Saturday	o	o	o
Attending a concert which starts Friday at 7pm	o	o	o
Attending a festival which lasts all day on Saturday	o	o	o
Attending a concert which starts Friday at 7pm	o	o	o

The map now shows the available parking around Verizon Center. Green indicates 5+ parking spots available, Yellow 2 - 4 spots available, and Red up to 1 spot available. No parking is allowed on Black streets.



17. **You plan to stay in the area for 5 hours or less. You can access above mobile app to acquire parking information before and during your trip. Choose your preferred location if you are:**

	On-Street; 0-20 min walk; $2.3/hr ($0 on Sunday)	Garage; 7 min walk; $20	Garage at Verizon Center; 0 min walk; $40
Attending a festival which lasts all day on Saturday	o	o	o
Attending a concert which starts Friday at 7pm	o	o	o
Attending a festival which lasts all day on Saturday	o	o	o
Attending a concert which starts Friday at 7pm	o	o	o

APPENDIX D: SURVEY QUESTIONNAIRE 3

Dear Participant,

We greatly appreciate your participation in our research to evaluate the acceptance and effectiveness of parking availability information provisions. Your participation is of great importance in this study. Please fill in the appropriate choice for each question.

Thank you.

1. Did you have any of these symptoms?

	None	Slight	Moderate	Severe
General discomfort	○	○	○	○
Fatigue	○	○	○	○
Headache	○	○	○	○
Eye strain	○	○	○	○
Blurred vision	○	○	○	○
Salivation increase/decrease	○	○	○	○
Sweating	○	○	○	○
Dizziness	○	○	○	○
Nausea	○	○	○	○
General discomfort	○	○	○	○
Fatigue	○	○	○	○
Headache	○	○	○	○
Eye strain	○	○	○	○
Blurred vision	○	○	○	○
Salivation increase/decrease	○	○	○	○
Sweating	○	○	○	○
Dizziness	○	○	○	○
Nausea	○	○	○	○

2. Rate the usefulness of the parking information you provided via the MOBILE APP

	1	2	3	4	5	
Useless	○	○	○	○	○	Extremely helpful

3. **Rate the usefulness of the parking information you provided via the PARKING MESSAGING SIGN**

	1	2	3	4	5	
Useless	○	○	○	○	○	Extremely helpful

4. **Which method of providing parking information did you prefer?**

- o Mobile app
- o On-street parking messaging sign

5. **What type of parking information would you like to be provided to ease your parking decisions (Choose all that apply):**

- o Location of the parking location
- o Routes to the parking location
- o Parking Rate to be charged
- o Parking time limitation
- o Number of available parking spots in the same location

6. **Based on previous experiences, do you think Variable Message Signs (VMS) are helpful in providing parking information for travelers?**

- o Absolutely
- o Potentially
- o I don't think so

7. **Based on previous experiences, do you think a parking mobile app is helpful in providing parking information for travelers?**

- o Absolutely
- o Potentially
- o I don't think so

Participant Number:

APPENDIX E: VTTI CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Parking Sign Design Study

Investigators: Hesham Rakha, Ihab El-Shawarby, Jianhe Du, Mia Li, Karim Fadhloun, Maha Elouni, and Mohammad Aljamal.

THE PURPOSE OF THIS RESEARCH PROJECT

The project is intended to test different designs of parking availability signs to evaluate the best design that provides accurate and necessary information to the drivers. The data collected will help in the evaluation and improvement of future design. Up to 180 participants older than 18 will be used to conduct the research. The results from this study will be used for writing a project report, as part of theses/dissertations, journal/conference papers, and/or future research.

PROCEDURES

During the course of this experiment, you will be asked to perform the following tasks:

1) Read this Informed Consent Form and sign it if you agree to participate.
2) Show the experimenter your valid driver's license.
3) Read parking signs from a computer screen in a lab or office at the Virginia Tech Transportation Institute (VTTI).
4) Complete the questionnaire.
5) Complete a W9 tax form for payment purposes.

It is important for you to understand that we are not evaluating you or your performance in any way. You are helping us to evaluate the designs of our parking signs and to improve its ease of understanding. The opinions you have will help us determine appropriate guidelines for a better design. The information and feedback that you provide is very important to this project. **Total experiment time will be approximately 1 hour**.

The experiment requires you to read different designs of parking signs from a computer screen with different information regarding on-street parking availability. Assuming these signs will be placed on the roadside while you are driving to a destination (such as a convention center) in a downtown area where it is difficult to find a parking spot quickly. The signs will be shown on the computer screen for a limited time period. The length of this time period will be approximately the same as the time you would have in the real world as you approach a sign and pass it while driving. You will need to read the signs and make sure you understand the information. When each sign is turned off, you will be asked to select the types of information that is provided to you on the sign you are shown. After all six signs are shown to you, you will be asked to pick the best sign/signs.

RISKS

The tasks described here are believed to pose no more than minimal risk and similar to that of working in an office environment completing computer-related tasks.

The following precautions will be taken to ensure minimal risk to you:

- You may take breaks or decide not to participate at any time.

BENEFITS

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of future parking sign designs.

EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You may elect to have your data withdrawn from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed.

VTTI researchers will not release data identifiable to an individual to anyone other than VTTI staff without your written consent. The data collected in this study may be used in future VTTI transportation research projects. De-identified data (study data that cannot be used to identify you) may be given to the study sponsor.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

COMPENSATION

You will be paid $20 per hour. The study is expected to last approximately one hour for the whole experiment (preparation room + actual testing). Your payment is prorated at $5 for each quarter hour, or fraction thereof. You will be paid at the end of the session, using a pre-loaded MasterCard. Please allow up to 1 full business day for activation of the card. Once activated, this card cannot be used past its expiration date. The issuing bank will begin deducting a monthly service fee of $4.50 after three months of inactivity.

You will be asked to provide researchers with your social security number or Virginia Tech I.D. number for the purposes of being paid for your participation. For tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number or Virginia Tech I.D. number to receive payment for participation in our studies.

Participant Number:

FREEDOM TO WITHDRAW

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty. If you choose to withdraw during the study session, please inform the experimenter of this decision.

APPROVAL OF RESEARCH

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

PARTICIPANT'S RESPONSIBILITIES

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties of any type.

PARTICIPANT'S PERMISSION

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. **If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.**

____

Participant's name (Print) Signature Date

____

Researcher's name (Print) Signature Date

QUESTIONS OR CONCERNS

Should I have any questions about this research or its conduct, I may contact:

Hesham Rakha @(540) 231-1505, or by email: HRakha@vtti.vt.edu
Ihab Elshawarby @ (540) 231-1577, or by email: IEl-Shawarby@vtti.vt.edu
Jianhe Du @ (540) 231-1094, or by email: jdu@vtti.vt.edu
Mia Li @ (646) 717-3568, or by email: kuier94@vt.edu

If I should have any questions about the protection of human research participants regarding this study, I may contact: Dr. David Moore, Chair of the Virginia Tech Institutional Review Board for the Protection of Human Subjects, telephone: (540) 231-4991; email: moored@vt.edu;

APPENDIX F: MORGAN STATE CONSENT FORM

INFORMED CONSENT FORM **Subject No: ______**

You are invited to participate in our studies namely Parking. In parking project, we want to study the effect of on-street parking information on parking decisions. These project is being conducted by Dr. Celeste Chavis and Dr. Mansoureh Jeihani of Morgan State University. You were selected as a possible participant in this study because you kindly responded to our invitation and accepted to participate.

If you decide to participate, we will ask you to fill out three survey questionnaire forms. You will be trained how to drive the simulator. Then you will drive the simulator several times in different traffic and driving conditions. It will take no more than 2 hours in each visit. You may participate in different days. You will be paid $15 per hour of driving the simulator. When you drive the simulator, you may feel dizzy in the first few experiments until you get used to it. There is no risk of driving the simulator, you just may feel dizzy or fatigue or get headache. You may find it fun to drive the simulator and have some experiences such as crashes that are dangerous in the real world.

Your decision whether or not to participate will not prejudice your future relation with the Morgan State University. If you decide to participate, you are free to discontinue participation at any time without prejudice.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

If you have any questions, please do not hesitate to contact us. If you have any additional questions later about the study, please contact Dr. Celeste Chavis at 443-885-5061 or Dr.

Mansoureh Jeihani at 443-885-1873 who will be happy to answer them. If you have further administrative questions, you may contact the MSU IRB Administrator, Dr. Edet Isuk, at 443-885-3447.

You will be offered a copy of this form to keep.

You are making a decision whether or not to participate. Your signature indicates that you have read the information provided above and have decided to participate. You may withdraw at any time without penalty or loss of any benefits to which you may be entitled after signing this form should you choose to discontinue participation in this study.

______________________________ ______________________

Signature **Date**

____ ______________________

Signature of Parent/Legal Guardian (If necessary) **Date**

____ ______________________

Signature of Witness (If appropriate) **Signature of Investigator**