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Smart Parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration; Final Report

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SMART PARKING MANAGEMENT FIELD TEST:

A BAY AREA RAPID TRANSIT (BART) DISTRICT

PARKING DEMONSTRATION

FINAL REPORT

Task Order 6109

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ABSTRACT

This report presents an evaluation of the first transit-based smart parking project in the U.S. at the San Francisco Bay Area Rapid Transit (BART) District station in Oakland, California. The report begins with a review of the smart parking literature; next the smart parking field test is described including its capital, operational, and maintenance costs; then the results of the participant survey analysis are presented; and finally lessons learned from the institutional, user, and operational perspective are documented. Some key changes in participant travel behavior include increases in BART mode share, reductions in drive alone modal share, decreased average commute time, and an overall reduction in total vehicle miles of travel. Key lessons learned include that it would have been beneficial to anticipate additional time for project scoping and permitting, and fixed wayfinding signs were beneficial in both directing vehicles from the highway to the smart parking lot and addressing resident concerns about increased traffic. Additionally, the majority of participants continued to use the service when fees were implemented. However, the CMSs were not widely employed in users' decision-making processes in this application. Finally, the wireless counting system worked well, with the exception of the in-ground sensors, which were prone to miscounts.

KEY WORDS: Parking management, travel behavior, intelligent transportation systems

EXECUTIVE SUMMARY

In suburban areas, quick convenient auto access to park-and-ride lots can be essential to making transit competitive with the auto. Most people will only walk about one quarter of a mile to transit stations or stops, and fixed route bus or shuttle feeder services can be expensive and less convenient than the auto. Smart parking management technologies may provide a cost-effective tool to address near-term parking constraints at transit stations. Smart parking can be defined broadly as the use of advanced technologies to help motorists locate, reserve, and pay for parking. Smart parking management systems have been implemented in numerous European, British, and Japanese cities to more efficiently use parking capacity at transit stations. These smart parking systems typically provide real-time information via changeable message signs (CMSs) to motorists about the number of available parking spaces in park-and-ride lots, departure time of the next train, and downstream roadway traffic conditions (e.g., accidents and delays).

To test transit-based smart parking in the U.S., public and private partners jointly launched a field operational test at the Rockridge Bay Area Rapid Transit (BART) District station in Oakland, California, on December 8, 2004. In the San Francisco Bay Area, peak hour parking at most of the 31 suburban BART District stations had recently been at or near capacity. This field test was the first transit-based smart parking system implemented in the U.S.; however, since its launch two other transit-based smart parking systems have been implemented at Metro stations in Montgomery County, Maryland, and at three Chicago Metra stations in Illinois.

In this report, the authors present the commute travel effects of the first transit-based smart parking project in the U.S. at the Rockridge BART station in Oakland, California. The following are some key findings from the user response analysis:

- Most respondents used smart parking to travel to their on-site work location one to three days per month.
- Most respondents used the advanced reservation service via phone or Internet to access the smart parking system.
- 37 percent of respondents had seen one or more of the CMSs on Highway 24 with smart parking information, but only 32 percent of those used this information to decide whether to continue driving or take BART instead.

The following are key findings from the analysis of participant survey travel results:

- Increases in BART modal share and reductions in drive alone mode share (30.8 and 55.9 percent, across frequencies, would have driven to on-site and off-site work locations, respectively, without smart parking);
- Reductions in carpooling and bus modes (due to smart parking 16.8 and 6.6 percent, across frequencies, were diverted from these modes for commute travel to on-site and off-site work locations, respectively);
- Increased driving (or access mode) to the BART station (without smart parking and across frequencies, 14.3 and 15.3 percent would have taken the bus or a non-motorized mode to the BART station for on-site and off-site work commutes, respectively);
- Decreased average commute time (47.5 minutes using smart parking and BART compared to 50.1 minutes without smart parking); and
- Reduction in total VMT (on average, 9.7 fewer VMT per participant per month).

A review of the institutional issues associated with the smart parking field test indicates some key success factors including the strength of the public-private partnership and the use of static wayfinding signs to direct travelers to the BART station smart parking lot. Lessons learned include the following:

- Allocating additional time for the project scoping phase and permitting process;
- Anticipating and budgeting for an impact evaluation on highway traffic flow due to the CMSs;
- Project branding for additional publicity and user understanding; and
- Increased investment in enforcement technology.

Users noted a preference for the online reservation system over the telephone IVR system, despite more reservations having been made via IVR throughout the field test due to project parameters. The majority also continued to use the service once fees were implemented, but indicated that the service should not cost more than nearby commercial parking nor monthly reserved parking at the BART station. Lessons learned include:

- Making the website more user friendly;
- Improving IVR system communications (e.g., ensuring it can repeat and confirm information);
- Installing a courtesy phone or kiosk in the parking lot for users to make reservations;

- Increased lot signage, including signs in Spanish, to help travelers find smart parking spaces;
- Charging parking reservation fees on a per-transaction basis instead of carrying a balance; and
- Installing CMSs on all nearby, popular commute routes with access to the transit station.

From an operational perspective, initial testing of the user interface technology ensured that the systems worked well prior to the project launch. The wireless counting system, with the exception of problems associated with the in-ground sensors, also performed well during the field test, and temporary barriers helped direct vehicles over the sensors. Lessons learned include:

- Using an IVR system that is better able to understand all users (e.g., those with accents and who speak Spanish);
- Selecting a mobile service standard that will keep the costs associated with the CMSs low; and
- Employing sensors that can account for a range of parking lot vehicle movements.

The results of this transit-based smart parking field test suggest that such applications may be an effective way to expand transit ridership. However, the capital, operation, and maintenance costs presented in this paper do suggest that the system has to operate at a scale that is significantly larger than the field test (50 spaces at one station) to recover system costs. Expanding smart parking to more stations would also have the added benefit of reducing the VMT generated by those riders who might be inclined to drive farther from the station closest to their home without smart parking to access the service at another station. Additionally, future applications of the smart parking concept should carefully consider the cost-effectiveness of implementing CMSs on highways and/or arterials leading to the transit stations. The field test evaluation results suggest that few participants used information on CMSs posted on the highway to make their parking and travel decisions.

The next phase of this research is a new smart parking pilot project that is planned for five stations on the COASTER commuter line in San Diego. The pilot is supported by the California Department of Transportation and by the Federal Highway Administration's Value Pricing Pilot program. The larger scale of this next research phase will allow for a fuller

accounting of the revenues required to cover the capital, operation, and maintenance costs of the system as well as a detailed analyses of COASTER commuters' willingness to pay for smart parking at the stations. More importantly, project partners will work together to specify pilot objectives beyond system cost recovery.

Careful design and application of smart parking systems hold the promise of accomplishing a number of public policy objectives. Paying for parking at transit stations may be more acceptable to transit riders, if they feel that they are receiving service benefits in exchange, such as guaranteed parking spaces and premium parking locations. Such service benefits may also attract new riders to the system, as was the case for the Rockride BART field test. Smart parking applications can also be used to make more efficient use of existing facilities, for example, by providing real-time information about available parking at stations and departure times of the next train and by offering reduced parking fees and premium parking locations to those who carpool to stations. The revenues obtained from smart parking system may also provide the funds needed to expand station parking facilities and/or better transit service and thus allow for further ridership expansion. In the end, improved transit accessibility and service are keys to promoting more compact land development patterns and reducing auto travel and vehicle emissions.

1. Introduction

In suburban areas, quick convenient auto access to park-and-ride lots can be essential to making transit competitive with the auto. Most people will only walk about one quarter of a mile to transit stations or stops, and fixed route bus or shuttle feeder services can be expensive and less convenient than the auto. Smart parking management technologies may provide a cost-effective tool to address near-term parking constraints at transit stations. Smart parking can be defined broadly as the use of advanced technologies to help motorists locate, reserve, and pay for parking. Smart parking management systems have been implemented in numerous European, British, and Japanese cities to more efficiently use parking capacity at transit stations. These smart parking systems typically provide real-time information via changeable message signs (CMSs) to motorists about the number of available parking spaces in park-and-ride lots, departure time of the next train, and downstream roadway traffic conditions (e.g., accidents and delays).

To test transit-based smart parking in the U.S., public and private partners jointly launched a field operational test at the Rockridge Bay Area Rapid Transit (BART) District station in Oakland, California, on December 8, 2004. In the San Francisco Bay Area, peak hour parking at most of the 31 suburban BART District stations had recently been at or near capacity. This field test was the first transit-based smart parking system implemented in the U.S.; however, since its launch two other transit-based smart parking systems have been implemented at Metro stations in Montgomery County, Maryland, and at three Chicago Metra stations in Illinois.

This report begins with a general review of the literature on smart parking. Next, the smart parking field test is described, and the capital, operational, and maintenance costs of the field test are outlined. Then, the results of a survey administered to field test participants are analyzed to identify participants' demographic attributes, response to the service, and changes in travel patterns. Next, lessons learned from the institutional, user, and operational perspective are documented. Finally, conclusions are drawn from the field text experience.

2. Literature Review

Early examples of smart parking management included parking guidance information (PGI) systems that attempted to minimize parking search traffic in large parking facilities and central cities by dynamically monitoring available parking and directing motorists with CMSs (Griffith, 2000). Lessons learned by evaluating and modeling these systems suggest that awareness and understanding of PGI signs can be relatively high, but in order to be effective, messages must display accurate information that meets travelers' needs. Interestingly, visitors are more likely than resident commuters to use city-center PGI systems (Thompson and Bonsall, 1997). PGI systems were found to reduce parking facility queue lengths; however, system-wide reductions in travel time and vehicle travel and economic benefits may be relatively small (Thompson and Bonsall, 1997; Waterson et al., 2001).

Building upon the objectives of PGI systems, transit-based systems seek to increase transit use and revenues and reduce vehicle travel, fuel use, and air pollution. A review of the literature suggests that parking shortages at suburban rail stations may significantly constrain transit ridership (Merriman, 1998; Ferguson, 2000). In addition, motorists may respond to pre-trip and en-route information on parking availability at transit stations by increasing their transit use (Ferguson, 2000). Finally, regular commuters appear to be more responsive to parking information in conjunction with transit than more basic PGI systems because this type of real-time information has greater relevance to their commute trip (e.g., transit station parking availability, next train information, and/or roadway accident downstream) (Rodier et al., 2004).

In addition to providing real-time information about space availability and transit schedules, smart parking systems can take advantage of new technologies to improve the ease and convenience of parking payment. Contactless smart cards with wireless communication capabilities (e.g., short-distance radio frequency identification) can minimize transaction time by allowing a user to simply wave their card in front of a reader (Communication News, 1996). Mobile communication devices can also be used in smart payment transactions. Smart parking payment systems are now being developed and implemented worldwide by mobile phone developers, credit card companies, and other technology and service providers. Smart payment systems were found to reduce operation, maintenance, and enforcement costs as well as improve collection rates (Communication News, 1996; Glohr, 2002). When transit agencies attempt to induce drivers off of highways to take transit into a city center, time saving technologies may mean the difference between a decision to park and ride transit or to drive the remainder of a trip.

Combining the concepts of its forerunners, e-parking is an innovative business platform that allows drivers to inquire about parking availability, reserve a space, and even pay for parking upon departure—all from inside an individual's car (Halleman, 2003; Hodel and Cong, 2003). Drivers access the central system via cellular phone, personal digital assistant (PDA), and/or Internet. Bluetooth technology recognizes each car at entry and exit points and triggers automatic credit card payment. E-parking promises to reduce search time, facilitate parking payment, guarantee parking at a trip destination, offer customized information, provide parking information before and during a trip, improve use and management of existing spaces, and increase security of payments and total revenues (Hodel and Cong, 2003). One e-parking system has recently become operational at the London Stansted airport (e-parking homepage, 2006).

The parking pricing and cash-out literature demonstrate that charging for parking can result in substantial decreases in single-occupant vehicle modal share (Wilson and Shoup, 1990; Wilson, 1997). However, officials may be hesitant to implement these innovative solutions for fear of charging for a historically free resource (Kolosvari and Shoup, 2003). However, it is possible that the public may be more amenable to paying for parking if they feel they are getting an advanced benefit from it, which guaranteed parking reservations provide (Kolosvari and Shoup, 2003; Minderhoud and Bovy, 1996).

3. Smart Parking Field Test

To evaluate the feasibility of the smart parking concept in a transit context, the California Department of Transportation, the BART District, California Partners for Advanced Transit and Highways (PATH), ParkingCarma, Inc.'s ParkingCarma™ technology, Quixote Corporation, Intel, and Microsoft jointly launched a smart parking field test at the Rockridge BART station in Oakland, California, on December 8, 2004. BART provided 50 spaces to be used for peak period commuter parking that had previously been reserved exclusively for off-peak parking (i.e., after 10:00 am).

The smart parking field test involved two real-time user interfaces: (1) two CMSs that displayed parking availability information to motorists on an adjacent commute corridor into downtown Oakland and San Francisco (Highway 24), and (2) a centralized intelligent reservation system that permitted commuters to check parking availability and reserve a space via telephone, mobile phone, Internet, or PDA. Those who used the system for en-route reservations called in their license plate number via mobile phone when they parked in the smart parking lot. BART enforcement personnel ensured that those parking in the smart parking lot either had: (1) an advanced reservation parking permit or (2) a license plate number, which matched one of the numbers provided real-time to enforcement personnel via PDA for en-route reservations.

The smart parking system integrated traffic count data, from entrance and exit sensors at the BART station parking lot, with an intelligent reservation system to provide accurate up-to-the-minute counts of parking availability. Smart parking facilitated pre-trip planning by permitting users to reserve a space up to two weeks in advance, but it also enabled en-route decision making, providing real-time parking availability information to encourage motorists to use transit. If a motorist confronted congestion on Highway 24, he/she could check parking availability on the CMS, drive off of the freeway, and park in the smart parking area at the Rockridge BART station. Reservations were initially free of charge. A pricing structure was introduced for both types of parking reservations in October 2005. Users who made en-route reservations were charged $1.00 for this service, while those making pre-trip reservations were charged $4.50. As of March 2006, no new reservations were taken and the field test ended.

To the authors' knowledge, this smart parking system, integrating real-time traffic sensor data from a transit station parking lot with a web-based reservation system and two CMSs on an adjacent highway, was the first of its kind. Similar transit-based systems in Europe and Japan provide motorists with en-route information, but the literature suggests that there was no other program that currently enables both pre-trip planning (via an Internet-based reservation system) and en-route planning (through real-time parking information on CMSs on highways) at the time this project was launched.

The smart parking field test was the first transit-based program implemented in the U.S., but two other transit-based systems are currently in the process of implementing systems, one in conjunction with the Chicago Metra Commuter Rail system and the other with Washington, D.C. Metro. In Chicago, the system under development plans to collect real-time data to provide en-route information via CMS to travelers about parking availability, the location of parking spaces in large lots or garages, departure times for the next train, and advice to use transit when alternate roadway routes are congested (Kopp et al., 2001). Northeastern Illinois' Regional Transportation Authority, Metra Commuter Rail Division, and the Illinois Department of Transportation in the Gary-Chicago-Milwaukee corridor are sponsoring the project (Orski, 2003). This system includes electronic guidance signs located along expressways and arterials that lead to commuter rail stations to provide real-time information for motorists on the availability of parking (Orski, 2003). The system has been installed on the Rock Island Line at the Hickory Creek/Mokena station and the Tinley Park/80th Avenue station near Interstate 80. The "Smart Park" project has been implemented in Montgomery County, Maryland, at the Glenmont station of the Washington D.C. Metro system. This project incorporates video cameras in park-and-ride lots to encourage drivers to use the spillover parking lot, with the goal of decreasing parking search time and congestion. The Federal Transit Administration will be evaluating the effectiveness of both these systems with respect to increased transit use and passenger satisfaction.

More recently in California, a new smart parking pilot project is planned for five stations on the COASTER commuter line in San Diego. The pilot is supported by the California Department of Transportation and by the Federal Highway Administration's Value Pricing Pilot program.

3.1 Capital, Operational, and Maintenance Costs

Much of the equipment and labor for the smart parking field test was donated; however, interviews with vendors and the smart parking contractor (ParkingCarma, Inc.) based on the experience of the field test allowed for an estimation of the capital, operational, and maintenance costs. See Table 1 for a description of these costs.

The three major hardware components of the information collection and relay system included: (1) in-ground sensors (six), (2) local base units (two), and (3) master base unit (one). Plastic barricades were also required to channel traffic over the sensors. In addition, a digital subscriber line (DSL) was connected to the master base unit to send the information collected by the system to a central data center (through the Internet). The total capital cost for the equipment used in the field test is estimated to be approximately $58,900.

Microsoft donated the software required to operate the voice recognition system and, Intel donated the hardware. The purchase of these materials would have amounted to about $20,000 in capital expenditures. In addition, significant cost of approximately $125,000 was incurred to customize the software for the needs of the smart parking operation. The operation of the interactive voice response (IVR) system, which speaks to the users, carried a monthly expense of approximately $500 per month. The system used in the field test could handle 25 calls at one time.

The smart parking system required several system communication components. One important component was the website through which users made online reservations. This website costs about $1,000 per month to operate, which is higher than typical websites. Because of the sensitivity of data communications, extra expenses were incurred to ensure that the reservation system and general communications could not be hacked. In addition, the data were stored in a secure data center, which was physically inaccessible and could only be accessed with a specific password sent from a specific Internet protocol address. Communications to the CMSs were sent from this data center. The cost of calling out of the data center to the CMSs was $0.40 per call, which typically yielded a monthly expense of $150. In addition, calls were made to the CMSs during the morning commute hours to ensure that the correct number of spaces was displayed. This communication occurred over a cellular line and was a monthly fixed cost of $80 per sign. Finally, a DSL line at the Rockridge BART station cost approximately $100 per month.

The smart parking field test required three types of labor to operate including: executive, technical, and customer support. A senior executive with technical knowledge was required to manage the system and troubleshoot technical and managerial matters. Such an executive would command a salary of about $125 per hour. In addition, customer support for user complaints and conflicts was required for three hours per weekday during the peak morning commute period when the smart parking service operates. These morning hours would eliminate the potential for many other full-time jobs, and thus the hourly wage would most likely be higher than customer support labor for a full-time position. It is estimated that the salary for a customer support technician would be about $35 per hour. Finally, a supporting engineer was required to assist the executive on technical issues and also to maintain the online reservation system. This person would be full-time and be paid about $60 per hour. If the smart parking system expanded, more engineers, executives, and customer support technicians would be necessary.

Table 1. Estimated Field Test Capital, Operational, and Maintenance Costs

Hardware Components[a]	Quantity	Cost per Unit
In-Ground Sensors	6	$1,400
Local Base Units	2	$4000
Master Base Units	1	$4000
Changeable Message Signs	2	$19,000
DSL Line (installation)	1	$500
Voice Recognition System[b]	**Frequency**	**Cost per Unit**
Voice Recognition System Hardware	1	$20,000
Software Customization	1	$125,000
Communication[c]	**Frequency**	**Cost**
Website	Per month	$1,000
Secure Communication	Per month	$150
Cellular Sign Connection	Per month per sign	$80
Labor[d]	**Hours per Month**	**Cost**
Senior Executive	170	$125 per hour
Supporting Engineer	170	$60 per hour
Customer Support	42.5	$35 per hour

[a]Source: Interview with a Nu-Metrics representative; Price list from Consolidated Traffic Controls, Inc., a Texas-based distributor of Nu-Metrics Products; Interview with Craig Theron, Product Manager at US Traffic Corp, a Quixote Company.
[b]Source: Interview with senior representative of ParkingCarma, Inc.
[c]Source: Interview with senior representative of ParkingCarma, Inc.
[d]Source: Interview with senior representative of ParkingCarma, Inc.

4. Survey Evaluation

The evaluation of the smart parking field test is based on 177 surveys completed by participants in February and March 2006, after the implementation of the smart parking field test. Approximately 35.8 percent of field test participants completed the voluntary survey. All field test participants who had used the smart parking system more than once were sent emails requesting that they complete the on-line survey. The survey results capture respondents' demographic, employment, and travel attributes and changes in travel patterns. It is important to note the responses to this survey represent self-reported behavior as opposed to observed behavior.

4.1 Attributes of Respondents

Table 2 (below) describes the demographic attributes of survey respondents. Respondents' ages were fairly evenly divided over the range of 31 to 60 years. Generally, they were highly educated (57.1 percent have a graduate degree or higher), and no respondent had less than a high school education. Respondents also had a relatively high-income level (59.7 percent earned more than $110,000 per year). The most common household type included one or two adults with a child or children (40.3 percent).

Table 2. Demographic Attributes

Age (n = 177)	**Percent**
0 – 30	9.0%
31 – 40	30.5%
41 – 50	26.6%
51 – 60	27.7%
61 – or older	6.2%
Household Structure (n = 176)	**Percent**
Self only	20.5%
Self with spouse/partner only	31.8%
Self with or without spouse/partner and child(ren)	40.3%
Self with roommate(s) or other	7.4%
Education (n = 177)	**Percent**
Graduate/Professional	57.1%
College	41.8%
High School	1.1%
Income (n = 154)	**Percent**
Under $49,999	7.1%
$50,000 - $79,999	13.6%
$80,000 - $109,999	19.5%
$110,000 or more	59.7%

Total income categories sum to 99.9% rather than 100% due to rounding error.

The survey also examined the attributes of participants' employment. More than half of the respondents were not required to be at work at a certain time (57.1 percent). However, despite the potential opportunity to work flexible hours, it seems that most respondents worked during regular business hours, five days per week. More than half (53.7 percent) worked more than 40 hours per week, and most worked five days a week (81.4 percent). Free employer-provided parking was rarely provided to respondents at their place of work and off-site work locations.

Table 3 (below) describes participants' typical commute modal shares at the time the survey was administered and for those who used BART, the access mode shares by frequency of use. Across frequencies, BART is the primary long-haul commute mode (67.8 percent) followed by driving alone (17.0 percent) and then carpooling and bus (11.3 percent). Over half (54.8 percent) of respondents, across frequencies, take BART as their commute mode three or more days per week. Driving alone is the most common BART access mode (83.7 percent), followed by carpooling and bus (13.5 percent), and walking and biking (2.7 percent).

Table 3. Primary Commute Mode and BART Station Access Mode

Mode Shares by Frequency of Use					
Primary (n = 177)	**BART**	**Drive Alone**	**Carpool/Bus**	**Other**	**Total**
Less than 1 day a week	6.8%	0.6%	0.0%	0.0%	7.4%
1 to 2 days a week	6.2%	2.3%	0.0%	0.6%	9.1%
3 to 4 days a week	29.4%	6.8%	7.9%	1.7%	45.8%
5 or more days a week	25.4%	7.3%	3.4%	1.7%	37.8%
Total	**67.8%**	**17.0%**	**11.3%**	**4.0%**	**100.1%**

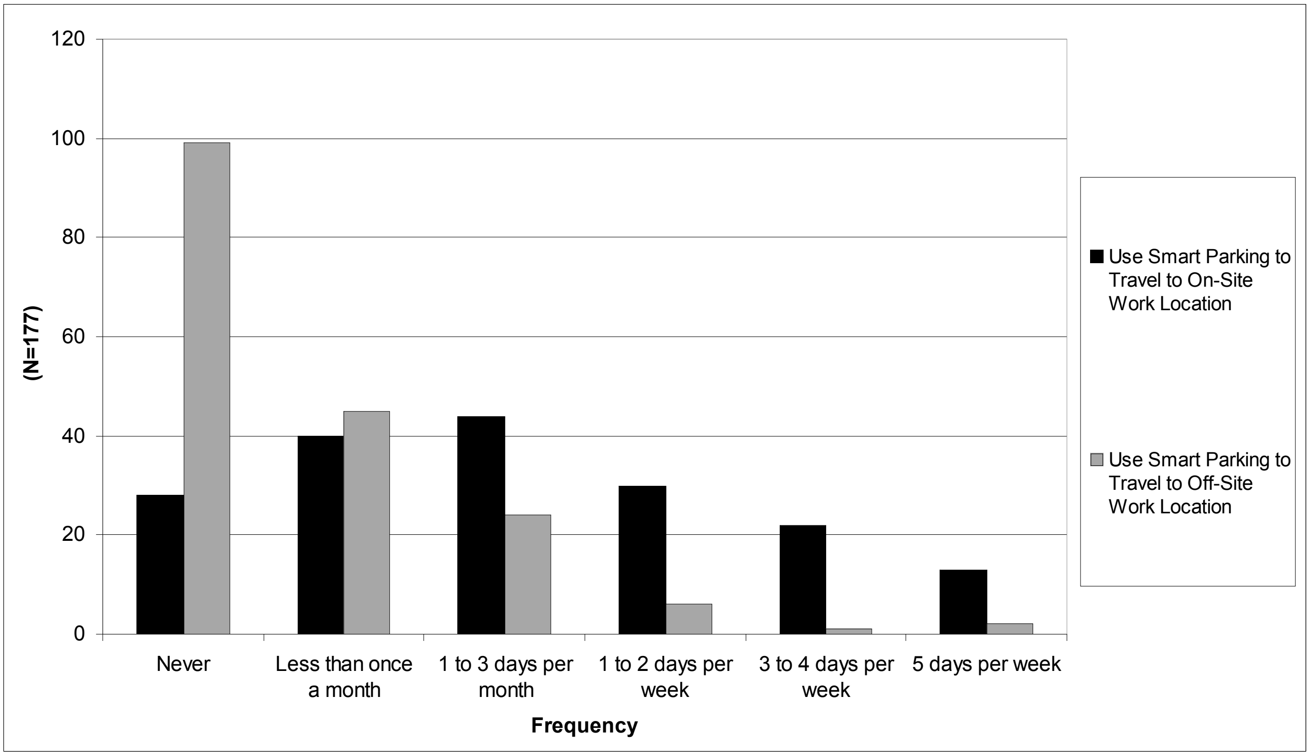
BART Access Mode Shares by Frequency of Use				
Primary (n = 110)	**Drive Alone & Park**	**Carpool/Bus**	**Walk/Bike**	**Total**
Less than 1 day a week	7.2%	0.9%	0.0%	8.1%
1 to 2 days a week	9.9%	0.0%	0.0%	9.9%
3 to 4 days a week	36.0%	7.2%	0.9%	44.1%
5 or more days a week	30.6%	5.4%	1.8%	37.8%
Total	**83.7%**	**13.5%**	**2.7%**	**99.9%**

Total mode shares by frequency of use sum to 100.1% rather than 100% due to rounding error.
Total BART access mode shares, by frequency of use, sum to 99.9% rather than 100% due to a rounding error.

4.2 System Use and Performance

Figure 1 (below) presents the frequency of smart parking and BART use by respondents to travel to their on-site and/or off-site work location. Most respondents used smart parking to travel to their on-site work location one to three days per month. Close to half of respondents used smart parking to travel to off-site work locations with some frequency. The majority of survey respondents used smart parking and BART for on-site or off-site work trips (88.7 percent), and the remaining (11.3 percent) used the service for other trip purposes, such as shopping or volunteering.

Figure 1. Frequency of Smart Parking Use



Participants were asked to indicate what they like most and what they liked least about the smart parking system. The top five responses are presented in Table 4. Respondents liked knowing that a spot would be available when they needed it, parking closer to the station, knowing how long it would take to find a spot, the ability to leave home at a later time, and the safety of the smart parking lot. Respondents disliked the cost of smart parking, lack of smart parking spaces, the cost of riding BART, using the system when work schedules varied, and the possibility that the system may fail to secure their parking space.

Table 4. Top Five Perceived Strengths and Weaknesses of the Smart Parking System.

Strengths	**n=177**
I have more confidence that a parking spot will be available when I need it.	16.0%
I can park closer to the station.	12.2%
I have a better idea of how long it will take me to find a parking spot.	10.7%
I can leave my home for work at a later time.	9.8%
I feel safer parking in the smart parking lot.	8.7%
Weaknesses	**n=177**
The cost of smart parking is too high.	13.3%
Smart parking spaces have already filled.	12.8%
The cost of BART is too high.	10.9%
My personal work schedule varies some days.	8.9%
I don't think the smart parking space will be there when I arrive at the lot.	8.5%

Note that respondents could choose more than one answer.

Participants were also asked a number of questions designed to assess the performance of the smart parking system. Thirty-seven percent of respondents indicated that they had seen one or more of the CMSs on Highway 24 with smart parking information, and 32 percent of those used this information to decide whether to continue driving or take BART instead; 16.1 percent did so less than once a month, 7.6 percent one to three days a month, 6.1 percent one to two days per week, and 1.5 percent 5 days per week. Approximately 22 percent of respondents had, at least once, reserved a smart parking space, and found it not to be available when they arrived at the station.

About 45 percent of respondents indicated that they were in favor of expanding the smart parking system to other BART stations. About 70 percent of respondents expressed interest in displaying other informational messages on the CMS signs. The top ranking messages included: (1) parking availability at downstream BART stations, (2) highway travel times to key destinations, (3) downstream highway accidents or other delays, (4) BART delays, and (5) departure times of the BART trains at the next station (see Table 5).

Table 5. Top Five Preferences for CMS Information

CMS Information Needs	**n=177**
Total available parking at downstream BART stations	65.0%
Highway travel times to key downstream destinations	43.9%
Downstream highway accidents or other delays	40.6%
BART delays	36.5%
Departure times of BART trains at the next station	35.6%

4.3 Travel Effects

4.31 Change in Commute Mode Shares

The questionnaire asked participants to state how frequently they used smart parking and BART to commute to work both at their place of work and to off-site work locations (e.g., client meetings). Survey respondents were also asked, if smart parking at BART was not available, what mode they would typically use to commute. If respondents indicated that they would still use BART, even without smart parking, they were asked how they would travel to the BART station in the absence of smart parking.

For commute to place of work, Table 6 presents the results of a cross tabulation of the responses to the following questions:

(1) How frequently do you use smart parking to commute to your place of work?

(2) If smart parking were not available, how would you commute to your place of work?

Also for commute to place of work, Table 6 presents the results of a cross tabulation of responses among those who indicated that they would commute by BART with and without smart parking to the following questions:

(1) How frequently do you use smart parking to commute to your place of work (only respondents who would take BART with or without smart parking)?

(2) If smart parking were not available, how would you commute to your place of work (only respondents who would take BART with or without smart parking)?

Table 7 is the same as Table 6, except that commute travel is to the off-site work location.

Across frequencies, smart parking encouraged 30.8 percent of respondents to use BART instead of driving alone to their on-site work location and 13.3 percent to divert to BART from carpooling (Table 6). Smart parking also increased drive alone access to the BART station; 14.3 percent of users, across frequencies, drove alone and parked at the BART station instead of taking the bus or using non-motorized modes.

More respondents, across frequencies, shifted commute modes from drive alone to smart parking and BART when commuting to off-site work locations compared to on-site work locations (Table 7). Given the availability of smart parking, 55.9 percent of users, across smart parking frequencies, shifted their long-haul commute mode from drive alone to BART for off-site work commutes. Again, smart parking encouraged some users to access the BART station by auto instead of taking the bus or walking (15.3 percent).

The figures that are reported across frequencies above from Tables 6 and 7 indicate the number of respondents who shifted from the drive alone mode to BART given the availability of the smart parking system. However, it is important to note that overall use of BART would be more influenced by respondents in the higher frequency categories (e.g., five days per week versus less than once a month). As illustrated in Tables 6 and 7, those who would have taken BART with or without smart parking used the smart parking service significantly more frequently than those who would have driven alone.

Participants were also asked how their overall work-related BART use had changed since they had joined smart parking. Thirty-five percent of respondents indicated that it had increased or greatly increased, 53 percent indicated that it had stayed the same, and five percent indicated that their use of BART had decreased or greatly decreased.

The smart parking service improved auto accessibility to the Rockridge BART station, and thus encouraged some respondents (11.2 percent) to use this station instead of one that was closer to their home. Among these 16 respondents, 62.5 percent traveled further, and 37.5 percent traveled a shorter distance to the Rockridge station from the station they had used previously.

Table 6. Cross Tabulation of Stated Frequency of Smart Parking/BART Use by Commute Mode Used if Smart Parking is Not Available To *Your On-Site Work Location*

If smart parking were not available, how would you commute to your place of work? (n=177)	**How frequently do you use smart parking to commute to on-site work?**					
	< 1 day per month	1-3 days per month	1-2 days per week	3-4 days per week	5 days per week	Total
BART (without smart parking)	11.9%	10.5%	11.9%	10.5%	6.3%	51.1%
Drive Alone	12.6%	9.1%	6.3%	2.1%	0.7%	30.8%
Carpool	1.4%	6.3%	1.4%	2.1%	2.1%	13.3%
Bus	0.7%	2.1%	0.7%	0.0%	0.0%	3.5%
Walk	0.0%	0.7%	0.7%	0.0%	0.0%	1.4%
Total	26.6%	28.7%	21.0%	14.7%	9.1%	100.1%
If you would use BART without smart parking (2nd row above), how would you travel to the BART station? (n=70)	< 1 day per month	1-3 days per month	1-2 days per week	3-4 days per week	5 days per week	Total
Drive Alone & Park in regular parking area	17.4%	15.9%	21.7%	15.9%	11.6%	82.5%
Walk/Bike	4.3%	4.3%	1.4%	2.9%	0.0%	12.9%
Driven as passenger	0.0%	0.0%	0.0%	1.4%	1.4%	2.8%
Bus	1.4%	0.0%	0.0%	0.0%	0.0%	1.4%
Total	23.1%	20.2%	23.1%	20.2%	13.0%	99.6%

Total commute mode to on-site place of work sums to 100.1% rather than 100% due to rounding error.
Total BART access mode to on-site place of work sums to 99.6% rather than 100% due to rounding error.

Table 7. Cross Tabulation of Stated Frequency of Smart Parking/BART Use by Commute Mode Used if Smart Parking is Not Available To *Your Off-Site Work Location*

If smart parking were not available, how would you commute to your place of work? (n=75)	**How frequently do you use smart parking to commute to off-site work?**					
	< 1 day per month	1-3 days per month	1-2 days per week	3-4 days per week	5 days per week	Total
BART (without smart parking)	21.3%	12.0%	0.0%	1.3%	1.3%	35.9%
Drive Alone	29.3%	20.0%	5.3%	0.0%	1.3%	55.9%
Carpool	4.0%	1.3%	0.0%	0.0%	0.0%	5.3%
Bus	1.3%	0.0%	0.0%	0.0%	0.0%	1.3%
Walk	1.3%	0.0%	0.0%	0.0%	0.0%	1.3%
Total	57.2%	33.3%	5.3%	1.3%	2.6%	99.7%
If you would use BART without smart parking (2nd row above), how would you travel to the BART station? (n=26)	< 1 day per month	1-3 days per month	1-2 days per week	3-4 days per week	5 days per week	Total
Drive Alone & Park in regular parking area	46.2%	30.8%	0.0%	3.8%	3.8%	84.6%
Walk	11.5%	0.0%	0.0%	0.0%	0.0%	11.5%
Bus	0.0%	3.8%	0.0%	0.0%	0.0%	3.8%
Total	57.7%	34.6%	0.0%	3.8%	3.8%	99.9%

Total commute mode to off-site work location sums to 99.7% rather than 100% due to rounding error.
Total BART access mode to off-site work location sums to 99.9% rather than 100% due to rounding error

4.32 Changes in Commute Travel Time and Commute Stress

Smart parking appears to have decreased time spent commuting for respondents. Overall, for respondents who used smart parking with some frequency to travel to their on-site work location, commute minutes per month dropped from 43,652 to 40,394 minutes per month. Using a paired sample t-test for dependent samples, it was determined that there was a statistically significant difference ($p = 0.002$) in commute time to work using smart parking and BART (47.5 minutes) in comparison to commute time to work if smart parking at BART was not available (50.1 minutes). This result suggests that the availability of smart parking at BART contributed to decreased commute times.

In addition, participants were asked how their commute stress had changed since they joined smart parking. Sixty-six percent of respondents indicated that that their stress had been reduced or greatly reduced, 23 percent indicated that it has stayed the same, and 5 percent stated that it had increased.

4.33 Change in Commute Vehicle Miles Traveled

A number of factors affected the change in vehicle miles traveled (VMT) by field test participants to commute to their on-site place of work including: (1) riding BART as their primary mode instead of driving alone; (2) driving to BART instead of taking the bus, walking, or biking; and (3) driving to Rockridge to access smart parking instead of driving to a BART station that was closer to their home. The change in VMT was calculated by multiplying each user's two-way VMT by the frequency per month of their commute method with and without smart parking and then taking the difference between these two values. It is estimated that an average participant reduced their monthly VMT by 9.7 miles. Approximately 33 percent of the reduction in VMT was offset by an increase in drive access mode to the BART station and driving further to the Rockridge BART station instead of a BART station closer to home. This distance calculation used home and work zip codes.

5.0 Lesson Learned

5.1 Institutional Understanding

The smart parking field test provided a unique opportunity to document the institutional success factors and lessons learned from a real-world smart parking field test. Institutional lessons address the following areas: the public-private partnership, site selection, smart parking signage, operating and encroachment permits, and enforcement.

5.11 Public-Private Partnership

A key success factor of the smart parking field test was the strength of the public-private partnership. A collection of interagency agreements and contracts outlined specific roles and responsibilities for each partner, which facilitated the use of private resources to implement smart parking at a transit station. Furthermore, the project agreements documented that the partners were willing to work together to implement and launch the field test at the Rockridge BART station.

The strength of the public-private partnership resulted from the set of skills and resources that each partner applied to the field test, such as Caltrans' development of the smart parking design and funding commitment, PATH's research expertise, ParkingCarma, Inc.'s technical knowledge and equipment access, and BART's parking facility and enforcement personnel. Primary partners and subcontractors were identified while the project proposal was developed. Periodic meetings and weekly updates helped to maintain these relationships throughout the project. Researchers learned that it is helpful to anticipate project delays, such as refining the project scope, coordinating numerous agencies, and addressing additional project variables (e.g., parking payment policies). Approximately six months were allocated for the field test project scoping phase. In the future, an additional three months is advised for this step.

5.12 Site Selection

The criteria for selecting the smart parking transit site were as follows: 1) the field test should be located at a station at or near maximum parking capacity; 2) the location should be near a major freeway or arterial; 3) there should be structured access (entrances and exits) to the parking lot for placement of vehicle sensor technology to ensure accurate parking counts; and 4) agreement among the BART District and other partners on the selected site.

Initially, the field test was envisioned to incorporate an overflow parking strategy for the Dublin/Pleasanton BART station in Pleasanton, California. However, an economic downturn in the Bay Area lessened the parking demand at the station before the project began. Thus, a new site was selected. This was an early lesson learned: changes in the economy can impact congestion and affect parking demand and ultimately site selection.

Three additional stations were then considered based on the site selection criteria: 1) El Cerrito Del Norte in the City of El Cerrito, 2) downtown Walnut Creek, and 3) Rockridge in the City of Oakland. The Walnut Creek BART station was excluded based on city zoning laws that prevented CMS use on roadways. An analysis of 1998 BART passenger survey data demonstrated that of all the stations considered, the Rockridge station was among the least likely to be accessed by auto. Researchers hypothesized that this might be the result of high parking demand. Observational analyses conducted by researchers in April 2003 found that parking demand was the highest at the Rockridge station (between the El Cerrito Del Norte and Rockridge stations). Thus, it was selected as the smart parking test site (Shaheen et al., 2005).

5.13 Smart Parking Signage

The smart parking CMSs were placed on Highway 24 before and after a heavily traveled three-bore tunnel in the East Bay. Researchers examined the effects of the CMSs on travel times to determine whether the signs impeded traffic by recording driving times at three checkpoints before and after the CMSs were deployed in November 2004 and again in April 2005 (Shaheen and Rodier, 2006).

Driving times varied due to different drivers, whether there was an unrelated traffic accident, and changes in traffic flow. The limited analysis did not indicate sign-related traffic impediments. A limitation of this evaluation, however, was that variables other than the CMSs could have affected the observed traffic flow including: weather, driving behavior, and traffic conditions. In addition, travel times on the highway were recorded to the nearest minute, and actual times could have differed by as much as 30 seconds (Shaheen and Rodier, 2006). A lesson learned is to plan and budget for a CMS impact evaluation, if CMSs are to be used in future projects.

Fixed station and wayfinding signs for the smart parking service were installed on local streets leading up to and at the smart parking site. Wayfinding signs directed vehicles from Highway 24 to the Rockridge BART station and helped to address community concerns that vehicles searching for the smart parking lot would create more traffic. This also provided BART with additional advertising. Fixed signs located at the Rockridge BART station designated smart parking spots and hours of operation. While the signs were a success factor of the field test, focus group participants and final survey respondents indicated that better fixed signage would have been beneficial to designate the smart parking spaces at the station. Existing artwork (a large-scale mural), however, made it difficult to install additional signs at the lot. The smart parking project manager also suggested that better project branding (i.e., a project name and logo) and additional monthly reserved parking signs may have helped to distinguish the smart parking spaces. Also, fixed signage in Spanish may prove beneficial in areas with diverse populations.

5.14 Operating and Encroachment Permits

Both BART and the local Caltrans district require permits for installing and operating equipment on their rights-of-way. The smart parking field test secured a construction (Permit to Enter) and an operation (Concession Permit) permit from BART for the wireless sensors and associated parking lot technology. An encroachment permit from Caltrans was required for the CMSs on Highway 24. These permits addressed local site conditions, insurance, and the amount of time the project was permitted to operate. The field test did not have a separate budget for permitting; however, time to obtain the permits was built into the implementation project phase. Two months were allocated for permitting; however, it ultimately took between six to seven months. A lesson learned is that more time should be designated for the permitting process (at least six months), and a budget should be prepared for this stage of the project, including permit funds, review, and safety fees. The cost to obtain the permits and safety inspection from BART was approximately $2,000.Caltrans did not charge for the permit because they were the research funding agency and exempt all public agencies from such fees. Otherwise, Caltrans charges $328 to review encroachment permit applications, and agency inspectors charge $82 per hour to inspect equipment installation. One Caltrans permitting engineer estimated that the installation of two CMSs would require four hours of inspection time at a cost of $328, plus the application fee for a total of $656.

5.15 Enforcement

Enforcement personnel, comprised of BART police officers and paid community service assistants, used two methods to enforce parking reservations during the field test. First, a list of license plate numbers for vehicles with reservations was faxed to Rockridge BART enforcement officers at both 9:30 and 10:05 AM by ParkingCarma, Inc. Second, in January 2006, ParkingCarma, Inc. decided to test PDAs as an enforcement tool. Two PDAs were assigned to enforcement personnel to access registered smart parking user license plate information, which enabled them to identify vehicles that did not have a valid reservation. ParkingCarma, Inc.

provided the necessary personnel training on accessing the registered vehicle data. One ParkingCarma, Inc. staff member noted that the field test did not employ enough PDAs for every enforcement officer to use because the initial budget did not include them. Due to enforcement staff rotations, it was not possible to consistently implement this method of enforcement during the research project. If vehicles parked in a smart parking space were not in the database, they were issued a ticket. If they were in the database but did not have a reservation, their account was charged. As part of the registration process, users entered a credit card that was charged a flat fee of $30. Reservation fees were deducted from their account balance. An additional $30 was added automatically, as needed. Later, as the field test approached its end, users were charged on a per-transaction basis.

Since free parking was offered at the Rockridge BART station at 10 AM, it made it difficult to determine if an unreserved vehicle had parked legally using the faxed list of confirmed reservations. One officer used chalk to mark tires at 9:30 AM and issued a ticket if the vehicle did not have a reservation by 10:05 AM. One ParkingCarma, Inc. staff member indicated that it was helpful to have a live operator available to assist users when parking tickets were issued in error; an employee of ParkingCarma, Inc. assisted users as requests came in. The provision of a live operator introduces additional costs of approximately $26,775 over 18 months for a full-time employee (estimating 40 hours per week and 255 days per year) to the service (Shaheen and Rodier, 2006). The authors discuss lessons learned from the user perspective in the following section.

5.2 User Perspective

At the conclusion of the field test in 2006, there were over 13,000 successful smart parking events (Acme Innovation, Inc., 2006). Users provided feedback on the online reservation system, telephone reservations, CMSs, and pricing (as described above).

5.21 Online Reservation System

More than 4,000 smart parking reservations were made through the online reservation system. The ParkingCarma, Inc. website enabled users to register for the service and reserve parking spaces up to two weeks in advance. Users also had access to account services (e.g., billing information), directions to the smart parking site, and pricing information once fees were introduced. Through focus groups and a final survey, users expressed greater satisfaction with reserving spaces online in contrast to the telephone-based IVR system. Furthermore, users indicated that they wanted to make more advanced reservations than the limit allowed (i.e., three reservations every two weeks).

Participants noted that the online reservation system could be improved and indicated the following concerns:

- It was not user-friendly (e.g., one participant said she had to re-teach herself how to use the reservation system every time she visited the website).
- Parking spaces could only be reserved before 10:00 AM, and some wanted the time extended later in the day.
- It was difficult to change the primary car listing (e.g., if a user purchased a new vehicle).

Survey respondents also indicated they had difficulty creating an online account. One ParkingCarma Inc. staff member noted that the website wizard—a tool created to help first-time users—was underused.

Participants generally liked that they could access their reservation history and the printout feature for advanced reservations. A few survey respondents noted that they did not like having to print the advanced reservation receipt to post in their windshield, and one suggested using a decal sticker instead. Another recommended a reminder of their parking reservation via PDA. Overall, 75 percent of survey respondents indicated that their reserved space always had been available when they arrived at the smart parking lot.

5.22 Telephone Reservations

Telephone reservations, facilitated through a customized IVR system, accounted for approximately 9,000 reservations during the smart parking field test. Users dialed a ParkingCarma, Inc. telephone number, displayed on the smart parking fixed signage in the BART station lot, to make reservations. If they had previously registered with the service, they provided their user ID and PIN. If it was an individual's first time as a user, she entered her license plate number to reserve a space. The user was then provided with a space number—a unique number painted on the smart parking space—to indicate where her vehicle was parked.

Participants indicated that they liked the ability to call in reservations real time. The majority of concerns with the reservation process involved the IVR system. They include:

- The IVR system voice, known as "Kate," did not repeat nor confirm information stated by the user, and it did not decipher verbal commands consistently.

- Participants indicated that it was easier to make drive-in reservations than advanced reservations via the IVR system.
- Survey respondents reported that the system had an introductory message that was too long for repeat users, and no by-pass option was available.
- Other respondents were concerned about using the IVR in a transit environment that was often noisy and had poor mobile phone reception.
- Respondents also indicated that the IVR space count was unreliable.

Respondents suggested that the system have a numerical keypad option, in addition to the IVR, to address the concern that verbal commands were not well understood. Furthermore, a Spanish language option might be helpful.

Finally, participants did not like that there was not an easily accessible phone nor kiosk near the smart parking lot, making it difficult for users without mobile phones to make drive-in reservations. It was suggested that a courtesy phone be placed closer to the smart parking area to make it more convenient for users without mobile phones.

5.23 Changeable Message Signs

CMSs located on Highway 24 in Oakland displayed real-time parking availability information for morning commuters from 7:30 to 9:40 AM, Monday through Friday. The signs displayed two alternating messages: 1) the number of available smart parking spaces at the Rockridge BART station, which was continuously updated by the wireless counting system, and 2) static directions to the smart parking site from the highway (i.e., "Exit College Ave."). Expert interviews with the smart parking project manager indicated that the CMSs were beneficial because they provided general project awareness and, after seeing the parking availability everyday at the same time, some travelers were encouraged to participate in the field test. CMS placement is important, and the location should be on users' commute routes.

Results from the focus groups and final survey indicate, however, that the signs were underused. Only 39 percent of users reported seeing the CMSs on Highway 24. Of survey respondents, 58 percent reported that they had never used the signs in their decision-making process; among focus group participants, this number was as high as 87 percent. Survey results also indicated that 35 percent had found the information on the CMSs to be accurate, compared to 54 percent who were "unsure," and 11 percent who did not. Focus group participants generally expressed one of two concerns: 1) the CMSs were not located on their commute route, and 2) the information on the signs was not descriptive enough. Some participants indicated that travelers might not be sure if the spaces would be available when they pulled off the highway, particularly as the number of available parking spaces displayed on the signs did not change frequently. One suggestion from the focus groups is that more public outreach could be developed to help motorists better understand the purpose of the information displayed on the CMSs. Finally, participants indicated that they were confused about what information the signs were trying to convey; in addition, some felt that only project users would understand what the messages meant.

5.24 Pricing

The smart parking field test began charging users in October 2005, ten months after the initial launch. This provided researchers with an opportunity to test the effects of pricing on smart parking behavior. Users were charged $1.00 per day for drive-in reservations and $4.50 per day for advanced reservations, as determined by BART managers.

After fees were implemented, reservation data from ParkingCarma, Inc.'s central computer revealed that drive-in reservations increased while advanced reservations decreased. From January to March 2005, before charges began, "drive-ins" averaged 57 percent of total reservations. For the same time period in 2006, after users were charged to park, drive-in reservations averaged 80 percent of total reservations, an increase of 23 percentage points.

Sixty-four percent of survey respondents reported that they continued smart parking use when fees were introduced; however, nearly 75 percent of respondents noted that they would stop using the service, if daily parking fees equaled or exceeded $5.00 per day. Furthermore, 43 percent answered "yes" when asked if they made fewer advanced versus drive-in reservations when parking fees were implemented, while 46 percent answered "no" and 11 percent were "unsure."

Focus group participants agreed overall that they would be willing to pay for smart parking, but that it should not be more expensive than monthly reserved parking—$84 per month at the Rockridge BART station parking lot, equivalent to $4.00 per workday. Others suggested that it should not cost more than nearby commercial parking. Commercial parking lots within a three-mile radius of the Rockridge BART station have average parking rates as follows: $3.00 hourly, $13 daily, and $158 monthly.

Respondents indicated that their greatest concern with smart parking pricing was that the cost of parking combined with BART fares was too expensive. Roundtrip BART fares average $6 to $8, depending on the user's end station (Rodier and Shaheen, 2007). Using the smart parking reservation service every workday, in addition to the cost of a roundtrip BART ticket, would range $147 to $189 monthly for drive-in reservations and $220.50 to $262.50 monthly for advanced reservations, assuming 21 workdays per month.

Others indicated that the smart parking fees were too expensive, particularly those for the advanced reservations, and that they did not like the price discrepancy between the advanced and drive-in reservations. Some suggested not charging for the service. There were also concerns about charging flat increments of $30 into an electronic account; some preferred a per transaction charge. For instance, one respondent noted that she was borrowing a vehicle for a short period and would not use all her balance because she did not own a car. At the end of the field test, participants who had balances received refunds. A discussion of the operational perspective is provided in the next section.

5.3 Operational Perspective

Smart parking relied on the successful installation and operation of an integrated network of technologies. Since a majority of the hardware was off-the-shelf, there were numerous challenges in customizing the equipment. Operational lessons learned were garnered from the user interfaces and parking lot technology.

5.31 User Interfaces

Both the telephone and website reservation systems operated well and without significant problems. Substantial testing of the user interfaces (e.g., research staff testing phone and Internet reservations) in late 2004 before the field test launched enabled researchers to have a high degree of confidence that the system could perform accurately during peak periods (Shaheen et al., 2005). Since first-time, drive-in callers made smart parking reservations by providing their license plate numbers, technical experts at ParkingCarma, Inc. programmed the IVR system with California specific Department of Motor Vehicle license plate regulations (e.g., California license plates do not start with the number '5,' so the system would not recognize this as a first number), which successfully conserved computer data space. The longest caller wait time was two seconds, with peak load time occurring at 8:30 AM. According to one ParkingCarma, Inc. staff member, it was sometimes difficult for the IVR system to identify users' accents, and for some users, English was not their first language. Staff further indicated that it was helpful to have a live operator available, especially during peak periods, to answer questions about the service.

Overall, the smart parking website performed well. One ParkingCarma, Inc. employee suggested that less screens on the website would make it easier for users to navigate.

The project team encountered difficulties with the CMSs as both had intermittent, unreliable operations due to electronic and communication problems. One CMS in particular had trouble with mobile phone communication, which was the result of a defective modem and an improperly configured sign controller that was later repaired by the vendor (Rodier and Shaheen, 2007). Another concern was that the CMSs were expensive to operate due to frequent real-time updates of smart parking space availability. As a result, ParkingCarma, Inc. technical staff switched the mobile phone standard used for the signs to the global system for mobile communications (GSM) at the same time that Quixote replaced the signs, which resulted in airtime data charge savings of approximately 10 to 30 percent. One Quixote partner indicated that as the signs age (the first two CMSs used for the field test had been in storage for one year), repairs and firmware upgrades make replacement more cost effective.

Expert interviews revealed that the most difficulty arose from the in-ground sensors. Prior to this project, the sensors had been used on highways and streets with traffic in one direction only. Project partners modified the firmware to detect two-way vehicle movements, and testing at an off-site location indicated that they worked well. At the BART station, however, the sensors were unpredictable in their ability to accurately count vehicles moving at parking lot speeds. As a result, the hardware vendors determined that changes were necessary for the counter software (Shaheen and Rodier, 2006). Technicians and senior partner officials tried to fix the sensors and performed a number of investigations, but they continued to miscount vehicles. Project partners noted that this problem may have resulted from the magnetic field at the BART station, since the sensors work by detecting the changing magnetic fields from vehicles passing over the sensors. Also, sensors had difficulty accounting for atypical vehicle movements, such as cars driving into or out of the lot the wrong way. Researchers tried to minimize such movements through the use of temporary barriers. The sensors were eventually replaced during the field test with ones that were situated aboveground, which were more effective and less expensive. The integration of the new sensors with the wireless counting system resulted in communication protocol problems that were resolved by ParkingCarma, Inc. technicians. Researchers ultimately maintained count accuracy by using a proprietary algorithm developed by ParkingCarma, Inc. that corrected the sensor problems and accounted for instances when vehicles queued above the sensors. See Table 8 below, which summarizes key institutional, user perspective, and operational success factors and lessons learned.

Table 8. Lessons Learned from the Smart Parking Field Test

	Success Factors	Lessons Learned
Public-Private Partnership	The partnership was a success due to the resources and expertise of each partner.	Three additional months (nine months total) should be allocated for the project scoping phase to account for unexpected delays.
Site Selection	Identifying a site that reflects project criteria (e.g., high parking demand, potential to more efficiently manage parking) is critical to project success.	Local economic conditions can change and affect parking demand and subsequently site selection.
Smart Parking Signage	Wayfinding signs directing vehicles to the smart parking site can alleviate concerns that the project may create additional traffic on local roadways.	- Anticipate budgeting for a CMS impact evaluation, if using the signs on highway rights-of-way. - Additional fixed signage and project branding could help drivers locate spaces better in the future.
Operating and Encroachment Permits	Obtaining operating and encroachment permits from government agencies allowed equipment installation and operation.	A minimum of six months should be allocated and budgeted for the permitting process.
Enforcement	A live operator helped assist users when parking tickets were issued in error.	Increased investment in enforcement technology (e.g., handheld PDAs) may be beneficial in the future.
Online Reservation System	- Users liked the ability to make online reservations, and it was a popular feature of the smart parking service. - The reservation history and print-out feature for advanced reservations were generally liked.	- Websites should be user friendly, and the process for creating an account should be simple. - A parking reservation reminder via PDA would be helpful. - Consider another method for verifying reservations, such as decals.
Telephone Reservations	The telephone reservation system enabled users to make en-route and on-site parking reservations.	- A successful IVR system should repeat and confirm information. Additionally, it should understand verbal commands in noisy environments, such as transit stations. A touchtone option may be used as an alternative for users having difficulty with the system. - Introductory messages should be informative but concise. A bypass option should be provided. - A courtesy phone or kiosk could enable travelers without mobile phones access to the service.
Changeable Message Signs	After seeing the CMSs everyday on their commute route, some travelers were encouraged to try the service.	- CMS placement is important, and the location should be on users' commute routes. - Enhanced project publicity may increase confidence in the CMS messages. - Further study of message wording is necessary to ensure travelers understand sign communications.
Pricing	The majority of users continued using the service after fees were implemented.	Fees could be charged per-transaction for users who wanted to use the service only in the short term.
User Interface Operations	- Substantial testing before the field test began ensured the technology worked well. - IVR system data space was conserved by programming California specific license plate rules. - A live operator helped answer questions users had about making reservations.	- An IVR system that recognizes accents and is available in Spanish could be beneficial. - Changing the mobile phone standard used for the CMSs saved money.
Parking Sensor System Operations	- The local base units, master base unit, and computer server operated well. - Temporary barriers can help direct vehicles over parking lot sensors.	Above-ground sensors that can identify vehicles moving at parking lot speeds and can account for atypical vehicle movements (e.g., wide turns) should be used.

6.0 Conclusion

In this report, the authors present the commute travel effects of the first transit-based smart parking project in the U.S. at the Rockridge BART station in Oakland, California. The following are some key findings from the user response analysis:

- Most respondents used smart parking to travel to their on-site work location one to three days per month.
- Most respondents used the advanced reservation service via phone or Internet to access the smart parking system.
- 37 percent of respondents had seen one or more of the CMSs on Highway 24 with smart parking information, but only 32 percent of those used this information to decide whether to continue driving or take BART instead.

The following are key findings from the analysis of participant survey travel results:

- Increases in BART modal share and reductions in drive alone mode share (30.8 and 55.9 percent, across frequencies, would have driven to on-site and off-site work locations, respectively, without smart parking);
- Reductions in carpooling and bus modes (due to smart parking 16.8 and 6.6 percent, across frequencies, were diverted from these modes for commute travel to on-site and off-site work locations, respectively);
- Increased driving (or access mode) to the BART station (without smart parking and across frequencies, 14.3 and 15.3 percent would have taken the bus or a non-motorized mode to the BART station for on-site and off-site work commutes, respectively);
- Decreased average commute time (47.5 minutes using smart parking and BART compared to 50.1 minutes without smart parking); and
- Reduction in total VMT (on average, 9.7 fewer VMT per participant per month).

A review of the institutional issues associated with the smart parking field test indicate some key success factors including the strength of the public-private partnership and the use of static wayfinding signs to direct travelers to the BART station smart parking lot. Lessons learned include the following:

- Allocating additional time for the project scoping phase and permitting process;
- Anticipating and budgeting for an impact evaluation on highway traffic flow due to the CMSs;

- Project branding for additional publicity and user understanding; and
- Increased investment in enforcement technology.

Users noted a preference for the online reservation system over the telephone IVR system, despite more reservations having been made via IVR throughout the field test due to project parameters. The majority also continued to use the service once fees were implemented, but indicated that the service should not cost more than nearby commercial parking nor monthly reserved parking at the BART station. Lessons learned include:

- Making the website more user friendly;
- Improving IVR system communications (e.g., ensuring it can repeat and confirm information);
- Installing a courtesy phone or kiosk in the parking lot for users to make reservations;
- Increased lot signage, including signs in Spanish, to help travelers find smart parking spaces;
- Charging parking reservation fees on a per-transaction basis instead of carrying a balance; and
- Installing CMSs on all nearby, popular commute routes with access to the transit station.

From an operational perspective, initial testing of the user interface technology ensured that the systems worked well prior to the project launch. The wireless counting system, with the exception of problems associated with the in-ground sensors, also performed well during the field test, and temporary barriers helped direct vehicles over the sensors. Lessons learned include:

- Using an IVR system that is better able to understand all users (e.g., those with accents and who speak Spanish);
- Selecting a mobile service standard that will keep the costs associated with the CMSs low; and
- Employing sensors that can account for a range of parking lot vehicle movements.

The results of this transit-based smart parking field test suggest that such applications may be an effective way to expand transit ridership. However, the capital, operation, and maintenance costs presented in this paper do suggest that the system has to operate at a scale that is significantly larger than the field test (50 spaces at one station) to recover system costs.

Expanding smart parking to more stations would also have the added benefit of reducing the VMT generated by those riders who might be inclined to drive farther from the station closest to their home without smart parking to access the service at another station. Additionally, future applications of the smart parking concept should carefully consider the cost-effectiveness of implementing CMSs on highways and/or arterials leading to the transit stations. The field test evaluation results suggest that few participants used information on CMSs posted on the highway to make their parking and travel decisions.

The next phase of this research is a new smart parking pilot project that is planned for five stations on the COASTER commuter line in San Diego. The pilot is supported by the California Department of Transportation and by the Federal Highway Administration's Value Pricing Pilot program. The larger scale of this next research phase will allow for a fuller accounting of the revenues required to cover the capital, operation, and maintenance costs of the system as well as a detailed analyses of COASTER commuters' willingness to pay for smart parking at the stations. More importantly, project partners will work together to specify pilot objectives beyond system cost recovery.

Careful design and application of smart parking systems hold the promise of accomplishing a number of public policy objectives. Paying for parking at transit stations may be more acceptable to transit riders, if they feel that they are receiving service benefits in exchange, such as guaranteed parking spaces and premium parking locations. Such service benefits may also attract new riders to the system, as was the case for the Rockride BART field test. Smart parking applications can also be used to make more efficient use of existing facilities, for example, by providing real-time information about available parking at stations and departure times of the next train and by offering reduced parking fees and premium parking locations to those who carpool to stations. The revenues obtained from smart parking system may also provide the funds needed to expand station parking facilities and/or better transit service and thus allow for further ridership expansion. In the end, improved transit accessibility and service are keys to promoting more compact land development patterns and reducing auto travel and vehicle emissions.

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