TRANSIT-BASED SMART PARKING IN THE U.S.: BEHAVIORAL ANALYSIS OF SAN FRANCISCO BAY AREA FIELD TEST

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ABSTRACT

This paper presents the evaluation of the commute travel effects of the first transit-based smart parking project in the U.S. at the Rockridge Bay Area Rapid Transit (BART) District station in Oakland, California. The following are key findings from the analysis of participant survey travel results: 1) sizable increases in BART mode share (an average increase of 5.5 and 4.0 more BART trips per month for on-site and off-site commutes, respectively); 2) reductions in drive alone modal share (30.8 and 56%, across frequencies, would have driven to on-site and off-site work locations, respectively, without smart parking); 3) decreased average commute time (47.5 minutes using smart parking and BART compared to in 50.1 minutes without smart parking); and 4) reduction in total vehicle miles traveled (VMT) (on average, 9.7 fewer VMT per participant per month).

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

WORD COUNT: 6,056

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 (CMS) 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 evaluate the effectiveness of transit-based smart parking, 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 has 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 are planned—one at the Glenmont Metro Station in Montgomery County, Maryland, and two at Chicago Metra stations in Illinois.

This paper presents the results of smart parking participant surveys and evaluates the effect of the smart parking field test on participant commute travel behavior, including changes in transit ridership, auto access to transit, and vehicles miles traveled (VMT). This paper begins with a general review of the literature on smart parking. Next, the smart parking field test is described, then surveys results are discussed, and conclusions are drawn from the analysis.

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 (*1*). 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 (*2*). 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 (*2*, *3*).

Building upon the objectives of PGI systems, transit-based systems seek to increase transit use and revenues, reduce vehicle travel, lower fuel use, and reduce air pollution. A review of the literature suggests that parking shortages at suburban rail stations may significantly constrain transit ridership (*4*, *5*). Thus, more effective use of station parking may increase transit use and revenues. In addition, motorists may respond to pre-trip and en-route information on parking availability at transit stations by increasing their transit use (*5*). 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) (*6*).

In addition to providing real-time information about space availability and transit schedules, smart parking systems can take advantage of advanced 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 (*7*). 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 (*7*, *8*). 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 (*9*, *10*). Drivers access the central system via mobile 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 may address many of the same problems that PGI, smart parking, and smart payment technologies address, such as parking optimization, cost savings, search traffic, transit station constraints, related air pollution, and security (*10*). In addition, 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 (*10*, *9*). One e-parking system has recently become operational at the London Stansted airport (*11*).

The parking pricing and cash-out literature demonstrate that charging for parking can result in substantial decreases in single-occupant vehicle modal share (*12*, *13*). However, public agencies may be hesitant to implement these innovative solutions for fear of charging for a historically free resource (*14*). Smart parking may provide a means to implement some powerful market-based solutions to the problems associated with traditional parking practices. Smart parking technology could facilitate market rate pricing for parking depending on time of day. Moreover, people may be more amenable to paying for parking if they feel they are receiving an advanced benefit from it, which guaranteed parking reservations provide (*14*, *15*).

TRANSIT-BASED SMART PARKING FIELD TEST: SAN FRANCISCO BAY AREA

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), Acme Innovation Inc.'s ParkingCarma™, 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 in the field test.

The Rockridge BART 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, she could check parking availability on the CMS and 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. The smart parking field test ended on April 7, 2006. 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 is no other program that currently enables both pre-trip planning (via a web-based reservation system) and en-route planning (through real-time parking information on CMSs on highways).

FIGURE 1 Images of smart parking field test.

The smart parking field test was the first transit-based program implemented in the U.S., but two other transit-based systems are currently nearing implementation in conjunction with the Chicago Metra Commuter Rail system and the Washington, D.C. Metro. In Chicago, the system under development plans to collect real-time data to provide en-route information via CMSs 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 (*16*). 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 (*17*). This system includes electronic guidance signs located along expressways and arterials that lead up to commuter rail stations to provide real-time information for motorists on the availability of parking (*17*). In addition, a "Smart Park" project has been proposed in Montgomery County, Maryland, at the Glenmont station of the Washington, D.C. Metro system. This project plans to incorporate 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.

SURVEY AND RESULTS

The analysis presented here is based on 177 surveys completed by participants in the smart parking field test in February and March 2006, after the implementation of the smart parking field test. Approximately 35.8% of field test participants who used the system with some regularity (i.e., more than one time) completed the voluntary survey. The survey results capture respondents' demographic and employment attributes and commute travel pattern changes.

Demographic and Employment Attributes

Table 1 (below) describes the demographic attributes of survey respondents. More women than men used the program (62.7 vs. 37.3%). Respondents' ages are fairly evenly divided over the range of 31 to 60 years. Generally, they are highly educated (57.1% have a graduate degree or higher) and no respondent have less than a high school education. They also have a relatively high-income level (59.7% earn more than $110,000 per year). The most common household type includes one or two adults with a child or children (40.3%).

TABLE 1 Demographic Attributes

Gender (n = 177)	**Percent**
Female	62.7%
Male	37.3%
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 are not required to be at work at a certain time (57.1%). However, despite the potential opportunity to work flexible hours, it seems that most respondents work during regular business hours, five days per week. More than half (53.7%) work more than 40 hours per week, and most work five days a week (81.4%). Free employer provided parking is rarely provided to respondents at their place of work and off-site work locations.

Primary Commute Mode

Table 2 (below) describes participants' modal shares, and for those who use BART, the access mode shares by frequency of use. Across frequencies, BART is the primary long-haul commute mode (67.8%) followed by driving alone (17.0%) and then carpooling and bus (11.3%). Over half (54.8%) 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%), followed by carpooling and bus (13.5%), and walking and biking (2.7%).

TABLE 2 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.

Smart Parking Use

Figure 2 (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%) and the remaining (11.3%), used the service for other trip purposes, such as shopping or volunteering.

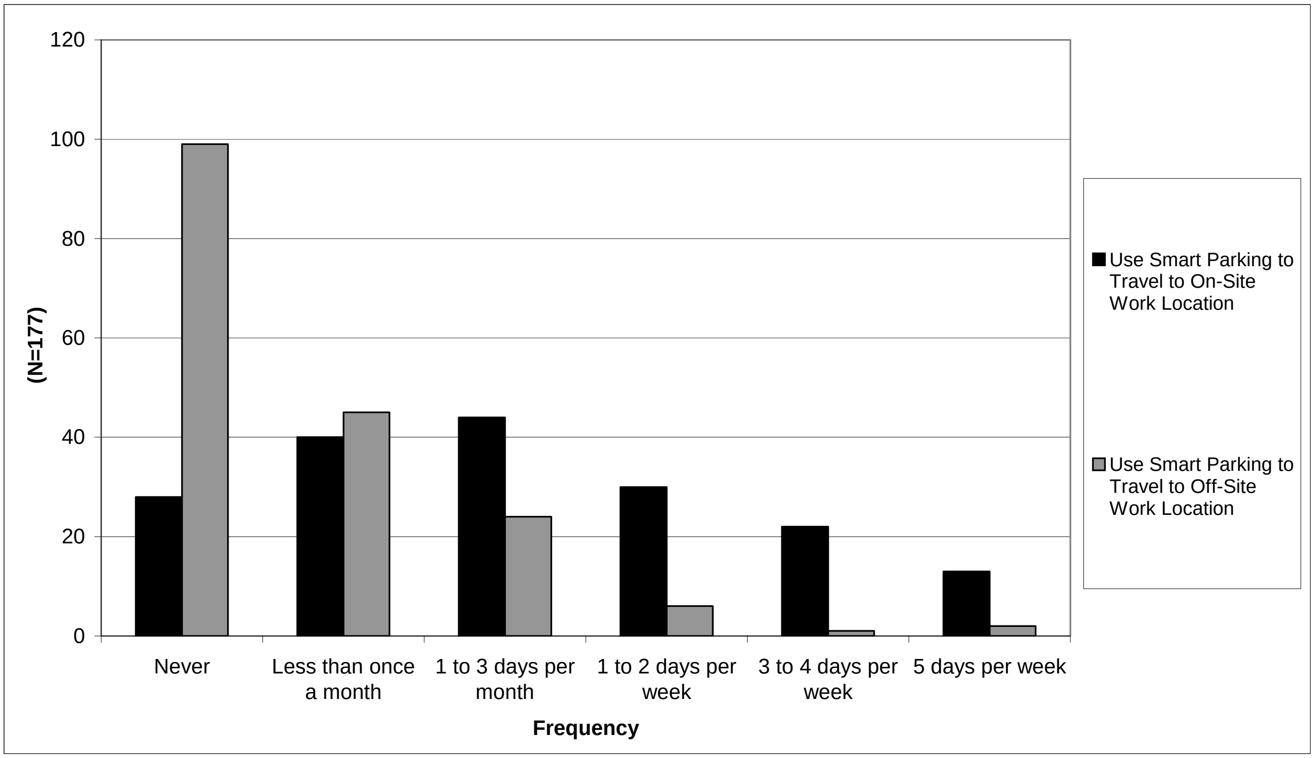

FIGURE 2 Frequency of smart parking use.

Change in Commute Modal Shares

The survey 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 3 (below) 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 4 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)?
3) 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)?

Tables 5 and 6 (below) are the same as 3 and 4, respectively, except that commute travel is to the off-site work location.

Across frequencies, smart parking encouraged 30.8% of respondents to use BART instead of driving alone to their on-site work location and 13.3% to divert to BART from carpooling (Table 3). Smart parking also increased drive alone access to the BART station; 14.3% of users, across frequencies, drove alone and parked at the BART station instead of taking the bus or using non-motorized modes (Table 4). On average, smart parking respondents (n = 143) increased BART use by 5.5 trips per month for on-site work commutes.

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 5). Given the availability of smart parking, 55.9% of users, across smart parking frequencies, shifted their long-haul commute mode from drive alone to BART for off-site work commutes (Table 5). Again, smart parking encouraged some users to access the BART station by auto instead of taking the bus or walking (15.3%) (Table 6). On average, those who used smart parking to access their off-site work location (n = 75) increased BART use by four trips per month.

TABLE 3 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?	**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%

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

TABLE 4 Cross Tabulation of Stated Frequency of Smart Parking/BART Use of Those Respondents Who Would Have Used BART Without Smart Parking (First Row Of Table 3) by Station Access Mode if Smart Parking is Not Available To *Your On-Site Work Location*

If you would use BART without smart parking, how would you travel to the BART station?	**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
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 BART access mode to on-site place of work sums to 99.6% rather than 100% due to rounding error.

TABLE 5 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?	**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%

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

TABLE 6 Cross Tabulation of Stated Frequency of Smart Parking /BART Use of Those Respondents Who Would Have Used BART Without Smart Parking (First Row Of Table 5) by Station Access Mode if Smart Parking is Not Available To *Your Off-Site Work Location*

If you would use BART without smart parking, how would you travel to the BART station?	**How frequently do you use smart parking to commute to off-site work?**				
	< 1 day per month	1-3 days per month	3-4 days per week	5 days per week	Total
Drive Alone & Park in regular parking area	46.2%	30.8%	3.8%	3.8%	84.6%
Walk	11.5%	0.0%	0.0%	0.0%	11.5%
Bus	0.0%	3.8%	0.0%	0.0%	3.8%
Total	57.7%	34.6%	3.8%	3.8%	99.9%

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

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

Change in Travel Time

Smart parking appears to have decreased time spent commuting for respondents. Overall, for participants 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.

Change in Vehicle Miles Traveled

A number of factors affected the VMT commute change to on-site work locations for field test participants:

- Riding BART as their primary mode instead of driving alone;
- Driving to BART instead of taking the bus, walking, or biking; and
- Driving to Rockridge to access smart parking instead of driving to a BART station that was closer to or farther from their home.

Those who indicated a change in commute mode from drive alone to BART, a change in access mode from a non-motorized mode to drive alone, and a change in primary BART station are shown in Table 7 (below). The change in VMT was calculated by multiplying each user's one-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% 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 uses home and work zip codes.

TABLE 7 Change in Vehicle Miles Traveled with Smart Parking

Reason for Behavioral Change	Effect on Total VMT	Change in VMT Per Month Due to Change
Modal shift from drive alone to BART (n = 143)	Decrease	2082.9 VMT total 11.8 VMT per person
Access mode shift to BART from bus, carpool, walk, or bike to driving alone (n = 69)	Increase	345.0 VMT total 5.0 VMT per person
Shift to smart parking at Rockridge BART station from another station closer to or farther from home (n = 16)	Increase	342.9 VMT total 21.4 VMT per person

CONCLUSION

In this paper, the authors presented 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 key findings from the analysis of participant survey travel results:

- Sizable increases in BART modal share (an average increase of 5.5 and 4.0 more BART trips per month for on-site and off-site commutes, respectively);
- Reductions in drive alone mode share (30.8 and 55.9%, across frequencies, would have driven to on-site and off-site work locations, respectively, without smart parking);
- Reductions in carpooling and bus modes (16.8 and 6.6%, across frequencies, were diverted from these modes for commute travel to on-site and off-site work locations, respectively, with smart parking);
- Increased driving (or access mode) to the BART station (without smart parking and across frequencies, 14.3 and 15.3% 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 in 50.1 minutes without smart parking); and
- Reduction in total VMT (on average, 9.7 fewer VMT per participant per month).

ACKNOWLEDGMENTS

The authors would like to thank the California Department of Transportation, California PATH, the BART District, ParkingCarma™, Quixote Corporation, Intel, and Microsoft for their generous contributions to the smart parking program. The Institute of Transportation Studies-Berkeley faculty, staff, and students also deserve special credit for their assistance with smart parking project (between 2002 and 2006), including Martin Wachs, Linda Novick, Elliot Martin, Amanda Eaken, Megan Smirti, Joshua Seelig, and Jade Benjamin-Chung. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein.

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