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Authors

Rodier, Caroline J
Shaheen, Susan A

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Caroline J. Rodier

Susan A. Shaheen

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Caroline J. Rodier, Susan A. Shaheen

Abstract

This paper presents an evaluation of the first transit-based smart parking project in the US at the San Francisco Bay Area Rapid Transit (BART) District station in Oakland, California. The paper begins with a review of the smart parking literature; next the smart parking field test is described including its capital, operational, and maintenance costs; and finally the results of the participant survey analysis are presented. Some key user response results are: (1) most participants used the smart parking system 1–3 days a month for commute travel and (2) 37% of respondents had seen the changeable message signs with parking information, but only 32% of those used this information to decide whether to continue driving or take BART. Some key changes in participant travel behavior include: (1) increases in BART mode share, (2) reductions in drive alone modal share, (3) decreased average commute time, and (4) an overall reduction in total vehicle miles of travel.

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 down-stream roadway traffic conditions (e.g., accidents and delays).

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 US; 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 paper presents the results of smart parking participant surveys and evaluates the user response to and travel effects of the field test. The paper 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. Finally, conclusions are drawn from the analysis of the results.

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 (Willson and Shoup, 1990; Willson, 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 2 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 US, 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, DC 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., 2000). 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, DC 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 web- site through which users made on-line reservations. This website costs about \$1000 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 3 h 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 on-line 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 2 – Estimated field test capital, operational and maintenance costs

Hardware components ^a	Quantity	Cost per Unit
In-ground sensors	6	\$1400
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	\$1000
Secure communication	Per month	\$150
Cellular sign connection	Per month per sign	\$80
Labor ^d	Hours per month	Cost per hour
Senior executive	170	\$125
Supporting engineer	170	\$60
Customer support	42.5	\$35

^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. Evaluation

4.1 Survey of Participants

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% 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.

4.2 Attributes of Respondents

Table 2 describes the demographic attributes of survey respondents. Respondents' ages were fairly evenly divided over the range of 31–60 years. Generally, they were highly educated (57.1% 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% earned more than \$110,000 per year). The most common household type included one or two adults with a child or children (40.3%).

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%). However, despite the

potential opportunity to work flexible hours, it seems that most respondents worked during regular business hours, 5 days per week. More than half (53.7%) worked more than 40 h per week, and most worked 5 days a week (81.4%). Free employer-provided parking was rarely provided to respondents at their place of work and off-site work locations.

Table 3 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%) 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 3 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 - 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
<i>Household structure (n = 176)</i>	
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
<i>Education (n = 177)</i>	
Graduate/professional	57.1
College	41.8
High school	1.1
<i>Income (n = 154)</i>	
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.

Table 3 – Primary commute mode and BART station access mode.

Primary (n = 177)	BART (%)	Drive alone (%)	Carpool/bus (%)	Other (%)	Total (%)
Mode shares by frequency of use					
Less than 1 day a week	6.8	0.6	0.0	0.0	7.4
1–2 days a week	6.2	2.3	0.0	0.6	9.1
3–4 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
Primary (n = 110)	Drive alone and park (%)		Carpool/bus (%)	Walk/bike (%)	Total (%)
BART access mode shares by frequency of use					
Less than 1 day a week	7.2		0.9	0.0	8.1
1–2 days a week	9.9		0.0	0.0	9.9
3–4 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.

4.3 System Use and Performance

Fig. 1 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 1–3 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.

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.

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% of those used this information to decide whether to continue driving or take BART instead; 16.1% did so less than once a month, 7.6% 1–3 days a month, 6.1% 1–2 days per week, and 1.5% 5 days per week. Approximately 22% 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% of respondents indicated that they were in favor of expanding the smart parking system to other BART stations. About 70% 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).

Fig.1. Frequency of Smary Parking Use.

Table 4 – Top five percieved 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
<i>Weaknesses</i>	
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 do not 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.

4.4 Travel Effects

4.4.1 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.

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

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.

	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 (%)
<i>If smart parking were not available, how would you commute to your place of work? (n = 177)</i>						
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
<i>If you would use BART without smart parking (2nd row above), how would you travel to the BART station? (n = 70)</i>						
Drive alone and 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.

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% 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 6). 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.

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% 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%).

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., 5 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% indicated that it had stayed the same, and 5% 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%) to use this station instead of one that was closer to 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.

In general, these results suggest that smart parking at BART, overall, tended to increase transit mode share and reduce auto mode share for the longest portion of respondents travel to on-site and off-site work locations, despite some shifts from carpool and bus modes.

4.4.2 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 min 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 min) in comparison to commute time to work if smart parking at BART was not available (50.1 min). 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 their stress had been

reduced or greatly reduced, 23% indicated that it has stayed the same, and 5% stated that it had increased.

4.4.3 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% 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.

4.5 Conclusion

In this paper, the authors presented the commute travel effects of the first transit-based smart parking project in the US 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 1–3 days per month.
- Most respondents used the advanced reservation service via phone or Internet to access the smart parking system.
- Thirty-seven percent of respondents had seen one or more of the CMSs on Highway 24 with smart parking information, but only 32% 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%, 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%, 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% 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 min using smart parking and BART compared to 50.1 min without smart parking); and
- reduction in total VMT (on average, 9.7 fewer VMT per participant per month).

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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