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Smart Parking Management Pilot Project: A Bay Area Rapid Transit (BART) District Parking Demonstration

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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

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SMART PARKING MANAGEMENT FIELD TEST:

A BAY AREA RAPID TRANSIT (BART) DISTRICT

PARKING DEMONSTRATION

Final Report

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EXECUTIVE SUMMARY

In almost every major city in the U.S. and internationally, parking problems are ubiquitous. It is well known that the limited availability of parking contributes to roadway congestion, air pollution, and driver frustration and that the cost of expanding traditional parking capacity is frequently prohibitive. However, less research has addressed the effect of insufficient parking at transit stations on transit use. In the San Francisco Bay Area, parking has recently been at or near capacity at many of the 31 Bay Area Rapid Transit (BART) District stations with parking facilities. Smart parking management technologies may provide a cost-effective tool to address near-term parking constraints at BART transit stations.

This report presents early findings from an application of advanced parking technologies to maximize existing parking capacity at the Rockridge BART station, which was launched in December 2004 in the East San Francisco Bay Area. The smart parking system includes traffic sensors that count the number of vehicles entering and exiting the parking lots at the station. A reservation system allows travelers to reserve spaces by Internet, personal digital assistant (PDA), phone, and cell phone. The real-time information obtained from the sensors and the reservation system is displayed on variable message signs (VMS) (on Highway 24 leading to the station) to alert drivers of parking space availability. Before and after surveys and focus groups will be used to evaluate the travel effects, economic potential, and system technology of the field test. This report consists of three major sections:

- A **literature review** in which the effectiveness of different types and applications of smart parking management systems are evaluated;
- A **feasibility analysis**, including focus groups, surveys, and observational analyses, which guides the development and initial evaluation of the smart parking field test; and
- A **smart parking project description,** which includes the applied demonstration design and technology.

What follows is a discussion of the major conclusions made from each key section.

Literature Review

Smart parking management systems have been implemented predominantly in Europe, the United Kingdom, and Japan since the early 1970s to reduce congestion, vehicle travel, and fuel use, and to increase transit travel. Early systems provided parking guidance information (PGI) to drivers in central city areas on available parking locations, including information that ranged from "lot empty" to the number of spaces available via VMS signs. Later PGI systems provided the exact location of a space in a large facility. A major objective of these systems is to minimize parking search traffic and travel in central cities and in large parking facilities. Evaluations (empirical and simulation) of PGI systems suggest that they are used primarily by visitors rather than commuters, can significantly reduce parking facility queues, and may produce relatively modest overall system-wide reductions in travel time and vehicle travel. In the U.S., city center PGI systems have been introduced in St. Paul, Minnesota, and Pittsburgh, Pennsylvania. Large airport parking garage PGI systems have been installed in Baltimore, Maryland; Houston, Texas; Orlando, Florida; and Minneapolis/St. Paul, Minnesota.

More recent smart parking applications provide real-time information to motorists about the number of available parking spaces in park-and-ride lots, the departure time of the next train, and downstream roadway traffic conditions (e.g., accidents and delays). PGI systems are also sometimes used to efficiently guide drivers to open spaces in park-and-ride lots. Literature review results indicate that a lack of parking at suburban rail stations may be a significant constraint to transit ridership; pre-trip and, perhaps, en-route information on parking availability at transit stations may have a important effect on transit ridership; and regular commuters are more likely to use transit-based parking information than PGI systems because this information may be critical to catching or missing a train during peak hours. Transit-based systems are concentrated in Europe and Japan; however, at least two have been proposed in the U.S.—in conjunction with Chicago's Metra System and San Jose's Valley Transit Authority.

Advances in smart payment systems (e.g., smart meters, smart cards, mobile communications, and e-parking) can improve parking payment convenience and reduce operation, maintenance, and enforcement costs to parking facility operators. E-parking is an innovative-business platform that uses advanced technologies to allow users to inquire about, reserve, and pay for parking, all without ever leaving their cars. Contactless smart cards can minimize transaction time by allowing a user to simply wave their card in front of a reader. In the context of transit station parking, these time saving technologies may mean the difference between a decision to park and ride transit, or drive the remainder of a trip. In the U.S., smart payment systems have been installed in Berkeley and Monterey, California; Lansing, Michigan; the University of Maryland College; and Orlando, Florida. E-parking systems are being tested in Brussels, Belgium.

In general, smart parking technology allows people to dynamically reserve and pay for parking. Such technology may facilitate the introduction of parking pricing policies and significantly reduce auto travel and increase transit ridership. Paying for parking at Bay Area transit stations[1] may be more palatable to motorists, if they feel they are getting an advanced benefit from it. Furthermore, motorists may pay a premium for the luxury of knowing that they won't have to circle for parking once they arrive at their destination.

The broader advantage of smart parking is that it permits an optimization of existing parking spaces. By serving as a virtual parking broker, smart parking technology can aid drivers in locating available parking, and facilitate parking pricing.

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[1] BART Parking is free to users with the exception of a monthly reserved parking program (implemented in December 2002) and a long-term airport parking program (implemented in March 2004).

Feasibility Analysis

The smart parking project was originally envisioned in 2001, when the Bay Area was still experiencing a strong economy. The initial design included overflow BART parking at the Dublin/Pleasanton station in a neighboring business park with underused parking. A shuttle bus would transport riders to the parking-constrained BART station. VMS signs located on highways adjacent to the BART station would alert and direct drivers to available overflow parking. Six months later, the Bay Area economy experienced a significant downturn and highway traffic conditions improved. At the Dublin/Pleasanton station, parking demand declined substantially, and BART later instituted monthly reserved paid station and long-term airport parking. As a result of these changed conditions, researchers reassessed the design and location of the planned field test.

The feasibility analysis began with a comparative evaluation of rider attributes at three BART stations (Rockridge, Walnut Creek, and El Cerrito Del Norte), identified by BART officials and researchers as potential project sites. BART ridership data at the three stations provided some insights into smart parking demand. All stations were used heavily for commute travel. Riders at the Rockridge and Walnut Creek stations had relatively high incomes and, as a result, may be more willing to pay for a smart parking service. Riders at these stations also appeared to use the Internet frequently and thus may be comfortable using the smart parking Internet reservation service. At the Rockridge station, BART riders were least likely to use autos to access the station. High station parking demand may be one explanation for low auto access, along with relatively good access to home- and workside destinations within walking distance (i.e., one-quarter mile or less). In addition, Rockridge station BART riders were least likely to use BART five or more times a week, which suggests that monthly reserved parking may not suit the needs of many and/or those that subscribe to monthly reserved parking may not use it every day[2].

Next systematic observations[3] were made of parking demand and activity in and around the three stations. Based on the results of the observational analyses, a number of recommendations were made for the smart parking field test.

- **El Cerrito Del Norte** BART station did not have sufficient peak parking demand to warrant a smart parking system (i.e., unpaid parking was not full by 8:00 am).

- A smart parking system at the **Walnut Creek BART station** could be implemented as part of the project to alert drivers to available monthly paid

[2] These data were gathered from BART's pre-existing station ridership profiles. See BART Ridership Profiles, p. 44 of this report.
[3] Systematic observations that involved: recording the time at which lots filled; counting the number of cars cycling through lots; noting nearby parking options in and around the three identified BART stations were conducted by the research team during April 2003. See Observational Analysis, p. 47 in this report for a full description of methodology and findings.

parking, using a VMS sign and sensor and messaging technology. While unpaid parking did fill early (before 8:00 am) at this station, monthly paid parking was not fully subscribed.

- A smart parking system at the **Rockridge BART station** could be implemented to maximize existing parking use. Parking demand at the station was very high. Regular unpaid parking typically filled around 7:30 am. Monthly reserved paid parking was fully subscribed, with a substantial waitlist; however, many of the monthly reserved paid parking spaces were not occupied on weekdays. Again, the system would include traffic sensors to monitor parking availability and VMS signs on Highway 24—an important commute corridor from the East Bay to downtown Oakland and San Francisco—to alert drivers to space availability. In addition, smart parking reservation technology would permit travelers to reserve daily paid spaces by Internet, PDA, phone, and cell phone. This station was ultimately selected for the field test due to its high parking demand—unpaid and monthly reserved.

The observational analyses were followed by two focus groups, one with BART riders and one with non-BART commuters, to explore attitudes toward commute modes, parking, and smart parking design concepts. The focus groups yielded a number of important conclusions about smart parking service demand and insights into service design:

- The most popular BART attributes were avoiding roadway traffic and the opportunities to sit and relax on the train.
- The biggest complaint about BART parking was that it filled up too early in the morning.
- Interest was expressed in using pre-trip and en-route parking information (free and daily paid) to reserve BART parking.
- Concern was expressed about the ability of the system to prevent someone from taking a reserved spot.
- Many participants volunteered that space-specific guidance information would be a valuable improvement to the proposed field test.

The findings from the focus groups suggested interest in smart parking information and that the field test design must guarantee accurate information and careful enforcement procedures.

To evaluate the technical accuracy of the vehicle counting sensors in the context of different parking lot designs and traffic flows, researchers compared observed manual vehicle counts and sensor counts at each of the five entrance and exit locations in the monthly reserved paid parking lot at the Walnut Creek BART station. Once Rockridge was chosen as the field test location, similar tests comparing observed counts with sensor counts were conducted to verify sensor accuracy. Knock-down delineators were installed to guide vehicles directly over sensor radii. A sensor can only count a vehicle accurately if some part of the vehicle drives over the sensor's six-foot diameter range in the proper direction without pausing. A number of conclusions were drawn from this analysis:

- Sensor accuracy is good (typically, a three percent or lower error rate) when the entrance or exit driveway design is narrow enough to ensure that vehicles cannot avoid passing over the sensor's detection range;
- Observations of traffic patterns in the parking facility can allow for adjustments to sensor placement to improve count accuracy;
- Entrance and exit driveways that are joined and/or too wide require traffic cones to ensure that vehicles travel over the sensors; and
- When there is significant through or circulating traffic in a parking facility, sensors must transmit data frequently to the central computer to eliminate such vehicles from parking lot occupancy calculations.

Finally, researchers conducted surveys during November 2003 of BART commuters who used monthly reserved paid parking and those who used regular unpaid parking to identify traveler information needs and assess potential travel effects. Demographic profile results suggest a potential market for a daily paid parking service among existing and new BART riders with relatively high incomes, high auto availability, and more varied work schedules (as opposed to a more strict 9 am to 5 pm work week). The survey results also suggest that limited parking at the Rockridge station may be a significant barrier to BART commuting; nine percent of BART riders, who used unpaid parking, indicated that this was the case. Many also stated that they dislike searching for parking (31 percent) and the lack of available parking (28 percent) at the Rockridge station. When these riders were asked if they would use a paid daily parking service at the station, 15 percent said they would and 28 percent of those said that they might use BART more often as a result. Analysis of the current monthly reserved paid parking service indicates that the service has increased frequency of BART use among subscribers, but it may not have reduced their net auto travel due to diversions away from carpool, bus, and bike modes for the main commute mode, and increased drive alone access to the BART station.

Smart Parking Field Test

The smart parking field test at the Rockridge BART station involves two real-time user interfaces: a VMS sign that displays parking availability information to motorists on Highway 24 and a centralized reservation system that permits commuters to check parking availability and reserve a space via telephone, cell phone, Internet, or PDA. BART has provided 50 spaces previously reserved for after 10:00 am parking (located in the monthly reserved paid parking lot) to be used in the smart parking field test. The smart parking system integrates traffic count data from entrance and exit sensors at the BART station parking lot with the reservation system to provide accurate up-to-the minute estimates of parking availability. The smart parking service can facilitate pre-trip planning by permitting users to reserve a space from 48 hours to two weeks in advance, but it will also enable en-route decision making by providing real-time parking availability information to encourage motorists to use transit. If a motorist confronts congestion on Highway 24, she can check parking availability on the VMS sign and instantly phone the reservation system to "lock-in" a space before exiting the freeway. The VMS sign will inform users how to reserve a space, and the reservation system will provide directions to the BART station. Fifteen of the 50 spaces will be available for advanced reservations and the remainder will be available for same-day reservation, but this ratio may change in response to demand. To maximize the number of project participants, one user will be allowed only three parking reservations during a two-week period.

The next step in the project will be the evaluation of the travel behavior, economic potential, and system technology of the fully launched smart parking field test at the Rockridge BART station.

CHAPTER 1. INTRODUCTION

For nearly one hundred years, planners, politicians, engineers and environmentalists have wrestled with the challenge presented by the increasing prevalence of the automobile: where to put cars. Ranging from the earliest parking garages—renovated horse barns—to fully automatic parking structures, innovative thinkers have attempted to devise clever ways to park vehicles. Some of the more creative but less practical ideas generated over the years include the parking ferris wheel, essentially a *lazy susan* for cars, and the "parking rack"—which allows vehicles of any shape or size to be stored at a 30 degree angle through the use of a hydraulic valve (Reichenberg, 2001, p. 26-29). A recent and promising contribution to the annals of parking innovations is the concept of smart parking—broadly defined as the application of advanced technologies to improve the speed and efficiency of locating, reserving, and paying for parking.

Smart parking may achieve what many of its forerunners have attempted to: more efficient use of existing land dedicated to parking. Frustration with parking shortages is universal. Most major metropolitan areas already suffer from heavy traffic congestion and subsequent air quality degradation. Faced with parking shortages, transportation planners respond with one of two solutions—either attempt to reduce demand or increase supply. Highly promising smart parking systems may do both. By making more efficient use of existing parking infrastructure, they increase parking supply.

Smart parking management systems have been successfully implemented in numerous European, United Kingdom, and Japanese cities to more efficiently use parking capacity at transit stations. Research suggests a significant relationship between transit use and transit station parking (Merriman, 1998; Ferguson, 2000). Quick, convenient auto access to park-and-ride lots can be essential to making transit competitive with the auto particularly in suburban areas. These smart parking systems typically provide real-time information via VMS signs to motorists regarding 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). Parking guidance information is sometimes also used to efficiently guide drivers to open spaces in park-and-ride lots. In the San Francisco Bay Area, parking has recently been at or near capacity at many of the 31 BART District stations with parking facilities. Future population and job growth in the region will worsen existing shortfalls. Meanwhile, the cost of providing additional parking capacity continues to rise due to increasing land values and construction costs. Smart parking management technologies could provide a cost-effective tool to address near-term parking constraints at transit stations.

This report documents the research and feasibility analysis for the design and implementation of a smart parking management field test at the Rockridge BART station in the East San Francisco Bay Area. Parking demand at the station is very high. At the time of our observational analysis, (in the winter of 2003) researchers found that regular unpaid parking typically filled around 7:30 am and more than 30 drivers cycled through the lot looking for parking and ultimately left each morning. Monthly reserved paid parking was fully subscribed at 225, with a substantial waitlist; however, many of the monthly reserved spaces were not occupied each weekday. In addition, the Rockridge station is adjacent to Highway 24, an important commute corridor from the East Bay to downtown Oakland and San Francisco. Researchers, thus, saw an opportunity to apply smart parking technologies with the goal of expanding effective parking capacity, transit ridership, and farebox revenues.

The Rockridge BART station smart parking field test involves two real-time user interfaces: a VMS sign that will display parking availability information to motorists on Highway 24, and a centralized reservation system that permits commuters to check parking availability and reserve a space via telephone, cell phone, Internet, or PDA. BART has provided 50 spaces previously reserved for after 10:00 am parking (located in the monthly reserved paid parking lot) to be used in the smart parking field test. Initially, fifteen of these spaces will be available for advanced reservations, and the remainder, less a buffer of five spaces, will be available for same day reservations, for those who see the VMS on Highway 24 and decide to take BART en-route. The smart parking system integrates traffic count data from entrance and exit sensors at the BART station parking lot with the reservation system to provide accurate up to the minute estimates of parking availability. Smart parking can facilitate pre-trip planning by permitting users to reserve a space from 48 hours to two weeks in advance, but it will also enable en-route decision making, providing real-time parking availability information to encourage motorists to use transit. If a motorist confronts congestion on Highway 24, she can check parking availability on the VMS sign and instantly phone the reservation system to "lock-in" a space before exiting the freeway. The VMS sign will inform users how to reserve a space, and the reservation system will provide directions to the BART station. Initially, fifteen of the 53 spaces will be available for advanced reservations and the remainder (less a buffer) will be available for same day reservation, but this ratio may change in response to demand. To maximize the number of project participants, one user will be allowed only three parking reservations during a two-week period.

This report begins, in Chapter 2, with an extensive review of the literature related to smart parking management systems conducted from Summer 2002 to Winter 2003. In this review, researchers sought to survey available smart parking management systems to understand their potential effect on travel behavior and air quality. The types of technologies included in the review are parking guidance information (PGI), transit-based information, smart payment systems, and e-parking. In addition, the literature on parking behavior and parking pricing is reviewed to inform the smart parking field test design and the evaluation of user effects.

Chapter 3 presents our feasibility analysis results, which guided project partners in the development and initial evaluation of the smart parking field test. First, researchers evaluated rider attributes at BART stations with existing BART data. Second, systematic observations were made of parking demand and activity in and around BART stations. Third, focus groups with BART and non-BART commuters were conducted to explore attitudes toward commute modes, parking, and smart parking design concepts. Fourth, vehicle sensor technology accuracy was tested. Finally, researchers conducted a survey of regular and monthly reserved paid parkers at the Rockridge BART station in November 2003 to identify traveler information needs and to assess potential field test travel effects.

This discussion is followed by a detailed description of the design and technology of the smart parking field test (in Chapters 4 and 5). Finally, in Chapter 6, conclusions for the field test research and feasibility analysis are presented. The subsequent study phase will evaluate the travel and economic effects of the fully implemented project.

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CHAPTER 2. REVIEW OF SMART PARKING SYSTEMS AND RELATED LITERATURE

I. Introduction

Smart parking management systems have been implemented throughout Europe, the United Kingdom, and Japan since the early 1970s. Early systems provided parking information to drivers in central city areas on available parking locations, including information that ranged from "lot empty" to the number of spaces available. More recent applications provide real-time information 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). Advances in smart payment systems (e.g., smart meters, smart cards, mobile communications, and e-parking[4]) improve parking payment convenience and reduce operation, maintenance, and enforcement costs.

In the United States, parking is an 11.8 billion-dollar industry. Parking availability influences how individuals commute, affecting transit use, single occupancy vehicle driving, and traffic congestion. This literature review seeks to contribute a greater understanding of smart parking strategies by evaluating the travel behavior, environmental, and economic effects of different types and applications of smart parking management systems. In addition, the literature on parking behavior and parking pricing are reviewed to inform the design of the smart parking field test at the Rockridge BART station and the evaluation of its user effects.

II. Parking Guidance Information Systems

Parking search traffic can be a significant contributor to central city congestion during peak commute hours. In fact, many have estimated that such traffic composes between 25 to 50 percent of all peak period traffic. Such figures are difficult to verify, but when the cost and convenience of available parking are not evenly distributed in a congested city center, parking search traffic should be significant (Topp, 1995). Search traffic inside large parking facilities can also be a problem. A 1994 study of U.S. airport operators indicated that passengers experience significant delays accessing airport parking (Burdette, 2001).

A major objective of parking guidance information (PGI) systems is to minimize parking search traffic in central cities and in large parking facilities. Vehicle counting technology or sensors are typically installed in parking facilities, at entrances and exits or in

[4] E-parking is an innovative business platform developed in Brussels, Belgium that allows users to locate, reserve and pay for parking, all without leaving their vehicles. By optimizing parking through the use of advanced technologies, e-parking serves as a virtual parking broker.

individual parking spaces, to collect data on the number of occupied parking spaces. Available sensor technology includes inductive loops, machine vision, ultrasonic, infrared, microwave, and lasers (Griffith, 2000). The data collected by the sensors are sent to a central computer for processing, and information about parking availability is communicated to drivers by static or variable message signs, phones, radio, the Internet, or in-vehicle navigation systems. These messages can include available parking location(s) and parking directions. Messages about available parking can range in specificity from "empty" or "full" lot, to total number of available spaces, or to the exact location of available spaces for city zones, parking facilities, and on-street parking.

PGI systems are designed and implemented with the goal of achieving a number of benefits including:

- Travel time savings;
- Reduced vehicle travel;
- Less congestion and driver frustration;
- Lower fuel and energy use;
- Reduced air pollution;
- Increased parking revenues; and,
- Improved enforcement of parking restrictions.

The first PGI systems were installed in Achen, Germany, in the early 1970s. In the mid-1990s, it was estimated that more than 100 smart parking management systems had been installed in cities throughout the world with the greatest concentration in Europe, the United Kingdom, and Japan (Axhausen and Polak, 1995). Most of these systems provided parking information for an entire city center, but increasingly they are used in large parking facilities outside city centers (e.g., in airports and shopping malls). A number of cities are also implementing on-street curb PGI systems (e.g., Southhampton, U.K.).

Within the last decade, a number of PGI systems have also been implemented in the U.S. City center PGI systems were introduced in St. Paul, Minnesota, and Pittsburgh, Pennsylvania. Large airport parking garage PGI systems have been installed in Baltimore, Maryland; Houston, Texas; Orlando, Florida; and Minneapolis/St. Paul, Minnesota. What follows is a more detailed description of different PGI systems implemented in Europe, the United Kingdom, Japan, and the U.S., as well as a discussion of PGI system evaluations.

City-Based Applications

In *Yokohama, Japan*, a PGI system provides information on parking availability and directions to parking facilities. The system includes 16 parking facilities with over four thousand spaces. The system provides information to drivers with increasing geographic specificity as they approach their final destination:

> The system divides the city into four concentric zones. In the first zone, drivers enter the city and are notified of parking availability via detailed information on boards. When entering zone three, a board shows directions to parking facilities. Finally, a board at the entrance displays the name of facility and space availability (Smith and Roth, 2003).

In the *United Kingdom*, the ROMANSE PGI system was installed in *Southampton, England* in 1992. This system includes 13 city center parking facilities and 26 VMS signs located on main roads that display real-time information about the number of parking spaces available in those facilities (Space Control, 1998). Plans are in place to incorporate the curbside parking in these systems by modifying parking machine software to communicate with the central processing computer (Space Control, 1998).

In *Europe*, a PGI system was originally installed in the late 1970s in *Frankfurt am Main, Germany*, to guide drivers to facilities with available parking. In 1992, the system was updated to provide parking information to drivers via VMS signs with increasing geographic specificity (i.e., city area, sub-area, and parking facility) as they approach their destination, like the Yokohama system (Smith and Roth, 2003; Botltze et al., 1994).

The PGI system in *Ghent, Belgium* includes five processing phases: "detection and local processing, central processing, control and checks, dynamic signs, and data transmission from the various system components" (Van den Berghe, 1998). A TV distribution network is used to transmit data from parking facilities sensors to the central processing computer and to send parking information messages to static and dynamic VMS signs. The system is constantly monitored to detect any failed connections between parking facilities and the central processing unit. If a connection fails, the system will predict parking availability using historical data on facility use (Van den Berghe, 1998).

In the *United States,* an operational test of a PGI system was conducted in *St. Paul, Minnesota*, although it has since been suspended. This system connected 10 parking facilities (seven garages and three lots) with a central computer system. Real-time data from the parking facilities was processed by the central computer and parking information was displayed on ten LED-based VMS signs and 46 color-coded wayfinder signs located at critical city intersections (Orski, 2003; Smith and Roth, 2003).

In *Pittsburgh, Pennsylvania*, a PGI system has been implemented to direct drivers to parking facilities and special attractions. City areas are assigned one of five color codes. Many signs in the system are static, but the dynamic signs (display messages of full or open lot) are used for parking facilities that serve the city's stadium (Parma, 1996; Smith and Roth, 2003).

In *San Jose, California, and New York City*, there have been recent proposals and plans for PGI systems that include dynamic message signs that display real-time information about parking availability (Spencer et al., 2000; Teng et al, 2002).

Applications within Parking Facilities

In the United Kingdom, one example of a PGI system that locates and guides drivers to available parking spaces in several parking structures (2,645 spaces) is in *Bristol, England*. This system uses infrared sensors to detect available spaces, transfers this information to a central computer, displays the number of free spaces by structure floor level on VMS signs, and guides vehicles to the location of these spaces. This system also has the ability to learn from historical parking facility use data to forecast parking demand by time of day. As a result, the system can predict when a facility will be full and redirect drivers, as necessary, to other available parking (Smith and Roth, 2003).

Another PGI system has been installed in a multi-story parking facility at the Blagnac Airport just outside of *Toulouse, France*. In this system, each parking space is monitored with ultrasonic sensors, and LED lights guide drivers to empty spaces. A similar PGI system is being installed in parking garages in an Istanbul, Turkey, shopping mall (Smith and Roth, 2003).

The most advanced PGI system implemented in the *U.S.* is in the *Baltimore-Washington International Airport* (Orski, 2003). This system currently uses ultrasonic sensors in each parking space in existing daily and hourly garages to monitor space occupancy. Lighted electronic signs guide drivers to available spaces, display the total number of available spaces by aisle, and indicate the occupancy status of each space. The system will be installed in newly constructed garages (hourly and daily) on each level (Orski, 2003; Smith and Roth, 2003).

Two other U.S. airport parking garages have installed PGI systems that monitor available spaces by parking structure level rather than by space. At the *Minneapolis/St. Paul International Airport*, vehicles entering and exiting levels at the Humphrey parking facility are monitored and lighted overhead signs indicate parking availability at each level (Smith and Roth, 2003). At the *George Bush International Airport*, the system uses wires embedded in a garage (seven levels with 6,500 spaces) to monitor space availability, wooden barriers to close levels when they are full, and digital displays to direct cars to levels with open spaces ("Drivers", 1998).

System Evaluations

Despite the large number of PGI systems installed in cities in Europe, the United Kingdom, and Japan, there have been relatively few published studies evaluating their effects (Thompson and Bonsall, 1997), and most of these studies focus on dynamic guidance systems for parking availability in city centers. The dominant approaches in these studies are before and after surveys of field trials and/or stated preference surveys. These studies tend to employ simple descriptive statistics rather than more sophisticated multivariate techniques (Thompson and Bonsall, 1997).

In Frankfurt am Main, it was found that awareness of the guidance signs grows quickly at first (three months) and marginally thereafter (Thompson and Bonsall, 1997). Other studies (in Kofu City and Matsuyama City, Japan) have found that the percentage of travelers who are aware of signs can range from 70 to 80 percent, but that those who actually use it range from only 20 to 24 percent (Asakura et al., 1995; Furuya, 1995).

Much of the literature indicates that these types of city-based PGI systems tend to be used most frequently by city visitors rather than regular commuters and/or local travelers. Studies conducted in Turo, Frankfurt, Leeds, and Shinjuku suggest that those who travel regularly or frequently to an area (e.g., commuters) are resistant to using the guidance information, preferring to rely on their own experiential knowledge, and those less familiar with the area (e.g., visitors and shoppers) are more likely to use the system information (Thompson and Bonsall, 1997). Interestingly, however, in an earlier study of several cities in Japan, Thompson et al. (1986) found that frequent travelers had a better understanding of the PGI signs than visitors or shoppers because of the types of messages used in the signs (i.e., names of parking facilities).

The travel effects of PGI systems have been assessed in a number of cities. The systems in Torbay and Turo were found to reduce queue lengths at full parking garages, and in Liecester a significant number of cars were diverted from parking garages that were full or almost full (Thompson and Bonsall, 1997). Reduction in queues and a more even distribution of parking facility use have been reported in the Osaka and Tokyo, Japan, systems (Kurauchi et al., 1996; Suzuki and Yamamoto 1997).

Based on their review of the published evidence of systems in eleven cities in Germany, England, and Japan, Thompson and Bonsall (1997) make several general recommendations for improving system effectiveness: (1) targeting messages to the information needs, decision points, and knowledge levels of market segments early on in the process of developing the system; (2) making the messages conspicuous and providing some form of reinforcement; and (3) providing messages that are consistently credible.

In the U.S., a 1996 evaluation of the PGI operational system in St. Paul found that, while survey participants reported that the system was valuable, researchers found no positive correlation between the system and increased efficiency/capacity of surface transportation (HNTB, 2001). Wright (1996), however, reports that the system produced "greater visitor satisfaction with trips to downtown St. Paul, Minnesota, along with decreased parking-related congestion around event sites, better use of available parking spaces in various ramps and lots, and improved patronage of St. Paul's cultural institutions, parks, businesses, hotels, and shopping complexes " (p. 35).

More recent evaluations of PGI systems involve the use of simulation techniques. These studies generally find that PGI systems reduce queue times; however, the evaluations differ somewhat on the significance of the total average reduction in travel times and distance. A modeling study of the Frankfurt am Main system (Polak and Axhausen, 1994) found that search times were reduced. Another study found that PGI systems reduced individual travel times (or avoided search times) by four percent and wait times (or time queuing) by five percent (Kurauchi et al., 1998). Another study (Minderhoud and

Bovy, 1996) found that city center traffic in a small town in the Netherlands could be reduced by 32 percent. Thompson et al. (2001), using an optimization model, found that a system in Tama New Town near Tokyo would significantly reduce queue lengths and vehicle kilometers traveled. However, Watterson et al. (2001), in their network modeling study of the Southampton (U.K.) PGI system, found "savings can be achieved for each section of the journey individually (driving, queuing, searching and walking)" but "the greatest proportionate savings are obtained in queuing time (up to 7% overall)" and thus the system "has the effect of spreading the demand more evenly across car parks" (p. 1075). However, they also found that when the study results were evaluated at the network-level, reductions in average travel time were minimal:

> Although benefits were discovered, their magnitude was small, with reductions in total travel time for all drivers in the network typically in the range of 0.1-1.0%, corresponding to economic benefits of up to 500 pounds per day for the test network of approximately 40,000 vehicles (p. 1076).

Summary

A major objective of PGI systems is to minimize parking search traffic and travel in central cities and in large parking facilities. Evaluations (empirical and simulation) of PGI systems suggest that:

- Awareness and understanding of PGI signs can be relatively high;
- Messages must be carefully designed to meet the information needs of travelers and must provide accurate information;
- Visitors to a city are more likely than regular commuters to use city center PGI systems;
- Parking facility queues can be significantly reduced; and
- System-wide reductions in travel time and vehicle travel and economic benefits may be relatively small.

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III. Transit-Based Information Systems

Parking problems are ubiquitous in almost every major city in the U.S. and internationally. It is well known that the limited availability of parking can contribute to roadway congestion, air pollution, and driver frustration. However, a problem that is less well recognized by the public is the negative effect of insufficient transit station parking on transit use. Research suggests a significant relationship between transit use and the provision of parking at transit stations (Merriman, 1998; Ferguson, 2000). Quick, convenient auto access to park-and-ride lots can be essential to making transit competitive with the auto in suburban areas.

Early smart parking management systems consisted of parking guidance information in central city areas (e.g., Achen, Germany in the early 1970s). More recent applications provide real-time information to motorists about the number of available parking spaces in park-and-ride lots, the departure time of the next train, and downstream roadway traffic conditions (e.g., accidents and delays). Parking guidance information is also sometimes used to efficiently guide drivers to open spaces in park-and-ride lots.

These smart parking management systems are designed and implemented with the goal of producing of a number of benefits over and above those of parking guidance information systems, including:

- Increased transit use,
- Reduced vehicle travel,
- Lowered fuel use,
- Reduced air pollution, and
- Increased transit revenues.

This is because smart parking management systems that improve transit access may increase transit mode share and revenues, and thus reduce vehicle travel, fuel consumption, and air pollution.

Applications

In *Europe*, one of the most sophisticated smart parking systems, called STADTINFOKOLN, is located in Cologne, Germany. This system

> …provides up-to-the-minute information about parking availability both at suburban park-and-ride lots and at the 31 affiliated underground and surface parking facilities in Cologne's city center. This information is displayed on automatically updated variable message signs situated on approaches to the city, enabling city-bound motorists to decide in advance if they should leave their car at a suburban park-and-ride and complete their journey by train, or continue all the way by car. Drivers who decide to drive all the way into the center are guided to parking facilities that have vacant spaces with the help of directional signs that display the number of vacant spaces available at any given time (Orski, 2003, p. 54).

The parking guidance information component of this system uses loop detectors to monitor available parking spaces in facilities and then transmits messages via VMS signs. The software employed by this system uses historical data by time to predict parking facility occupancy status. Planned improvements to the STADTINFOKOLN system include forecasts of available metered on-street parking and a parking reservation system via the Internet, phone, or in-car terminal (or e-parking, see detailed description in subsequent section) (Orski, 2003).

Another example, of an advanced smart parking system is the Frottmaning U-Bahn station park-and-ride lot (with 1,270 parking spaces) in *Munich, Germany*, on the A9 Autobahn. This system boasts three dynamic VMS screens along the nearby highway, which indicate the number of parking spaces, real-time transit schedules, and traffic news. Once motorists enter the parking facility, they are guided to the closest empty parking space by a real-time surveillance and control system. The smart "directing" system uses laser-scan detectors at entrance and exit lanes and ultrasound detectors at each parking space (Cervero, 1998).

Similar systems are located in cities and regions throughout Europe including the *German cities of Frankfurt, Koln, Stuttgart, and Dormund; Geneva, Switzerland*; the *French cities of Grenoble, Chambery, Lyon, and Strasbourg*; the *English cities of Southampton and York*; and *Dublin, Ireland* (Orski, 2003; Keller, 1995; Space hunting, 2003). Another smart parking management system is planned in *Berlin, Germany* (Bannert, 2003).

In *Japan*, the *Toyota* smart parking management system was originally developed to support the park-and-ride lots for the city's two major transit stations and the city's tradition of minimal on-street parking. The central computer system gathers information (via phone lines) on available spaces at parking facilities as well as traffic flows to the city center (e.g., highway closures). Parking and/or traffic information is provided to drivers via telephone, suburban and urban VMS signs, radio, and entrance signs at parking facilities (Sakai et al., 1996).

More recently, smart parking management programs have been initiated in the *United States*. In *Chicago*, a system is under development that would collect real-time data to provide en-route information via VMS signs to travelers about parking availability, the location of parking spaces in large lots or garages, departure times for the next train or bus, and advice to use transit when alternate roadway routes are congested (Kopp et al., 2001). The project is sponsored by Northeastern Illinois' Regional Transportation Authority, Metra Commuter Rail Division, and the Illinois Department of Transportation in the Gary-Chicago-Milwaukee corridor (Orski, 2003). This system is described by Orski (2003):

> Electronic guidance signs located along expressways and arterials that lead up to commuter rail stations will provide real-time information for motorists on the availability of parking. The intent is to offer alternative rail station choices at critical travel locations, based upon extent of parking available at each station. Where several satellite parking lots exist near a station, the variable message signs will show actual parking counts (or percentage utilization rates) at each lot, and direct motorists to the lots with the most available parking (p. 56).

The *Smart Park* proposal for the Santa Clara Valley Transit Authority (VTA) along Highway 17/880 in *Santa Clara County (San Jose area), California*, would incorporate advanced technologies in park-and-ride lots to encourage drivers on congested roadways to use transit or rideshare (CCS Planning, 1998). The project has been described as "an intermodal facility or system of park-and-ride lots capable of exchanging dynamic information with the regional transportation control systems" (Spillar, 1998, p. 50). This information would include "data on downstream congestion, availability of parking spaces at individual Smart Park facilities, and transit performance" (Spillar, 1998, p. 50).

<u>System Evaluations</u>

There appears to be only one published (English language) study that systematically evaluates the effectiveness of smart parking systems with respect to increasing park-and-ride lot use. Khattak and Polak (1993) evaluate a real-time parking information system in Nottingham, England, in which "real-time information was disseminated through the radio, while historical information regarding parking lots was disseminated through newspaper advertisements and leaflets" (p. 373). The results indicate that "drivers were more inclined to use the relatively under-utilized park-and-ride facilities instead of the city center car parks, if they received parking information from newspaper advertisements and leaflets" (p. 373). This study suggests the importance of pre-trip information with respect to parking choice and increased transit use.

Another study that suggests the potential significance of pre-trip traffic information with respect to mode change was conducted by Conquest et al. (1993). In this study, on-road survey data was collected (3,893 motorists) and evaluated to examine the effect of traffic information on driver behavior. The study found that 23.4 percent of respondents would not change their mode, route, or departure time and 50 percent were receptive to pre-trip information and as a result may alter their mode, route, or departure time (Conquest, et al. 1993).

Opinion surveys of two systems described above (Frottmaning, Germany and Toyota, Japan) are generally described in the literature. Cervero (1998) reports that the German Ministry of the Interior surveys cited the highway park-and-ride displays in the Frottmaning system as the main reason many motorists have shifted from driving to taking the train to work. A survey about the Toyota system indicated that after six months of operation: (1) 95 percent of respondents were aware of the signs; (2) 71 percent made use of the information; (3) 87 percent thought the system was helpful; and (4) 32 percent of those who used the system lived outside the city (Sakai et al., 1996).

There is also limited evidence on the effect of parking capacity at transit stations on transit demand (Merriman, 1998). One empirical study of parking-constrained commuter stations in the Chicago area (Metra) suggests that each additional parking space may generate between 0.6 to 2.2 additional transit users (Merriman, 1998). The author notes that "on the margin, new riders may use parking spaces a bit more intensively than the average (e.g., carpools may be more common), but it seems unlikely that an additional parking space could attract as many as two new riders" (p. 575). In addition, the analysis indicates that increased parking capacity at constrained stations produced positive net social benefits. Ferguson (2000) reports that "a market research study undertaken by Metra in 1985 identified lack of parking at surburban rail stations as the single largest factor contributing to the observed ridership losses" (p. 108). In addition, a survey conducted for a smart parking management project that is under development in Chicago (described above), also indicates that parking availability affects transit ridership (Havinoviski et al., 2000). The survey found that "although about 58% of all riders surveyed stated that they would simply park farther from the station if the parking lot nearest to the station was full, 18% of the riders stated that they would drive to their destination if their only choice was to travel to the next station downstream" (Havinoviski et al., 2000, p. 2).

The results of surveys and focus groups for proposed smart parking systems linked to transit in Chicago and Santa Clara (described above) indicate that the information needs of parkers at transit stations may be different from those who search for parking in city centers. The survey results for the Chicago proposal indicate that "80 percent of the Metra riders traveling [during] peak-hour travel period[s] thought that signage needed to be improved, while only 57 percent of those traveling after…peak hours desired improved signage" (Havinoviski et al., 2000, p. 2). It appears that time-constrained peak-hour travelers value timely information (i.e., open lot or spaces) more highly than off-peak travelers because this information may be critical to catching or missing a train. Focus group results from the Santa Clara proposal also identify "SOV drivers with fixed schedules and long commute distances" as a primary market for their proposed smart parking system (CSS Planning, 1998, p. 5).

Summary

Smart parking management systems that provide real-time information to motorists about the number of available parking spaces in park-and-ride lots, the departure time of the next train, and downstream roadway traffic conditions (e.g., accidents and delays) have been implemented in many cities in Europe and Japan. More recently, several transit-based smart parking management programs have been proposed in the U.S. The results of the literature on the potential effectiveness of these systems indicate that:

- Lack of parking spaces at suburban rail stations may be a significant constraint to transit ridership.
- Pre-trip and, perhaps, en-route information on parking availability at transit stations may have a significant effect on transit ridership.
- Regular commuters are more likely to use transit-based parking information than PGI systems because this information may be critical to catching or missing a train during peak hours.

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IV. Smart Payment Systems

Traditional parking payment methods typically have high capital, operational, and maintenance costs for a number of reasons. First, parking meter equipment is expensive and can be vandalized. Second, installation and removal of meters requires excavating concrete. Third, coin-operated meters require frequent repair because their multiple moveable parts are prone to malfunction. Finally, relatively high labor costs must be incurred to collect and enforce payment.

Traditional payment methods are also inconvenient to travelers. It requires time and effort to collect change or cash for payment and to physically make the payment. Moreover, parking meters can impede pedestrians and aesthetically disfigure sidewalks (Aronov, 1973).

A number of smart payment methods have been developed that address the limitations of traditional payment methods. Smart cards for parking access and payment include contact cards that must be inserted or touched to a reader and/or contactless cards with wireless communication capabilities. Certain smart cards can save users time at the entrance and/or exits of parking facilities because users simply touch or wave their card in front of a target. Mobile communication devices can also be used in smart payment transactions. These innovations allow payment for parking and other transportation services (i.e., transit and tolls) as well as for other goods and services (Cunningham, 1993). These cards are considered secure because "access to each file or application is controlled by multi-level passwords" (Cunningham, 1993 p. 23). Smart cards have also become very cheap to produce; they typically cost one to two dollars per unit (Hodder, 1995, p. 82). Smart parking payment systems are now being developed and implemented worldwide by cell phone developers, credit card companies, and other technology and service providers.

Contact Methods

Debit cards are a common method of contact payment with smart electronic parking meters, which can take both cards and coins. These electronic meters can use solar or battery power and can be reprogrammed to use other cards or infrared communicators (Harrop, 1993). Electronic parking meters without movable parts are less likely to malfunction and the meters that do not collect coins are less likely to be vandalized.

A number of cities in the U.S. use debit cards with smart electronic parking meters. For example, the city of Berkeley, California, installed 3000 new electronic parking meters in 1998, and in 2001 the city began selling non-expiring, non-refundable, pre-paid smart cards that could be inserted into the meters. Berkeley's new meters also "contain software that alert staff when they were due for repairs or new batteries" (Hendricks, 2001). The city of Monterey, California, encourages the use of debit card payment by discounting the cost of parking by 10 percent when the debit card is used. The city of San Francisco has also replaced all 23,000 traditional parking meters with electronic meters that accept coins other than quarters, and may eventually accept smart cards (SFDPT, 2005). The city also hopes to integrate the same card into TransLink®, a "regional transit debit card" that allows seamless transfers between multiple transit agencies (Hendricks, 2001).

The University of Maryland College is another example of a debit card parking payment program (Allen, 1998). This program uses smart debit cards for parking meters and allows for refunds of unused time in 30-minute increments. Meters are placed "in the most convenient parking" spots to encourage debit card usage and improve parking turnover (relative to permit parking). Parking revenues have increased, and the program is popular because of its provision for refunds. Recent technology advances have addressed some complications related to invalid refund claims (Allen, 1998).

Credit cards are also being used to pay for parking. Credit card transactions have become faster and more cost-efficient since the late 1980s because of technology improvements (i.e., off-line system processing and computing advances) (Curtis, 1999). Originally, concerns about the potential for fraud when credit cards are used without signature collection slowed its application for parking payment. However, technological advances have allowed some electronic parking payment machines to accept credit cards; these machines carry a "blacklist of cards which will not be accepted" that can be updated automatically or manually, significantly reducing the risk of fraud (Millet, 1995).

<u>Contactless Methods</u>

Lansing Community College in Michigan was searching for a way to combine payment of campus-wide services including parking, library copy cards, campus dining, and vending (Glohr, 2000). They developed a system that used *contactless cards that communicate to a card interface device (CID) via an antenna coil*. System information (e.g., fee tables, time schedules, parking groups, and parking expiration periods) are programmable into the cards, and information can be downloaded manually to a laptop or automatically online. The system has reduced revenue losses and improved parking with faster and controlled access (Glohr, 2000).

AVI (Automatic Vehicle Identification) technology tags can be used to "control cashless parking and frequent parker operations at airport parking facilities" (Tuxen, 2002 p. 48). High-security tags can combine a personal access card ID and vehicle ID to generate access for both driver and vehicle throughout the airport premises" (Tuxen, 2002, p. 48). These systems can also monitor taxis and other courtesy vehicles, to identify "known vehicles as they enter and exit the premises," and help focus security efforts (Tuxen, 2002).

<u>Mobile Communication Devices</u>

Groningen, a city in the northern Netherlands, developed a mobile communication payment system to help address its center city parking problems. Users first register their "address, mobile phone number, preferred method of payment, and license plate number" on the Internet into the central database (Dalbert, 2001, p. 52). Users are then mailed a transponder parking card (a contactless smart card) "each one specific to the individual driver who is given an identifying customer number" (Dalbert, 2001 p. 52). When parking, users: (1) dial a number into their mobile phones, (2) "type in the parking location," and (3) "he/she ensures that the Nedap transponder card is placed visibly behind the windscreen to inform enforcement officers that the car is legitimately parked" (Dalbert, 2001 p. 52). When the users return to their cars, they redial the phone number to complete the transaction and receive the charges on a monthly invoice. The transponder card is retained by the user for life and does not need to be changed if the user changes cars. Time is saved for both users and enforcement officers, since the latter can use "hand-held scanners without breaking their stride" to communicate with the transponder's long-reading distance (Dalbert, 2001 p. 52). Expected savings for the city are $60,500 per year on an initial investment of $725,300 due to easier enforcement, the reduced need for maintenance of parking meters, and dealing with "fraud and vandalism." Other benefits of this system are that it does not need any expensive devices that must be positioned in cars permanently, and the city can use the centralized information to improve parking policy in the future (Dalbert, 2001). The transponder card allows for electronic ticketing with enforcement units, improving collection rates for fines, and increases convenience for parking users, who do not need to worry about change or standing in line in person to apply for permits. The mobile phone system is independent of the mobile phone provider and requires no smart card within the phone (Krabben, 2002).

A similar program in Oulu, Finland, uses a mobile phone payment system without a card in the car or the phone. Parking users register on the Internet, then when they park they dial a number and choose the correct parking zone, and desired parking time. The service sends a reminder 15 minutes before time expires, to allow a user to increase the time if they wish. Traffic enforcers monitor parking through a Wireless Access Point (WAP) phone that enables them to see a list of cars in the area and write conventional tickets for expired cars. Again, no transponders or end user units are necessary (Muraskin, 2001, p.74). A similar program in Hull, UK, works with no paper tickets, and traffic wardens have WAP-enabled PDAs (de Bunsen, 2002).

Another program, in Dublin, includes a mobile phone system that is also operable with the existing smart meter system (Crawford, 2002). Mobile phone users dial a phone number, the number of a pay and display machine, and are issued a ticket from that machine.

In Ann Arbor, Michigan, when drivers find their cars towed, they can instantly pay their parking fines via a credit card transaction through their cell phones and a wireless receiver on the tow truck. This increases fine collection, improves customer convenience, and decreases assaults on parking officials (Communication News, 1996).

Visa and Nokia have teamed to develop smart cards that can go into cell phones or PDAs for an innovative smart payment method (Ctt, 2000). The smart card contains memory, has a microprocessor, uses a software platform, and costs between five and 30 dollars. Fare payment or advanced ticket purchases at kiosks can be made via wireless phones. While this option is no more convenient than a wired version at a kiosk, it may be cheaper to implement due to available technologies. Alternatively, wireless devices can be used just like contactless smart cards, and funds can be downloaded into the card in the phone or PDA via the Internet. A final use could be real-time network debiting from a user's account using the smart card in the mobile device (ITS Decision, 2001). The benefits of smart cards in mobile devices are similar to contactless smart cards: faster customer throughput, less risk of loss and vandalism, lower maintenance and operational costs, and better information collection (ITS Decision, 2001). The Visa and Nokia project involves a pilot program in Finland and Sweden with customers of MeritaNordbanken and allows "customers to pay securely over the Internet with a WAP-enabled phone." The Paiement CB Sur Mobile program in France incorporates existing charge cards and a special type of mobile phone that contains a smart card reader. Customers can shop online, either on their phones or PCs, or offline in a catalog. When paying, the customer simply inserts his card into the reader on his phone, and the payment goes to the bank for approval; "the customer's card number never goes out over the air, which heightens security (ITS Decision, 2001)."

Summary

In an increasingly digital and wireless age, parking managers can take advantage of available technology to reduce operation, maintenance, and enforcement costs as well as to improve motorist ease and convenience. 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 drive the remainder of a trip. Smart parking can take advantage of smart payment innovations to make efficient use of existing parking spaces and to facilitate fast, convenient, and reliable reservations and parking payment.

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V. E-parking

E-parking is an innovative-business platform that has been developed by a research consortium in Europe and is currently being tested in Brussels, Belgium (Halleman, 2003, p. 46). The distinctive feature of this parking management concept is its use of advanced technologies to combine and streamline parking reservation and payment systems; it could potentially provide a cost-effective method to optimize existing parking spaces and impose parking fees.

E-parking would allow drivers, without ever leaving their cars, to inquire about parking availability at a given destination, reserve an available space, and pay for parking upon departure. Essentially, this parking space optimization service (PSOS) acts as a parking brokerage service (Hodel and Cong, 2003). The PSOS is accessed by the driver via cellular phone, PDA, and/or Internet. Bluetooth technology allows recognition at parking entry and exit points, triggering the payment transaction via credit card or mobile payment. Hodel and Cong (2003) provide a more detailed description of e-parking:

1. The parking space provider offers parking spaces available for reservation. This information is registered in the PSOS database.
2. Users are able to access the PSOS via Internet or WAP to obtain parking information or to make a reservation request. Reservation requests are registered in the PSOS database.
3. The PSOS sends the booking information and access code to the end user subject to the acceptance of the reservation request by the Parking Space Provider.
4. The car enters and exits the parking facilities using Bluetooth to open the barrier.
5. Once the car exits the car park, electronic payments are made and the whole operation is registered in the PSOS. (p. 3)

Halleman (2003) also notes that this system can be adapted to include directions to the parking facility (in cooperation with a guidance service) and to link to other e-business services (e.g., movie tickets).

The e-parking concept addresses many of the same problems that parking guidance information, smart parking, and smart payment technologies address, such as parking optimization, cost savings, search traffic, transit station constraints, related air pollution, and security. Hodel and Cong (2003) cite a number of potential benefits:

- Reduced search time;
- Easier parking payment;
- Certain parking at trip destination;
- Customized information;
- Parking information provided before and during trip;
- Improved use and management of existing parking spaces;
- Greater security (cashless payment, knowledge of customers, and improved anti-fraud measures); and
- Increased revenues.

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VI. Valet and Automated Parking

No longer is *valet parking* available almost exclusively at luxury hotels, stylish restaurants, and exclusive nightclubs in major cities like Los Angeles, New York, and Chicago. Today, valet parking serves airports, hospitals, shopping malls, supermarkets, cinemas, and health clubs in numerous cities throughout the U.S. Over the last 20 years the number of valet companies in Los Angeles has grown from 60 to over 100 at more than 200 locations (How keen, 1997).

The proliferation of valet parking can be explained by three key attributes—efficiency, service, and safety. First, valet parking services allow for double and triple car stacking. By optimizing expensive and limited parking facility space, revenues are increased. Parking facility construction and maintenance costs are on the rise in many areas across the U.S. Second, in an increasingly competitive business environment, improved parking services can attract customers. Parking is frequently the first and last experience the customer has with a business. Third, personal valet parking services also increase customer security by allowing customers to avoid walking through empty lots or unsafe streets at night. Finally, valet parking can help businesses comply with the Americans with Disabilities Act.

Automated parking systems can be seen as the mechanical equivalent to valet parking. Orski (2003) reports that they use "half the space of conventional garages" and "are viewed as price-competitive despite their high initial cost" where parking space is scarce and expensive (p. 56). These systems use "computer-controlled, robotic transport devices with vertical and horizontal movement capacity to transport vehicles from the street level to a storage compartment and back without human intervention" (Smith, 2003, p. 80). Automated parking systems have been installed in Japan and more recently in the North American cities of Washington, D.C.; Hoboken, New Jersey; and Vancouver, British Columbia. New systems are being considered in Chicago, Illinois; Portland, Oregon; and New York City (Orski, 2003). What follows is a more detailed description of the three North American automated parking systems.

On July 5, 2002, an automated parking garage was installed in four months at the Summit Grand Parc Apartments in Washington, D.C. As Monahan (2002) describes:

> The project consists of a luxury residential tower with 98 rental units and 24,000 square feet of commercial/retail space in the adjacent five-story historic building. The parking structure is provided under the residential tower in a footprint of 60 ft by 106 ft on four levels within a total depth of 32 ft at a cost of approximately $1.5 million or approximately $20,000 per stall (p. 45).

The system is reported to be 99.5 percent reliable; however, in case of system failure, an insurance policy provides tenants with alternative transportation (Monahan, 2002). In addition, there is "no special ventilation requirement for vehicle emissions, because the vehicles are transported with the engines off" (Smith, 2003, p. 81).

In Hoboken, New Jersey, a fully automated parking facility, developed by Robotic Parking, Inc., uses "a computerized network of rails and pallets that handles cars with no human intervention" (Orski, 2003, p.56). This system is described by Orski (2003):

> To park a car, the driver pulls into one of four bays, locks the car and inserts a card into a computer. The car is lifted on a pallet and moved to an available slot. To retrieve the car, the driver again inserts the card in the computer and punches a secret code. The car is delivered in a bay with its front facing the street for easy exit. The process takes one to two minutes. The car is never driven once inside the facility and the driver never sets foot inside the garage or in a driveway, thus reducing the risk of personal injury. Multiple cars can be handled simultaneously. The computer allows the site to be monitored from a remote location, showing real-time vehicle movements for rapid detection of any mechanical problems. The garage is equipped with sensors, and if any unusual motion is detected (e.g., a child or a dog forgotten in the back seat), the parking systems will not operate (p.56).

In Vancouver, British Columbia, an automated parking system has been installed in a 33-foot wide lot (not large enough for an underground facility) (Smith and Roth, 2003). This system is described by Douglas Yip (1996; ctd. Smith and Roth, 2003):

> After obtaining security clearance to enter the building, the driver is directed to park in a designated area. The parking system monitors the vehicle position via an array of photo-electric sensors and uses a display monitor to provide information to the driver. After the vehicle is successfully parked, the driver and all occupants are directed to exit the parking area. A color graphics touchscreen is used by the driver to interact with the system. Before starting vehicle storage, the parking system closes the overhead door and secures the area… To retrieve a vehicle, the driver simply selects the vehicle to be retrieved via the touchscreen terminal. The system automatically retrieves the vehicle and presents it ready to drive out.

The capital and operational costs of automated parking services are likely only warranted in downtown urban areas with very high property values and parking demand. The operational costs of valet parking are more reasonable and may be a promising approach to expanding parking capacity at transit stations where supply is limited, which restricts transit use.

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VII. Parking Behavior

In this section, parking behavior research is reviewed to provide background for the investigation of user response to the smart parking field test at the Rockridge BART station. Early studies of parking choice tend to be based in microeconomic theory and use a random utility framework. More specifically, the choice of parking is a function of traveler attributes (i.e., socioeconomic characteristics) and the attributes of the available parking choices (i.e., time and cost). These models assume that travelers seek to maximize benefits and minimize costs. More recent research suggests that lexicographic models or simplified decision rules may better explain parking choice than microeconomic models under conditions of limited time and multiple alternatives. Much of this research is relatively new and based on experiments and driver simulations that may be limited due to the number of participants and the degree to which they represent the general population as well as the difference between the simulated experiments and real-life experiences (Mahmassani et al., 1990).

A number of studies have employed revealed and/or stated preference data and the random utility framework to model travelers' parking choice in response to parking attributes. Gillen (1978) used revealed preference data (the 1964 Metropolitan Toronto Regional Transportation Study) to estimate a discrete choice model of individual parking location choice and found that parking fees, time restrictions, and search and transaction costs were significant.

Goot (1982) used revealed preference data to estimate a logit model of visitor parking choice in the central areas of Haarlem (Netherlands) that included the variables of walking time, parking charges, facility occupation rates, parking-time restrictions, and other accessibility factors. The results indicated that walking time was a highly significant variable.

Axhausen and Polak (1991) used the results of stated preference surveys implemented in Karlsruhe, Germany, and Birmingham, UK to estimate a simple logit model of parking type choice and concluded that it is important to "separately identify the costs associated with different components of the parking activity (e.g., general in-vehicle time, parking search time, egress time) and also point to the existence of significant differences in the relative valuation of these components across different journey purposes" (p. 59).

Waerden et al. (1992) use data collected from an on-street survey of city center (Eindhoven, The Netherlands) visitors to estimate a logit model of adaptive choice behavior of travelers in the context of limited shopping center parking. They find that the probability of: (1) waiting depends on "expected waiting time, number of cars waiting, and number of parking lots visited;" (2) searching "depends on the attributes expected waiting time and number of parking lots visited before;" and (3) "parking the car illegally is affected most by expected waiting time, available space for illegal parking, and chance of getting a penalty" (p. 406).

Hunt and Teply (1993) use data from surveys of employees at 80 different employer locations in the city center of Edmonton, Canada (1983) to estimate a nested logit model of parking location choice. They found that "when modeling parking location choice using a logit model in which on-street areas, off-street facilities or small groups of either of these are represented as discrete alternatives, it is appropriate to use the nested form with a hierarchical structure that acknowledges the effects of the greater similarities among on-street parking location among off-street facilities" (p. 264). In addition, "parking location choice is influenced not only by monetary cost and proximity to final destination, but also by such other factors as position relative to the trip being made, nature of the parking surface and whether or not it is likely that it will be necessary to spend some time searching and/or waiting for a stall" (p. 264).

More recent research on parking and mode choice has tested the hypothesis that when the traveler is faced with many alternatives with different attributes and decision time is limited, travelers will employ simplified decision rules (lexicographic strategies) rather than simultaneously evaluate the attributes of the available alternatives as is predicted by random utility theory.

Holton and Fisher (1998) conducted "three experiments, a pencil-and-paper survey and two driving simulator studies" to test different parking choice models (p. 1237). They found that "two-thirds of the participants" employed a lexicographic strategy, "choosing the lot nearest the final destination if the number of open spaces was above some criterion" and that "the remaining one-third" used a more computational intensive utility maximization strategy, "choosing the lot which minimized the total expected travel time" (p. 1237).

Hester et al. (2002) conducted two experiments using driver simulators and found that drivers use a lexicographic strategy (i.e., "drivers decide to park in a lot if the number of open spaces is greater than or equal to some criterion number") and that drivers do not "seek to minimize either their walking distance or their likelihood of obtaining a parking space," but they may "minimize their total travel time" (p. 49).

Yamamoto et al. (2002) use stated preference data (Nagoya, Japan) to evaluate the choice to drive or use dynamic park-and-ride to access a congested city center and found that the semi-ordered lexicographic model performed best overall. He defines this model as follows:

> The semi-ordered lexicographic model assumes that the decision maker has his own important rank of attributes, and compares the alternatives in the most important attribute. The alternative with a better attribute value is chosen in binary choice if the difference in the attribute values of the alternative is larger than a specific threshold, which is assumed to follow lognormal distribution in the study. (p. 2)

In addition, they found that parking congestion and socioeconomic variables such as gender and presence of children in the household were significant choice variables.

The results of this literature review suggest potential theoretical frameworks upon which to test and evaluate the behavioral responses to the smart parking field test at the Rockridge BART station.

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VIII. Review of the Parking Cash-Out Literature

Collectively, Shoup, Willson, and Higgins (e.g., 1989; 1990; 1992; 1994, 1999a, 1999b) have created a body of literature that provides an important economic critique and powerful market-based solutions to the significant problems created by traditional parking practices in the U.S. The literature begins with a detailed analysis of the myriad economic, equity, and environmental problems created by the minimum parking requirements in traditional parking policies (Higgins 1989; Shoup 1990). Next, the authors propose a number of solutions to these problems including: parking cash-out—offering employees a subsidized parking space or its cash value in-hand (Shoup 1992); creating parking benefit districts where curb-parking revenues fund public amenities for neighborhood residents (Shoup 1994; Kolozsvari 2003); and allowing developers to pay in-lieu fees or reduce demand by encouraging alternatives to driving instead of providing a required number of parking spaces (Shoup 1999a). Finally, case studies of the effectiveness of their proposed solutions with respect to mode shares and average vehicle ridership are examined (e.g., Kenyon, 1983; Higgins, 1989; Willson and Shoup, 1990; Bevan, 1991; Willson, 1997), and the authors review the status of parking cash-out legislation.

The parking cash-out and parking pricing literature is relevant to the smart parking field test for two reasons. First, the criticisms of traditional parking help us to understand the problems associated with the current systems and how alternatives may be applied to address these problems. Second, any effort to improve upon existing parking shortcomings must be informed by alternatives proposed in the literature. By making the most efficient use of existing parking in a region, smart parking may reduce the need for minimum parking requirements. By leveraging advanced technologies, smart parking can facilitate some of the more promising solutions posed in the literature, which had previously been challenged on logistical grounds.

Critique of Traditional Parking Policy

By the 1950s most municipalities had adopted minimum parking requirements—strict regulations describing exactly how many parking spaces a developer had to provide for any given type of development by unit or square feet. These requirements forced residential developments and office buildings to provide a minimum guaranteed amount of free parking and as a result:

- Reduce the perceived cost of parking and driving and thus make auto travel more attractive relative to other available modes.
- Expands the land necessary for any given use, spreads uses away from each other and renders walking, bicycling, and transit more time consuming relative to auto travel.

Prior to a discussion of their mode share impacts, parking requirements must be examined at their most basic level—cost.

Minimum parking requirements are criticized for their high cost and negative equity effects. Depending upon location, structural type (surface, multiple-story or below ground), and the degree of landscaping, construction costs per parking space vary between $1,500 and $22,000 (Littman, 2000). Land costs per acre (100 - 150 spaces can fit into an acre) range from $50,000 to $1 million, or between $330 and $10,000 per space for land costs alone (Littman, 2000). Shoup contextualizes these costs, explaining that minimum parking requirements can increase development costs by more than ten times the impact fees for all other purposes combined. Shoup further argues that such substantial increases in development costs raise housing prices and reduce density because of the added land required for parking (Shoup, 1997). Minimum parking requirements therefore renders affordable housing less attractive to developers, and the resulting shortage minimizes the chance for low-income citizens to find suitable housing. Since residential parking is required per residential unit not per square feet, developers save money by constructing fewer larger units and charging more for them, further reducing the number of affordable units on the market (Shoup, 1994). Shoup also indicates that low-income residents frequently own fewer cars, yet cities will rarely make exceptions to minimum parking requirements for low-income housing (Shoup, 1997).

Minimum parking requirements also allow consumers to remain ignorant of the true monetary cost of the parking they use by bundling it into the price of housing and general goods and services (Shoup, 1999b). As a result, parking demand is high because consumers perceive the cost to be zero. In the context of the housing market, Adler (1985) argues that unbundling parking from housing in central urban areas would allow commuters and residents who face different modal options and time values to express their disparate parking preferences. For example, high-income commuters from the suburbs to the city may be willing to pay top dollar for a parking space near their workplace. By contrast, city dwellers may prefer lower cost housing without parking because of the high-quality transit service available to them. In the current system, those who would pay more are not permitted to and those who want to pay less and use less parking cannot.

Shoup (1992) further illustrates this market distortion in the context of employer paid parking. Since employers provide free parking as a pre-tax fringe benefit, but provide no similar subsidy for other modes, they in effect encourage driving, by offering employees a “take-it-or-leave-it” benefit, where those who do not take advantage of free parking forego a benefit worth, for example, of $50 per month (Shoup and Willson, 1992). A number of case studies indicate that significant reductions in employee drive-alone mode share, ranging from 20 to 40 percent, could be attained by charging for workplace parking (e.g., Willson, 1992; Shoup, 1997). Litman (2000) highlights that motorists in the U.S. are shielded from total annual automobile parking costs in excess of $100 billion, suggesting that driving behavior might change were users to bear the actual costs of their parking use.

Higgins (1989) adds that minimum parking requirements discourage other transportation mode use, by guaranteeing free, available parking thereby encouraging driving. His review of case studies suggests that cities with limited and costly parking have the highest transit shares. He cites San Francisco—where spaces downtown are the most limited compared with the number of employees—as generating a transit mode share of 60 percent. Denver, by contrast, has a transit ridership of only 28 percent, where parking capacity per employee is higher. Shoup (1997) argues that where parking is amply supplied, the demand for—and use of—automobiles and gasoline rise, resulting in more oil being imported and consumed, increased traffic congestion, and reduced air quality. In addition to inducing driving by simply providing free parking, Shoup also describes how minimum parking requirements indirectly encourage driving by discouraging other modes through reducing urban density. In a study of affordable housing in Oakland, California, Bertha (1964) found that housing density fell by 30 percent as a result of minimum parking requirements. With such decreases, more basic transportation modes, such as walking and bicycling, become less attractive because uses are spread out.

Citing the myriad problems with minimum parking requirements, critics also point out that the methods used to determine how much parking a particular development should provide are largely flawed (Shoup and Willson, 1999). Shoup explains that most jurisdictions either consult the Institute of Transportation Engineers' (ITE) Parking Generation manual or they borrow regulations from neighboring municipalities (1999b). He also criticizes the ITE Parking manual for providing highly precise parking estimates for several dozen categories of developments but failing to support these recommendations with legitimate analysis. The ITE bases its recommendations on a non-standardized number of observed studies submitted voluntarily, typically tracking peak period parking demand. In fact, 22 percent of the Parking Generation manual's recommendations are based on a single survey (Shoup, 1999b). Further, current practice fails to consider the quality of the urban environment for a given development. Most ITE estimates are based on suburban areas with ample free parking and very few real driving alternatives (Shoup 1999b). No distinction is made between parking requirements for walkable urban areas with ample transit services and suburban or rural areas with few driving alternatives. Such studies then set high standards for the amount of parking required and so perpetuate the paradigm of ample free parking, which encourages driving. Neither are exceptions made in the ITE manual for low-income individuals, even though Shoup (1997) points out that low-income residents are less likely to own cars than their wealthier neighbors. Shoup also argues that by copying a neighboring jurisdiction's parking requirements a municipality may simply repeat the mistakes of their predecessor (Shoup, 1999b).

The critique of minimum parking requirements outlined above has been questioned in a recent paper by Ferguson (2003). Ferguson argues that parking zoning represented a gradual policy innovation process in contrast to Shoup's (1997) characterization of off-street parking as an instant success in the late-1940s (Ferguson, 2003). Shoup had claimed that only 17 percent of municipalities had parking regulations in place by 1946, and 76 percent had adopted parking ordinances by 1951. In contrast, Ferguson provides that 12 percent of municipalities had adopted parking regulations by 1946, and 23 percent to 34 percent had by 1951. Minimum parking requirements may have been perceived by decision makers as a strategic policy response to parking demand. Nevertheless, this response did not correct the underlying market distortion that creates surplus parking demand: bundling free parking into the cost of general housing, goods, and services, making the perceived cost to drivers zero.

Solutions

Despite arguments in favor of parking zoning, few would argue that the current situation leaves something to be desired insofar as balancing supply and demand for parking, and several critics provide alternatives to the tradition of minimum parking requirements. Most pertain to the fact that a majority of employers currently provide free parking for all of their employees, and employees respond by driving to work. Shoup and Willson (1992) propose parking cash-out—a program that requires employers who offer free parking to provide employees with the option of taking the cash equivalent instead. A company implementing parking cash-out would first determine the monetary value of each subsidized parking space and inform employees of their option to receive a parking space or a check for its cash value. Proponents argue that parking cash-out would allow drivers to state their true preference for driving. For example, a low-income employee might value cash in hand—perhaps $50 per space per month—more highly than a guaranteed parking space, so they would choose to receive cash and employ an alternative mode to get to work (Shoup and Willson, 1992). More affluent employees who place a higher value on their time and convenience would forego the cash equivalent and keep their parking space, after weighing that benefit against the cash value.

Shoup and Willson (1992) highlight several advantages of parking cash-out. By unbundling parking costs from other employee benefits, parking cash-out allows each employee to state his/her parking preference. With this knowledge, parking cash-out permits employers to provide exactly the amount of parking that is necessary. Parking cash-out is also more equitable. By subsidizing driving but not other modes, employers can unintentionally create inequities, if employees who cannot afford a car receive no comparable transportation subsidy.

Faced with proposals to reduce or eliminate minimum parking requirements, supporters express concern that requirements are essential to mitigate increased demand generated by new developments and preclude neighborhood complaints about spillover parking. Shoup (1994) proposes that municipalities charge market rates for curb parking, as an alternative to minimum parking requirements, whereby guaranteeing that some parking is always available to motorists. Private parking garages often price parking with the specific goal of maintaining an occupancy rate of 85 percent to ensure availability (Shoup, 1999b). Traffic engineers recommend a curb vacancy ratio of 1:7 vehicles to ensure easy ingress and egress, yet most municipalities have no way of enforcing such vacancy rates (Shoup, 1994). Shoup agrees that significant opposition may come from neighborhood residents where planners attempt to charge for parking – a resource that has historically been provided free of charge. To overcome neighborhood opposition and to create supporters for such a proposal, Shoup proposes the development of parking benefit districts. Shoup believes that people are generally opposed to paying for parking because they are not informed about where their money goes, and they don’t see any benefit from their expenditures. If funds raised from parking meters were used very publicly to fund neighborhood amenities—landscaping, sidewalk improvements, benches, parks—it might be possible to create a constituency of neighbors in support. Neighborhood residents would receive special permits allowing them to park free; visitors would pay the market rate, currently fifty cents to one dollar per hour. Under this scheme, municipalities would be less concerned with providing an ample *supply* of parking, instead they could control *demand* for parking by charging to the point of availability (Shoup, 1994).

Some have expressed concern that such a scheme unfairly discriminates against the poor by charging for what is currently a free resource. Shoup responds that any criticism of minimal curb fees must acknowledge that free parking is not actually free. Rather its cost is borne by everyone in society in the form of higher housing costs and lower density, which makes life without a car more difficult (Shoup, 1994; Shoup, 1999b). Shoup proposes charging for curb parking *instead of* implementing minimum parking requirements, so low-income residents might realize substantial benefits of this policy reform. Further, carpooling presents low-income residents for whom the curb fees are a substantial burden with a means to split the cost (Shoup, 1994).

Critics also argue that forcing motorists to pay for curb parking may have a negative impact on small businesses, because it will discourage potential customers (Shoup 1994). Shoup points out that municipalities can price parking such that most parking will be occupied most of the time, and implement time limits, which result in high turnover that benefits businesses. Furthermore, if some are discouraged from parking to shop because of a small fee, those that do stop to pay for parking are likely to spend more at the stores (Shoup 1994).

Kolozsvari and Shoup (2003) evaluate the city of Pasadena's efforts to implement parking benefit districts. By charging one dollar per hour for curb parking, the Old Pasadena downtown neighborhood has addressed its parking shortage, raised substantial revenues to repair lighting, benches, sidewalks, and alleys and maintained an average occupancy rate of 83 percent, which is ideal according to transportation planners. In 2001, the system generated $1.2 million, after collection charges. By re-investing parking revenues back into a business improvement district, the City has created a new constituency of business leaders who support charging for curb parking. This model may be applicable elsewhere. Kolozsvari and Shoup compare Pasadena's success story with the declining infrastructure of Westwood Village, which lowered its parking fees and is suffering congestion, parking shortages, crumbling sidewalks, and un-maintained public spaces—all of which are bad for business.

Raising another alternative to minimum parking requirements, Shoup (1999a) points out that in-lieu fees can reduce costs and improve urban density and efficiency. Several municipalities currently allow developers to pay a fee in-lieu of providing the minimum required amount of parking, which the city uses to construct sufficient parking. In general, in-lieu fees can reduce the amount of land required for parking by maximizing the use of each parking space. In-lieu fees permit the city to provide shared public parking between sites where peak parking demands occur at different times (Shoup, 1999a). For example, instead of forcing developers of an office park and a movie theatre to each provide the minimum required parking, the city could take advantage of the fact that the peak demand periods for these uses do not overlap and thus provide one shared facility for both developments. In-lieu fees also facilitate improved urban design by allowing the city to place public parking lots where they have the least impact on vehicle and pedestrian circulation (Shoup, 1999a). In-lieu fees also provide developers an alternative in certain situations where providing on-site parking would be particularly difficult or expensive, for example in the case of rehabilitation and re-use of historic buildings.

Building on the concept of in-lieu fees, Shoup (1999a) proposes that developers be permitted to encourage alternatives to driving to reduce demand instead of providing a minimum number of spaces or ensuring supply. Shoup argues that if a developer can successfully reduce parking demand in her development, she ought to be able to realize a cost saving from providing fewer spaces. Examining the EcoPass program in California, Shoup found that it is substantially less expensive to provide transit passes to encourage transit use rather than to provide minimum required parking, and these programs can successfully reduce parking demand by increasing transit use (Shoup, 2003). Shoup found that every dollar spent on transit would save companies between $23 and $337 for initial capital costs of constructing parking, in addition to ongoing operating and maintenance costs.

Parking Cash-Out Legislation

In 1992, the California legislature attempted to implement parking cash-out. Assembly Bill (AB) 2109 required certain employers who provided employees with free parking to remove the benefit or to provide a similar cash benefit to employees who did not drive (Assembly Bill 2109, Katz; Chapter 554, Statutes of 1992, (ITS Review Online, 2002)). For years, negative tax implications limited the implementation of the law. Specifically, by offering the cash-out option, employers would have removed the tax-free status of their employees' transit, vanpooling, and parking subsidies. Thus, they were hesitant to implement cash-out. In 1998, the U.S. Congress amended the tax code to permit employers to offer a combination of cash and tax-free transportation benefits (transit, vanpooling, and parking subsidies) without losing any of the tax-free benefits (California Air Resources Board, 2004).

Unfortunately, many employers—twelve years later—remain unaware of AB 2109's provisions (ITS Review Online, 2002). Another limitation, is that the Bill only applies to companies comprised of over 50 employees, located in non-attainment areas for State air quality, and who lease rather than own, their spaces. Even if widely implemented, the Legislative Analyst's Office estimates that only three percent of the 11 million free parking spaces in the State would have to comply with the parking cash-out law (ITS Review Online, 2002).

Evaluation

The effectiveness of charging for workplace parking has been evaluated in numerous case studies. Results indicate that charging users for parking can have a substantial impact on mode choice. Several studies indicate that more employees drive to work because they know free parking awaits (Willson, 1992; Bevan, 1991). A survey of parking cash-out case studies suggests that charging employees directly for parking can reduce automobile commuting by up to 81 percent (Willson and Shoup, 1990).

The literature can be broadly divided into two categories where employer-provided parking is concerned. First, in-depth case studies depict companies that have engaged in extensive company-wide efforts to reduce single-occupant vehicle travel and encourage other modes. In addition to ceasing to pay for single occupant vehicle parking, these companies employed a variety of strategies including: financial incentives for walking, bicycling, carpooling, vanpooling, and transit; flexible work hours; penalties for leaving with a single occupant vehicle during the day, but free carpool lunch trips; and coordinated ride-matching services. Second is a survey of several companies who reduced or discontinued employer-paid parking for employees and made few additional efforts to encourage other modes. The literature employs two methods to assess the impact of employer-paid parking: (1) before and after surveys—where a company changed its parking policies—and (2) with/without studies—where the employee mode share breakdown of two companies in similar locations are compared in which one provides free parking and the other charges. The case studies employ a broad range of measurement criteria including: reduction in single occupant vehicle mode share, increase in carpooling and transit, and average vehicle ridership (as a proxy for carpooling). Tables 2-1 to 2-4, following, describe the results of each of the programs.

Table 2-1. Percentage Change in Mode Share from Extensive Employer Transportation Management Programs (Kenyon, 1983, p. 12 – 14; Bevan, 1991, p. 269)

Location	Parking Management Strategy Implemented	Mode Share Change
Bellevue, Washington	Single Occupancy Vehicles (SOVs) charged $60/month for parking, carpools of two charged $45, carpools of three park free and receive preferential parking; two vanpools operated by employer; SOVs must pay to leave garage during day and carpools return free.	Drive Alone: -24% Carpool: +136%
Bellevue, Washington	Transportation allowance of $40 to all employees, $15 subsidy to carpoolers, $40 monthly parking fee (increased to market rate gradually), $15 subsidy to vanpools or buspass purchasers, walk/bike received $40 subsidy but nothing additional, flexible work hours.	Drive Alone: - 42% Transit: + 190%

Table 2-2. Increase in Average Vehicle Ridership Resulting from Transportation Management Strategies of Two Companies in Glendale, California (Willson, 1997, p. 83)

Location	Parking Management Strategy Implemented	Increase in Average Vehicle Ridership
Glendale, Los Angeles	Charged $40/month for solo drivers; 40% cash subsidies to vanpools, carpools. and transit; preferential parking for carpools	32%
Glendale, Los Angeles	Charged $50 for solo parkers, $3/day subsidy for all who arrive in a non-solo driving mode, preferential parking for carpools, and cash incentives for alternatives	29%

Table 2-3. Percentage Changes in Mode Share Resulting from Employer Parking Cash-Out and Parking Pricing Policies (Willson and Shoup, 1990, p. 146)

Location	Parking Management Strategy Implemented	Mode Share Change
Mid Wilshire, Los Angeles, California	Ended parking subsidies for drive alone commuters ($0 - $58)	Drive Alone: - 81% Carpool/Vanpool: + 246% Transit: -26%
Warner Center, Los Angeles, California	Charged solo drivers 2/3 market rate ($0 - $30)	Drive Alone: - 49% Carpool/Vanpool: + 700% Transit: 0%
Downtown Ottawa, Canada	Ended all employee parking subsidies ($0 - $23)	Drive Alone: - 20% Carpool/Vanpool: 0% Transit: +17%

Table 2-4. Percentage Difference in Mode Share Observed in Comparisons of Similar Employers with One Charging for Parking and the Other Providing Free Parking (Willson and Shoup, 1990, p. 150)

Location	Basis of Comparison	Mode Share Change
Civic Center, Los Angeles, California	No subsidy (parker pays $30) vs. full subsidy (Parker pays $0)	Drive Alone: - 44% Carpool/Vanpool: + 69% Transit: 175%
Century City, Los Angeles, California	No subsidy (parker pays $30) vs. full subsidy (parker pays $0)	Drive Alone: - 19% Carpool/Vanpool: +200% Transit: +225%

Summary

The mode shift benefits presented by innovative parking policies are substantial. However, the implementation of parking pricing and cash-out may present complex challenges. Beyond the hesitations of employers and municipalities to charge for a resource that has historically been provided for free, the implementation of these solutions may face logistical hurdles. For example, installing parking meters for curb parking would prove costly and time consuming, and the technology is relatively unsophisticated. Smart parking technology could facilitate the charging of market rates for parking depending on time of day and the creation of parking benefit districts. One smart parking meter can handle payments and reservations for dozens of parking spaces and can accept payments via credit and debit cards, potentially reducing maintenance and operational costs typically associated with parking meters. Smart parking technology can also enable individuals to dynamically reserve parking ahead of time. People may be more amenable to the idea of paying for parking, if they feel they are getting an advanced benefit from it. Motorists may pay a premium for the luxury of knowing they will not have to circle for parking once they arrive at their destination. The broader advantage of smart parking is that it permits an optimization of existing parking resources (e.g., available spaces can be more efficiently managed overall). By serving as a virtual parking broker, smart parking technologies have the potential to enable dynamic parking pricing and better match supply and demand.

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IX. Conclusion

This literature review evaluates the effectiveness of various smart parking management strategies and gathers lessons on parking behavior and parking cash-out and pricing to inform the design of the Rockridge BART station smart parking field test.

Early examples of smart parking management included 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 variable message signs. 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. 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.

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. These systems provide motorists with information about spaces in park-and-ride lots, transit schedules, and downstream traffic conditions. This literature is particularly relevant to the smart parking field test. A review of the literature suggests that parking shortages at suburban rail stations may significantly constrain transit ridership. 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. Finally, regular commuters are more responsive to parking information in conjunction with transit than more basic PGI systems because this information may be essential to catching a train during peak hours. These findings provide a promising context for the Rockridge BART field test in terms of its potential effects on transit ridership.

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 can minimize transaction time by allowing a user to simply wave their card in front of a reader. Mobile communication devices can also be used in smart payment transactions. Smart parking payment systems are now being developed and implemented worldwide by cell 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. 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 best concepts of its forerunners, e-parking is an innovative business platform that would allow drivers to inquire about parking availability, reserve a space, and even pay for parking upon departure—all from inside an individual's car. Drivers access the central system via cellular phone, 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 parking guidance information, smart parking, and smart payment technologies address, such as parking optimization, cost savings, search traffic, transit station constraints, related air pollution, and security. In addition, e-parking promises to: reduce search time, facilitate parking payment, guarantee parking at 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.

Another impressive parking innovation, fully automated parking systems employ robotic transport devices to deliver automobiles to parking spaces without human intervention. While they use space more efficiently than conventional parking, the capital and operational costs of automated parking services are likely only warranted in downtown urban areas with very high property values and parking demand. The operational costs of valet parking are more reasonable and may be a promising approach to expanding parking capacity at transit stations where supply is limited and restricts transit use.

Despite the most innovative designs, parking information systems must consider and anticipate human parking behavior to be successful. A survey of behavioral literature suggests that lexicographic models or simplified decision rules may better explain parking choice than the traditional microeconomic models under conditions of limited time and multiple alternatives. In this section, several potential theoretical frameworks were presented that could be employed to test and evaluate the behavioral responses to the smart parking field test.

Finally, the parking pricing and cash-out literature indicates that charging for parking can result in substantial decreases in single-occupant vehicle mode share. However, many are hesitant to implement these innovative solutions for fear of charging for a historically free resource. Smart parking may provide a means to implement some of the powerful market-based solutions to the problems of traditional parking practices. Smart parking technology could facilitate the charging of market rates for parking depending on time of day. People may be more amenable to paying for parking if they feel they are getting an advanced benefit from it—which guaranteed parking reservations provide.

In the next twenty years, California will add fifteen million new residents, most of them moving to metropolitan areas where automobile infrastructure is currently at or near capacity. By combining smart parking with transit stations, new technology systems have demonstrated potential to encourage increased transit ridership and to help balance the population's mobility needs.

CHAPTER 3. FEASIBILITY ANALYSIS

I. Introduction

The smart parking project was originally envisioned in 2001, when the Bay Area was experiencing a strong economy. The initial design included overflow, BART station parking at the Dublin/Pleasanton station in a neighboring business park with underused parking. A shuttle bus would transport riders to the parking-constrained BART station. VMS signs located on highways adjacent to the BART station would alert and direct drivers to available overflow parking. Six months later, the Bay Area economy experienced a significant downturn and highway traffic conditions improved. At the Dublin/Pleasanton station, parking demand declined significantly and BART instituted monthly reserved paid and airport parking. As a result of these changed conditions, researchers reassessed the design and project location. This chapter describes the feasibility analysis, which guided the development and initial evaluation of the field test. First, researchers conducted a comparative evaluation of rider attributes at three BART stations—Rockridge, Walnut Creek, and El Cerrito Del Norte. Second, systematic observations were made of parking demand and activity in and around those stations. Third, focus groups with BART and non-BART commuters were conducted to explore attitudes toward commute modes, parking, and smart parking design concepts. Fourth, vehicle sensor accuracy was tested. Finally, a survey of regular and paid parkers was conducted to identify traveler information needs and to assess potential travel effects.

II. BART Ridership Profiles

After initial discussions with BART District officials about parking demand at different stations, researchers and BART staff identified the El Cerrito Del Norte, Walnut Creek, and Rockridge stations as potential field test sites. The first step in the feasibility analysis was an evaluation of BART's 1998 survey of riders at the three stations (BART, 1999). Table 3-1, following, summarizes the results with an emphasis on the three proposed field test locations.

Table 3-1. Profiles for BART Riders at the Rockridge, Walnut Creek, and El Cerrito Del Norte Stations (BART, 1999)

	Rockridge	Walnut Creek	El Cerrito Del Norte
Mode to Station			
Walk only	32%	10%	12%
Bus/transit	5%	10%	27%
Car	58%	78%	61%
Bicycle	3%	2%	1%
Other	2%	<1%	<1%
Age			
Under 18	<1%	0%	1%
18-24	7%	5%	11%
25-44	54%	50%	46%
45-64	33%	38%	39%
65 over	5%	7%	4%
Gender			
Male	41%	50%	39%
Female	59%	50%	62%
Total Household Income			
Less than $30,000	17%	9%	24%
$30,001 to $60,000	27%	25%	35%
$60,000 to $100,000	28%	31%	30%
Over $100,000	28%	35%	11%
They are Traveling to:			
Work	75%	82%	77%
School	7%	4%	9%
Shopping	2%	1%	1%
Other	16%	13%	13%
Other Factors			
Use BART 5 or more days/week	65%	73%	76%
Have car available to make BART trips	78%	80%	71%
Employer pays all or part of BART ticket	13%	15%	17%
Use the Internet (at least once in prior week)	72%	66%	49%

Source: BART (1999) Final Report. BART Station Profile Study. Office of External Affairs, August.

Access Mode. The auto is the dominant access mode to BART for all three stations: 58 percent for Rockridge, 78 percent for Walnut Creek, and 61 percent for El Cerrito Del Norte. Del Norte has the highest transit access (27 percent), followed by Rockridge (10 percent), and Walnut Creek (five percent). About one-third of commuters walk to the Rockridge station, 12 percent to Del Norte, and 10 percent to Walnut Creek.

Commute Travel. Most of the riders at the three stations use BART for work-related travel (77 to 82 percent).

Frequency. Riders at the Rockridge station (65 percent) are less likely than riders at Walnut Creek (73 percent) and Del Norte (76 percent) to use BART five or more times a week.

Income. The Walnut Creek and Rockridge stations have the highest average rider income. The total household income of most riders at these station is greater than $60,000. The total household income of most riders at Del Norte is less than $60,000.

Age. The median age of riders at all three BART stations is between 25 and 44 years old. However, the average rider tends to be somewhat younger at the Del Norte station than at the Rockridge and Walnut Creek stations.

Gender. In general, more women than men ride BART at all three stations. Del Norte has the greatest number of women riders (62 percent); Rockridge has 59 percent; and Walnut Creek has the fewest at 50 percent.

Internet Use. Riders at the Rockridge station are most likely to use the Internet (72 percent) relative to Walnut Creek (66 percent) and Del Norte (49 percent).

Household Origin. The BART station profiles also identify the home locations relative to origin BART stations. For the Rockridge station, many households are within a half-mile radius, more are within a three-mile radius in Berkeley, and a number are also located along the Highway 13 and 24 corridors in Oakland and Orinda. For the Walnut Creek station, the home origin for most riders is Walnut Creek (three-mile station radius), but riders also originate from Danville, San Ramon, Pleasant Hill, and Martinez along Highway 680. For the Del Norte Station, most riders come from El Cerrito, Richmond, and Hercules, and a smaller number come from Vallejo, Napa, and Fairfield along Interstate-80.

The BART profiles for the three stations provided some insights into the demand for a smart parking field test. All stations were used heavily for commute travel. Riders at the Rockridge and Walnut Creek stations had relatively high incomes and, as a result, may be more willing to pay for a smart parking service. Riders at these stations also appeared to use the Internet frequently and thus may be comfortable using the smart parking Internet reservation service. At the Rockridge station, riders were least likely to use an auto to access the station. High parking demand at this station may be one explanation for low auto access. In addition, riders at the Rockridge station were least likely to use BART five or more times a week, which suggests that monthly reserved parking may not suit the needs of many riders and/or those that subscribed to monthly reserved parking may not use it everyday.

III. Observational Analysis

Next, researchers supplemented the BART ridership profile data on the Rockridge, Walnut Creek, and El Cerrito Del Norte stations with systematic observations of peak period and weekend parking demand and activity in and around the stations. These observations were conducted during the month of April 2003 for three weekdays in the morning (6:00 to 10:00 am) and on Saturday afternoon (1:00 to 3:00 pm) at each station. See Appendix A for the forms used by researchers to record observations. The results of the weekday observational analyses are described below in Table 3-2.

Table 3-2. Synthesis of Weekday Observational Analysis (6:00 to 10:00 am)

Demand Attributes	Rockridge Station	Walnut Creek Station	El Cerrito Del Norte Station
Time unpaid parking fills	7:30–7:45 am, Mon-Thurs 8:25 am, Friday	7:40–8:00 am, Mon-Thurs After 10:00 am, Friday	7:50 –8:15 am, Mon-Thurs 10:00 am, Friday
Time paid parking fills (free after 10:00 am)	After 10:00 am	After 10:00 am	After 10:00 am
Number of unused paid spaces before 10:00 am	80-95 spaces, Mon-Thurs 150 spaces on Friday	10-15 spaces, Mon-Thurs 20 spaces on Friday	40-60 spaces, Mon-Thurs 70 spaces on Friday
Parking search behavior	Peak cycle time is 7:30-8:00 am with 3 min search duration; about 33 cars cycled and left after unpaid lot filled.	Peak cycle time is 7:40-9:30 am with 3 min search duration; about 60-80 cars cycled; about 20 cars left after lot full.	Peak cycle time is 7:50-9:00 am with 2-3 min search duration; cars observed leaving after lot full.
Park at station and do not use BART?	No	No	No
Restricted on-street parking?	2-hour metered and residential parking	Some paid street parking but not particularly close to the station	Lots with 4-hour restrictions that are enforced and one lot with a $5 daily use fee
Number of off-street parkers using BART	Very few	Very few	Very few
Paid parking lot station access	Closest available parking to station; about 2 min (pleasant) walk	Close to station but not as close as curb parking; about a 3 min (pleasant) walk	Not as close to station as curb parking and poorly advertised
Unpaid parking lot station access	About 4 min (pleasant) walk	2-3 min (pleasant) walk without using parking structure elevator; 4-5 min (pleasant) walk with parking structure elevator.	2-4 min walk
Land use characteristics of area around station	Transit-oriented with residential and retail shops	Close to Highway 680; large office buildings around 3 sides; one restaurant across the street	Close to Interstate-80; strip malls with shops (e.g., Target, Staples, and Walgreens), cafes, and gas station

Parking Demand. Of the three stations, parking demand is highest at the Rockridge station where the unpaid parking lot fills between 7:30 and 7:45 am (on all weekdays except Friday). Walnut Creek has the next highest demand; unpaid parking fills from 7:40 to 8:00 am. Del Norte has the lowest demand; unpaid parking fills from 7:50 to 8:15 am.

Cycling in Search of Parking. The number of cars cycling in search of parking and leaving the unpaid parking lot was greatest at Rockridge (33), followed by Walnut Creek (20), and then Del Norte. Cycling tended to take about two to three minutes at all stations during peak times.

Demand for Monthly Reserved Paid Parking. Paid parking did not fill at all the stations before it became free at 10:00 am. This finding was noteable with respect to the Rockridge station because there is and was a waiting list for monthly reserved parking. The observational results suggest that monthly parkers do not use their spots everyday. The BART profile for the Rockridge station indicates that 65 percent of station users used BART five or more days a week. Furthermore, there were approximately 80 to 90 open monthly reserved spaces[5] (prior to 10:00 am) from Monday through Thursday and about 150 spaces available on Friday. Thus, a daily parking service could offer a complementary service to those that would like to park on an as needed basis.

Because of the greater availability of unpaid parking at Walnut Creek and Del Norte, the monthly reserved paid parking program was not fully subscribed, and both stations had available spots in their reserved lots before 10:00 am. The number of open spots for Walnut Creek was relatively low (20 Monday through Thursday and 20 on Friday) because BART was waiting for more subscribers before opening more paid parking. At Del Norte, there were about 40 to 60 paid spots open before 10:00 am Monday through Thursday and about 70 on Friday.

Location of Monthly Reserved Paid Parking. The paid parking lot was optimally located at the Rockridge station with an approximately two-minute walk time savings compared to the unpaid parking lots. At both Walnut Creek and Del Norte, paid lot parking was located less than optimally; there was no consistent difference in average walk access times between the paid and unpaid lots.

Off-Street Parking. Off-street parking was not conveniently available at the Walnut Creek and Rockridge stations but was at the Del Norte station. Not surprisingly, because of the low supply of convenient off-street parking at Walnut Creek and Rockridge and available unpaid BART parking at Del Norte, the number of off-street parkers using BART at all three stations was not significant.

Weekend parking at the three stations was observed because researchers wanted to examine the possibility of charging for use of BART parking for non-BART travelers

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[5] There are a total of 279 spaces in the reserved monthly lot at the Rockridge BART station.

when weekend space is plentiful. The results of the weekend observational analyses are described in Table 3-3 (below). The results suggest that while weekend parking at Rockridge is in relatively high demand, street parking is still available; thus such a service would not be possible at this station. Weekend demand for parking was too low at Walnut Creek to warrant a weekend service. Although the El Cerrito Del Norte station observation was made on a day when a special event was held, further investigations indicated that parking is plentiful at this station on most weekends.

Table 3-3. Synthesis of Weekend Observational Analysis (1:00 to 3:00 pm)

Demand Attributes	Rockridge Station	Walnut Creek Station	El Cerrito Del Norte Station
Time parking fills	Full at 1:00 pm, but some spaces are intermittently free to 3:00 pm; high turnover	Never	Full from 1:00 to 3:00 pm because of special event
Parking search behavior	Minimal parking search times	Minimal parking search times	Peak cycle time is 8:00-9:00 am with 2-3 min duration; cars observed leaving after lot full.
Number of off-street parkers using BART	Very few	Very few	Used for overflow parking on afternoon of observation
Park at station and do not use BART?	No	No	No
Restricted on-street parking?	Plenty of free and unrestricted on-street parking	Some paid street parking but not particularly close to the station	Some unpaid street parking with 4-hour restrictions nearby

Based on the results of the station profiles and the observational analyses, a number of recommendations were made for the smart parking field test. First, El Cerrito Del Norte did not have sufficient parking demand to warrant a smart parking system (i.e., unpaid parking was full after 8:00 am). Second, at the Walnut Creek station, unpaid parking did fill early (before 8:00 am); however, monthly paid parking was not fully subscribed. Thus, the first technology-testing phase of the project was deployed at the Walnut Creek BART station where the research team installed temporary sensors to test their accuracy and to monitor available parking.

During the second testing phase, permanent traffic sensors were installed at the Rockridge station to maximize the use of existing parking by alerting travelers to the number of available spaces via a VMS located on an adjacent highway. This station was selected for the field test, as unpaid parking did fill early (around 7:30 am) and monthly paid parking was completely reserved, but many of the paid spaces were empty until after

10:00 am. In addition, smart parking reservation technology would be added to the field test service to permit travelers to reserve daily paid spaces in the monthly reserved parking lot by Internet, PDA, phone, and cell phone.

IV. Summary of Smart Parking Focus Group Results

To explore the parking information needs of BART riders (current and potential) and to refine smart parking design concepts for the project, two focus groups were conducted in late-May 2003 at the Walnut Creek Chamber of Commerce. One focus group was composed of commuters who used BART as their primary commute mode. These participants were recruited with flyers distributed at the Walnut Creek BART station. The other focus group was composed of commuters who drove to work but could ride BART. These participants were recruited with flyers distributed outside a shopping mall near the Walnut Creek BART station. A summary of the key results obtained from the focus groups follows. Also, see Appendix B for a detailed description of the focus group results.

Background

This section includes a description of the socio-demographic characteristics and commute travel of focus group participants.

BART Commuter Focus Group. This group was composed of 12 participants (seven men and five women) with the following demographic characteristics:

- Most were 41 to 64 years old and some were 24 to 40;
- Most used a cellular phone and/or a PDA; and
- Many reported a pre-tax household income greater than $110,000; some were within the $80,000 to $109,999 ranges; and others were within the $50,000 to $75,000 or the $20,000 to $49,999 range.

Participants in the BART commuter focus group provided some details about their typical commute travel patterns:

- Most used BART three to five times a week;
- Some used autos more than twice a week;
- Half reported that their most frequently used destination-end BART station was in downtown San Francisco; and
- Total one-way commute times ranged from 25 minutes to one hour.

Auto Commuter Focus Group. This group was composed of seven participants (two men and five women) with the following demographic attributes:

- Most were 24 to 40 years old, and several were 41 to 64;
- Most use a cellular phone and/or a PDA; and
- Many reported a pre-tax household income greater than $110,000; some were within the $20,000 to $49,999 range; and one was within the $50,000 to $75,000 range.

Participants in the auto commuter focus group typically used the following modes for their commute:

- About one-third used a single occupancy vehicle more than two times a week;
- About one-third used a single occupancy vehicle and BART;
- One used a single occupancy vehicle and carpooled;
- One carpooled and used BART; and
- One carpooled, rode BART, and used a single occupancy vehicle.

More than half of the participants in the auto commuter focus group reported that they park in facilities near their workplace for a daily fee that ranged from $7 to $25.

Participants noted the following factors that influence their choice to drive or carpool rather than use BART for their commute:

- The low cost of employer paid parking;
- Commuter check incentive for carpooling;
- Reduced roadway congestion related to the economic downturn;
- Lack of free BART parking; and
- A time consuming and unpleasant walk through the Walnut Creek BART parking lot to a work location in downtown Walnut Creek.

Attitudes toward Primary Commute Mode

This section includes a discussion of focus group participants' attitudes toward their primary commute modes.

BART Commuters. Avoiding traffic was the most popular attribute of commuting by BART for participants in this focus group, followed by the opportunity to sit and relax on the train. However, participants expressed frustration with the availability of BART parking, the cost of BART parking (i.e., monthly reserved), BART fares, and lack of available seating on trains. A few participants suggested monthly or semi-annual passes that would reward frequent BART use.

Auto Commuters. This group indicated that the most positive auto attributes were flexibility, door-to-door service, and the cost savings of carpooling. The most popular negative attributes were unpredictable traffic, unproductive time, and wear and tear on vehicles. The most common reasons participants reported for not commuting by BART were longer travel times (as compared to the car) and the need to make other trips after work (e.g., errands) that could not be efficiently accomplished by BART or other transit.

Attitudes Toward Parking

Focus group participants' attitudes toward parking are summarized below.

BART Commuters. Many participants appreciated covered BART parking, the close proximity of parking to the BART station, and the consistent availability of BART parking. Only one participant subscribed to monthly reserved paid parking at a cost of $780 a year. This participant stated that he preferred to pay for a guaranteed parking space rather than "gamble" for a free spot or pay for parking outside of the station. Most participants indicated that their biggest complaint about BART free parking was that it filled up too early in the morning.

Auto Commuters. The most popular positive attributes of parking were low cost, convenience, and availability. Common negative parking attributes were expense, lack of availability, and walking distance to the office. Six of the seven participants were aware of BART's monthly reserved parking. These six obtained their information about the service from television, newspapers, signs, and flyers.

Attitudes Toward Smart Parking Services

This section includes a discussion of focus group participants' attitudes toward the smart parking services (e.g., daily, weekly).

BART Commuters. Two participants indicated that they might use pre-trip and en-route paid parking information occasionally (e.g., if running late), and many like the idea of en-route information about available parking. Concerns, however, were raised about the ability of the system to guarantee a reserved parking space. Another participant suggested that services could be improved by providing guidance on the location of the available parking space.

Many participants expressed interest in a shuttle service from overflow parking to the BART station. Participants noted a number of potential concerns about such a service including longer commute time, personal safety, safety of cars, and availability of shuttles late at night. These participants generally indicated a weak willingness-to-pay for monthly reserved parking even if parking at the station filled up earlier than it currently does. The participants also reported that they would not be more willing to pay for BART monthly reserved paid parking if they knew how revenues were directed.

Some of the participants expressed support for paid parking on a shorter-term basis (i.e., daily and/or weekly). One stated that he would pay for certain critical days when he knew he would need parking later in the day. Some participants said they would pay for daily parking approximately one to two times a month, and some participants said that they would use it only occasionally. Most participants indicated that they would pay $2 or $3 for daily parking. However, one participant commented that she would pay up to $15 for a parking spot, if she had no other BART parking options.

Most participants expressed interest in a paid space sharing system (e.g., in San Francisco that enables parking in front of participant's driveways using a reservation system accessed by cell phone). They noted that secured parking and inexpensive rates would be positive attributes of such a service. However, most would not allow their own property to be used in such a system because of increased traffic, more strangers in the neighborhood, potential homeowner liability, and upset neighbors.

Auto Commuters. A few focus group participants expressed interest in a prepaid daily parking space and indicated that they would be willing to pay between $2 and $5 a day for such a service, depending on the time when free parking filled. One said that she would use a prepaid daily parking spot approximately ten days a month. Another commented that paid parking is prohibitively expensive in combination with BART ticket prices. There was less interest in a prepaid weekly parking service.

Given the adequate supply of parking at the Walnut Creek station, participants showed little support for an overflow parking service. However, if free parking began to fill-up earlier, some mentioned that they might consider using a daily reserved, paid parking service. One participant expressed concerns about safety in off-site parking lots.

A majority of participants agreed that the concept of space sharing sounded interesting. When asked if the participants would allow their own property to be included in such a service, only two participants said yes (at a rate that ranged from $5 to $10 an hour). Participants reported that they had a number of concerns about "renting" their driveway, including homeowner liability, oil stains, logistics, safety, and enforcement.

<u>Summary and Conclusions</u>

The focus groups yielded a number of important conclusions about the demand for smart parking services and insights into the design of a service:

- The most popular BART attributes in the BART commuter focus group were avoiding roadway traffic and the opportunity to sit and relax on the train.

- The biggest complaint about BART parking in the BART commuter focus group was that it filled up too early in the morning.

- Participants in both groups expressed interest in pre-trip and en-route parking information (free and daily paid).

- Participants in both groups expressed concern about the ability of the system to prevent someone from taking a reserved spot.

- Participants in both groups suggested that space-specific guidance information would be a valuable enhancement to the proposed smart parking system.

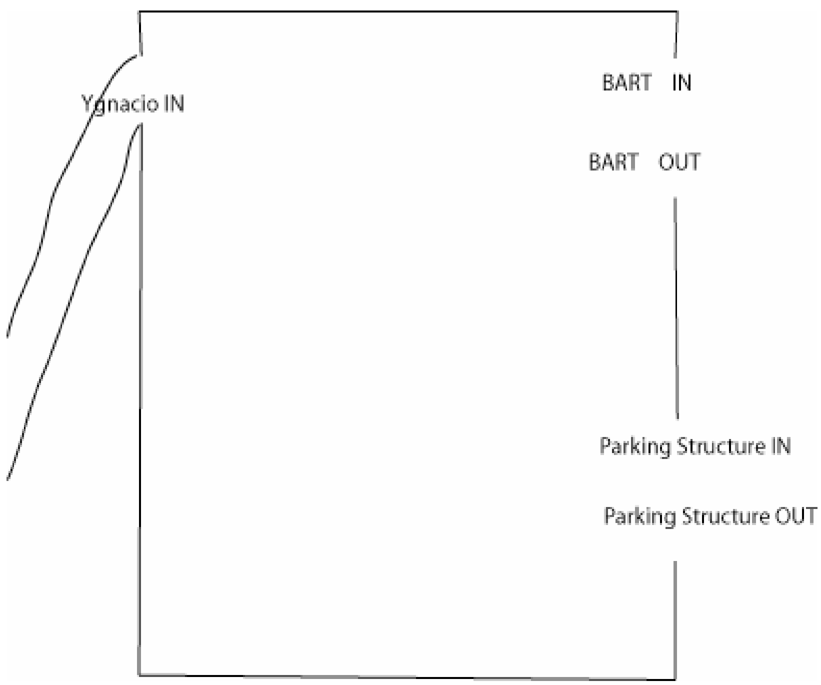
V. Evaluation of Vehicle Sensor Parking Accuracy at Walnut Creek Station

Smart parking management systems must provide accurate parking information to travelers to be effective. Thus, an understanding of the potential accuracy of vehicle counting technology (sensors) under different parking lot conditions is a critical step in smart parking system development. To evaluate sensory accuracy, researchers compared vehicle counts from temporary wireless sensors with observed counts. Lessons learned from this phase have been implemented in the second phase of the smart parking field test at the Rockridge BART Station.

Method

Researchers installed five temporary wireless sensors at each entry and exit point in the monthly reserved parking lot at the Walnut Creek BART Station. See Figure 3-1 below.

Figure 3-1. Sensor Locations in the Monthly Reserved Parking Lot at the Walnut Creek BART Station



The sensors are small (six-inch diameter circle) but have a sensing radius of approximately three feet. A car that passes over the six-foot diameter sensing area will trigger the sensor, which also records the direction and speed of passing traffic.

From July 22 to August 22, 2003, researchers manually retrieved vehicle count data from the installed sensors. During this same period, researchers made weekly manual counts of the number of vehicles at each entrance and exit sensor location in the morning peak hours. Experience gained during the initial observations improved the accuracy of the manual vehicle counts (i.e., counting methods and observational location points), and thus only the last three observations are used in the analysis below. These observations were considered the most accurate, however, some error is inevitable given high peak hour traffic volumes.

Results

The results of the analysis of sensor accuracy at the Ygnacio-In (Walnut Creek BART station) parking lot location for three observations are presented in Table 3-4, below. This particular entrance is narrow with little space for a vehicle to avoid passing over the sensor. Thus, these results indicate the potential accuracy of the sensor under ideal conditions. For each observation date by time interval, the absolute average percentage error ranges from 3.0 to 4.7. There appears to be no correlation between the number of counts and error rates. In general, these results indicate a relatively high degree of sensor accuracy under favorable conditions.

Table 3-4. Sensor Error Results at Ygnacio-In (Walnut Creek) Parking Lot Location

Observation Date and Time	Manual	Sensor	Error	Absolute Percentage Error
July 29, 2003				
7:00 to 7:30 AM	168	174	6	3.6%
7:31 to 8:00 AM	147	151	4	2.7%
8:01 to 8:30 AM	99	102	3	3.0%
Interval Average	145	145	4	3.1%
August 6, 2003				
7:00 to 7:30 AM	181	178	-3	1.7%
7:31 to 8:00 AM	148	143	-5	3.4%
8:01 to 8:30 AM	146	140	-6	4.1%
Interval Average	158	154	-5	3.0%
August 15, 2003				
7:00 to 7:30 AM	148	140	-8	5.4%
7:31 to 8:00 AM	138	141	3	2.2%
8:01 to 8:30 AM	121	129	8	6.6%
Interval Average	136	137	1	4.7%

Under conditions that are less than favorable, such as wide entrance and exit spaces and atypical parking traffic behavior, sensor traffic count errors were much higher. Table 3-5, following, presents the accuracy test results at Parking Structure-In/Out, and BART-Out locations on July 19, 2003. This table documents significant error levels, ranging from 31.1 to 64.4 percent for an absolute interval average.

Table 3-5. Sensor Error Results by Walnut Creek BART Parking Lot Location on July 29, 2003

Lot Location	Manual	Sensor	Error	Absolute Percentage Error
BART-Out				
7:00 to 7:30 AM	155	87	-68	44%
7:31 to 8:00 AM	145	82	-63	43%
8:01 to 8:30 AM	102	69	-33	32%
Interval Average	140.25	78.25	-55	39.9%
Structure-In				
7:00 to 7:30 AM	30	20	-10	33%
7:31 to 8:00 AM	46	33	-13	28%
8:01 to 8:30 AM	44	30	-14	32%
Interval Average	35.5	23.75	-12	31.1%
Structure-Out				
7:00 to 7:30 AM	22	41	19	86%
7:31 to 8:00 AM	20	25	5	25%
8:01 to 8:30 AM	11	20	9	82%
Interval Average	35.5	23.75	11	64.4%

The use patterns of the monthly reserved parking lot are atypical for a number of reasons:

- The Ygnacio Valley-In and BART-Out are used as a through street by approximately 87 percent of cars that pass through during peak morning hours.
- Many cars use the Parking Structure-In/BART-Out or BART-In/Parking Structure-Out pair to make U-turns on the outside street.
- U-turns are also made within the Parking Structure-In/Out and BART-In/Out points.
- Taxis also make frequent U-turns at the Parking Structure-In/Out and BART-In/Out points and also circle in the lot waiting for the taxi queue.

The wide physical design of the Parking Structure and BART road entrance and exit driveways allow for unusual driving behavior, including:

- Through traffic that enter via Ygnacio-In frequently exit in-between the BART-Out and BART-In sensors.
- Cars at the Parking Structure-In and -Out Sensors often make wide turns and drive over the wrong sensor or drive in-between the sensors.

Sensors were adjusted to try to eliminate some of the unusual use and driving patterns that increased sensor error rates. Table 3-6, following, documents the error results after adjustments to sensor placements were made. Significant improvements were made to the error rates at Parking Structure-In/Out locations and marginal improvement was made in the BART-Out location.

Table 3-6. Sensor Error Results by Walnut Creek BART Parking Lot Location on August 15, 2003 (after sensor placement adjustment)

Location	Manual	Sensor	Error	Absolute Percentage Error
BART-Out				
7:00 to 7:30 AM	10	9	-1	10.0%
7:31 to 8:00 AM	10	13	3	30.0%
8:01 to 8:30 AM	4	7	3	75.0%
Interval Average	8	10	2	38.3%
Structure-In				
7:00 to 7:30 AM	142	135	-7	4.9%
7:31 to 8:00 AM	124	137	13	10.5%
8:01 to 8:30 AM	108	104	-4	3.7%
Interval Average	125	125	1	6.4%
Structure-Out				
7:00 to 7:30 AM	32	21	-11	34.4%
7:31 to 8:00 AM	29	27	-2	6.9%
8:01 to 8:30 AM	30	32	2	6.7%
Interval Average	30	27	-4	11.5%

However, despite the improvements in the error rates, the wide design of these entrance and exit points made accurate parking counts difficult to obtain. As documented in Table 3-7, below, the accuracy of total parking by time interval was low.

Table 3-7. Parking Error Results by Time Interval on August 15, 2003 (after sensor placement adjustment)

Time	Manual	Sensor	Error	Absolute Percentage Error
7:00 to 7:30 AM	24	3	-21	87.5%
7:31 to 8:00 AM	43	30	-13	30.2%
8:01 to 8:30 AM	39	46	7	18.0%
Interval Average	34	17	-17	45.3%

These results indicate that a smart parking system that uses sensors in parking lot entrance and exit locations must address two potential challenges:

1. Wide or adjoining design of entrance and exit driveways.

2. Atypical use patterns such as through-traffic, circulating taxis, and U-turns.

Summary and Conclusions

To evaluate the potential accuracy of the vehicle counting technology (sensors) under different parking lot design and traffic flows, researchers compared observed manual vehicle counts and sensor counts at each of the five entrance and exit locations in the monthly reserved paid parking lot at the Walnut Creek BART station. A sensor can count a vehicle accurately only when some part of a vehicle passes over its six-foot diameter sensing area.

A number of conclusions can be drawn from this sensor accuracy test:

- Sensor accuracy is adequate when the design of the entrance or exit driveway is narrow enough to ensure that a vehicle cannot avoid passing over the sensor's range.

- Observations of traffic patterns in the parking facility can allow for adjustments to the placement of sensors to improve count accuracy.

- Entrance and exit driveways that are joined and/or wide require traffic cones to make sure that vehicles travel over the sensors.

- When there is significant through or circulating traffic in a parking facility, sensors must transmit data frequently to the central computer to eliminate such traffic from the estimates of parking lot occupancy.

VI. Evaluation of Travel Behavior Survey Results

The final step in the feasibility analysis was the implementation of travel behavior surveys at the Rockridge BART station. The survey was developed with the focus group results to better understand the travel patterns, demographic attributes, and attitudes of BART riders at this station. The survey also explored the travel effects of the current reserved paid parking program at BART and the potential travel effects of a daily paid smart parking service. The survey results would be used to help tailor the smart parking services and information to best suit the needs of Rockridge BART station riders and to achieve one of the project's key goals: increased BART ridership.

Two travel behavior surveys, one for commuters who did and one for commuters who did not use monthly reserved paid parking, were administered in person by UC Berkeley students at the Rockridge BART station from the hours of 5:30 to 7:30 pm Monday to Thursday during the month of November 2003. See Appendix C for the questionnaires. One hundred and fifty-eight questionnaires were completed by BART commuters who did not use monthly reserved paid parking. Sixty questionnaires were completed by BART commuters who did use monthly reserved paid parking. This constituted about 25 percent of the monthly reserved paid parkers.

What follows is a detailed discussion of the survey results. First, the general commute patterns of Rockridge BART station riders are presented. This is followed by a discussion of the demographic characteristics of BART riders at the station. Next is a description of rider attitudes toward BART, its current parking services, and potential smart parking services including daily paid and valet parking. The travel effects of the monthly reserved paid parking service are then explored as well as the potential effect of a new daily paid smart parking service. Finally, key conclusions from the survey are made, and implications for the design of the smart parking service are described.

Commute Travel Patterns

The commute travel patterns of BART riders at the Rockridge station who use monthly paid parking and those who do not are described in Table 3-8, following. The survey results indicate that the dominant destination location for BART commuters at this station is downtown San Francisco (74 percent for monthly paid and 80 percent for others). The high time and monetary cost of auto travel in this origin and destination corridor provides the economic context for the demand for BART commute travel and parking at this station. Congestion on freeways in this corridor is severe and parking cost in downtown San Francisco is high. As a result, many commuters find BART travel, even with the additional cost of monthly paid parking, to be less expensive and more convenient than auto travel.

The auto is the dominant alternative to BART for commuters at the Rockridge station (80 percent of paid parkers use the auto and 64 percent of other parkers). The top alternative commute modes for both groups are the drive alone and carpool modes, but commuters with reserved paid parking are more likely to drive alone than carpool (50 percent of paid parkers drive alone versus 32 percent of other parkers). Buses, telecommuting, and motorcycles are also used occasionally as alternative commute modes.

The flexibility afforded by the auto relative to BART travel is a major reason commuters chose a private vehicle most often as their alternative commute mode. Both monthly paid parkers and other parkers report that they do not use BART for commute travel because they need a car before, during, or after work (63 percent for paid and 50 percent for other parkers). Other important reasons for both groups are time constraints (six percent for paid and 15 percent for other parkers) and variation in personal schedules (six percent for paid and 11 percent for other parkers).

Difficulty finding parking is an important barrier to BART use for those without reserved paid parking (nine percent).

The survey results related to frequency of BART commute use and propensity to use an alternative commute mode suggest that the monthly paid parking service is correlated with greater BART commute travel. Those with monthly paid parking commute more frequently via BART than those without it; 92 percent of paid parkers use BART four or more times a week versus 65 percent of other parkers. In addition, those with monthly paid parking are less likely to use a commute mode other than BART (28 versus 46 percent).

Table 3-8. Travel Patterns of BART Commuters at Rockridge Station

Attributes	Monthly Paid	Others
BART Use Frequency	*n=60*	*n=158*
Only occasionally	0%	7%
1-2 days per month	2%	6%
1-3 days per week	7%	22%
4-5 days per week	75%	53%
More than 5 days per week	17%	12%
Origin Station Area	*n=60*	*n=158*
Rockridge	95%	81%
Other East Bay	5%	17%
Other	0%	2%
Destination Station Area	*n=58*	*n=158*
San Francisco	74%	80%
East Bay	17%	13%
Other	12%	7%
Alternate Commute Mode?	*n=60*	*n=158*
Yes	28%	46%
No	72%	54%
Top Reasons Why Don't Use BART	*n=16*	*n=111*
Need car	63%	50%
Time constraints	6%	15%
Variation in personal work schedule	6%	11%
Too hard to park at BART	0%	9%
Top Alternate Modes	*n=20*	*n=111*
Drive alone	50%	32%
Carpool	30%	34%
Bus	5%	10%
Telecommute	0%	1%
Motorcycle	5%	0%

Demographic Attributes

In addition to commute travel patterns, the questionnaires also explored the demographic attributes of riders with and without monthly reserved paid parking. The results are presented in Table 3-9, following.

The demographic characteristics of Rockridge station BART riders without monthly reserved paid parking are consistent with the 1999 BART station profile. These riders are more likely to be women (56 versus 44 percent), to be 25 to 44 years old (49 percent), and to have a household income between $45,000 to $100,000 (42 percent).

Not surprisingly, the survey results suggest that riders with monthly reserved paid parking have demographic characteristics that differ from other riders at the station. First, the average household income of those commuters with monthly paid parking tended to be significantly higher than that of commuters without monthly paid parking (55 versus 32 percent have household incomes greater than $100,000). Thus, these riders are more likely to have the resources to pay for the additional BART parking costs. Second, riders with monthly reserved paid parking are more likely than other riders to have two cars available to their households (48 versus 40 percent). Thus, they have the means to drive and park at the station and thus have less incentive to carpool, bus, walk, or bike to the station. Third, those with monthly paid parking permits are somewhat less likely to belong to the professional/technical, sales, and education category (56 versus 60 percent) and somewhat more likely to belong to the manager/administrator and clerical/administrative support categories (39 versus 26 percent). The last two categories tend to have a less flexible, fixed nine to five, five-day work schedule than the former categories that tend to have more varied schedules. Finally, those with monthly reserved paid parking are more likely to be men (55 versus 44 percent) and tend to be more educated (e.g., 15 versus seven percent have a Ph.D. or higher), older (40 versus 32 percent are 45 to 64 years old), and less likely to have a one-commuter household (47 versus 55 percent) than other riders. These characteristics are consistent with the distribution of income and occupation types of the monthly reserved paid parking riders.

Approximately 90 percent of commuters surveyed at the Rockridge BART station use a cell phone. Thus, many could easily access a smart parking service that includes cell phone reservations.

In general, these results suggest that the profile of those riders who use monthly reserved paid parking and those who do not differ most significantly with respect to income, auto availability, and flexibility of work schedule. High income and an available auto are necessary conditions to subscribe to monthly reserved paid parking and the constraint of a relatively inflexible five-day work schedule makes the monthly service particularly attractive to these riders. It appears that a market may exist for a daily paid parking service among other riders and new riders with relatively high incomes, high auto availability, and flexible work schedules.

Table 3-9. Demographic attributes of Rockridge Station BART Commuters

Attributes	Monthly Paid	Other
Gender	*N=60*	*n=156*
Male	55%	44%
Female	45%	56%
Age	*N=60*	*n=155*
24 or younger	7%	16%
25-44	50%	49%
45-64	40%	32%
65 or older	3%	3%
Key Education Levels Attained[a]	*N=60*	*n=157*
Some college	13%	13%
Associate's degree	3%	3%
Bachelor's degree	39%	39%
Some graduate school	6%	6%
Master's degree	25%	25%
Ph.D or higher	7%	7%
Law degree	4%	4%
Key Occupations[a]	*N=59*	*n=158*
Manager/administrator	27%	22%
Clerical/administrative support	12%	4%
Sales	5%	9%
Professional/technical	46%	48%
Student	5%	13%
Use Cell Phone	*n=60*	*n=157*
Yes	87%	91%
Household Commuters	*n=60*	*n=157*
One	47%	55%
Two	43%	32%
Three	8%	9%
Four	2%	3%
Household Car Availability	*n=60*	*n=157*
Zero	0%	3%
One	35%	43%
Two	48%	40%
Three	13%	11%
Four or More	3%	3%
Household Income	*n=58*	*n=150*
Under $45K	14%	26%
Between $45K and 100K	31%	42%
Over 100K	55%	32%
Household Members by Age	*n=60*	*n=158*
Children Under 5	4%	8%
Children 6 to 18	16%	12%
Adults 19 to 64	78%	76%
Adults 65+	2%	4%

[a] Category does not sum to 100% because types with one or less responses were omitted.

Attitudes Toward Current and Hypothetical BART Services

Attitudes toward BART services were also explored in the surveys. Key findings are described in Table 3-10 (below). A majority of the riders surveyed are either very satisfied or somewhat satisfied with BART services overall. However, commuters with monthly paid permits are somewhat more satisfied with overall BART services than those without permits (80 versus 74 percent are somewhat or very satisfied). When asked about the quality of the BART parking service used by the rider, most of the monthly paid parkers indicated that they like the convenience and reliability of their reserved spot (65 percent) but disliked the cost of the service (64 percent). Most of those without a monthly paid permit prefer that BART parking is free (36 percent) and the close proximity of parking to the station (27 percent), but dislike searching for parking (31 percent) and the fact that parking is often unavailable (28 percent).

Table 3-10. Attitudes Toward BART Services by Rockridge Station Commuters

Attitudes	Monthly Paid	Other
BART Satisfaction	*N=60*	*n=158*
Very satisfied	27%	27%
Somewhat satisfied	53%	47%
Neutral	13%	16%
Somewhat unsatisfied	5%	8%
Very unsatisfied	2%	2%
Top Parking Likes	*N=60*	*n=158*
First	Convenience & reliability (65%)	No cost (36%)
Second	Close proximity (20%)	Close proximity (27%)
Third	Pay once a month (10%)	Well lit (13%)
Fourth	Time flexibility (4%)	Secure (7%)
Fifth	Reasonable price (1%)	Carpool parking (3%)
Top Parking Dislikes	*N=60*	*n=158*
First	Too costly (64%)	Searching for parking (31%)
Second	Space not always available (25%)	Parking is often unavailable (28%)
Third	Waitlist for spot (4%)	Paying for parking (15%)
Fourth	Lack of enforcement (3%)	Poor lighting (5%)
Fifth	Not close enough (1%)	Carpool parking full (5%)

Attitudes toward a hypothetical valet parking service at the station were also explored in the survey. Table 3-11, following, presents the results. Most of the respondents in both groups like the idea of saving time by not having to park their car (41 to 46 percent) and the potential for increased personal and car security (15 to 18 percent). However, both groups also do not like the idea of giving their key to an attendant (50 to 64 percent) or waiting for the attendant to deliver their car to them (20 to 24 percent). If such a service were introduced at BART stations, service design and outreach efforts would likely be necessary to highlight the benefits of the service and address potential concerns.

Table 3-11. Attitudes Toward a Hypothetical Valet Parking Service at the Rockridge BART Station

Likes And Dislikes	**Monthly Paid**	**Other**
Top Valet Parking Likes	*n=39*	*n=88*
Increased personal security	18%	15%
Increased car security	23%	20%
Time saved by not parking car	46%	41%
Time saved by shorter walk to station	10%	13%
Increased capacity	3%	8%
Top Valet Parking Dislikes	*n=59*	*n=157*
Don't like idea of giving my keys to attendant (possible theft)	64%	50%
Would not like to wait for the attendant to retrieve my car	20%	24%

Attitudes toward the current monthly reserved paid parking program and a hypothetical daily paid parking service were also examined in the survey. The results are summarized in Table 3-12, following. First, respondents were asked why they did or did not purchase paid parking. The primary reasons why commuters subscribe to paid parking are: searching for parking is a hassle (49 percent), and parking is often unavailable when they need it (41 percent). Among those who have not subscribed to monthly paid parking, the primary reasons are the high cost (62 percent) and lack of monthly need (22 percent). When regular parkers were asked if they would use a paid daily parking service at the station, 15 percent said that they would, and 28 percent of those said that they might use BART more often as a result. When monthly paid parkers were asked if they might switch to daily paid parking, about 10 percent said that they might and about 21 percent of those respondents said, as a result, that they might use BART less often.

Table 3-12. Attitudes Toward Daily Paid Parking at the Rockridge BART Station

Monthly Paid		Others	
Why monthly parking?	*n=59*	Why not monthly parking?	*n=157*
Searching for parking is a hassle	49%	Paid parking is too expensive	62%
Parking is often unavailable	41%	Don't need parking on a monthly basis	22%
Safety	4%	Not aware of the paid parking option	5%
More convenient	2%	Paid parking is already full	5%
Travel patterns changed	2%	No trouble finding a space	4%
Walking distance too far	1%	Not Democratic	1%
Daily paid instead of monthly?	*n=60*	Use daily paid?	*n=157*
Very likely	10%	Yes	15%
Somewhat likely	8%	No	71%
Neutral	35%	mixed	9%
Unlikely	0%	Uncertain	4%
Very unlikely	47%		
Why daily paid?	*n=19*	Why daily paid?	*n=57*
Need daily not monthly	42%	Need daily not monthly basis	31%
Daily paid parking more affordable	53%	Daily paid parking more affordable	19%
More departure time flexibility	0%	More departure time flexibility	31%
Convenience & assured space	5%	Convenience & assured space	9%
If daily paid, use BART less often?	*n=31*	If daily paid, use BART more often?	*n=57*
Yes	21.9%	Yes	28%
No	59.4%	No	47%
Mixed	12.5%	mixed	11%
Uncertain	3.1%	Uncertain	14%

Note: Only those who said that they would consider using daily paid parking were included in the calculations of whether BART use would increase.

Travel Before and After Monthly Reserved Paid Parking

The survey also examined the before and after travel patterns of monthly paid parking subscribers. The results are documented in Table 3-13, following. As the primary commute mode, BART travel increases by 15 percentage points, drive alone travel decreases by 8 percentage points, and carpool, bus, and/or bike travel decreases by 6 percentage points when a commuter subscribes to monthly paid parking. With respect to BART access mode share, there was a significant increase in drive alone access (23 percentage points) and a decrease in carpool, bus, and walk mode shares (at least 19 percentage points). In general, it appears that monthly paid parking increases BART use among subscribers but may not reduce their overall auto travel because of diversions to BART from carpool, bus, and bike modes for the main commute mode and increased drive alone access to the BART station.

Table 3-13. Travel Before and After Joining Monthly Reserved Paid Parking at the Rockridge BART Station

Main Commute Mode Share (n=59)	Before	After	Change
BART	85%	100%	15%
Drive alone exclusively	8%	0%	-8%
Carpool & bus	3%	0%	-3%
Carpool, bus & bike	3%	0%	-3%
BART Access Mode Share (n=47)	**Before**	**After**	**Change**
Drive alone	77%	100%	23%
Drive alone & carpool	2%	0%	-2%
Drive alone & bus	2%	0%	-2%
Carpool	11%	0%	-11%
Bus	6%	0%	-6%
Walk	2%	0%	-2%
BART Frequency (n=50)	**Before**	**After**	**Change**
Only occasionally	1	0	-1
1-2 days/month	1	1	0
1-3 days/week	6	3	-3
4-5 days/week	37	37	0
More than 5 days/week	5	9	4

Summary and Conclusions

More than three-fourths of Rockridge BART station commuters are headed for work locations in downtown San Francisco. Congestion on freeways in the corridor from Rockridge to San Francisco is severe and the cost of parking in the downtown is very high. As a result, many commuters find BART travel, even with the additional cost of monthly reserved paid parking, to be overall less expensive and more convenient than auto travel. On the other hand, many commuters at this station do not use BART everyday to commute to work; instead, they regularly travel to work by car because of its greater flexibility with respect to running errands before, during, and after work.

Demographic profile results suggest that those riders who use monthly reserved paid parking and those who do not differ most significantly with respect to income, auto availability, and flexibility of work schedule. High income and an available auto are necessary conditions to subscribe to monthly reserved paid parking and the constraint of a relatively inflexible five-day work schedule makes the monthly service particularly attractive to these riders. These results suggest a potential market for a daily paid parking service among other riders and new riders with relatively high incomes, high auto availability, and flexible work schedules.

The survey results do suggest that limited parking at the Rockridge station may be a significant barrier to BART commuting. In fact, nine percent of riders without monthly reserved paid parking indicated that this was the case. Many also stated that they dislike searching for parking (31 percent) and the lack of available parking (28 percent). The primary reasons why riders do not purchase monthly parking are the high cost (62 percent) and the lack of monthly need (22 percent). When these riders were asked if they would use a paid daily parking service at the station, 15 percent said they would and 28 percent of those said that they might use BART more often as a result.

The analysis of the travel effects of the current monthly reserved paid parking service indicates that it has increased the frequency of BART use among subscribers, but may not have reduced their net auto travel because of diversions to BART from carpool, bus, and bike modes for main commute and increased drive alone access to the BART station. Seventy-five percent of paid parkers use BART four to five times a week versus 53 percent of other parkers. As the primary commute mode, BART travel increased by 15 percentage points; drive alone travel decreased by eight percentage points; and carpool, bus, and/or bike travel decreased by six percentage points. With respect to BART access mode share, there was a significant increase in drive alone access (23 percentage points) and a decrease in carpool, bus, and walk mode shares (at least 19 percentage points).

VII. Conclusion

The results of the feasibility analysis indicate that the smart parking technology may be applied to the Rockridge BART station to meet the unmet demand for parking and transit use by a segment of travelers in the area and thus maximize existing parking at the station and increase transit ridership. Chapters 4 and 5 discuss the design and technology of the smart parking field test.

CHAPTER 4. SMART PARKING FIELD TEST DESIGN

I. Introduction

As discussed in Chapter 3, researchers used observational analyses, sensor testing, focus groups, and surveys to conduct the feasibility analysis. The feasibility analysis focused on two key stations: the Walnut Creek and Rockridge BART stations. This chapter describes the feasibility analysis process and how it guided the final field test design at the Rockridge BART station.

II. Analysis of the Walnut Creek BART Station

This phase began with an analysis of consumer parking information needs and potential responses to different smart parking services. In addition to the observational analysis of parking behavior at the Walnut Creek BART station, exploratory in-person interviews were conducted with commuters who accessed BART at Walnut Creek. The results of these interviews helped inform the design of the protocol for the two focus groups. The first focus group solicited feedback from BART commuters who used the Walnut Creek Station. The second included those who drove to work but could commute by BART using the Walnut Creek station. The focus groups provided valuable insight into the feasibility study and where to ultimately site the field test. Chapter 3 presents a detailed discussion of the focus group results.

Next, temporary sensors were installed in the reserved paid parking lot for accuracy testing. These sensors collected data on the number of drivers entering and exiting a parking lot by time of day. Since the temporary sensors could not remotely communicate data to a central computer, researchers manually retrieved them and downloaded the data in their offices. Additional observational analyses were conducted at the site of sensor installation in the Walnut Creek parking lot. Researchers counted the number of cars entering and exiting a lot for specific time intervals. The numbers obtained from the sensors and observational analyses were then compared to evaluate sensor accuracy. The results of the analysis indicated that the sensors were capable of producing accurate counts and yielded important insights about how to optimize their accuracy. The detailed analysis is presented in Chapter 3.

VMS signs ultimately could not be installed at this station because of institutional barriers. Researchers attempted to locate a VMS sign with information about BART parking on a major intersection in Walnut Creek to encourage drivers to take BART instead of using the freeway to get to work. Researchers worked closely with the city’s transportation department to obtain all necessary approvals; however, the city’s zoning requirements and strict signage restrictions could not be modified for purposes of the field test.

The Walnut Creek BART station analysis yielded a number of key findings:

- Sensors are accurate enough (typically, a three percent or less error level) to be used in a smart parking field test.

- There is consumer interest in pre-trip and en route parking information on free and daily paid BART parking.

- Smart parking services may increase transit ridership.

- Institutional barriers can present significant problems for implementation of VMS signs on arterials and/or highways.

III. Analysis of the Rockridge BART Station

As described above, the Rockridge BART station was identified as a viable location for the smart parking field test for a number of reasons.

- Parking demand at this station is high; unpaid parking is full by 7:30 am on many weekdays, and there is a waiting list for monthly reserved paid parking.

- Although monthly paid parking is fully booked, many spaces remain available during peak morning commuter hours because subscribers do not use BART on a daily basis. These spaces could be reserved on a daily basis with a pre-trip and/or en-route smart parking system with or without charge.

- This BART station is adjacent to Highway 24, an important commute corridor from the East Bay to downtown Oakland and San Francisco. Locations along Highway 24 would allow for the placement of VMS signs that alert commuters to available parking at the Rockridge station.

BART granted 50 parking spaces to be dynamically managed in the smart parking field test from the monthly paid parking lot, which were formerly reserved for after 10:00 am parking. During the field test, commuters will be able to make advanced (up to two weeks) or same day reservations for these spaces. Initially, fifteen of these spaces will be available for advanced reservations and the remainder, less a buffer of five spaces to ensure availability, will be set aside for same day reservations. This ratio may change in response to demand. In addition, each motorist is initially limited to three daily reservations over a two-week period to ensure that the project is attracting new riders rather than repeat riders. BART has also authorized the use of printed permits, which smart parking participants will receive electronically and display on their dashboards. In addition, at the start of the project, these spaces will be offered at no cost, but later a fee may be charged. To participate in the field test and reserve a daily parking space, BART patrons are required to join ParkingCarma™, use BART at least one to three times a week, complete a user questionnaire, and use the Internet, phone, or PDA to make a reservation.

The smart parking field test at the Rockridge BART station involves two real-time user interfaces: 1) a VMS sign that displays parking availability information to motorists on Highway 24 and 2) a centralized reservation system that permits commuters to check parking availability and reserve a space via telephone, cell phone, Internet, or PDA. The smart parking system integrates traffic count data from entrance and exit sensors at the BART station parking lot with the reservation system to provide accurate up-to-the-minute estimates of parking availability. Smart parking can facilitate pre-trip planning by permitting users to reserve a space from 48 hours to two weeks in advance, but it will also enable en-route decision making, providing real-time parking availability information to encourage motorists to use transit. If a motorist confronts congestion on Highway 24, he can check parking availability on the VMS sign, and instantly phone the reservation system to "lock-in" a space before exiting the freeway. Chapter 5 provides a more detailed discussion of this technology.

The following scenarios describe how commuters might use the smart parking field test at the Rockridge BART station for advanced and same day reservations.

Scenario One: Commuter without an Advance Reservation

It is 7:45 am and a westbound commuter on Highway 24 passes a VMS sign that indicates 20 parking spaces are available at the Rockridge BART station. This commuter could use BART to get to his morning meeting in San Francisco (and save money on parking). The commuter exits the freeway to find parking. Upon arrival at the lot, he parks in one of the 50 designated smart parking spaces. Then, he calls (either on his cell phone or a pay phone close by) the ParkingCarma™ reservation number, joins ParkingCarma™, with his license plate and space number, and catches the train. He is actually early to his meeting in San Francisco.

Similarly, a ParkingCarma™ member sees the same sign at 8:00 a.m., indicating that there are 12 spaces available. This commuter immediately calls into the ParkingCarma™ system on her cell phone and reserves a space for the day. Upon arrival at the Rockridge BART station, she pulls into any one of the 50 designated smart parking spaces and catches the train.

The BART police in both of these scenarios receive a real-time message via PDA that these commuters have legitimate reservations for the smart parking field test at Rockridge BART.

Scenario Two: Commuter with an Advance Reservation

Every day, between 7:45 and 8:15 am, a commuter sees a VMS sign on Highway 24 indicating that there are parking spaces available at the Rockridge BART station. Each week, there are at least two days that this commuter could take BART but has never tried because she assumes that the parking lot is always full. Upon arrival at the office, she enters the BART/parking web site, clicks on the smart parking pilot icon, enters the ParkingCarma^{TM} reservation system, and joins ParkingCarma^{TM}. She then reserves a space on the following Thursday and prints out a permit to display in her windshield. By the time of the reservation, she also receives a ParkingCarma^{TM} membership sticker to place in the windshield.

The following Thursday, she pulls into the Rockridge BART parking facility at 8:30 a.m., parks in one of the 50 designated smart parking spaces, places the smart parking permit on the dashboard, and catches the next train.

The BART police check the membership sticker and permit on the car to ensure that this commuter has a legitimate smart parking reservation.

IV. Conclusion

The feasibility analysis process provided important guidance to the design of the smart parking field test at the Rockridge BART station. Next, in Chapter 5, the technology customization for the smart parking field test is described.

CHAPTER 5. TECHNOLOGY CUSTOMIZATION AND IMPLEMENTATION

I. Introduction

As the smart parking management contractor, ParkingCarma™ worked with California Partners for Advanced Transit and Highways (PATH) researchers to develop the technology design and implementation plan. The smart parking field test at the Rockridge BART station involves two real-time user interfaces: 1) a VMS sign that displays parking availability information to motorists on Highway 24 and 2) a centralized reservation system that permits commuters to check parking availability and reserve a space via cell phone, telephone, Internet, or PDA. The smart parking system integrates traffic count data from entrance and exit sensors at the BART station parking lot with the reservation system to provide accurate up-to-the-minute estimates of parking availability. By providing motorists with accurate real-time information about parking availability and a simple way to lock-in a space, the project team believes the field test may improve the convenience of using BART and encourage increased ridership. This section describes the technology testing and implementation, in addition to summarizing educational tools and user features designed by ParkingCarma™ to facilitate system use.

II. Technology Donations

A donation of technology equipment from the Quixote Corporation was secured by ParkingCarma™ for the field test. This technology included:

- ***Five Temporary Wireless Counters*****:** These above-ground temporary counters are inexpensive and easily installed. They have a short operating life of only five days before they need to be recharged, and data need to be downloaded from them manually, thus they are not ideal for the field test. They serve a key purpose, however, in verifying the optimal location of permanent sensors before the station is impacted (by boring holes in the ground) to install the in-ground sensors.

- ***Six In-Ground Wireless Sensors*****:** Once the proper location for sensors was determined with the temporary counters, the in-ground wireless sensors or "groundhogs" were installed. These sensors are buried beneath the surface and have the advantage of wireless Internet capability. They can communicate data about parking availability real-time via the Internet. They can last five years in the ground and are very unobtrusive. Each groundhog is approximately six inches in diameter, but has a sensing radius of roughly three feet. A car passing anywhere over this sensing radius will trigger the sensor.

- ***Two Local Base Units, One Master Base Unit:*** Both are wireless computerized data relay points. The two local base units collect information directly from the groundhogs and transfer it to the master base unit that has Internet capability and relays the parking availability information to the central computer. The key differences between the local base unit and the master base unit are that the local base units (LBUs) are designed to pull information from the groundhogs, which the master base unit (MBU) cannot do, and the MBU is more sophisticated and can communicate via the Internet. The LBUs are necessary because there are six groundhogs at the Rockridge parking lot, and the MBU does not have the range to pull data from all six groundhogs. Both LBUs and the MBU are solar-powered.

- ***Two Variable Message Signs with Cellular Communication Capabilities*:** These quasi-temporary signs will provide motorists on Highway 24 with real-time information about parking availability at the Rockridge station. VMS signs with cellular capabilities allow instantaneous remote updates of the messages they display. With a simple phone call, smart parking managers can alter the format or content of the display. The VMS signs are less expensive to install and more flexible than a wired solution because the signs can be moved if the originally conceived location does not prove effective. These signs are also solar-paneled so they are less costly to operate and do not require a power source.

- ***Eight Knock-Down Delineators*:** These brightly colored flexible traffic cones are placed at entrances and exits to stations to ensure that cars trigger sensors for accurate data counts.

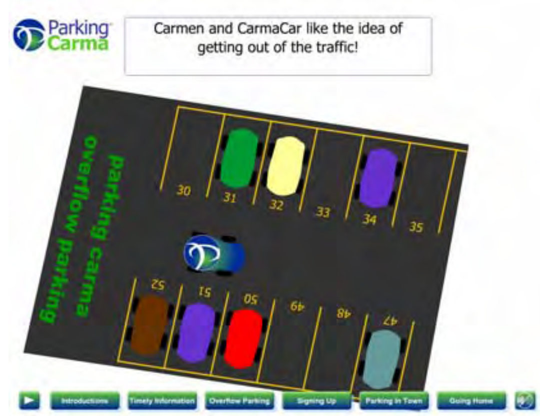
In addition, ParkingCarma™ has also donated the use of its software, server capacity, and associated in-kind engineering time necessary to customize technology for use at the Rockridge BART station.

ParkingCarma developed a partnership with Microsoft and Intel to enhance the smart parking service with a speech recognition system. Donations from these project partners permit users to call using a cell phone or land line to reserve a parking space in advance, or inform the system that they have arrived at the parking lot after seeing the sign on the freeway. Microsoft is providing software; Intel is providing hardware for this feature.

III. Smart Parking Management Educational Tool

A three-minute video for display on the Internet was developed by ParkingCarma™ to familiarize commuters with the benefits of a smart parking service. Highlighting the frustrations of traffic congestion, the video provides a thorough explanation of the mechanics of the proposed alternative: the smart parking reservation system. The video demonstrates how the smart parking technology facilitates reserving parking in advance, locating parking, and riding BART. Originally conceived for the Dublin-Pleasanton BART station configuration, the video depicts a user leaving her car at overflow parking and riding a short shuttle to catch the BART train. While the Rockridge station field test does not involve overflow parking at an off-site location, the video serves a useful purpose in explaining the mechanics and benefits of the smart parking system. Below are a series of screen shots from the video highlighting some key points.

First, there appears a potential smart parking user who is driving down a congested freeway into San Francisco and reads that there is available parking at a nearby BART station on a variable message sign.



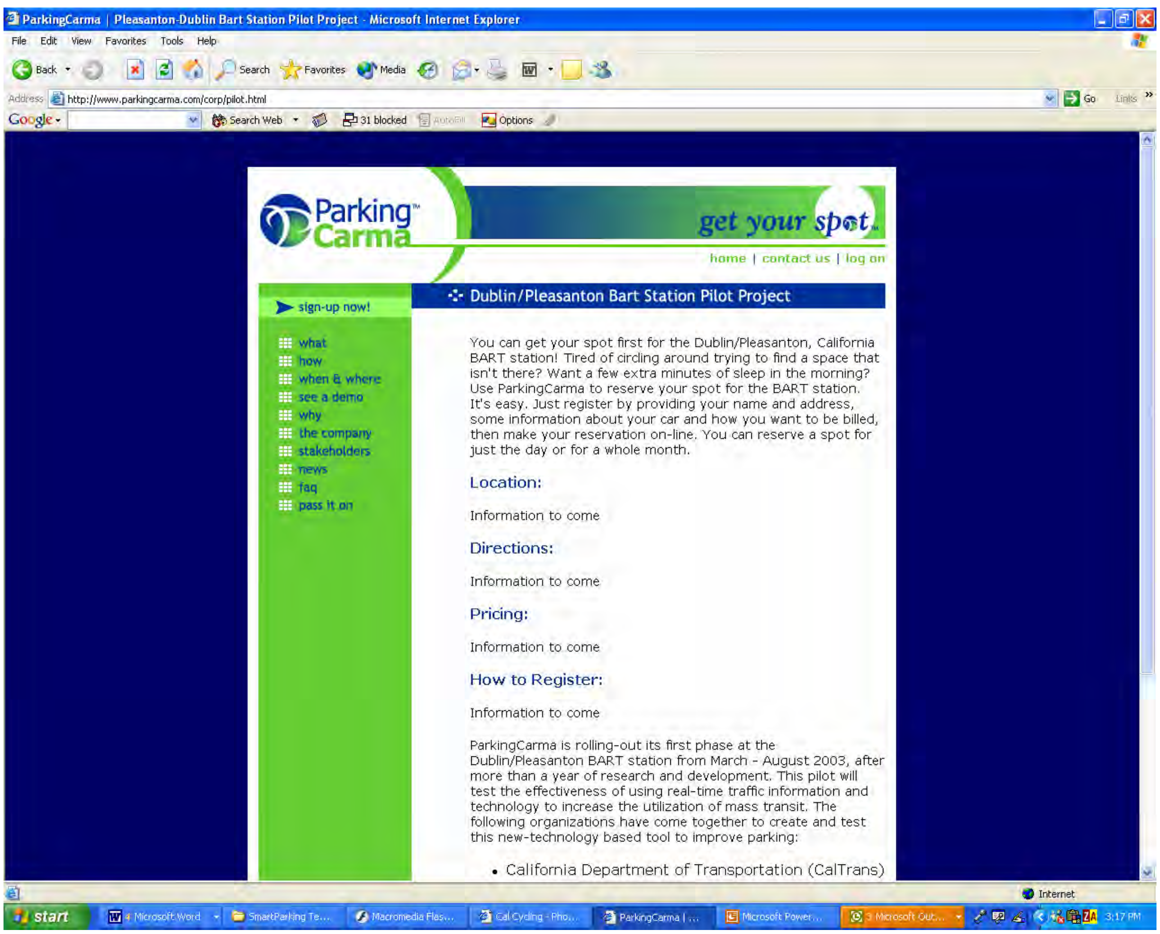
When the motorist arrives at the station, ground sensors at the entrance track one new arrival and send a message to a central computer that one fewer space is available. Instantaneously, the display on the freeway reduces the available parking tally by one.

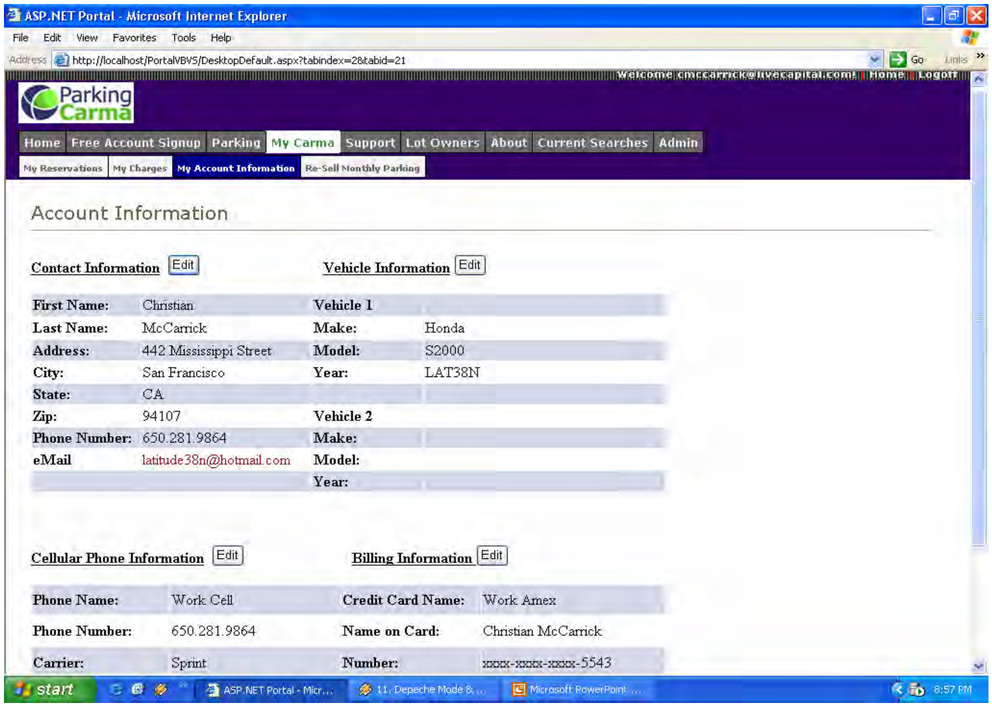
The user rides BART to the city center and walks to her destination.

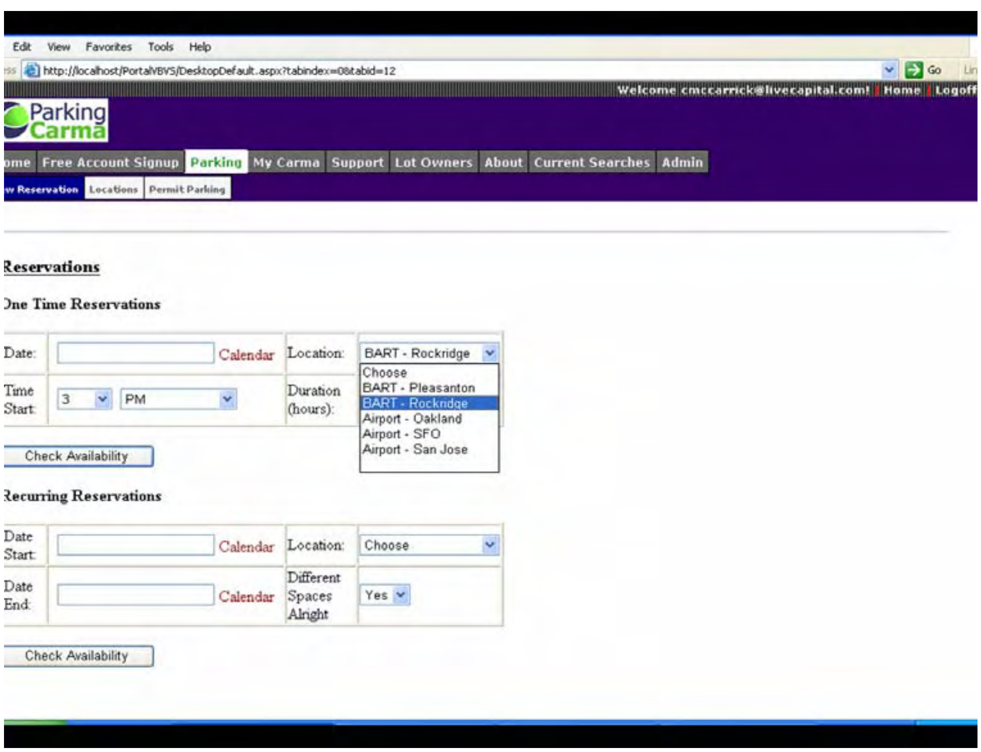
Once she has arrived at her office, the commuter visits the ParkingCarma web site to register for the service.

IV. Web-Based User Interface

As described in the literature review on PGI systems, providing travelers with accurate parking availability information is essential to the success of a smart parking service. To make riding transit as convenient as possible, ParkingCarma^{TM} developed a unique web-based user interface to provide commuters with up-to-the-minute parking availability information and to facilitate advanced trip planning. The web site allows users to reserve a space up to two weeks in advance, print parking permits, receive directions to the transit station, and link to a site with train fare and schedule information. ParkingCarma^{TM} refined the web interface several times to incorporate focus group feedback and to reflect the evolving focus of the field test. The resulting web site is highly intuitive and user-friendly. It is also one of the first "dot-net" based systems for parking reservations. The advantage of "dot-net" technology is that it is very easily scaled up or down to meet the specific demands of other smart parking arrangements. Following are a series of pages from the reservation web site.




ASP.NET Portal - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://localhost/PortalVBVS/DesktopDefault.aspx?tabindex=2&tabid=21
Welcome cmccarrick@livecapital.com! Home Logoff
Parking Carma
Home Free Account Signup Parking My Carma Support Lot Owners About Current Searches Admin
My Reservations My Charges My Account Information Re-Sell Monthly Parking
Account Information
Contact Information Edit
Vehicle Information Edit
First Name: Christian
Last Name: McCarrick
Address: 442 Mississippi Street
City: San Francisco
State: CA
Zip: 94107
Phone Number: 650.281.9864
eMail latitude38n@hotmail.com
Vehicle 1
Make: Honda
Model: S2000
Year: LAT38N
Vehicle 2
Make:
Model:
Year:
Cellular Phone Information Edit
Billing Information Edit
Phone Name: Work Cell
Phone Number: 650.281.9864
Carrier: Sprint
Credit Card Name: Work Amex
Name on Card: Christian McCarrick
Number: xxxx-xxxx-xxxx-5543
start
ASP.NET Portal - Micr...
11. Depeche Mode &...
Microsoft PowerPoint ...
8:57 PM


Edit View Favorites Tools Help
http://localhost/PortalVBVS/DesktopDefault.aspx?tabindex=0&tabid=12
Welcome cmccarrick@livecapital.com! Home Logoff
Parking Carma
ome Free Account Signup Parking My Carma Support Lot Owners About Current Searches Admin
w Reservation Locations Permit Parking
Reservations
One Time Reservations
Date: Calendar
Location: BART - Rockridge
Choose
BART - Pleasanton
BART - Rockridge
Airport - Oakland
Airport - SFO
Airport - San Jose
Time Start: 3 PM
Duration (hours):
Check Availability
Recurring Reservations
Date Start: Calendar
Location: Choose
Date End: Calendar
Different Spaces Alright Yes
Check Availability

Prior to explaining the benefits of the user interface to BART, ParkingCarma™ engineers conducted quality assurance technical testing of the web-based reservation system. Engineers made the following system tests: 1) verified that the reservation engine interface works properly and that reservations made by users are accurately received; 2) ensured that the database properly calculates the number of available spaces given inputs from the Internet, PDA, telephone or cellular phone; and 3) verified that the web site and hyperlinks function as designed around the clock. Engineers resolved all issues that were discovered prior to the Rockridge testing phase.

V. Technology Customization

Once Rockridge was chosen for the field test, UC researchers and ParkingCarma™ worked with BART to tailor the smart parking technology to the circumstances of this station. Since the original system was customized for the Dublin-Pleasanton station, which had a substantially different configuration, the reservation system was updated with new directions to the Rockridge station, and the shuttle schedule and capability was removed. The system was upgraded with a newer version of the Microsoft software that provided greater stability and enhanced security. Since the entrance/exit configuration is unique at the Rockridge BART station, ParkingCarma™ installed four temporary sensors to determine the proper placement of permanent in-ground sensors.

Once locations were finalized, ParkingCarma™ installed four in-ground sensors, one in each lane of ingress and egress at each of the two entry/exit locations into the monthly reserved parking lot at Keith Ave. and Miles Ave. Two additional sensors were installed at the entrance/exit to the area of the lot containing the 50 designated smart parking spaces. This permits project managers to monitor exactly how many spaces are available at any given time. Knock-down traffic cones were also installed to guide cars passing through entrances and exits directly over sensors. The sensors send parking count data to two LBUs—solar-powered computerized data relay points. These LBUs relay the data from the in-ground sensors to a MBU—a computer transceiver that has wireless Internet capability. The LBUs and the MBU were located at the rail/freeway level to allow access to clear solar power and connection to the Internet. These nine components—the six groundhogs, two LBUs and the MBU—act as a wireless counting system. This information gathering system transmits data through local DSL to the ParkingCarma™ computer servers.

VI. Beta Testing of Communications Integration

The goal of the beta communications testing was to evaluate whether the system is operational and to integrate focus group feedback to ensure that the commuting public understands the service.

ParkingCarma™ is testing the technology to ensure that it is operational by the time the VMS signs are placed on the freeway. Specifically, the technology team is testing the functionality of the LBUs and MBU, and soliciting individuals to test the three user-interfaces, including: messages on the VMS sign, reservations by phone, and reservations via Internet. ParkingCarma™ will coordinate the testing to ensure integrity of the system with multiple simultaneous users. During the testing period a VMS sign was placed at the PATH headquarters, at the Richmond Field Station, so that messages could be evaluated before the sign was placed on the freeway.

Beta-testers include: UC researchers, project partners, and, ParkingCarma™ technology experts. An evaluation form was developed to solicit comments on areas for improvement. ParkingCarma™ consolidated the evaluation form feedback and prioritized it based on "wants" and "needs." Some changes were made immediately and some will be scheduled for a later release of the product. ParkingCarma™ will provide a record of user feedback, changes, and release schedule prior to launch. Caltrans, BART, and UC Berkeley researchers will review the release schedule and provide approval prior to public implementation.

ParkingCarma™ is examining and testing the following components to verify that:

1. The system is communicating information accurately from the Rockridge site to the servers, back to the VMS signs, Internet, and voice interface, located at PATH;

2. The system is able to obtain and confirm reservations, and confirm the reservation count by comparing the reservation data with the counts sent to the central computer by the wireless ground sensors;

3. The User Interface and site structure including the look and feel of the web site and reservation engine are appealing, easy to understand, and convenient to use;

4. The content of the web site and technology are appropriate, comprehensive and easy to understand; and

5. Multiple members can use the system simultaneously without inconvenience, user delay, or loss of information (this includes five or more testers doing the same activities at the same time, which will test the system's load capacity for the field test at its bottle neck and the voice IVR system).

VII. Conclusion

During the first phase of the field test, UC Researchers and ParkingCarma™ worked with BART to incorporate smart parking technology into the BART parking system. A donation from the Quixote Corporate permitted the integration of smart parking software with technology known to count vehicles and communicate with variable message signs. The product is a smart parking technology that can be modified to meet the highly specific requirements of the individual BART stations or other transit stations or smart parking facilities. The advanced reservation system also assists in way-finding, providing users with directions to BART stations.

Responding to the evolving project scope, ParkingCarma^{TM} modified the original design of the technology several times during the planning phases. The final design reflects the specific constraints and circumstances of the Rockridge BART station. ParkingCarma^{TM} installed the technology at the Rockridge BART facility and initiated testing to ensure a seamless transition for BART commuters. ParkingCarma^{TM} also refined the customer interface based on focus group feedback and will continue to enhance the smart parking system.

CHAPTER 6. SUMMARY AND CONCLUSIONS

I. Introduction

This report documents the research and feasibility analysis for the design and implementation of a smart parking management field test at the Rockridge BART station in the East San Francisco Bay Area. The report began with an extensive literature review of smart parking systems, continued with a detailed feasibility analysis, and culminated with a description of the smart parking field test and its technology. What follows is a discussion of the major conclusions from each section.

II. Literature Review

Smart parking management systems have been implemented predominantly in Europe and Japan since the early 1970s to reduce congestion, vehicle travel, and fuel use, and to increase transit travel. Early systems provided parking guidance information (PGI) to drivers in central city areas about the location of available parking with information that ranged from "lot empty" to the number of spaces available via VMS signs. Later PGI systems provided the exact location of a space in a large facility. A major objective of these systems is to minimize parking search traffic and travel in central cities and in large parking facilities. Evaluations (empirical and simulation) of PGI systems suggest that they are used largely by visitors rather than commuters, can significantly reduce parking facility queues, and may produce relatively modest overall system-wide reductions in travel time and vehicle travel. In the U.S., city center PGI systems have been introduced in St. Paul, Minnesota, and Pittsburgh, Pennsylvania. Large airport parking garage PGI systems have been installed in: Baltimore, Maryland; Houston, Texas; Orlando, Florida; and Minneapolis/St. Paul, Minnesota.

More recent smart parking applications provide real-time information to motorists about the number of available parking spaces in park-and-ride lots, the departure time of the next train, and downstream roadway traffic conditions (e.g., accidents and delays). PGI systems are also sometimes used to efficiently guide drivers to open spaces in park-and-ride lots. The results of the literature review indicate: 1) a lack of parking at suburban rail stations may be a significant constraint to transit ridership; 2) pre-trip and, perhaps, en-route information on parking availability at transit stations may have a important effect on transit ridership; and 3) regular commuters are more likely to use transit-based parking information than PGI systems because this information may be critical to catching or missing a train during peak hours. Transit-based systems are concentrated in Europe and Japan; however, at least two have been initiated in the U.S.—in conjunction with Chicago's Metra System and San Jose's Valley Transit Authority.

Advances in smart payment systems (e.g., smart meters, smart cards, mobile communications, and e-parking) can improve the convenience of parking payment and reduce operation, maintenance, and enforcement costs of parking facility operators. For example, smart cards can minimize transaction time by allowing a user to simply wave their card in front of a reader. In the context of transit station parking, these time saving technologies may mean the difference between a decision to park and ride transit or drive the remainder of a trip. In the U.S., smart payment systems have been installed in Berkeley and Monterey, California; Lansing, Michigan; the University of Maryland College; and Orlando, Florida. E-parking systems are being tested in Brussels, Belgium.

In general, smart parking technology allows people to dynamically reserve and pay for parking in advance of travel. Such technology may facilitate the introduction of parking pricing policies and significantly reduction auto travel and increase transit ridership. Paying for parking may be more palatable to motorists, if they feel they are getting an advanced benefit from it. Motorists may pay a premium for the luxury of knowing that they won't have to circle for parking once they arrive at their destination.

The broader advantage of smart parking is that it permits an optimization of existing parking. By serving as a virtual parking broker, smart parking can facilitate parking pricing and better match parking supply with demand.

III. Feasibility Analysis

This smart parking project was originally developed in 2002, when the Bay Area was still experiencing a strong economy. The initial design included overflow, BART parking at the Dublin/Pleasanton station in a neighboring business park with underused parking. A shuttle bus would transport riders to the parking-constrained BART station. VMS signs located on highways adjacent to the BART station would alert and direct drivers to available overflow parking. Six months later, the Bay Area economy experienced a significant downturn, highway traffic conditions improved, and BART ridership dropped. At the Dublin/Pleasanton station, parking demand declined significantly, and BART instituted monthly reserved paid station parking and airport parking. As a result of these changed conditions, researchers reassessed the design and location of the project.

The feasibility analysis began with a comparative evaluation of rider attributes at three BART stations (Rockridge, Walnut Creek, and El Cerrito Del Norte) identified by the project team as potential sites. BART data on riders at the three stations provided some insights into the demand for a smart parking pilot project. All stations were used heavily for commute travel. Riders at the Rockridge and Walnut Creek stations had relatively high incomes and, as a result, may be more willing to pay for a smart parking service. Riders at these stations also appeared to use the Internet frequently and thus may be comfortable using the smart parking Internet reservation service. At the Rockridge station, riders were least likely to use a private auto to access the station. High parking demand at this station may be one explanation for low auto access, which may be explained by limited parking capacity. In addition, riders at the Rockridge station were least likely to use BART five or more times a week, which suggests that monthly reserved parking may not suit the needs of many riders and/or those that subscribed to monthly reserved parking may not use it every day.

Next systematic observations were made of parking demand and activity in and around the three stations. Based on the results of the observational analyses, a number of recommendations were made for the smart parking field test.

- **El Cerrito Del Norte** BART station did not have sufficient peak parking demand to warrant a smart parking system (i.e., unpaid parking was not full by 8:00 am).

- A smart parking system at the **Walnut Creek BART station** could be implemented as part of the project to alert drivers to available monthly paid parking, using a VMS sign and sensor and messaging technology. While unpaid parking did fill early (before 8:00 am) at this station, monthly paid parking was not fully subscribed.

- A smart parking system at the **Rockridge BART station** could be implemented to maximize existing parking use. Parking demand at the station was very high. Regular unpaid parking typically filled around 7:30 am. Monthly reserved paid parking was fully subscribed, with a substantial waitlist; however, many of the monthly reserved paid parking spaces were not fully occupied on weekdays. Again, the system would include traffic sensors to monitor parking availability and VMS signs on Highway 24—an important commute corridor from the East Bay to downtown Oakland and San Francisco—to alert drivers to space availability. In addition, smart parking reservation technology would permit travelers to reserve daily paid spaces by Internet, PDA, phone, and cell phone. This station was ultimately selected for the field test due to its high parking demand—unpaid and monthly reserved.

The observational analyses were followed by two focus groups, one with BART riders and one with non-BART commuters, to explore attitudes toward commute modes, parking, and smart parking design concepts. The focus groups yielded a number of important conclusions about the demand for smart parking services and insights into the design of the service:

- The most popular BART attributes were avoiding roadway traffic and the opportunities to sit and relax on the train.
- The biggest complaint about BART parking was that it filled up too early in the morning.
- Interest was expressed in using pre-trip and en-route parking information (free and daily paid) to reserved BART parking.
- Concern was expressed about the ability of the system to prevent someone from taking a reserved spot.
- Many volunteered that space-specific guidance information would be a valuable improvement to the proposed smart parking system.

These findings suggested interest in smart parking information and that the design of the project must guarantee accurate information and careful enforcement procedures.

To evaluate the potential accuracy of the vehicle counting technology (sensors) in the context of different parking lot designs and traffic flows, researchers compared observed manual vehicle counts and sensor counts at each of the five entrance and exit locations in the monthly reserved paid parking lot at the Walnut Creek BART station. A sensor can count a vehicle accurately only when some part of the vehicle passes over the six feet diameter range of the sensor in the proper direction without pausing. A number of conclusions were drawn from this analysis:

- Sensor accuracy is good (typically, a three percent or lower error rate) when the design of the entrance or exit driveway is narrow enough to ensure that a vehicle cannot avoid passing over the range of the sensor;
- Observations of traffic patterns in the parking facility can allow for adjustments to the placement of the sensors to improve count accuracy;
- Entrance and exit driveways that are joined and/or wide require traffic cones to make sure that vehicles travel over the sensors; and
- When there is significant through or circulating traffic in a parking facility, sensors must transmit data frequently to the central computer to eliminate such traffic from the calculation of parking lot occupancy.

Finally, a survey of BART commuters who used monthly reserved paid parking and those who used regular unpaid parking was conducted to identify traveler information needs and assess potential travel effects. The results of the demographic profiles suggested a potential market for a daily paid parking service among other riders and new riders with relatively high incomes, high auto availability, and more varied work schedules (as opposed to a more strict 9 am to 5 pm work week). The survey results also suggested that limited parking at the Rockridge station may be a significant barrier to BART commuting; nine percent of riders without monthly reserved paid parking indicated that this was the case. Many also stated that they dislike searching for parking (31 percent) and the lack of available parking (28 percent). When these riders were asked if they would use a paid daily parking service at the station, 15 percent said they would and 28 percent of those said that they might use BART more often as a result. The analysis of the travel effects of the current monthly reserved paid parking service indicates that it has increased the frequency of BART use among subscribers, but it may not have reduced their net auto travel because of diversions to BART from carpool, bus, and bike modes for the main commute mode and increased drive alone access to the BART station.

IV. Smart Parking Field Test

The smart parking field test at the Rockridge BART station involves two real-time user interfaces: 1) a VMS sign that displays parking availability information to motorists on Highway 24 and 2) a centralized reservation system that permits commuters to check parking availability and reserve a space via telephone, cell phone, Internet, or PDA. BART has provided 50 spaces previously reserved for after 10:00 am parking (located in the monthly reserved paid parking lot) to be used in the smart parking field test. The smart parking system integrates traffic count data from entrance and exit sensors at the

BART station parking lot with the reservation system to provide accurate up-to-the-minute estimates of parking availability. Smart parking can facilitate pre-trip planning by permitting users to reserve a space from 48 hours to two weeks in advance, but it will also enable en-route decision making, providing real-time parking availability information to encourage motorists to use transit. If a motorist confronts congestion on Highway 24, he can check parking availability on the VMS sign and instantly phone the reservation system to "lock-in" a space before exiting the freeway. The VMS sign will inform users how to reserve a space, and the reservation system will provide directions to the BART station. Initially, half of the 50 spaces will be available for advanced reservations and half will be available for same day reservation, but this ratio may change in response to demand. To maximize the number of project participants, one user will be allowed only three parking reservations during a two-week period.

The next step in the project includes the evaluation of travel behavior, economic potential, and system technology of the fully launched smart parking field test at the Rockridge BART station.

APPENDIX A: OBSERVATIONAL ANALYSIS RECORD FORMS

Station: ____________________

Date: ____________________

Time:

Weekday Observational Questions:

1) What time does the regular parking lot fill up? _________

2) What time does the paid parking fill up? _________

3) If paid parking does not fill up, how many paid spaces are available prior to 10:00 am when they become free? _____________

(Note that even a small number of spaces would be significant, since all spots should be filled, so this estimate must be very accurate.)

4) Once the unpaid BART spaces are filled, how many people seem to be parking in off-street parking? (keep a tally)

tally:________________ total:________

5) Describe the searching behavior of individuals once regular parking spots begin to fill up, and they become harder to find:

____

(a) How often do cars cycle in search of parking? (keep a tally)

tally:_________________________ final total:__________

(b) About how many cars have to cycle?

tally:_________________________ final total:__________

(c) What is the average duration of the cycling? __________

(d) How often do individuals leave BART when not finding a parking location?

tally:_________________________ final total:__________

6) Is nearby on-street weekday parking paid? _____________

7) What percentage of the parkers park to ride BART?

tally:_________________________ final total:__________

8) What percentage of the parkers do not park to ride BART?

tally:_________________________ final total:__________

9) ***Rockridge only***. When do cars start pulling out, freeing up additional spaces?

____

10) Is paid parking in the best location, that is, is there quick and close access to the BART station? __________

11) If the answer to (10) is no, then describe the location and quality of the paid parking lot.____

12) How long does it take to walk to the BART station from the unpaid parking spots that fill up last? (walk at normal pace, not a stroll) _____________

13) What is the quality of the walk from the unpaid parking spot to the BART station? (For example, would it be an enjoyable walk on a nice day or would it not be enjoyable due to traffic and fumes? Describe scenery, amount of crosswalks if any, and any other factors that may lengthen the walk or make it uncomfortable.)

____

14) Describe the land use characteristics surrounding the station(s).______________________

Weekend Observational Questions:

1) Does the regular parking lot fill up?

2) If the answer to (1) is yes, at what time(s) does regular parking fill up and at what time(s) does regular parking begin to empty?

3) Does the paid parking that is free on weekends fill up?

4) If the answer to (3) is yes, at what time(s) does paid parking fill up and at what time(s) does paid parking begin to empty?

5) Describe the searching behavior of cars once parking spots begin to fill up, and they become harder to find:

- **(a)** How often do cars cycle in search of parking?
- **(b)** About how many cars have to cycle?
- **(c)** What is the average duration of the cycling?
- **(d)** How often do individuals leave BART when not finding a parking location?

6) Is nearby on-street weekend parking paid?

7) What percentage of the weekend parkers park to ride BART?

8) What percentage of the weekend parkers do not park to ride BART?

APPENDIX B: SMART PARKING FOCUS GROUP SUMMARIES

BART RIDERS—WALNUT CREEK STATION
SMART PARKING FOCUS GROUPS SUMMARY

May 21, 2003

Two smart parking focus groups composed of BART riders and auto commuters were conducted in late-May 2003 at the Walnut Creek Chamber of Commerce. This summary describes the findings from the BART riders focus group held on May 21, 2003. Rachel Finson of California PATH facilitated each of the focus groups with student researchers assisting and taking notes.

Background

Focus group participants included five women and seven men. According to the transportation questionnaire completed by participants prior to the start of the focus group, all twelve use BART as their primary mode of transportation from home to work, and four of the twelve reported also using single occupancy vehicles more than twice a week. Four participants reported Montgomery as their most frequently used destination-end BART station; three reported Walnut Creek; one reported Civic Center; one reported Rockridge; and one reported Powell. Only one participant currently uses BART's monthly reserved paid parking. Eight participants were between the ages of 41 and 64, and three participants were between the ages of 24 and 40. Also, eight participants use cellular phones; two participants use both a cellular phone and PDA; and one participant uses neither a cellular phone nor a PDA. One participant reported pre-tax household incomes between $20,000 and $49,999; two participants reported household incomes between $50,000 and $79,999; three listed household incomes of $80,000 to $109,000; and five participants reported household incomes of more than $110,000.

Introductions

Nine participants reported using BART three to five times a week. All twelve participants reported either personally owning a car or having access to a car on a regular basis. The participants' commute times varied from 25 minutes to one hour in one direction. Some commented that drive time and BART travel time were equivalent for their commute. One person mentioned that he uses BART whenever possible to avoid traffic on the bridge. One participant also takes a bus along with BART to get to work. Some participants stated that they only use BART to commute to work, and others reported using BART for other purposes such as traveling to sporting events, concerts, the Oakland Airport, and activities in San Francisco. One participant remarked that he does not have any problems finding parking at BART because he arrives at the station very early in the morning. Another participant said that parking is very difficult. One participant mentioned that, if BART parking cannot be found, she must drive to work. Another participant mentioned that she has a flexible job and can wait to leave for work until 10:00 am when the BART reserved paid monthly parking becomes free. However, many times she would prefer to leave at 8:00 am but cannot because there is no parking available. One participant remarked that she really appreciates the carpool parking at BART.

Attitudes about BART Commute

Participants were asked to describe and rank the positive attributes of their BART commute to work. Responses are presented in Table 1, below. The most popular positive attribute for BART by far was avoiding traffic. Opportunities to relax and sit on the train were also important to participants. After the positive BART attributes were ranked, one participant mentioned that using BART is cost-effective, and another participant remarked that her BART use was encouraged by a commuter check from her employer.

Table 1. Rankings of Positive BART Attributes

Positive Attributes of BART Commute	**Choice**		
	1st	**2nd**	**3rd**
Avoids traffic	10	0	1
Convenient (after parking)	0	1	1
Opportunity to relax	1	3	4
Opportunity to exercise	0	0	1
Dependable schedule (almost exact timing for BART arrivals/departures)	0	0	1
Accommodates demand (larger trains run at peak hours)	0	0	0
Lots of destinations	0	1	0
Less wear and tear on cars (lower car maintenance required)	1	2	1
Opportunity to sit	0	3	2
Opportunity to work	0	1	1
Generally consistent (can trust train schedules)	0	1	0
Usually less stressful than driving	0	0	0
Saves gas	0	0	0
Saves miles on vehicles	0	0	0
Total votes	12	12	12

Participants were asked to describe and rank the negative attributes of their BART commute to work. Responses are presented in Table 2, following. Many participants expressed frustration with the availability of parking, the cost of parking, the cost of BART tickets, and seating availability on trains. A few participants expressed a desire for monthly or semi-annual passes that would reward frequent BART use.

Table 2. Ranking of Negative BART Attributes

Negative Attributes of BART Commute	Choice	
	1st	2nd
Out-of order ticket machines	1	0
Parking between 8-10 am is difficult to find	3	1
Paying for parking	2	1
Cost of BART tickets increasing, while quality of services decreasing	3	3
Broken escalators	0	1
Unsure of train size	0	1
Seating availability (not enough seating)	2	2
Personal safety (especially at night)	1	0
Inconsistent signs (trains do not always match with what sign indicates)	0	0
Homeless and mentally ill people	0	1
Parking validation (often broken)	0	0
Crowded	0	0
Difficult to read how much money remains on BART tickets	0	0
Trains out of service too often	0	0
Have to put more money on tickets too often	0	0
Unclean trains (trains smell and have stained seats)	0	2
No monthly or semi-annual passes available	0	0
Broken air-conditioners	0	0
Inattentive and uninformed agents	0	0
Intercom system too public (intercom projects to all cars in train instead of just to the train conductor)	0	0
Total votes	12	12

*There was not enough time to rank 3rd choice

Attitudes about BART Parking

Participants were asked to describe and rank the positive attributes of BART parking for their commute. Responses are presented in Table 3, following. Many participants appreciated covered BART parking, the proximity of parking to the BART station, and the consistent availability of BART parking. Only one participant pays an annual fee of $780 for a reserved parking space at BART. This participant prefers to pay for a guaranteed parking space as opposed to gambling for a parking spot and, possibly, paying for a daily parking spot.

Table 3. Rankings of Positive BART Parking Attributes

Positive Attributes of BART Parking	Choice
	1st
Covered parking	4
Uncovered parking	0
Carpool parking	1
Consistent parking (if early enough)	2
Parking lots close to BART stations	3
Large parking lots	0
Safety (cars in a safe location)	0
Spaces wide enough to accommodate large cars	0
Walnut Creek parking is condensed (unlike Lafayette or Concord)	0
Paid parking (consistent parking for a price)	1
Total votes	11*

*One participant did not vote.

Participants were asked to describe and rank the negative attributes of BART parking for their commute. Responses are presented in Table 4, below. Most participants indicated that their biggest complaint was that BART parking filled up too early in the morning. One participant said that she would like to see staggered parking (e.g., one lot starts at 8:00 am, another lot starts at 9:00 am, and the rest start at 10:00 am).

Table 4. Rankings of Negative BART Parking Attributes

Negative Attributes of BART Parking	Choice
	1st*
Parking lot full too early in the morning	8
Parking validation (annoying and broken machines)	1
People who arrive later get better parking spots (i.e., 10:00 am when unused paid parking becomes free)	1
Only one elevator works (broken elevator)	0
SUVs at ends of rows hinders visibility	0
Total votes	10

*Two participants did not vote.

Smart Parking Concepts and Design Elements

Attitudes about Pre-trip Smart Parking

Participants were provided with the following description of the service:

> The system would provide pre-trip information on dynamic VMS signs letting commuters know about the availability of shorter-term (e.g., day and week) paid parking by accessing a web site or calling a phone number to allow the driver to reserve a parking spot in advance.

In general, there was not a lot of support for this service among participants. Two indicated that they might use the service occasionally (e.g., if running late). Another participant expressed concern about how the system would prevent someone from taking his reserved parking spot.

Attitudes about En-route Smart Parking

Participants were provided with the following description of the service:

> The system would provide en-route information on a dynamic VMS sign alerting travelers to available paid parking spaces at a BART station that a traveler could access and reserve via cell phone.

The participants, again, expressed some concern about how such a system could be managed, in particular, how the system would prevent someone from taking the reserved spot. One participant stated that he would use the service if parking was competitively priced. Another participant responded that if there were no other alternative parking spots available, then once in a while she would pay for parking. Other participants also questioned the cost of implementing such a system.

Attitudes about En-route Information on Available Free Parking Spaces

Many participants liked this service, but one noted that if the information announced only a few available parking spaces, then he would not even bother trying to obtain one of the spots because they would most likely be filled by the time he arrived at the parking lot. Another participant stated that the system would be more beneficial if it notified drivers which floor parking spaces were available. Safety concerns were also expressed because such a system may cause drivers to take risks to obtain one of the last remaining parking spots.

Attitudes about BART VMS Messages

The participants said the signs were clear enough. Many agreed that the VMS messages would be most helpful right outside of the BART stations.

Attitudes toward a Shuttle Service from Overflow Parking to the BART Station

Participants were provided with the following scenario:

> Drivers would park their cars at a parking lot a short distance away from the station and a shuttle that operates on a regular schedule would come and take the BART commuters to the station for a small fee. The service would add an additional ten minutes to commute times.

If free parking filled up earlier than it currently does, eight participants said that they would use the shuttle, and one participant said he would use it occasionally. Another participant commented that if she had to go to work and there was no other less expensive parking options available, then she would definitely use the shuttle service. Participants reported the following concerns with a shuttle service to the BART station:

- Longer commute time,
- Personal safety,
- Safety of cars, and
- Availability of shuttles late at night.

Willingness-to-Pay for Parking

Participants' willingness-to-pay for BART a monthly reserved parking space, if free parking was full by 7:45 or 7:15 am is presented in Table 5 (below). Only one participant was willing to pay $42/month, if free parking filled by 7:15 am.

Table 5. Willingness-to-Pay for Monthly Reserved Parking, if Free Parking Filled at the Walnut Creek BART Station

Pricing for Monthly Reserved Parking at Walnut Creek	**Number of Participants Willing-to-Pay for Monthly Reserved Parking if Free Parking Filled**	
	At 7:45 am	**At 7:15 am**
$42	0	1
$63	0	0
$84	0	0
$105	0	0
Total Votes	0	1

Participants reported that they would not be more willing-to-pay for BART parking, if they knew how revenues were directed, for the following reasons:

- Already pay for BART tickets and those funds should go toward security and cleanliness;
- Parking situation is not going to change; and
- Trains are not going to be cleaner.

In general, it was felt that an increase in BART fees would not improve service, security, or cleanliness of trains.

Some of the participants expressed support for paid parking on a shorter-term basis (i.e., daily and/or weekly). One stated that he would pay for certain critical days when he knew he would need parking later. Some participants said they would pay for daily parking approximately one to two times a month, and some said that they would use it only occasionally.

Table 6, below, presents willingness-to-pay for daily parking. Most participants would only pay $2 or $3 for daily parking. However, one participant commented that she would pay up to $15 for a parking spot, if she had no other BART parking options.

Table 6. Willingness-to-Pay for Daily Parking

Daily Parking Price	Number of Participants Willing-to-Pay for Daily Parking
$2	12
$3	10
$4	6
$5	3
$6	1

<u>Attitudes about Smart Paid Space Sharing Using a Reservation System Accessed by Cell Phone</u>

Participants agreed that the concept of space sharing (e.g., legally parking in front of an individual's driveway in San Francisco) sounds interesting as long as it is close and convenient. Five participants were willing to pay $2 an hour, if the parking space was within five blocks of their destination. When asked if the participants would be willing to put their own private property on the market, only two participants said that they would consider the idea. A majority of participants were willing to purchase a shared space, but they were not willing to put their personal property on the market. One participant expressed concerns about increased traffic in her neighborhood from such a system. Table 7 (below) presents participants' willingness-to-pay for a shared space in the San Francisco Marina.

Table 7. Willingness-to-Pay for a Shared Space at the San Francisco Marina

Possible Pricing for Shared Space at Marina per Hour	Number of Participants Willing to Pay for a Shared Space at Marina
$2	11
$3	10
$4	8
$5	4
$6	2
$7	1

One participant said that he would pay up to $10 per hour for a parking space at the Marina.

Participants reported that they liked the following ideas of space sharing:

- Secured parking, and
- Inexpensive rates.

Participants reported that they disliked the following ideas of space sharing:

- Congestion,
- Traffic,
- Strangers,
- Liability for home owners,
- Home owner organizations, and
- Upset neighbors.

AUTO COMMUTERS—WALNUT CREEK STATION
SMART PARKING FOCUS GROUPS SUMMARY

May 22, 2003

Two smart parking focus groups composed of BART riders and auto commuters were conducted in late-May 2003 at the Walnut Creek Chamber of Commerce. This summary describes the findings from this focus group. Participants in the focus group were commuters who could take BART to work using the Walnut Creek station, but most frequently chose to drive to work instead. Rachel Finson of California PATH facilitated each of the focus groups with researchers assisting and taking notes.

Background

Focus group participants included two men and five women. According to the transportation questionnaire completed by participants prior to the start of the focus group, participants use the auto (and/or carpools) as their primary commute mode and use BART as a supplemental mode:

- Two participants use a single occupancy vehicle more than two times a week;
- Two participants use a single occupancy vehicle and BART;
- One participant uses a single occupancy vehicle and a carpool;
- One participant uses a carpool and BART; and
- One participant uses a single occupancy vehicle, BART, and a carpool.

Five of the participants use a cellular phone; one uses both a cellular phone and PDA; and one participant does not use a cellular phone or a PDA. Four participants were between the ages of 24 and 40, and three were between the ages of 41 and 64. Two participants reported pre-tax household incomes of $20,000 to $49,999; one reported a household income of $50,000 to $79,999; three participants listed household incomes of more than $110,000; and one declined to respond.

Introductions

Four participants commented that they park in parking structures near their office for a daily fee ranging from $7 to $25 (in San Francisco). One participant mentioned that the low cost of employer provided parking in downtown San Francisco was an important factor in his decision to drive rather than take BART. Another reported that her employer encourages carpooling by providing a commuter check. One participant mentioned that he used to commute by BART, but since commute traffic has eased with the slowing of the economy in the Bay Area, he now drives to work. Another reported that she would like to use BART to commute to downtown San Francisco once or twice a week and is frustrated by the lack of free parking. Frequently, she will drive from one BART station to the next looking for a parking space. One participant mentioned that she finds the design and size of the BART station parking makes it time consuming and unpleasant to walk from the station to her workplace in downtown Walnut Creek.

Attitudes about Commute Modes

Participants were asked to describe and rank the positive attributes of driving a car to work. Responses are presented in Table 1 (below). The most popular positive attributes of the car were flexibility, door-to-door service and the cost savings from carpooling.

Table 1. Rankings of the Positive Attributes of Auto Use to Commute

Likes about Auto Commuting	**Choice**	
	1st	**2nd**
Flexibility	6	1
Opportunity to listen to music	0	0
Air conditioning	0	0
No crowds (alone in car)	0	0
Comfort	0	1
Door-to-door service	0	2
Faster than BART	0	1
Carpooling saves money	0	2
Ability to run errands	1	0
Late night work access	0	0
Personal safety at night	0	0
Total votes	7	7

Participants were asked to describe and rank the negative attributes of driving an auto to work. Responses are presented in Table 2, following. The most popular negative attributes of autos were unpredictable traffic, unproductive time, and wear and tear on the car.

Table 2. Rankings of the Negative Attributes of Commuting by Auto

Dislikes about Commuting by Auto	**Choice**	
	1st	**2nd**
Unpredictable traffic	5	0
Wear and tear on vehicles	0	2
Costs more than BART (i.e., gas, maintenance, insurance, parking, etc.)	1	0
Driving in bad weather	0	0
Unproductive time	0	5
Cannot sleep (not very relaxing)	0	0
Stressful due to traffic and road rage	1	0
Total votes	7	7

Participants were asked to describe and rank the reasons why they do not use BART as a regular means of commuting. Responses are presented in Table 3, below. The most popular reasons were longer travel time as compared to the car and the need to make other trips after work (e.g., errands) that could not be efficiently accomplished by BART or other transit. One participant commented that all the listed reasons (below) added together to cause her to commute by car instead.

Table 3. Ranking of Reasons to Not Use BART Regularly to Commute

Reasons to Not Use BART	**Choice**
	1st
No door-to-door service	1
Too much time (time spent waiting for trains and getting to destinations)	2
Difficulty finding parking	0
Crowded	1
Need for other trips	2
Concern for safety (on train and at station)	1
Expensive (prices of BART tickets increasing)	0
Total votes	7

Participants were asked to describe and rank the positive attributes of their parking experience. Responses are presented in Table 4, following. The most popular positive attributes of parking were low costs, convenience, and availability. The participant that voted for "safety of vehicle" noted that she feels her car is safer at her work than at a BART parking lot.

Table 4. Ranking of the Positive Parking Attributes

Likes about Parking at Office	Choice	
	1st	2nd*
Free or low cost	3	0
Always available	0	3
Convenient (proximity)	3	2
Costs about the same as parking at a BART parking lot and taking BART	0	1
Safety of vehicle	1	0
Total votes	7	6

*One participant did not vote.

Participants were asked to describe and rank the negative attributes of their parking experience. Responses are presented in Table 5 (below). The most popular negative attributes of parking were expense, lack of availability, and walking distance to the office. Two participants were completely happy with their parking situations and had no complaints.

Table 5. Ranking of Negative Parking Aspects

Dislikes about Parking at Office	Choice
	1st*
Expensive	3
Limited parking	1
Parking lots unsafe	0
Long walk to/from office	1
Possible car damage	0
Having to park outdoors	0
Total votes	5

*Two participants did not vote.

Awareness of BART's Monthly Reserved Parking

Six participants were aware of BART's monthly reserved parking. One participant was not aware of the monthly reserved parking, but commented that if she had known about, it would not have affected her commute mode choice. Participants reported the following sources of information regarding the monthly reserved paid parking program at BART:

- Television,
- Newspapers,
- Signs, and
- Flyers.

Smart Parking Concepts and Design Elements

Attitudes about VMS Messages

Participants reported that they liked the idea of using VMS messages to provide pre-trip information about BART parking. On the other hand, some participants reported that they disliked the following attributes associated with VMS messages:

- Seems like advertising,
- Unclear (of what the prepaying is),
- The signs do not indicate how many spaces are available,
- Have to wait to go home/office to go to web site (no immediate knowledge), and
- Annoying having to tune into a radio station.

Some participants commented that they might not respond to these signs. Two participants said that they would tune into a radio station, if it provided pre-trip information.

Participants reported the following improvements to VMS messages:

- Placing the signs right next to BART stations,
- Placing the signs next to congested highways,
- Displaying signs approximately every mile before the BART station so drivers can see how many free parking spaces are available as they are driving.
- Showing parking availability at different BART stations,
- Placing the signs on main streets (in Walnut Creek), and
- Providing information on the location of free parking spaces at the BART stations.

Attitudes about Prepayment for Weekly Parking

Participants showed little support/interest for a prepaid weekly parking spot with the exception of one participant. One participant noted that parking is not a problem.

Attitudes about Prepaid Daily Parking

A few participants said that they would use a prepaid daily parking spot, while four participants stated that they would not be interested in prepaying for a daily parking space. Two of these participants were not interested because they take a bus; one did not want to pay for parking; and one commented that paid parking is prohibitively expensive in combination with BART ticket prices. Another participant said that she would use a prepaid daily parking spot approximately ten days per month. Also, when asked if participants would prepay for a parking permit that they could print at home, some said that they would use this service.

Attitudes about En-Route Information on Free Parking Spaces

All participants agreed that providing real-time information about free parking spaces would be beneficial. If a sign indicated that there were 20 parking spaces available, some participants commented that the sign would affect their travel decisions. If the number of parking spaces available went down to five spots, four of the participants stated that they would not respond to the sign. One participant noted that signs at the Metreon in San Francisco are very helpful because they indicate which floors of the parking structure have available spaces. One of the participants said that a similar system at BART parking lots would be beneficial because the drivers would not have to circle around the parking lot searching for available parking spaces.

Willingness-to-Pay for Monthly Guaranteed Parking

None of the participants were willing-to pay $42 per month for a reserved parking spot at Walnut Creek.

Willingness-to-Pay for Daily Parking

Participants' willingness-to-pay for daily parking on an occasional basis is presented in Table 6, below. Five participants were willing-to-pay $2 per day, and three were willing-to-pay $3 a day. Participants were not willing-to-pay any more than $3 a day. Some participants mentioned that paying $4 to $5 a day plus the cost of a BART ticket would make driving to work a better travel option for them. However, two participants commented that if BART free parking filled up earlier (e.g., 7:00 am), then they would be willing-to-pay $5 a day for parking.

Table 6. Willingness-to-Pay Occasionally Pay for Daily Parking

Daily Parking Price	Number of Participants Willing-to-Pay for Daily Parking
$2	5
$3	3
$4	0
$5	0

When asked if participants would call a number that provides information about parking availability (i.e., 511), most said yes.

Attitudes about a Shuttle Service from Overflow Parking to the BART Station

Participants were provided with the following scenario:

> Drivers would park their cars at a parking lot a short distance away from the station, and a shuttle that operates on a regular schedule would come and take the BART commuters to the station for a small fee. The service would increase commute time by ten minutes.

Participants showed little support for the BART shuttle service given the current situation with free parking at the Walnut Creek station. However, if free parking began to fill-up earlier, some mentioned that they might consider the service. Another participant voiced a safety concern for parking off-site. When asked if the additional ten minutes would affect participants, some agreed that this would not affect them.

Attitudes about Paid Space Sharing Via Cell Phone Reservations

A majority of participants agreed that the concept of space sharing (e.g., in front of people's driveways in San Francisco) sounded interesting. When asked if participants would be willing to put their private property on the market, only two said yes. The remaining five participants were willing to purchase a shared space, but they were not willing to put their personal property on the market. One participant mentioned that space sharing might work in downtown Walnut Creek because of the availability of parking at local businesses and churches. However, another participant believed that the local businesses would not be willing to rent their spaces. Also, a participant commented that her friend has a condominium in San Francisco that uses a park-share system where residents share parking spaces with friends and family. Table 7, below, describes participants willingness-to-pay for a shared space in North Beach in San Francisco.

Table 7. Participants' Willingness-to-Pay for a Shared Space in North Beach (San Francisco)

Prices for Shared Space in North Beach	Participants Willing-to-Pay for Shared Space in North Beach
$5	7
$8	4
$10	0

Participants reported that they disliked the following aspects of space sharing:

- Homeowner safety at risk (liability),
- Oil stains,
- Logistics (when and where drivers would park),
- Parker screenings necessary,
- Invasion of privacy (possibilities of burglary), and
- Possibility of drivers who use the shared space not leaving on time.

When asked how much they would personally charge for allowing someone to use their private property, one participant said $5/hour, while another said that $10/night would be fine.

FasTrak™

Two participants currently use FasTrak™ to conveniently pay tolls. One commented that it would be great if FasTrak™ could also deduct BART daily parking charges (if such as payment system was initiated).

APPENDIX C: TRAVEL BEHAVIOR QUESTIONNAIRES

BART REGULAR PARKING SURVEY FOR COMMUTERS

Caltrans & BART Smart Parking Study

Hello, I am a UC Berkeley student working on a research project for the California Department of Transportation and BART, and we are evaluating parking at BART stations. I would like to ask you a few questions; it will only take about five minutes.

(1) Do you currently use BART to commute to work or school?

□ Yes □ No

If the answer is ***yes****, continue to administer the survey.*
If the answer is ***no****, thank the respondent for their interest.*

(2) Do you have a BART monthly reserved paid parking permit for this station? (*Guaranteed reserved parking is Monday through Friday until 10:00 am, after that time others may use the same "preferred" spots for free.)*

□ Yes □ No

If answer is ***no****, continue with this survey.*
If answer is ***yes****, switch to the reserved paid parking survey.*

(3) How frequently do you use BART to commute?

- Only occasionally
- 1-2 day per month
- 1-3 days per week
- 4-5 days per week
- More than 5 days a week

(4) Which BART station do you use most frequently when you start your commute trip from home? ___________________________

(5) What is your most frequently used destination-end BART station for your commute trip? _____________________

(6) Overall, how satisfied are you with the services provided by BART? *List options for respondent.*

- Very satisfied
- Somewhat satisfied
- Neutral
- Somewhat unsatisfied
- Very unsatisfied

(7) During a typical week are there some days when you make your commute trip using a mode other than BART?

□ Yes □ No

*If **no**, then skip to **10**.*

(8) On days that you do not use BART to commute, what are the primary reasons? *Please check all that apply. Probe for additional responses. If respondent lists more than one reason, then ask which is the most common and place an * next to the answer.*

- Do not have time (e.g., get a late start, day too busy, need to leave early)
- Need my own car on the way home or on the way to work
- Need a car during work hours
- Need to carry heavy/inconvenient items to or from work
- Personal work schedule varies some days
- Need to drop off/pick up somebody or something
- Weather
- Other____

(9) How do you commute on days that you do not use BART? *Please check all that apply. If respondent lists more than one, then ask which is the most common and place an * next to the answer.*

□ Drive Alone □ Carpool □ Vanpool □ Bus □ Bike

□ Walk □ More than one mode □ Telecommute □ Don't commute

□ Other_________________________

(10) In general, what do you like about the parking lots and services provided by BART? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- Parking is always available
- Free parking
- Reserved monthly paid parking
- Long-term paid parking
- Parking is close to station entrance
- Parking lots are secure
- Parking lots are well lit
- Carpool parking
- Other, please specify____

(11) What don't you like about the parking lots and services provided by BART? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- o Searching for parking is a hassle
- o Walking distance from parking to station is too far
- o Parking is often unavailable
- o I'm concerned about having to pay for parking, please specify____
- o Parking lot lighting is poor
- o Carpool parking is often filled
- o Carpool parking is unfilled and takes up valuable spaces
- o Other, please specify____

(12) What are the primary reasons why you don't use BART's monthly reserved paid parking? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- o No trouble finding a space
- o Paid parking is too expensive
- o Don't need parking on a monthly basis
- o The paid parking is not in a preferred location
- o Not aware of the paid parking option
- o Other, please specify____

(13) Would you be more likely to use BART's paid parking if **daily paid parking** was made available in addition to monthly reserved parking? *The cost for daily paid parking would be approximately equal to the average daily cost of monthly reserved paid parking (e.g., $5.00).*

□ Yes   □ No   □ Mixed   □ Uncertain

*If the answer is **yes, mixed, or uncertain**, go to **14**.*
*If the answer is **no**, skip to **16**.*

(14) What are the primary reasons why you would be more likely to use **daily paid parking**? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- o Need BART parking on a daily rather than a monthly basis
- o Daily paid parking would be more affordable

- More flexibility with respect to departure time (i.e., could leave home later in morning)
- Other, please specify____

(15) Do you think that you would travel by BART more frequently if **daily paid parking** were made available?

□ Yes □ No □ Mixed □ Uncertain

To increase the number of available parking spaces, BART is considering the introduction of ***attended parking****. Under this program, patrons would be able to provide their keys to an attendant who would park their car.*

(16) In general, what do you like about the attended parking service just described? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- Increased personal security
- Increased car security
- Time saved by not having to park my car
- Time saved by not having to walk as far to the station
- Other, please specify____

(17) In general, what don't you like about the attended parking service just described? *Open-ended.* ***Don't read list.*** *Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- Don't like the idea of giving the attendant my keys because of possible theft
- Would not like to wait for the attendant to retrieve my car
- I like to walk to my car
- Other, please specify____

Next we have a few demographic questions that help us categorize our data. All responses are confidential.

(18) *Observe whether the respondent is male or female and check answer below.*

□ Male □ Female

(19) Do you use a cellular phone?

□ Yes □ No

(20) How many commuters (including yourself) are there in your household? A commuter is defined as someone who travels to work or school at least three to five days a week.________________

(21) How many autos are available to your household?_____________________________

(22) Please indicate the number of your household members (including yourself) that fall into the different age groups listed below. *Then list the age groups.*

_______0-5
_______6-15
_______16-18
_______19-23
_______24-44
_______45-64
_______65-74
_______75+

(23) What is your age? *If they refuse to answer, then observe an answer and place an * by the answer to indicate that it is your observation.*

□ 24 or younger □ 25-44 □ 45-64 □ 65 or older

(24) What is the last level of school that you completed?

- Grade school
- Some high school
- Graduated high school
- Some college
- Associate's degree
- Bachelor's degree
- Some graduate school
- Master's degree
- Ph.D. or higher
- Other

(25) Which of these categories best describes your occupation? *Then list the categories.*

- Manager/administrator
- Service/repair
- Clerical/administrative support
- Sales
- Professional/technical
- Production/construction/crafts
- Student
- Other, please specify____

(26) Which of the following categories best describe your household's 2002, pre-tax income?

□ Under $45K □ Between $45K and 100K □ Over 100K

Thank the respondent for participating in the survey.

BART RESERVED PAID PARKING SURVEY
Caltrans & BART Smart Parking Study

Hello, I am a UC Berkeley student working on a research project for the California Department of Transportation and BART, and we are evaluating parking at BART stations. I would like to ask you a few questions; it will only take about five minutes.

(1) Do you have a BART monthly reserved paid parking permit for this station?
(Guaranteed reserved parking is Monday through Friday until 10:00 am, after that time others may use the same "preferred" spots for free.)

□ Yes □ No

*If answer is **yes**, continue to administer this survey.*
*If answer is **no**, switch to the survey of regular parking BART riders.*

(2) Do you use BART to commute to work or school?

□ Yes □ No

*If the answer is **no**, then skip to **17**.*

(3) How frequently do you use BART to commute?

- Only occasionally
- 1-2 day per month
- 1-3 days per week
- 4-5 days per week
- More than 5 days a week

(4) Overall, how satisfied are you with the services provided by BART? *List options for respondent.*

- Very satisfied
- Somewhat satisfied
- Neutral
- Somewhat unsatisfied
- Very unsatisfied

(5) Which BART station do you use most frequently when you start your commute trip from home? ___________________________

(6) What is your most frequently used destination-end station for your commute trip?
____

(7) During a typical week are there some days when you make your commute trip using a mode other than BART?

□ Yes □ No

*If **no**, then skip to **10.***

(8) On days that you do not use BART to commute, what are the primary reasons? *Please check all that apply. If respondent lists more than one reason, then ask which is the most common and place an * next to the answer.*

- Do not have time (e.g., get a late start, day too busy, need to leave early)
- Need my own car on the way home or on the way to work
- Need a car during work hours
- Need to carry heavy/inconvenient items to or from work
- Personal work schedule varies some days
- Need to drop off/pick up somebody or something
- Weather
- Other____

(9) How do you commute on days that you do not use BART? *Open-ended. Please check all that apply. If respondent lists more than one, then ask which is the most common and place an * next to the answer.*

□ Drive Alone □ Carpool □ Vanpool □ Bus □ Bike □ Walk

□ More than one mode □ Telecommute □ Other________________________

(10) What do you like about BART's monthly reserved paid parking service? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- Guaranteed reserved space (convenience)
- Pay once a month
- Close proximity to BART station entrance/exit
- Other____

(11) What don't you like about BART's monthly reserved paid parking service? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- Too costly
- Guaranteed space is not always available
- Not close enough to BART station entrance/exit
- Other______________________________________

(12) How frequently do you typically use your BART monthly reserved paid parking space?

- Only occasionally
- 1-2 day per month
- 1-3 days per week
- 4-5 days per week
- More than 5 days a week

(13) Did you commute to work by BART before you purchased your BART monthly reserved paid parking permit?

□ Yes □ No

If yes**, go to** 14.
*If **no**, skip to **16**.*

(14) How frequently did you typically use BART for your commute before you purchased your BART monthly reserved parking permit?

- Only occasionally
- 1-2 day per month
- 1-3 days per week
- 4-5 days per week
- More than 5 days a week

(15) How did you typically travel to the BART station prior to purchasing your BART monthly reserved paid parking space?

□ Drive Alone □ Carpool □ Bus □ Bike □ Walk

□ More than one mode □ Other________________________

*Skip to **17**.*

(16) What mode or modes did you usually use to commute before you purchased your BART monthly reserved paid parking permit? *Please check all that apply. If respondent lists more than one, then ask which is the most common and place an * next to the answer.*

□ Drive Alone □ Carpool □ Vanpool □ Bus □ Bike □ Walk

□ More than one mode □ Telecommute □ Don't commute

□ Other________________________

(17) What are the primary reasons why you purchased your BART monthly reserved paid parking permit? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- o Searching for parking is a hassle
- o Walking distance from parking to station too far
- o Parking is often unavailable when I need it
- o Other, please specify____

(18) If daily paid parking were made available for about $5 a day, how likely is it that you would use daily parking instead of monthly reserved parking?

□ Very likely □ Somewhat likely □ Neutral □ Unlikely □ Very unlikely

If the answer is ***very likely or somewhat likely****, go to* ***19****.*
If the answer is ***neutral, unlikely, or very unlikely****, skip to* ***20****.*

(19) What are the primary reasons why you would be less likely to reserve monthly paid parking? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- o Don't use BART every day
- o Daily parking would be cheaper than monthly paid parking for me
- o Other, please specify____

(20) Do you think that you would travel by BART less frequently if you used daily paid parking instead of monthly reserved paid parking?

□ Yes □ No □ Mixed □ Uncertain

To increase the number of available parking spaces BART is considering the introduction of ***attended parking****. Under this program, patrons would be able to provide their keys to an attendant who would park their car.*

(21) In general, what do you like about the attended parking service just described? *Open-ended. Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- o Increased personal security
- o Increased car security
- o Time saved by not having to park my car
- o Time saved by not having to walk as far to the station

- Other, please
  specify____

(22) In general, what don't you like about the attended parking service just described? *Open-ended.* ***Don't Read List.*** *Probe for additional responses. Please check all that apply. If respondent lists more than one, then ask which is the most important and place an * next to the answer.*

- Don't like the idea of giving my keys to attendant because of possible theft
- Would not like to wait for the attendant to retrieve my car
- I like to walk to my car
- Other, please
  specify____

Next we have a few demographic questions that help us categorize our data. All responses are confidential.

(23) *Observe whether the respondent if male or female and check answer below.*

□ Male □ Female

(24) Do you use a cellular phone?

□ Yes □ No

(25) How many commuters (including yourself) are there in your household? A commuter is defined as someone who travels to work or school at least three to five days a week.________________

(26) How many autos are available to your household?____________________________

(27) Please indicate the number of your household members (including yourself) that fall into the different age groups listed below. *Then list the age groups.*

_______0-5
_______6-15
_______16-18
_______19-23
_______24-44
_______45-64
_______65-74
_______75+

(28) What is your age? *If they refuse to answer, then observe an answer and place an * by the answer to indicate that it is your observation.*

□ 24 or younger □ 25-44 □ 45-64 □ 65 or older

(29) What is the last level of school that you completed?

- o Grade school
- o Some high school
- o Graduated high school
- o Some college
- o Associate's degree
- o Bachelor's degree
- o Some graduate school
- o Master's degree
- o Ph.D. or higher
- o Other, please specify____

(30) Which of these categories best describes your occupation? *Then list the categories.*

- o Manager/administrator
- o Service/repair
- o Clerical/administrative support
- o Sales
- o Professional/technical
- o Production/construction/crafts
- o Student
- o Other, please specify____

(31) Which of the following categories best describe your household's 2002, pre-tax income?

□ Under $45K □ Between $45K and 100K □ Over 100K

Thank the respondent for participating in the survey.