CALIFORNIA PARTNERS FOR ADVANCED TRANSPORTATION TECHNOLOGIES
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

San Diego Smart Parking System: Concept of Operations

François Dion, PhD, Senior Development Engineer
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California PATH Research Report
UCB-ITS-CWP-2011-5

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This work was performed by the California Center for Innovative Transportation, a research group at the University of California, Berkeley, in cooperation with the State of California Business, Transportation, and Housing Agency's Department of Transportation, and the United States Department of Transportation's Federal Highway Administration.

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1. INTRODUCTION

This document develops a concept of operation (ConOps) for a *Smart Parking* system to be implemented at transit park-and-ride facilities across the San Diego region in California. The aim of the proposed system is to improve the management of available parking at transit stations through the use of various sensing, electronic transaction, computing and communication technologies. It seeks more specifically to provide an ability to monitor parking supply in real-time and to disseminate this information to travelers via various traveler information systems, such as roadside changeable message signs (CMSs), SANDAG's 511 services, web applications, and mobile phones. While the Smart Parking system described within this document introduces powerful parking management and customer information tools designed to help regional travelers, it is anticipated that an implemented Smart Parking system will be integrated within the San Diego Regional Architecture and will eventually constitute the basis for a regional parking management system.

This ConOps establishes the need for a Smart Parking system, identifies user needs and key system requirements, defines the roles and responsibilities of system stakeholders, explores applicable supporting technologies, maps main system functions, and develops basic operational scenarios that should be considered before initiating the design or implementation of a specific Smart Parking system. A preliminary benefit/cost analysis is also presented following the description of the envisioned system.

The targeted audience for the ConOps includes transit system operators, parking lot owners and managers, professionals responsible for the development and implementation of parking management systems, and transit system users. The concept is developed to help create a strong basis of communication among Smart Parking stakeholders, promote the development of consensus regarding system operations and policies, and facilitate the design and implementation of viable systems. Given the vast array of individuals potentially interested in the document, discussions are kept in relatively general terms to enable individuals from all professional backgrounds to use it.

While the conceptual descriptions presented herein are developed in the context of implementation within the San Diego region, these descriptions could easily be transposed to implementations elsewhere as the core Smart Parking user needs and system functionalities will typically remain the same from one region to the next.

2. SAN DIEGO SMART PARKING PROJECT HISTORY

The *San Diego Smart Parking Value Pricing Pilot (VPP) Project* was initiated in 2006. The original intent was for this project to build upon a transit-based smart parking field test that was being conducted at the Bay Area Rapid Transit (BART) Rockridge station in the San Francisco area by researchers from the University of California, Berkeley (Shaheen *et al.*, 2005; Shaheen and Rodier, 2006; Shaheen and Kemmerer, 2008). The aim of the present project was to help address parking issues at various stations along the COASTER commuter rail line in the San Diego area.

2.1. INITIAL PROJECT SCOPE

At the beginning of the study, parking facilities at most of the COASTER stations typically filled well before the departure of the final morning commute train. This inadequate parking capacity clearly limited train ridership. The pilot project would use recent advances in sensor, payment, and enforcement technologies to implement a system that would allow a more efficient operation of parking facilities more, with additional short-term goals of enhancing customer parking experience, increasing the effective supply of existing parking with minimal investment, and increasing ridership and overall revenue. Over the longer term, these innovative systems were envisioned to generate revenues that could be used to add parking capacity, improve access, and expand ridership.

The problem identification analysis and proposed near-term parking management strategies to address those problems were presented to the NCTD staff and their Board in September 2008. Proposed alternatives for the near term included strategies to:

- Free up more space for COASTER riders by restricting non-COASTER and overnight parking or allowing non-COASTER and overnight parking through fee payments.
- Generate more COASTER riders per parking space by encouraging carpooling and vanpooling and by providing preferential parking for those commuters adjacent to the platforms.
- Attract new or more frequent daily COASTER riders through the provision of reserved paid parking located at preferential locations within parking facilities and real-time information on the availability of general free parking at the COASTER stations via a reservation website operated by ParkingCarma™.

Following a conditional approval by the NCTD Board, work began in September 2008 on the design of a system that would include the deployment of preferential carpool and vanpool parking at several COASTER stations, the implementation of reserved paid parking services, and the provision of real-time parking availability information via a ParkingCarma™ website. The proposed deployments received NCTD approval in May 2009 and implementation was initiated in August of 2009 at the Carlsbad Village, Poinsettia and Encinitas COASTER stations. The pilot system allowed COASTER riders to reserve s at each of these stations one of 10 advanced paid parking spaces for solo drivers and 6 free spaces for carpool/vanpool via the QuickPark reservation system linked to SD511.org, as well as and available via the ParkingCarma™ reservation website.

2.2. RE-SCOPED PROJECT

During the initial pilot project implementation, the economy entered into a deep recession, causing a significant drop in transit ridership. NCTD also increased fares and cut service back due to significant budget deficits. In turn, this drop in ridership significantly affected the demand for parking at the various COASTER stations. Following a period during which only 10 reservations for solo parking spaces were made over a three-month interval, project partners began working with the NCTD and SANDAG to develop a work plan that could take advantage of existing instrumentation for research and planning purposes, and thus capitalize on efforts completed to date while improving the outcome of the project.

Given the aforementioned circumstances, the research team worked with NCTD and SANDAG on the development of a path forward that would be consistent with the original scope of work of the VPP project, but customized to prevailing transit parking demand conditions and placing greater focus on improving the usefulness of the final project for SANDAG and FHWA. The objective was to lay the foundation for future expansion of the smart parking program once the economy turned around and greater demand for service returned. These discussions led to having the focus of the project turned to examining and assessing the impacts of transit fares and transit ridership levels when considering transit parking pricing. The revised work plan was presented to NCTD, SANDAG, and the FHWA. This revised work plan was subsequently approved by the FHWA in September 2010.

The underlying principles that guided the development of the revised work plan included:

- Maintaining consistency with the original VPP deliverables,
- Assuring that all deliverables can be used in regional toolkit/implementation plan for future smart parking deployments,
- Using lessons learned from the qualitative experience and quantitative evaluations of the COASTER smart parking pilot deployments, as well as other available evidence from the professional literature, to assist SANDAG, FHWA, MPOs, and transit agencies as they consider the application of smart parking pricing at transit stations in the San Diego regional context.

The re-scoping effort finally included the completion of following three main elements:

- Execution of a thorough analysis gauging public acceptance of Smart Parking systems through the completion of a **Transit Parking Pricing, Fare, Revenue and Ridership Trade-Offs analysis.** This effort included a review of implemented parking pricing strategies, and the implementation of a stated preference survey designed to understand the effects of changing transit fares and station parking pricing on mode shares. This survey, which was executed between July 11 and July 22, 2011, resulted in the collection of 1,632 responses from individuals using COASTER stations, with 816 responses from individuals who used their car to drive to one of the COASTER stations.
- Collection of statistics on the utilization of the Smart Parking/QuickPark COASTER Parking reservation system. During the pilot project, COASTER users would continue to access ParkingCarma's QuickPark website through 511sd.com to make reservations for carpool/vanpool spaces available for free to COASTER riders. This part of the project resulted in approximately 250 reservations being made from August 2009 to September 2011. A new feature of the program would require patrons to place reservations by providing the number of their Compass Card (regional rail pass). The intent of this effort was to continue to monitor the

functionality and use of the QuickPark reservation system operated by Parking Carma.

- Development of documents aiming to serve as handbooks to SANDAG, Caltrans, and other local jurisdictions interested in the implementation of Smart Parking systems. Three documents were to be developed: a generic Smart Parking Concept of Operations (this document), a preliminary System Engineering Management Plan (SEMP), and a System Engineering Review Form (SERF). While these documents are usually produced for a well-defined implementation project, the intent in this project is instead to produce general guidance documents that could be subsequently refined as part of a specific Smart Parking implementation project. The purpose of the ConOps was to establish the need for Smart Parking, identifies user needs and key system requirements, defines the roles and responsibilities of system stakeholders, explores applicable supporting technologies, maps main system functions, and develops basic operational scenarios that should be considered before initiating the design or implementation of a specific Smart Parking system. The SEMP would provide further guidance in how system engineering principles could be used to deploy Smart Parking systems within the San Diego region. A SERF was finally to be developed to summarize how key elements of the system engineering process have been applied to the deployment of Smart Parking systems.

3. BACKGROUND

Many transit agencies currently operate parking lots near transit stations to enable transit riders to park their vehicle at a convenient location before boarding a bus, subway train, light-rail train or commuter train. These parking facilities, commonly known as park-and-ride lots, are often marketed as a way for commuters to avoid the stress of driving on congested roads and facing scarce, expensive parking in city centers. They are generally meant for people who may not be able to travel easily from one location to another solely by transit and for whom the use of a car for a portion of their journey presents a significant advantage. A major aim is to make it easier for people to use public transport.

This section presents background information regarding the offering of parking around transit stations and smart parking systems in general. Elements covered include:

- Current practice in transit park-and-ride offering
- Characterization of transit park-and-ride customers
- Current advanced parking management options
- Available parking payment options
- Current parking pricing schemes
- Examples of Smart Parking systems in the United States

The section concludes by presenting the case for the development and implementation of Smart Parking systems at transit park-and-ride stations.

3.1. CURRENT PRACTICE IN TRANSIT PARK-AND-RIDE

Typically, public transit agencies make parking investments around transit stations according to simplified decision-making processes. For instance, many agencies decide where to develop park-and-ride lots based on parking demand estimates developed using ridership projections and assuming that a constant proportion of riders would reach a station using a vehicle. Many agencies also simply tend to direct their investments to stations with the most overcrowded parking lots or where they wish to induce new demand. One reason why many agencies do not use comprehensive decision models is that they often do not fully internalize the cost of building a new lot or garage since much of the funding for these projects often come from the federal, state, or local government in the form of grants or bonds.

Park-and-ride lot sizes can vary significantly across transportation modes, from one city to the next, and even across lots along a given transportation corridor. Because riders dislike uncertainty and inconvenience in finding parking, lots are often designed with some spare parking capacity relative to average occupancy to accommodate stochastic fluctuations in parking demand. A general rule of thumb is to design lots for an 85% average occupancy (Shoup, 2005).

Similar to lot size, the proportions of riders using transit park-and-ride lots can also vary. At stations with park-and-ride lots, the proportion of transit riders reaching the station by car has been found to range between 10 and 80 percent, with the highest proportions of patrons using a vehicle for the first portion of their travel typically associated with stations along express commuter lines. Heavy rail transit and subway systems generally support the higher demand for parking and largest park-and-ride facilities, particularly at suburban and end-of-line stations with good highway access. Many end-of-line or suburban stations feature for instance parking lot with capacities exceeding 1,500 vehicles. On the other hand, stations located in urban cores often have limited parking spaces, if parking is offered at all.

In the densest U.S. cities, many lots are regularly filled prior to the end of the morning rush hour, even where parking fees are charged. Reported system-wide average parking lot utilization is generally between 75 and 90 percent but ranges from roughly 50 to 100 percent. Within such systems, the proportion of transit riders who utilize formal park-and-ride facilities ranges from about 1 percent for older central city operations to over 50 percent for some systems oriented to the suburbs.

Park-and-ride facilities serving light rail transit (LTR) systems have usually proven popular with riders, but are generally smaller than those associated with heavy rail and subway systems. LRT station parking lot sizes average 100 to 700 spaces, with smaller lots possibly offering as low as 20 spaces. In such systems, end-of-line stations once again often have the largest parking facilities. Commuter rail and LRT lots are generally well utilized, with utilization typically ranging between 70 and 85 percent, with extremes ranging between 17 and 98 percent. The lesser demand per facility found on certain LRT systems may be a function of less frequent service, lower travel time savings, shorter station spacing, or simply the relatively smaller size or lower densities of the employment centers served.

Smaller facilities, including shared-use lots, are also often found along express and local bus routes, with the largest lots typically associated with express bus routes. In these cases, lot sizes typically range between 30 and 250 spaces. Utilization rates further vary widely, with 60 percent occupancy considered as a rough median.

3.2. CHARACTERIZATION OF TRANSIT PARK-AND-RIDE CUSTOMERS

Park-and-ride users are trip makers with choices, as almost all of them have access to an automobile. Studies have found that between 80 and 100 percent of weekday park-and-ride users are making work related trips (Turnbull *et al.*, 2004). At many facilities, proportions of work-related trips ranging between 95 and 100 percent are not atypical.

From a socio-economic standpoint, park-and-ride users further tend to be busy professionals in their mid-20, individuals with family with children, and individuals with average income higher than that of the average transit rider. The distance traveled to reach a park-and-ride facility appears to vary somewhat by mode of transportation and size of the metropolitan area, with longer driving distances being typically associated with exceptionally good transit service and park-and-ride facility located in outlying locations. A majority of park-and-ride users drive less than 5 miles to reach a station, and 80 percent of them drive less than 10 miles. Trips for end-of-line park-and-ride lots, outer commuter rail lots, and park-and-pool lots tend to be longer than average. 40 to 60 percent of park-and-ride lot users have further been found to be individuals who were previously commuting alone in a vehicle.

Key reported incentives for using park-and-ride lots include (Foote, 2000; Turnbull *et al.*, 2004):

- Cost and ease of parking in urban centers
- Cost of transit trip with respect to driving costs
- Level of congestion on regional roadways
- Frequency of transit service
- Competitiveness of transit travel times when compared to driving
- Location and ease of access of transit station

Studies of outlying park-and-ride facilities show an average daily turnover of about 1.1 cars per space, with about 1.2 transit passengers per parked car, suggesting a relationship of roughly 1.3 transit passengers per occupied parking space. Some of these transit rides would occur regardless of park-and-ride availability, while other would be lost. A study conducted in Connecticut estimated that roughly 0.2 new transit riders may be gained for each additional space provided in capacity-constrained parking situations.

3.3. ADVANCED PARKING MANAGEMENT OPTIONS

Advanced parking management systems (APMS) are often developed to help travelers find parking spots. Most systems seek to collect data about available parking spaces within a lot or multiple lots and to communicate this information to motorists or travelers planning their trip. In doing so, these systems help to reduce frustration and enhance traveler satisfaction. Advanced parking management systems may also include tools helping parking lot operators track parking demand, set more effective pricing policies, enhance enforcement activities, and develop improved business strategies (FHWA, 2007).

There are several different types of advanced parking management systems currently in use in the United States. These include:

- Pre-trip parking information system
- System within parking facilities informing travelers of the number of open spaces
- System informing motorists on nearby roads of the number of open spaces in nearby facilities
- Parking reservation system

Pre-trip parking information systems range from low-tech systems simply publishing a map of available parking facilities to high-tech systems providing parking information over the Internet. At the most basic level, web sites may be used to provide a map of facilities relative to major access routes and attractions. Other relevant information may also be provided, such as the hours of operation of each parking facility, the cost of parking, the total number of parking spaces, forms of payment accepted, and contact phone number for each facility.

Information systems within parking facilities are typically deployed to inform motorists about the number of available parking spaces within each structure. In most system, the information is presented using signs that have both passive and active components. Passive components, such as arrows, are used to provide simple directions, while active components typically consist of digital displays showing the number of open parking spaces. In most facilities, signs are installed near the entrance to enable motorists to decide whether they should enter the facility. More advanced systems may also have signs installed on every floor of a garage or at the start of every aisle to indicate how many spaces may be available on the floor or aisle, or signs installed in front of every parking space to indicate whether it is available. In addition to site-specific signs, many systems also use dynamic roadside signs installed at key decision points along a road network to inform travelers of the number of spaces available within a given parking facility or set of facilities. Such advanced information systems can for instance frequently be seen in central business districts and at airports.

Some advanced parking management systems further allow travelers to reserve and pay for parking spaces ahead of time. An example includes the reservation system used by the Bay Area Rapid Transit (BART). This system allows system riders to buy online monthly parking permits at many stations in the San Francisco Bay Area in California. Other examples include services offered by private companies such

SpotScout, and ParkingCarma, which offer parking space reservation systems in Boston and the San Francisco area, respectively.

3.4. PARKING PAYMENT OPTIONS

In traditional parking lot operations, parking fees are collected by an attendant at the entrance or exit of the facility, depending on whether a fixed or time-based rate is charged. In lots focusing on short-term parking, parking fees may instead be collected using parking meters installed in front of each space.

In recent years, however, many parking lot operators have eliminated parking fee attendants or single-space meters by systems requiring individuals to pay parking fees at an automated fee collection station. Enforcement is executed by either asking parking lot users to place a receipt at a visible spot inside their vehicle or to register the number of the parking stall their vehicle is occupying.

In addition to automated fee collection systems, various alternative advanced payment systems have started to appear. Some of the most commonly used systems include:

- **Smart card systems** – These systems allow drivers to electronically load money onto a card with an integrated circuit chip and then have the money debited with each use of the card. Smart card technology is highly secure and relatively inexpensive. Fee calculations are performed by reading and writing to data files on smart media with the smart card. This leads to large reductions in ticket consumption costs, major improvements in equipment and system reliability, significant decreases in field maintenance costs, and decreases in transaction times.

- **Pay-by-phone systems** – These systems use automated answering machines or short messaging services (SMS) to allow prepayment of parking. Drivers use their mobile phones to wirelessly deposit money towards time in a parking space, and most systems can give users updates about remaining or expired time via SMS messages. Drivers usually must register their license plate and credit card information to use the wireless metering. Pay-by-phone systems have been widely implemented for paid street parking or surface lots because they require minimal up-front costs – mainly signage, advertising, and handheld devices for parking enforcement officers. The pay-by-cell method also works within multiple parking zones, rates, and tariffs. Enforcement is typically accomplished by providing an officer with a list of license numbers that have paid their parking within a given area. The officer can then check the license plate of a parked vehicle against this list to determine if parking has been paid.

- **RFID tags** – RFID tags have long been used to support highway toll operations. Similar tags can be used to automatically charge vehicles entering a parking facility. Upon parking, a driver simply has to turns on an in-vehicle device that would communicate with the parking management system and debit the parking fee from the user’s account. Information about vehicles entering the parking lot can also be sent to enforcement officers to ensure that all parked vehicles have paid their fee.

- **In-vehicle meters** – Such systems are typically an extension of smart card or pay-by-phone systems. When drivers pull into a parking spot an in-vehicle meter communicates wirelessly with a centralized management system. Since different meters can be installed in different vehicles, this technology easily allows for price discrimination. It can also be used for pay-asyou-go parking pricing schemes. It allows for easy, visual parking enforcement similar to pay and display meter receipts. Typically, the user must purchase the in-vehicle meter. To date, however, the relatively high-cost of in-vehicle meters has resulted in the adoption of this technology primarily at parking lot serving commuters.

- **E-Parking systems** – E-parking is an advanced parking management concept for off-street parking that brings together parking reservation and payment systems. E-parking systems rely on an electronic parking brokerage for parking providers. Drivers use their cellular phones, PDAs, or the internet to access a portal website where they can view available spaces and prices and subsequently reserve a space. The system confirms a reservation with the parking provider and provides the user with an access code. The car enters and exits the parking facilities using Bluetooth to open the barrier. Once the car exits the parking facility, an electronic payment is made and the whole operation is registered on the brokerage site.

3.5. PARKING PRICING SCHEMES

Many transit agencies do not change for use of park-and-ride lots. Agencies levying a parking fee, either at some or all their facilities, are primarily those offering commuter rail and HRT/metro services in large urban areas such as Boston, New York, Philadelphia, Washington, Chicago and San Francisco. Very few transit agencies report charging for park-and-ride at lots servicing LRT lines.

Parking lots where fees are levied tend to be facilities experiencing strong parking demand. Often, fees are charged as an attempt to shift excess demand to existing facilities with available parking capacity and where a lower parking fee is charged. At paying facilities, the fees levied are generally much lower than those charged by private lot operators in central business districts. Daily parking rates at transit stations typically vary between $1 and $3, while corresponding daily rates in the central business district of large cities typically vary between $10 and $75 (Moore, 2010).

Some systems offer more than one pricing scheme at individual facilities. For instance, free parking may be offered for carpools and vanpools to encourage ridesharing and maximize available capacity. Discounts may also be offered for monthly parking programs, or a premium charged for services adding convenience, such as the right to park on a space near the entrance of a transit station.

3.6. EXAMPLES OF ADVANCED PARKING MANAGEMENT SYSTEMS IN THE UNITED STATES

Transit-based Smart Parking systems have operated for several years in major European and Japanese cities. These systems predominantly provide motorists with en-route information, with some systems also providing both pre-trip planning (via a telephone and/or web-based reservation system) and en-route planning (through real-time parking information on CMSs installed at parking lots and on nearby roadways). Some systems have been tested or implemented in the United States. Four examples are:

- Bay Area Small Parking Field Test
- Smart Park system at the Baltimore Washington International Airport
- RTA/METRA Parking Management System Guidance in Chicago, Illinois
- Advanced Parking Information System in Montgomery County, Maryland

3.6.1. Bay Area Smart Parking Field Test

In 2002, the Innovative Mobility Research Group at California PATH, in affiliation with the California Center for Innovative Transportation (CCIT), Acme Innovation, Caltrans, and the Bay Area Regional Transit (BART) began developing a concept for a Smart Parking operational test in the San Francisco Bay Area (Shaheen *et al.*, 2005; Shaheen and Rodier, 2006; Shaheen and Kemmerer, 2008; Rodier *et al.*, 2010). This effort led to the testing of a pilot system at BART's Rockridge station in December 2004. BART provided 50 spaces to be used in the field test. These spaces previously reserved by BART for use after 10:00 am only and were made available prior to 10:00 am for travelers wishing to place reservations. 15 of these spaces were made available for advanced reservations, with the remaining 35 spaces assigned for same day, en-route reservations. Each user was further allowed to place three parking reservations during a two-week period. This system represents one of the very first true applications of Smart Parking concept in a transit environment in the United States.

The Rockridge field test involved two real-time user interfaces. The first interface consisted of two CMSs displaying parking availability information to motorists traveling on Highway 24, an adjacent commute corridor into downtown Oakland and San Francisco. The second interface consisted of a centralized reservation system that permitted commuters to check parking availability at the 50 designated spaces and reserve a space via telephone, mobile phone, Internet, or personal digital assistant (PDA). Individuals using the system for en-route reservations simply called in their license plate number via mobile phone to secure a space. Reservations could be made for up to two weeks in advance. BART enforcement personnel ensured that vehicles parked in the Smart Parking lot either had an advanced reservation parking permit or a license plate number matching one of the numbers that were provided by individuals making en-route reservations. Accurate up-to-the-minute parking availability data were The Smart Parking service was free until October 2005, when BART implemented a $1 daily fee for parking at the station and new fee-based monthly parking space reservation permits were introduced.

The results of the field test suggested that Smart Parking applications may be an effective way to expand transit ridership and reduce vehicle miles traveled. However, the capital, operation, and maintenance costs of the system indicated that it had to operate at a scale significantly larger than the 50 spaces covered by the Rockridge field trial to enable a Smart Parking system to recover its deployment and operating costs. An analysis of the costs to install and operate the system over a one-year period came up with an $800,000 estimate for a system covering 50 spaces at a single station, in mid-2000 dollars.

3.6.2. Baltimore Washington International (BWI) Airport Smart Park System

BWI was the first airport in the United States to use Smart Parking technology. The airport Smart Park system was implemented in 2004 to provide airport travelers with real-time information about parking availability at the airport and help them find available spaces (FHWA, 2007). This system covers more than 13,000 parking spaces distributed between two parking garages. It monitors the availability of each parking stall using overhead ultrasonic sensor. A central computer then continuously processes the information collected from the space sensors to determine whether parking spaces are available within each garage and relay to information to dynamic message signs located on the airport access road. Upon reaching a garage, travelers further encounter a billboard sign at the entry of each level indicating the number of available spaces on each level. The newer of the two garages also has a sign at the main entrance displaying the numbers of spaces available on all levels.

On each level, illuminated signs at the end of each row further indicate the number of available spaces on the row. These signs were set up specifically to help motorists find available spaces. A green arrow guides motorists to available spaces, while a red “x” indicates that there is no space available on the aisle. A blue arrow further directs users to handicapped parking spaces. At each space, a LED displays the parking status: green for available and red for unavailable. Users are also informed of the available parking spaces on the floors above and below their level by signs on the up and down ramps.

The estimated cost of the Smart Parking systems was approximately $6 million, or $450 per space. According to the Maryland Aviation Administration, parking occupancy increased to nearly 100 percent with the system. With parking occupancy maximized, revenue also increased. The maximum daily rate of the Hourly Garage was raised to $30 when the system was implemented in 2001. This rate was subsequently lowered, with a maximum daily of $20 being charged as of January 2011.

3.6.3. Chicago RTA/METRA Parking Management Guidance System

The Chicago Regional Transportation Authority (RTA) and METRA, the regional commuter rail system serving the city of Chicago implemented in August 2006 a pilot project to test the usefulness of a real-time parking information system for two commuter rail stations in suburban Chicago (FHWA, 2007). These stations were Tinley Park/80th Avenue and Mokena/Hickory Creek stations. These stations were selected because of their proximity and ridership level. The Tinley Park station featured parking lots that were often at or near capacity, while the Mokena station had underutilized lots. Officials envisioned that travelers who couldn’t find a space at the Tinley Park station would be directed by the system to the Mokena station.

The RTA/Metra parking management guidance system was comprised of two main components: a parking monitoring system and an en-route information system. The parking monitoring system detected vehicles utilizing two-channel loop detectors located beneath the pavement at parking lot entrances and exits. A central workstation maintained collected the entry and exit information and continuously updated the inventory of parking spaces. Parking availability information was then relayed by radio signal to eight CMSs located along Interstate 80 and nearby major arterials. Static arrows on the CMSs also provide positive guidance to the parking facility (SAIC, 2008).

A before/after evaluation sought to determine if the system increased lot utilization, improved customer satisfaction, reduced traffic circulation, and increased METRA’s ridership, transit mode share and mid-day arrivals at the two pilot project stations. The evaluation was unfortunately affected by missing and inconsistent data and the fact that the initial assumption, namely that the Tinley Park station was operating at capacity, was incorrect. Between August 2006 and August 2007 the evaluation team found minimal impact on the utilization of the park-and-ride lots. While the Tinley Park and Mokena stations experienced increments of 1.0% and 5.5% in parking utilization, respectively, this change was perceived to be too small to be directly attributed to the Smart Parking system, especially given other possible explanatory variables such as increasing population and increasing gas prices. The same problem was faced when examining the impacts on ridership. Surveys conducted at the two stations over a two-day period in March 2007 indicated that only 2% of the Mokena station respondents and 4% of the Tinley Park station respondents had chosen METRA because of the parking system. Nevertheless, the participants in the focus group and survey respondents generally expressed satisfaction with the system’s information system.

The pilot project was funded by the RTA and the Federal Highway Administration, had a cost of approximately $1 million, with an additional $100,000 spent on concept development and $150,000 on engineering design.

3.6.4. Montgomery County Advanced Parking Information System

The Montgomery County Advanced Parking Information System was activated in April 2007 to provide availability information for the Glenmont Metro park-and-ride lot in Montgomery County, Maryland (SAIC, 2008). This system was implemented to encourage greater utilization of Maryland's transit facilities by providing commuters with more timely information about parking availability at transit stations. In 2007, the Glenmont station had 1,738 parking spaces, of which 32 were reserved for patrons with disabilities and 280 for individuals purchasing a parking permit ahead of time for the privilege to park there before 10:00 AM. A $4 daily fee was charged to all patrons for use of the parking lot.

The Glenmont station park-and-ride lot operated at capacity on most weekdays. The primary objective of the system was to inform en-route motorists when the lot had reached capacity and to suggest alternate parking facilities, such as using the nearby Wheaton Metro Station and Norbeck park-and-ride lot. The Wheaton station, which was the next station along the Metro line, was rarely operating at capacity during weekdays. The Norbeck park-and-ride lot was 4 miles north of the Glenmont station and offered free parking. However, it required taking the bus to travel back to the Glenmont station.

The parking management system consisted of a video detection system and an en-route information system. Video detectors were used at each of the four garage access and exit points to monitor and count vehicles entering and leaving the lot. Real-time parking availability information was transmitted to three trailer-mounted CMSs via cellular modems to inform approaching motorists whether the Glenmont garage was open or full. When the garage became full, the CMSs provided a second message encouraging users to use an alternative nearby parking lot.

The system was found to have increase awareness of alternative parking availability and affected the travel decision of a few travelers. A shift towards earlier arrivals at the Glenmont station following system implementation was potentially attributed to the system. An observed reduction in the number of vehicles exiting the station during the morning peak was further linked to a reduction in vehicles circling the lot when it reaches capacity. However, there was no evidence that the information system enticed travelers to use the Norbeck park-and-ride facility once the Glenmont station is full, or that the system helped increase transit ridership.

4. CASE FOR SMART PARKING SYSTEM

Experience suggests that the difficulty of finding parking near transit stations can significantly reduce the attractiveness of transit services for individuals who need to drive a vehicle to reach a station. Recognizing that travelers dislike uncertainty, particularly with respect to the need of finding parking, transit agencies often seek to design parking lots offering spare capacity relative to the expected parking demand so that demand fluctuations can be accommodated. Despite this approach, unanticipated increases in transit ridership can still result in some parking lots regularly filling up entirely, particularly at end-of-line stations. When this occurs, one or more of the following consequences may be observed:

- Commuters have to spend significant time trying to locate an available parking space. This not only increases overall travel times but often results in added frustration, especially if the time spent looking for an open space results in the traveler missing a scheduled train or bus departure.
- Individuals who cannot find parking within a given lot may elect to park their car on neighboring streets, resulting in additional traffic on residential streets and increased difficulty for local residents in finding on-street parking. Individuals unable to find parking in transit lots may also choose to park their car in the lots servicing nearby stores, causing increased difficulties for store customers in finding convenient parking and potential loss of business to store owners.
- Commuters who cannot find a parking spot and do not elect to leave their vehicles on a neighborhood street or nearby parking facility due to tight ticketing or towing policies will return to the freeway or arterial they were previously traveling on. For individuals seeking to board a train or bus, this results in a wasted trip to the transit station, a loss of valuable time, and unnecessary fuel consumption and vehicle operating costs. For individuals traveling on roads leading to and from the transit station, these unnecessary trips may cause additional congestion and result in increased delays.
- Commuters who cannot find a parking spot at a given station and who do not elect to leave their vehicles on a neighborhood street or nearby parking facility may try to find parking at other transit stations. This can be a desired effect if the parking lots at other stations are underutilized. However, this effect may also just transfer parking issues to other stations if parking at alternate stations is equally in short supply or problematic.
- Commuters who habitually have problems finding parking at park-and-ride facilities may eventually elect not to travel by transit and choose to drive to their destination, thus resulting in lost ridership, and revenues, for transit agencies.

In addition to accessibility problems, the following issues may be associated with overflowing park-and-ride lots:

- Unnecessary trips to full parking lots, as well as excessive circling around in a parking lot to find an open space, result in avoidable fuel consumption and vehicle emissions that may contribute to a degradation of life quality, particularly for residents and business owners surrounding transit stations.
- Frustration associated with the difficulty of finding parking spots may entice some motorists to become more aggressive. This may increase collision risks, both within parking lots and on streets leading to the facilities.

- Vehicles continuously circling around parking lots create a heightened hazard risks for individuals walking between their vehicle and the transit station, as well as for other pedestrians.

The problems caused by overcrowded transit parking facilities cannot necessarily be solved by adding new parking spaces. Due to the vast number of factors affecting why travelers may choose to park-and-ride, adding new parking spaces often only results in small marginal returns on investment. As an example, a study of parking conditions at METRA commuter rail stations in the Chicago area (SAIC, 2008) showed that the addition of new parking spaces may simply result in the additional spaces being used by transit passengers who previously used overflow lots or on-street overflow parking spaces . In this case, the new parking spaces did not create an increase in ridership proportional to the number of new spaces. Another study (Ferguson, 2000) found that adding parking spaces does not necessarily induce travelers their cars other alternative modes of transportation to start taking buses or trains. While new park-and-ride users tend to be individuals who previously drove alone to work or other destination, some new users may be individuals who previously used buses or other public transit modes.

From a general standpoint, new parking spaces should only be added if the marginal expected revenue from their availability is greater than their marginal deployment and operation cost. At transit stations, potential revenues from supplying additional parking spaces mostly come from a potential for increased transit ticket sales due to increased ridership and parking fee revenue if a price is charged for using the new spaces. Where the cost of additional parking spaces is sufficiently high due to land values or the type of construction necessary, real estate development may also bring more benefits in revenue and ridership than investing in parking. Shoup (2005) provides a useful discussion of the costs of supplying additional parking and the opportunity cost of investments.

5. CONCEPT OF PROPOSED SYSTEM

This section describes key concepts of the proposed Smart Parking system. The concept is described using a general, high-level system view, without any intent to specify or imply particular designs or implementations. Elements presented herein include:

- Core system concept
- Key operating concepts
- Systems goals and objectives
- Potential system benefits
- Functional strategies
- Support environment
- Key assumptions and constraints
- Relation with Smart Growth concept

5.1. CORE CONCEPT

The core function of the Smart Parking system described in this ConOps is to help travelers find available parking spaces at transit park-and-ride stations and reduce unnecessary trips to parking facilities that may be full. This is done by collecting information about available parking spaces in monitored lots and disseminating this information to travelers via roadway signs, a phone system, or the internet. By informing travelers whether parking is available at a given lot, either before they start a trip or at key decision points along their route, an informed decision can then be made regarding whether a trip to the facility is likely to result in finding an open space and should therefore be attempted. If no space is available, an unnecessary trip to the park-and-ride facility can be otherwise avoided, thus reducing wasted time, fuel consumption and vehicle operating costs for the traveler. Disseminating parking availability information may also increase the attractiveness of transit services and entice individuals who normally travel by car to ride buses or trains, particularly those who had not considered transit as a viable option simply because of a lack of awareness about park-and-ride possibilities. The ability to affect parking decisions further promotes a more effective utilization of available parking supply. Smart Parking systems may for instance be implemented to help reduce overflow demand at lots that frequently reach their capacity, shift excess parking demand towards less utilized lots, or create new demand for chronically underutilized lots.

In addition to disseminating parking availability data, Smart Parking systems may use various technologies to offer park-and-ride customers various optional convenience features, such as automated payment of parking fees, in-lot guidance systems helping motorists locate open parking spaces, or advance parking reservation options. While such features are optional, they must be discussed as they are logical extensions of the basic functionalities provided by core Smart Parking features and are likely to be offered in many Smart Parking systems. These features may be offered as part of an initial deployment or a planned future system expansion. They may also be used to increase the attractiveness, and thus acceptability, of a proposed system.

The primary anticipated impact of such a system is to facilitate access to transit services by reducing uncertainties and problems associated with the need to find suitable parking near transit stations. This would improve transit accessibility, contribute to making transit a more attractive travel option, and could lead to increases in transit ridership. Smart Parking could reduce congestion and traffic safety risks within parking lots by decreasing the time and fuel spent searching for parking spaces. Traffic congestion and safety risks on roads leading to parking lots may also be reduced through the elimination of unnecessary trips to full parking lots. Any reduction in time spent driving vehicles or unnecessary trip may further contribute in reducing overall transportation emissions and in promoting the development of sustainable transportation systems. On a regional level, integrated Smart Parking systems could be an important tool for the promotion of smart growth strategies.

While the focus of the Smart Parking concept presented herein is to support the management and operations of park-and-ride lots servicing transit stations, the concept can be equally applied to the management of other parking facilities, whether operated by public or private entities.

5.2. KEY UNDERLYING CONCEPTS

Basic Smart Parking functionalities are based on the following concepts:

- Use of sensing technologies to accurately determine the level of occupancy of monitored parking facilities.
- Use of communication technologies to disseminate real-time parking availability information to travelers.

Optional functionalities are further based on the following concepts:

- Use of vehicle identification technologies to enable the implementation, and enforcement, of a parking space reservation system.
- Use of emerging electronic payment methods to facilitate the payment of parking fees.
- Use of parking availability data to implement a variable pricing scheme linking parking fees to available supply and aiming to contain parking demand overflow or better distribute the overflow across multiple facilities.

5.3. SYSTEM GOALS AND OBJECTIVES

Smart Parking systems are typically developed with one or more of the following general goals:

- **Provide travelers with an enhanced transit trip planning tool** – Provide travelers with advanced information regarding parking availability at individual transit stations to help them decide when and where they should travel to a specific station.

- **Improve parking management capabilities** – The ability to collect real-time information about parking availability will enable parking lot operators to better assess the demand for parking and to implement strategies aiming to increase the utilization of parking lots with spare capacity and redistribute the demand for parking at over utilized lots towards lesser used facilities.

- **Enhance the convenience of parking at transit stations** – Increase the convenience and reliability of using transit by offering advanced parking availability information, parking space reservation options, and electronic payment methods that may be compatible with other payment systems.

- **Increase transit system ridership** – Help travelers perceive transit as a viable travel option by making it easier and more convenient to find and pay for parking near transit stations.

These goals may further lead to the following desirable secondary effects:

- **Improve parking lot safety** – Reduced circling activities within parking lots should reduce accident risks with other vehicles and pedestrians within parking lots.
- **Improve the enforcement of parking rules** – The ability to collect detailed information about parking lot utilization will enable lot operators to better assess whether parking facilities are used by non-authorized users and to implement effective measures to curb illegal parking uses.
- **Increase parking availability for transit riders** – Enforcement methods implemented as part of a Smart Parking system may help curb unauthorized utilization of parking facilities intended for transit riders, thus resulting in an increase in the effective number of available spaces.
- **Reduce parking spillover onto neighboring streets and facilities** – A more effective management of parking facilities may help reduce the potential for travelers to park on neighboring streets and parking facilities once a park-and-ride lot becomes full.
- **Improve customer satisfaction with transit services** – Facilitating the process of finding parking may lead to an improved level of satisfaction of transit services.
- **Improve economic vitality of areas surrounding transit stations** – Reductions in spillover parking may result in an increase of parking spaces available for use by individuals seeking to visit shops and business surrounding transit stations.
- **Improve financial sustainability of parking operations** – Increases in overall parking lot utilization rates may lead to increased revenue collection. Reduced operational costs may also be obtained through the implementation of more cost-effective parking fee collection and enforcement methods.
- **Reduce the environmental impacts of park-and-ride activities** – A reduction in the number of unnecessary trips to full parking lots and circling activities within parking lots may lead to a reduction in vehicle emissions within and around parking lots.

Other potential uses for the monitoring, information dissemination and flexible pricing capabilities offered by the Smart Parking technologies considered include:

- **Measure of user acceptance of paid and preferential-based parking strategies** – Use of collected information about parking utilization to evaluate the response of travelers to various pricing schemes under various levels of parking demand.
- **Evaluation of parking pricing management strategies and business models** – Use of parking monitoring system to evaluate the effective of various parking pricing strategies in increasing available parking supply for transit riders and/or generating alternate funding sources.

5.4. POTENTIAL SYSTEM BENEFITS

The type and magnitude of benefits provided by Smart Parking systems depend on the environment in which each system is implemented. For implementations at transit park-and-ride lots, there are two distinct situations that must be considered for assessing potential benefits:

- Underutilized parking facility
- Facility with demand for parking exceeding the number of spaces available

The first scenario is one in which parking is below capacity on a regular basis. Motorists reaching a parking lot usually find open spaces. Here, a Smart Parking system offers an opportunity to increase lot utilization by better informing travelers of parking availability at the lot. Increased utilization could result from new induced demand or a shift of existing patrons from other overcrowded parking facilities. Benefits for specific system stakeholders in this situation include:

- Transit system users:
  - New users may benefit from the convenience of a park-and-ride system. Parking at a peripheral station and riding the train into a city center can often be faster than driving, especially when there is congestion. By doing so, users save time, gasoline and wear and tear on their vehicle.

- Businesses near park-and-ride lots
  - Businesses near parking lots may benefit from an inflow of additional park-and-ride commuters into the area.

- Parking lot owners and operators:
  - Parking low owners can enjoy increased utilization of their lot.
  - Increases in lot utilization may translate into increased revenues if parking fees are charged.
  - Collected data about parking availability can be used to support various operational analyzes and generate detailed performance reports.
  - Automation of some parking management operations, such as parking fee collection, may result in reduced staffing requirement for traffic control.
  - Improved enforcement capabilities may result in a reduction of use of the park-and-ride lot for non-transit purposes. This could translate into more space available for transit riders at locations where parking spaces may have been used for other purposes.

- Transit agency:
  - Transit agencies may collect additional fare revenues if the implementation of the Smart Parking system results in an overall increase in transit ridership.
  - Additional parking revenues may be realized if fees are charged for the privilege of using at park-and-ride lots.
  - Improvements in customer satisfaction may lead to an enhanced public image.

- Trip information providers:
  - Trip information providers may use parking data to promote services to travelers. This may result in increased registrations or an ability to charge increased advertisement fees for web applications experiencing increased in customer traffic.

The second scenario is one in which the parking lot reaches capacity relatively early in the day prior to Smart Parking implementation. This situation results in many people traveling to the parking lot only to find it full. By providing travelers within information about available parking spaces, or the lack thereof, a Smart Parking system diminishes the need for travelers to physically travel from the highway to the parking lot to determine whether a parking lot is full and the potential for wasted trips. This leads to the following potential stakeholder benefits:

- Park-and-ride users:
    - Transit riders may benefit from receiving information that a parking lot is full. This would allow them to save an unnecessary trip to the parking lot and thus save time, fuel and other vehicle operating costs.
    - Transit riders who would have traveled to a full parking may be directed to other lots where parking is still available.
    - Systems with reservation options may guarantee travelers that a parking space is available at the station they are traveling to at the desired time.
    - Travelers may experience reduced stress associated with the knowledge that parking is still available and thus have less a desire to rush to the lot to try to catch one of the last few spots available.

- Transit agency:
    - Smart Parking systems may result in more balance demand for parking among facilities along transit lines. This may result in an overall increase in the number of vehicles parking at existing facilities and in increased revenues if fees are charged for the privilege of parking.
    - Increased customer satisfaction may result from reduced difficulties in finding parking spots. This could promote increases in ridership.

- Parking lot owners and operators:
    - Parking low owners may enjoy a reduction in problems associated with motorists circling around to try to find an open spot or behaving aggressively and putting at risk the safety of other parking lot patrons.
    - Collected data about parking availability can be used to support various operational analyzes and generate detailed performance reports.
    - Improved enforcement capabilities may result in a reduction of use of the park-and-ride lot for non-transit purposes. This could translate into more space available for transit riders at locations where parking spaces may have been used for other purposes.

- Individuals residing near park-and-ride lots
    - Individuals residing near park-and-ride lots may benefit from a decrease in traffic from transit riders circling residential streets trying to find a parking space. A decrease in residential street traffic could result in less accident risks and fewer vehicle emissions. However, it should be considered that these benefits may be offset by the introduction of new users.

- Businesses near park-and-ride lots
    - Businesses near parking lots may benefit from increased parking availability on nearby streets following a decreased in overflow park-and-ride demand.
    - Owners of shopping malls near park-and-ride stations may experience fewer vehicles using their parking lot as an overflow parking facilities, thus increasing the supply of parking for business customers.

- Trip information providers
    - Trip information providers may use parking data to promote services to travelers. This may result in increased registrations or an ability to charge increased advertisement fees for web applications experiencing increased in customer traffic.

In each case, realization of the benefits described above will depend largely on the number of people who are affected by a Smart Parking system. To a certain extent, notoriety, education and marketing will play a role in how substantial realized benefits can be.

5.5. FUNCTIONAL STRATEGIES

Smart Parking systems typically use the following primary strategies to achieve their goal:

- **Real-time monitoring of parking availability** – Collection of real-time information about parking availability at individual parking facilities and, if required, within specific areas within a given facility.
- **Dissemination of real-time parking availability data** – Dissemination of real-time parking availability data to various information outlets to help potential transit travelers make more informed travel decisions before getting into their car and help travelers already on their way efficiently find open parking spaces.
- **Use of electronic identification, transaction and guidance technologies to assist parking activities** – Reduce inconveniences associated with the need to find suitable parking at transit stations by using technology to help guide travelers to open spaces and to facilitating parking transactions.
- **Dynamic management of parking demand** – Parking prices be adjusted periodically and gradually to help meet availability targets so that travelers can find, most of the time, available parking in the park-and-ride facilities under management.
- **Use of technology to enhance the enforcement of parking rules** – Enhanced enforcement methods may be used to ensure that parking rules are respected and that park-and-ride facilities are used by the intended travelers.
- **Improved convenience of parking** – Reduce inconveniences associated with the need to find suitable parking close to transit stations by helping guide travelers to open spaces and facilitating parking transactions.

5.6. SUPPORT ENVIRONMENT

The support environment for a Smart Parking system consists of systems that are not part of such a system but that are necessary for the system to function. For Smart Parking systems, the support environment includes the following elements:

- **Parking facilities** – Parking facilities provide the parking spaces that are to be managed.
- **Regional communication network –** Smart Parking systems may require data collected by sensors and other equipment installed within individual parking facilities to be sent to a remote

central computer server. Data may also need to be sent to various CMSs located along regional roadways. To implement these communication channels, existing communication infrastructures, such as the IMTMS communication network in San Diego, may be used.

- **Mobile phone communication systems –** Travelers may use their cellular phone to access parking availability information, reserve parking spaces, or use specific system functions.

5.7. ASSUMPTIONS

The following assumptions are made in the development of the Smart Parking ConOps:

- The implementation of a Smart Parking system is not associated with an expansion of existing park-and-ride facilities. While expansions may be considered, the core focus is to improve the management of the existing parking supply.
- All parking lots used for park-and-ride only serve nearby transit stations. There are no mixed-used facilities in which parking may be shared between a transit station and nearby stores.
- At each park-and-ride facility, a method exists to determine how many vehicles are present in the facility at any given time. The basic assumption is that in-pavement or non-intrusive traffic sensors are used at the entrances and exits of each lot to count vehicles entering and leaving each facility. While alternative detection methods may be used, such as sensors monitoring whether individual parking spaces are occupied, these represent different and usually more expensive methods of collecting the same information.
- Implementation of a parking space reservation system is an optional, albeit highly desirable, feature.
- Initial parking lot operation may or may not include parking fees.
- Implementation of a variable pricing strategy is an optional, albeit desirable, feature.

5.8. CONSTRAINTS

Potential constraints associated with the development, implementation and operations of a Smart Parking system include:

- Accurate parking space availability data is required for the implementation of a reservation system or a variable parking pricing scheme.
- Implementation of an advanced reservation system is only possible if a method exists to uniquely identify vehicles entering a parking facility of parking in specific stalls.
- Travelers may only embrace a system providing reliable parking availability information on CMSs.
- Budget constraints may prevent investments in new technologies central to the effectiveness of Smart Parking systems.
- The demographic makeup of commuters in a corridor may put into question the utilization of the new technology for the deployment of Smart Parking systems, particularly technology that may affect their privacy.

- While CMSs help motorists make informed travel decisions, their true effect on travel mode choices is not clear due to complex interactions between factors affecting travel decisions.
- Integration with existing information management systems and established Regional ITS Architecture elements may result in a need to supply data and develop system interfaces in formats that are compatible with existing systems.
- Coordination among several agencies may be required to implement an information dissemination system bringing information to motorists beyond the immediate entrance of a parking lot.
- Coordination with private parking lot operators may be required where park-and-ride lots are not directly operated by transit agencies.
- Coordination with agencies responsible for managing traffic and parking around park-and-ride lots, particularly if significant changes in traffic patterns and parking behavior are expected to occur.
- Smart Parking deployments need to be coordinated with long-range transportation plans and urban growth visions.
- Owners/operators of private parking facilities used for park-and ride need to earn a reasonable return on their investment. This generally translates into a desire to impose parking fees to cover lot operations.
- Parking prices are influenced by competition in the private market based on the laws of supply and demand. Charging a parking fee too high may result in travelers seeking to park elsewhere if parking at a lower cost is available. Conversely, charging a fee too low in comparison to other nearby lots may attract non-transit users to the parking lot.
- The implementation of variable parking pricing schemes may be considered a political risk due to the equity issues raised by such schemes.
- When considering advanced payment options, cash-based methods of payment may still need to be offered to accommodate casual parking lot users.
- Enforcement methods must be considered to prevent unauthorized use of the parking facilities or parking fee payment evasion.

5.9. RELATION WITH REGIONAL SMART GROWTH CONCEPT

Smart growth is an urban planning concept focusing on the development of compact urban centers to avoid sprawl. This concept advocates the development of compact, transit-oriented, pedestrian-friendly, and environmentally-sensitive neighborhoods. The underlying ideas are to focus growth away from rural areas and closer to existing and planned job centers and public facilities, preserve open spaces and natural resources, and make more efficient use of existing infrastructures (SANDAG, 2004).

With respect to parking, smart growth principles aim to prevent the offering of too many parking spaces. The principles do not advocate the complete elimination of parking, but that land or facilities dedicated to parking must instead be utilized efficiently. This entails that the supply of parking spaces must not significantly exceed demand. An example of smart growth strategy related to parking is to develop shared central parking facilities that could be used at different times, such as by commuters during the week and individuals making shopping or leisure trips during off-work hours. Other examples are to change minimum parking requirement standards into maximum requirements, and to relax parking provision requirements in special transit zones. There also exist smart growth strategies that attempt to manage the demand for parking rather than the supply. Examples of such strategies include plans to provide incentives to reduce car ownership and increase non-motorized travel, as well as attempts to use parking pricing mechanism to reduce the potential demand for parking (EPA, 2006).

Smart Parking contributes to the smart growth goals by providing tools for the efficient management of parking demand in cities. Through the provision of en-route information regarding parking availability or provision of a parking reservation system, Smart Parking systems offer a mechanism to distribute parking demand among available park-and-ride facilities, in addition to promoting the use of such facilities. Smart Parking also relaxes some of the smart growth constraints by introducing flexibility in the decision making process and providing technologies that may be required for practical applications of certain strategies. For example, uncertainty in parking demand analysis could hinder the implementation of shared parking facilities due to fear of developing parking lots that may end up overflowing regularly. By attempting to provide en-route parking availability, Smart Parking systems reduce the possibility that unsuspecting users arrive en masse at a parking lot and may reduce concerns regarding the approval of a new parking structure. By enabling variable pricing according to time of day or level of occupancy, Smart Parking systems can also attempt to moderate the demand for parking. The provision of a wider array of payment methods, if offered, could further increase convenience for individuals to choose a park-and-ride option and promote transit ridership. It can also be argued that Smart Parking systems can indirectly contribute to the development of pedestrian and bicycle friendly communities by attempting to reduce the amount of unnecessary vehicle travel to and around parking lots.

6. STAKEHOLDER NEEDS

Smart Parking systems are developed and implemented to satisfy various user needs. This section defines:

- Potential stakeholders in a system that may be deployed within the San Diego region
- Potential characterizations of system users
- General user needs.
- Function-specific needs

6.1. SYSTEM STAKEHOLDERS

Stakeholders in a Smart Parking system include individuals and entities having an interest in improved management of park-and-ride lots at transit stations. Potential system stakeholders for systems that may be deployed within the San Diego region may be categorized into the following broad groups:

- Travelers
- Providers of transit services
- Governmental agencies
- Private companies
- Interest groups

6.1.1. Travelers

Travelers are generally seen as the primary beneficiaries of Smart Parking systems. Stakeholders within the traveling public include the following groups of individuals:

- Transit park-and-ride users : Park-and-ride users are the main expected users of Smart Parking systems. These individuals would benefit from both the dissemination of information regarding parking availability and improvements in parking lot operations. However, park-and-ride users may also oppose systems that may lead to increases in parking costs or reductions in available parking as a result of too many spaces being reassigned to specific groups of users.

- Transit users without vehicle : Transit users who do not use park-and-ride facilities may experience more crowded transit vehicles if the implementation of a Smart Parking system leads to a significant increase in transit ridership. On the other hand, these individuals may also experience fewer problems while heading to a transit station as a result of smoother or reduced traffic flows around parking lots.

- Highway users : This group may benefit from the dissemination of information enabling them to consider alternative transportation modes. Smart Parking services such as parking reservation and electronic payment may further help promote transit as a convenient mode of transportation and entice motorists to consider this mode as a viable alternative to driving.

6.1.2. Transit Providers

Transit service providers, whether publicly or privately operated, have an interest in any system helping them manage the parking facilities they operate at rail stations or along bus routes. An interest in Smart Parking systems may also be derived from the opportunities provided to increase transit ridership and revenues. Within this group, potential stakeholders include:

- Local Transit agencies : Local transit agencies may benefit from potential increases in ridership induced by the increased convenience of finding parking near transit stations. These ridership increases may further translate into increased revenues that may in turn be used to improve transit services. As operator of park-and-ride facilities, transit agencies may also benefit from a more effective management of existing parking facilities, as well as increased revenues from these facilities. Potential stakeholders in this group within the San Diego region include the San Diego Metropolitan Transit System (MTS) and North County Transit District (NCTD).
- AMTRAK : A Smart Parking system may enable AMTRAK to manage more effectively the park-and-ride facilities it operates near its train stations. As a provider of intercity travel services, AMTRAK may also benefit from increased ridership, and thus increased revenues, induced by the attenuation of parking problems near train stations. These benefits may be obtained whether a Smart Parking system directly includes AMTRAK's parking facilities or only covers nearby facilities operated by other entities.
- Intercity bus companies : Intercity bus companies such as Greyhound and charter bus services may benefit from increased ridership and revenues induced by the attenuation of the difficulties of finding parking near bus depots. Companies operating their own parking facilities and opting to participating in a Smart Parking system may further benefit from the ability to implement enhanced parking management functions.

6.1.3. Governmental Agencies

A variety of governmental agencies may have an interest in the deployment of a Smart Parking system. For systems deployed with the San Diego region, the following federal, state and city agencies may be potential system stakeholders:

- Federal Transit Administration (FTA) : Because of potential impacts on transit operations, the FTA may play a role as a financial backer of the project. It may also provide guidance in how a system should be developed or operated.
- Federal Highway Administration (FHWA) : Because of potential interactions with vehicular traffic, the FHWA may financially back the project and provide guidance in how a system should be developed or operated.
- Caltrans : Caltrans may be providing financial support for Smart Parking projects, in addition to access to their right of way and/or operational methods for the installation of CMS and communication devices used for

disseminating parking data to motorists along freeways and highways. Caltrans may also own and operate park-and-ride lots included in a Smart Parking system deployment. The agency may further manage the roads leading to some parking facilities and have consequently interests in how a Smart Parking system will impact traffic conditions on the roadways it manages. Finally, Caltrans may manage part of the regional ITS architecture with which a Smart Parking system may be required to connect in order to disseminate parking availability information.

- SANDAG : As the regional transportation planning and coordination authority, SANDAG may be concerned with the effects that a Smart Parking system may have on mode choice and land development. SANDAG may play a role in the planning, implementation and operation of a Smart Parking system reaching multiple transit service providers across a region, in addition to setting and/or influencing policies that may potentially concern Smart Parking deployments and operations. As the owner of the San Diego Regional ITS Architecture, SANDAG may further influence how a Smart Parking system may interact with the San Diego Regional Architecture, more particularly with the architecture's Intermodal Transportation Management System (IMTMS) data hub.

- Government of San Diego County : As the operator of regional roads, the Department of Public Works of San Diego County governments may have interests in the potential impacts that a Smart Parking project may have on local traffic conditions. The Department may be involved in the installation and operation of CMSs located along county-maintained roads, as well as the operations of park-and-ride facilities.

- City traffic engineering departments : City traffic engineering departments may have interests in the potential impacts of Smart Parking projects on the roads they manage. Cities that may have an interest in Smart Parking projects include San Diego, Carlsbad, Chula Vista, Del Mar, El Cajon, Encinitas, Escondido, La Mesa, Lemon Grove, National City, Oceanside, Poway, San Marcos, Santee, Solana Beach, and Visa. These are all cities within which transit park-and-ride facilities already exist or cities located near such facilities.

- City/Transit police departments : City or Transit Agency Police Departments may be tasked to enforce rules governing the operation of Smart Parking systems. This may include patrolling parking facilities and issuing parking tickets to motorists who have failed to pay the required fee.

- Judiciary : Local courts may have an interest in how parking rules are to be enforced, particularly if this affects the process by which individuals may contest parking tickets.

- City Planning Departments : Along with regional planning organizations, city planning departments may play a role in determining at which locations and how Smart Parking systems may be deployed.

- Other city/county agencies : Cities may own the right-of-way on which parking facilities are located and have therefore some vested interested in how their properties are developed.

6.1.4. Private Companies

Various private companies may have interests in a Smart Parking system. Potential stakeholders within this group include:

- Private parking lot owners and operators : Owners and operators of private parking lots near transit stations may partner with transit agencies to have parking availability data from their lots disseminated by a Smart Parking system. Inclusion in a Smart Parking system may help increase parking lot utilization and enable the implementation of more efficient parking management functions. Parking operations may also be affected without participating in a Smart Parking system as such a system may cause indirect shifts in parking demand.

- Business owners near park-and-ride lots : Individuals owning businesses in areas surrounding park-and-ride lots may benefit from increased retail sales due to an increase in the number of persons traveling to the transit station, as well as increased parking availability on local streets following a reduction in overflow parking activities from transit lots.

- Information service providers : The information generated by a Smart Parking system could be of interested to companies providing trip information services and applications to their customers.

6.1.5. Interest Groups

Additional system stakeholders include the following groups of individuals or entities:

- People living near park-and-ride lots : Individuals living in the area surrounding park-and-ride lots may benefit from a more efficient utilization of existing facilities through a reduction of traffic and parking activities on neighborhood streets.

- Smart growth advocate groups : Interest groups concerned with urban form and the impacts of motoring activities on the environment, safety and quality of life may lobby in support of or against Smart Parking projects. These groups may notably provide expertise or opinions that could influence the nature or operation of Smart Parking networks.

- Civil liberties groups : Smart Parking could be opposed by groups concerned with the impacts of using specific technologies, such as RFID, on traveler privacy of and other civil liberties.

6.2. CATEGORIES OF USERS

Smart Parking systems, particularly those offering reservation options, may distinguish various categories of users. A first categorization may be based on whether users of parking lots have a Smart Parking account identifying their vehicle:

- Registered users : Users who have a Smart Parking account.
- Non-registered users : Casual, anonymous users without a Smart Parking account.

A more functional categorization may further distinguish the privileges granted to specific users:

- Premium users : Registered users with a Smart Parking account. These individuals are likely to be regular customers of reserved parking areas. They are likely to use advanced identification technology such as a smart cards or RFID tags to facilitate their entry into and exit from parking facilities, and automate the parking of parking fees.

- Reserved users : Registered users who have reserved a parking space only for the day they show up at the lot. These may be regular or casual users. While they may use advanced identification technology, many users falling in this category may not have such technology.

- Drive-in users : Individuals, whether registered users or not, who have not reserved a parking space before showing up at a facility.

The above categorizations may come in addition to others that may exist as a result of local parking operations. For instance, some facilities may provide spaces to distinguish parking lot users holding handicap placards or vehicles used as carpools.

6.3. USER NEEDS

As outlined in Section 5.3, Smart Parking systems seek to provide an enhanced transit-related travel decision tool, improve parking management capabilities, enhance transit services, and increase transit system ridership. These general goals typically translate into the high-level requirements and general objectives listed in Table 1.

Table 1 – High Level Smart Parking System Objectives

Requirements	Objectives
1. Travelers shall have the informational tools to make smart travel choices in the region.	a) Collect data characterizing parking lot utilization (e.g., number of available spaces, parking fee charged, etc.). b) Collect and validate data characterizing travel conditions on roads leading to park-and-ride lots (e.g., expected travel time to facility). c) Provide traveler with reliable information about the number of parking spaces available within each parking facility. d) Inform travelers of the fee that they should expect to pay to park at a specific facility before entering it, particularly if the fee is variable. e) Enable parking availability data to be displayed on roadside signs, 511 information websites, and other regional traveler information applications f) Enable third-party travel information application developers to access relevant parking availability data. g) Disseminate reliable parking information to travelers in real time. h) Create a data warehouse to facilitate data collection, sharing and storage.
2. A Smart Parking system shall improve accessibility to travel options, encourage modal shifts and enhance mobility for a region's travelers.	a) Inform travelers in real-time of parking availability at park-and-ride lots. b) Provide travelers with the ability to reserve parking spaces ahead of time. c) Implement technologies facilitating the payment of parking fees. d) Implement technologies facilitating the validation of parking activities. e) Promote the use of a unified method of payment for transit fares, public parking fees, and roadway tolls. f) Incorporate Smart Parking concepts into regional planning approaches to encourage carpooling, vanpooling, transit, biking and walking.
3. A Smart Parking system shall maximize parking capacity at existing facilities	a) Collect comprehensive data on parking lot utilization (available spaces, entry/exit volumes, turnover rate, etc.) to determine current or projected parking availability at given points in time. b) Track parking utilization in real time. c) Guide motorists to parking facilities with available spaces. d) Guide motorists to available parking spaces within a given facility to reduce unnecessary circling around. e) Dynamically adjust the price for parking to ensure that the current or projected demand for parking does not exceed the available supply. f) Implement appropriate enforcement methods to reduce or eliminate unauthorized parking utilization.
4. A Smart Parking system shall create revenue for parking operators	a) Create incentives for owners and operators of parking lots/structures to install Smart Parking technology and enter into partnerships with cities or metropolitan planning organizations.

Table 3 – Specific Smart Parking System Objectives (cont'd)

Requirements	Objectives
5. Smart Parking operations shall be coordinated with regional parking management policies and vision	a) Ensure that implement parking management strategies are in line with regional policies and regulation regarding parking operations. b) Ensure that the deployment of Smart Parking systems respect and strengthen transportation system development and urban growth goals set up in long-range transportation plans.
6. Smart Parking's institutional partners shall create a seamless parking management system for travelers.	a) Establish/enhance joint agency plans create parking management guidelines at transit stations. b) Establish partnerships with cities to promote parking management policies and technologies. c) Develop data collection and dissemination systems compatible with systems used at parking facilities operated by other public agencies and/or private companies. d) Create means for sharing data collected by different lot operators to improve availability of information to travelers. e) Develop standardized methods of communicating information to travelers. f) Strengthen existing communication linkages among all parking facility stakeholders and establish new communication linkages where appropriate (e.g., private owners and operators). g) Utilize public/private partnerships to provide travelers with comprehensive, timely, and accurate information on traffic, transit and parking conditions and available alternatives. h) Conduct outreach activities to promote stakeholder and public participation.

6.4. FUNCTION-SPECIFIC NEEDS

From the general list of user needs listed in Table 1, system specific needs linked to the following functionalities can further be developed:

- Parking lot monitoring
- Information dissemination
- Parking pricing
- Reservation system
- Enforcement
- Data analysis and reporting
- Integration with Regional ITS Architecture

6.4.1. Monitoring of Parking Lot Utilization

At the core of Smart Parking systems is the ability to provide travelers with real-time information about parking space availability at park-and-ride lots. This ability leads to a need for a parking lot monitoring system capable of tracking parking the number of vehicles parked within the facility. This can be accomplished using one of two basic approaches:

- Monitoring of vehicles entering and exiting parking lots.
- Sensing of whether individual parking stalls are occupied by a vehicle or available.

The first approach consists of installing vehicle sensors at the entrances and exits of parking facilities. Parking availability is then indirectly derived by tracking the cumulative number of vehicles that have entered and exited the facility. The second approach relies on vehicle sensors installed within each parking stall. In this case, parking availability is directly determined by compiling the number of sensors reporting their stall as being unoccupied. While this approach is more expensive, it provides more detailed information about parking space utilization, enabling notably to determine where travelers typically park and which sections have open spaces.

Regardless of the approach adopted, a system capable of accurately monitoring parking lot utilization is required to ensure that reliable information is provided to travelers and parking management functions. Travelers would typically perceive as failures systems providing inaccurate information. This could lead travelers to stop paying attention to the information being dissemination, which would then lead to a potential reduction of benefits that may be obtained from a system implementation.

Another important need for system operators is the ability to characterize parking lot utilization. This also implies tracking the number of vehicles present within a facility at a given time. However, parking operators are also interested in information helping them characterize parking demand, such as how long individual vehicles are typically park, what types of users are parking in a given facility, etc. Parking lot operators may also be interested in using compiling current parking utilization rates with reservation records and historical data to assess near-future parking demand. Such information could notably allow them to better direct upcoming patrons to facilities with available spaces, or adjust the price for parking to minimize the risk of demand exceeding capacity.

6.4.2. Information Dissemination

Smart Parking systems aim to improved park-and-ride operations by better informing travelers of parking space availability at parking facilities. While parking space availability displayed at the entrance of facilities help travelers to decide whether they should enter and reduce unnecessary in-lot traffic, such information does not prevent travelers from potentially making wasted trips to filled parking lots. A key need is therefore to disseminate parking availability beyond the immediate vicinity of park-and-ride facilities. This can be achieved using various methods:

- Displaying availability and pricing information on CMSs located near the entrance of parking facilities.
- Displaying availability and pricing information on CMSs located near key decision points along nearby roadways.
- Displaying availability information on travel information websites.
- Provision of information to third-party information service providers for redistribution to their customers.

Another important consideration is the need to disseminate reliable information. In particular, travelers should ideally be provided with information indicating how many spaces might be available at the time they will reach a facility. This is particularly important for parking lots nearing capacity. This need implies tracking in real time parking availability and, if possible, displaying on remote information outlets information about projected the number of spaces that might be available in 10, 20 or 30 minutes into the future, perhaps along the current space availability.

6.4.3. Parking Pricing

Smart Parking systems seek to maximize utilization of existing parking facilities. For lots where the demand for parking chronically exceeds the number of spaces available, a primary need is to reduce the demand to a level matching the available capacity. While informing travelers that a lot has reached its capacity can result in some travelers choosing not to park there, this approach alone may not be sufficient to bring the demand down to a desirable level. In such a case, an effective method to control the demand for parking may lay in the instauration of new parking fees or alteration of existing fees.

Depending on the situation, new or altered parking fees may be implemented for one or more of the following objectives:

- Reducing use of park-and-ride lots by non-transit users.
- Reducing the overall demand for parking at locations where excessive parking demand is an issue.
- Passing the cost of building and operating the parking facility to users of the facility.
- Promoting use of the parking facility by specific types of users by setting a differential fee structure discounting the price of parking for specific users over others, often to achieve specific economic, strategic of policy objectives.
- Increasing the attractiveness of the transit alternatives by setting parking prices below what drivers would pay to drive and park at their destination.

For parking facility owners/operators, the primary objective of setting a price on parking is to cover the costs of operating the facility and to earn a reasonable return on investment. However, this objective must be balanced against the desire to attract customers, as setting prices too high may reduce the demand for parking and result in lower revenues for lot operators. Setting parking prices too high may also reduce transit ridership and reduce fare revenues. Prices are further influenced by competition with nearby private or public parking lot facilities, and could be manipulated by public agencies to realize specific public policy objectives. An effective implementation of a new parking pricing scheme requires careful consideration of the underlying policy objectives and coordination with regional transportation plans, as different pricing schemes may have different effects on traveler behavior.

While considering a parking pricing structure, it is of utmost importance to take into account the potential responses of travelers to the changes considered. In particular, the benefits that would be collected from the imposition of a new fee or a fee increase should *not* be out-weighed by a decrease in parking demand and/or transit ridership. Known characteristics of travel choices suggest that elements affecting the choice of a facility to use have more pronounced effects on travel behavior than elements affecting mode choice (Ferguson, 2000). Imposing or raising park-and-ride fees may there have more impacts on the use of park-and-ride facilities than on transit ridership. This is due to the fact that many users of park-and-ride lots have travel alternatives. In response to a parking fee increase, individuals who previously parked at a park-and-ride facility may choose to park in informal lots or on neighborhood streets, take a feeder bus, or arrange to be dropped off at the transit station. While these changes may result in a reduction of park-and-ride usage, they would not affect transit ridership. However, when facing increased parking fees, some individuals may also elect not to use transit at all, thus resulting in a reduction of both parking and transit demand.

Economists suggest that the optimum parking fee per unit time should be set equal to the marginal cost of providing a parking space, to reflect the fact that parking cost and availability are closely tied to vehicle usage and roadway congestion. While parking fees can be an effective instrument to influence commute travel, they may have limited or even perverse effects for through-travelers and those who can vary the length of time parked. Another concern when manipulating parking fees for policy purposes is the potential to trigger shifts in the locations of trips themselves, and with them the economic opportunity that trips represent, leading to economic dislocation.

Elasticity of demand with respect to pricing is a crucial parameter to consider in determining effective pricing schemes. Demand elasticity is a measurement of the change in demand in response to a change in price. When specific parking elasticity information is unavailable transit agencies usually assume a 5% reduction in demand given a 20% increase in price. In reality, however, demand elasticity is more complex because many agencies currently do not charge for parking. Another potential difficulty associated with park-and-ride facilities is how to estimate elasticity when the initial situation features free parking (ex: $0.00 x 20% =0).

While many transit agencies offer free parking, the imposition of new parking fees has been shown under certain circumstances to produce net benefits. Because congestion is one of the factors that may constrain demand, reducing congestion may attract new users. While some users may be turned off by the fee increase, others may be attracted to the facility despite the fee because of convenience and decreased congestion. For Smart Parking systems, the key is to assess whether they may attract enough new users to overcome any lost due to a price increase, and thus provide an overall increase in transit use. In this case, the findings of the Rockbridge study are encouraging: while many participants expressed their dissatisfaction with having to pay for parking, BART use increased by 15% among the participants (Rodier, 2005).

6.4.4. Reservation System

The possibility of reserving a parking space in advance can have important implications on the ability of a Smart Parking system to achieve its stated objectives. The greatest benefit is to travelers, who are provided with a tool enabling them to remove some uncertainty in their planned trip. This benefit can be particularly significant where scarcity of parking often creates travel difficulties and delays. In addition to helping plan trips, a reservation system can also significantly alter how travelers interact with a Smart Parking system, for instance by enabling travelers with reservation to pay for parking before initiating a trip. For system operators, the provision of a reservation system however adds a level of complexity that may significantly increase deployment costs and enforcement requirements.

To be effective, a reservation system should:

- Track the number of parking spaces that can be reserved within a given facility at a given time.
- Allow reservations to be placed not only on spaces that are currently available, but spaces that would be available at an expected arrival time in the future.
- Enable reservations to be placed online or through the phone.
- Offer options to alter or cancel existing reservations to accommodate unexpected changes in travel plans.
- Provide travelers with a convenient way to indicate that they have a valid reservation. This can be the generation of a parking confirmation ticket that must be printed and displayed on the dashboard of a vehicle, or the issuance of a reservation number that can be used to gained access to a gated parking facility.
- Assign a unique confirmation number to each new reservation to facilitate their tracking.
- Provide travelers with the ability to pay a reservation with convenient electronic means (credit cards, debit cards, COMPAS smart card account, PayPal account, etc.).
- Provide travelers with the ability to store commonly used user information online.

6.4.5. Enforcement

Wherever reserved parking is offered or fees charged for parking, a system for enforcing parking rules and regulations must be used to avoid unauthorized use of parking facilities. In the context of Smart Parking, enforcement primarily refers to the task of verifying the validity of a vehicle occupying a given parking space at a given time. Enforcement also includes processes that can be used to issue citations and/or remove vehicles parked in unauthorized spaces.

In many systems, enforcement activities may simply be a continuation of activities that are already being conducted. However, the implementation of a Smart Parking system may offer various opportunities to enhance enforcement:

- Physical gates may be installed to better control access to a facility or section of facility.
- While virtual gates do not physically restrict entry, a mechanism could be implemented to identify vehicles entering the facility without proper authorization and to provide a list of unauthorized facility users to enforcement officers.
- Parking validation information collected by a Smart Parking system may be used to compile lists of parking spaces that should be vacant. Enforcement officers could then use this list to verify that registered vacant spaces are truly vacant.

To be effective and politically acceptable, the enforcement process – from identification of the offence to follow ups, appeals against penalties and debt collection – must be perceived as efficient, considerate and fair (Litman, 2011). The need for issuing citations should be minimized by providing adequate information and options to users. Motorists sometimes violate parking regulations simply out of ignorance, because they lack the denomination required by a parking meter, or simply because a meeting took longer than expected. To address such one-time situations, it may be appropriate to have exemptions to parking regulations and fines, such as "First Time Free," so the first time a motorist violates parking rules they are given information about parking regulations instead of a citation.

Parking enforcement officers must be given adequate training and clear guidelines concerning how to enforce parking rules. They should be friendly, considerate and helpful. They should strive to be perceived as helpful community ambassadors. They should provide maps and brochures about local parking options, as well as general directions and tourist information.

6.4.6. Reporting

Data analysis and reporting capabilities are needed for evaluating the performance of Smart Parking systems and generating reports. Parking lot operators may for instance be interested to know whether a Smart Parking system has increased lot utilization to help them decide whether system expansions may be beneficial. Parking lot managers may be interesting in obtaining utilization reports detailing parking activities by various categories of users to assess the effectiveness of current pricing and marketing strategies and determined whether new strategies should be developed.

Performance metrics of interest to Smart Parking systems, if they can be produced, include:

- Total number of vehicles in facility.
- Number of reservation issued.
- Average parking lot utilization rate (ratio of spaces occupied to capacity).
- Average utilization rate of reserved parking section.
- Average utilization rate of unreserved parking section.
- Average facility turnover rate.
- Average turnover rate for reserved parking spaces.
- Average turnover rate for unreserved parking spaces.
- Revenues collected (if parking fees are charged).
- Price charged for parking (if dynamic pricing is used).

Depending on operational needs, these statistics may be reported as average for the entire reporting period, each day, or each time period within a day.

6.4.7. Integration with Regional ITS Architecture

As part of Section 5206(e) of the Transportation Equity Act for the 21st Century (TEA-21), the Federal Highway Administration (FHWA) and the Federal Transportation Administration (FTA) have established rules and policies requiring that all ITS projects funded from the Highway Trust Fund be in compliance with the National ITS Architecture. Within each region, conformance with the above rules and policies is obtained through the development of a Regional ITS Architecture that defines the framework within which local ITS applications must be developed.

The integration of a Smart Parking system within a Regional ITS Architecture is further supported by the fact that such a system is expected to interface with various ITS applications. Examples of data communication needs with other systems include:

- Distribution of parking availability and pricing data to traveler information systems operated by transit agencies and private information providers.
- Distribution of parking availability, and potentially pricing, data to the systems managing the CMSs located along urban arterials and freeways.
- Communications between Smart Parking system components installed at various facilities.

Figure 1 illustrates the context within which a Smart Parking system is expected to interact with other ITS systems within the San Diego region. The figure illustrates a preliminary architectural view of the Integrated Corridor Management System (ICMS) that is currently under development along the I-15 corridor. This system, which is expected to become operational in 2014, aims to develop a multi-agency, decision support system for proactively management congestion along the freeway and maximizing overall corridor system efficiency and mobility. Within the ICMS framework, a Smart Parking system is expected provide the basis for a regional parking management system. Interfaces with the IMTMS communication network, which is used to link together regional ITS applications, will enable it to interact with a range of existing and planned ITS applications and to efficiently disseminate parking availability and pricing data to travelers.

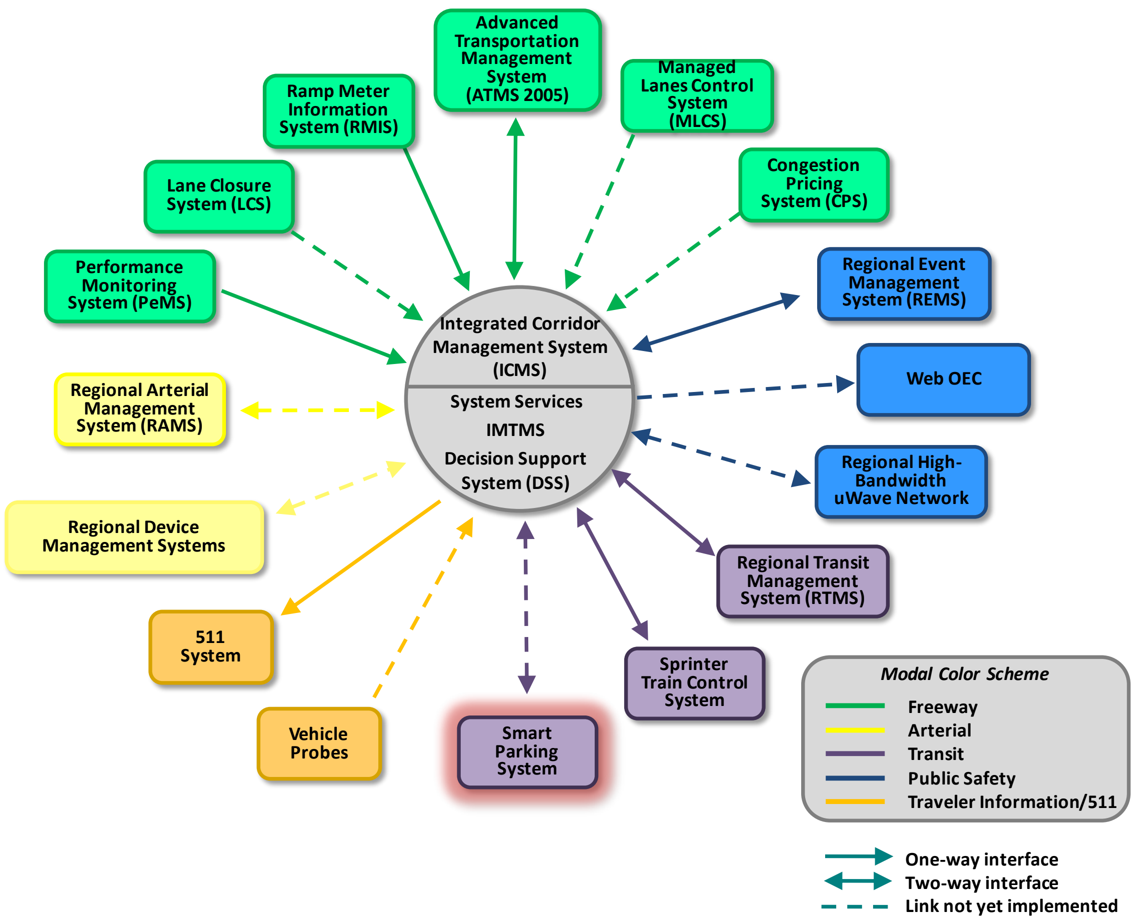

Figure 1 – Smart Parking Implementation Context within San Diego's Regional ITS Systems
(Adapted from SANDAG sources)

7. SYSTEM OVERVIEW

This section presents an overview of the envisioned Smart Parking system. Elements covered herein include:

- Core interactions between users and system
- Operational considerations
- Main system functions
- Physical system elements
- Supporting technologies
- Design control elements
- Operational environment
- System packages
- General implementation steps

7.1. CORE INTERACTIONS BETWEEN USERS AND SYSTEM

Figure 2, Figure 3 and Figure 4 present basic layouts of how motorists may interact with a Smart Parking system. Figure 2 presents interactions with the process of determining whether parking is available that may occur before initiating a trip while at home or at an office, during a trip, and upon reaching a parking facility. Figure 3 and Figure 4 respectively present subsequent interactions that may occur within a parking facility for registered and unregistered users. Based on the illustrated processes, travelers are expected to interact with a Smart Parking system in the following ways:

1. **Obtaining information about parking availability** – A user's interactions with the system begin when he either request or receive information about parking availability at a transit station. For example, a user can request this information from the transit agency website at a kiosk or from a home computer. The parking availability information can also be delivered to drivers in traffic via a CMS or a phone text message.

2. **Making a parking space reservation** – If the system provides parking reservations, a user can reserve a spot either on-line or on the phone. The Smart Parking either grants a parking permit or denies the reservation if no space is available for a particular time. If the reservation is denied, the system can provide information about alternative parking spaces in adjacent train stations' parking lots. Unless the reservation is free, the user is then requested to pay a fee. The reservation is then associated with a unique identifier: this can be a reservation number, a personal cell phone number, a smart card, an RFID tag, etc.

3. **Driving to parking lot** – While driving to a park-and-ride lot, motorists may be provided information on which facility has available parking spaces. Based on this information, motorists who have not made a parking reservation could then decide whether they still want to travel to a particular facility, will travel to another park-and-ride facility, or simply abandon attempts to use transit for the day.

4. **Detection of entry into parking lot** – Upon reaching a parking lot, a traffic sensor detects the vehicle being driven by a traveler as he enters the lot. The detection event is then sent to the parking management system, which updates the inventory of available spaces accordingly.

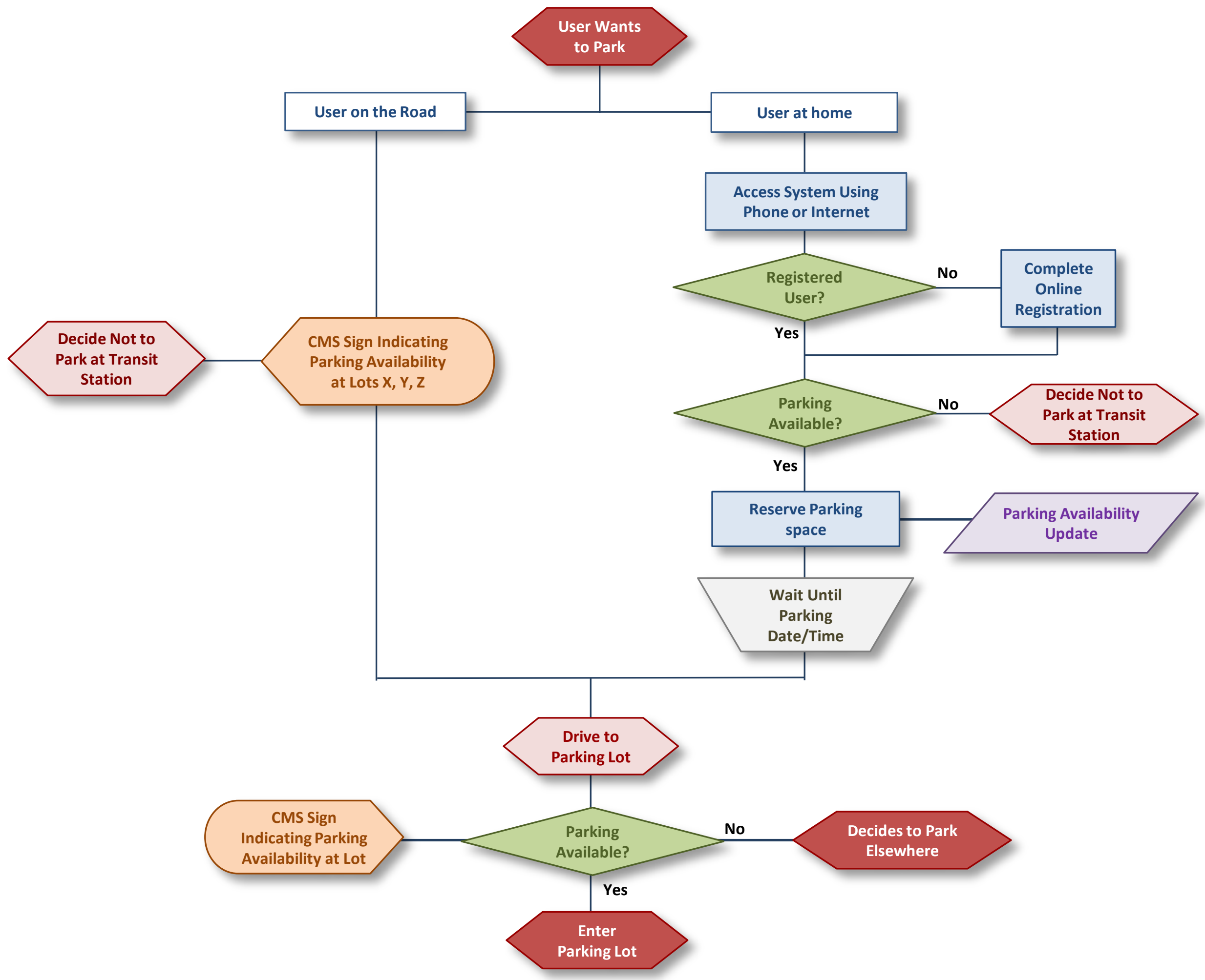

Figure 2 – System Interactions: Determination of Parking Availability

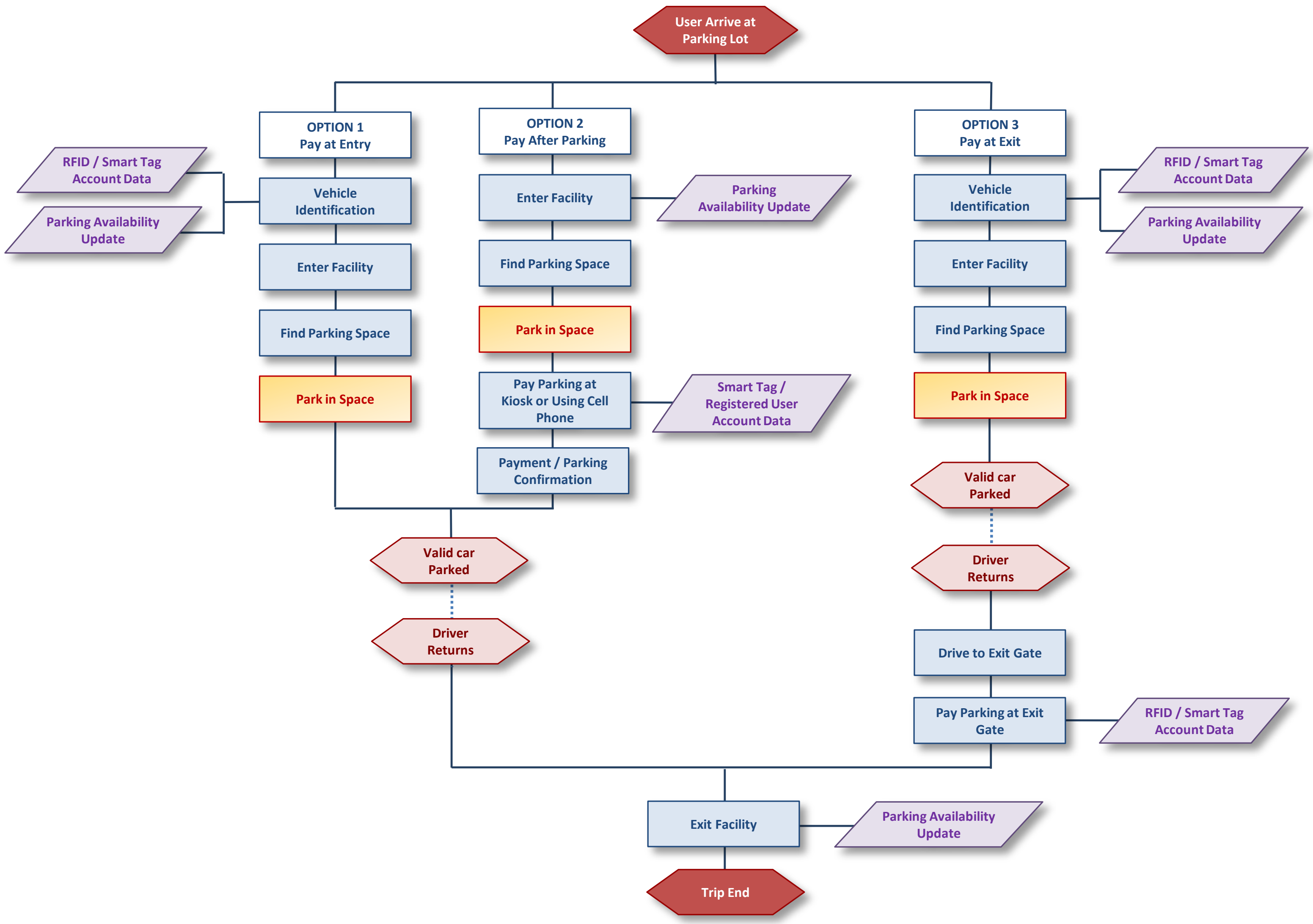

Figure 3 – In-Lot System Interactions: Registered Users

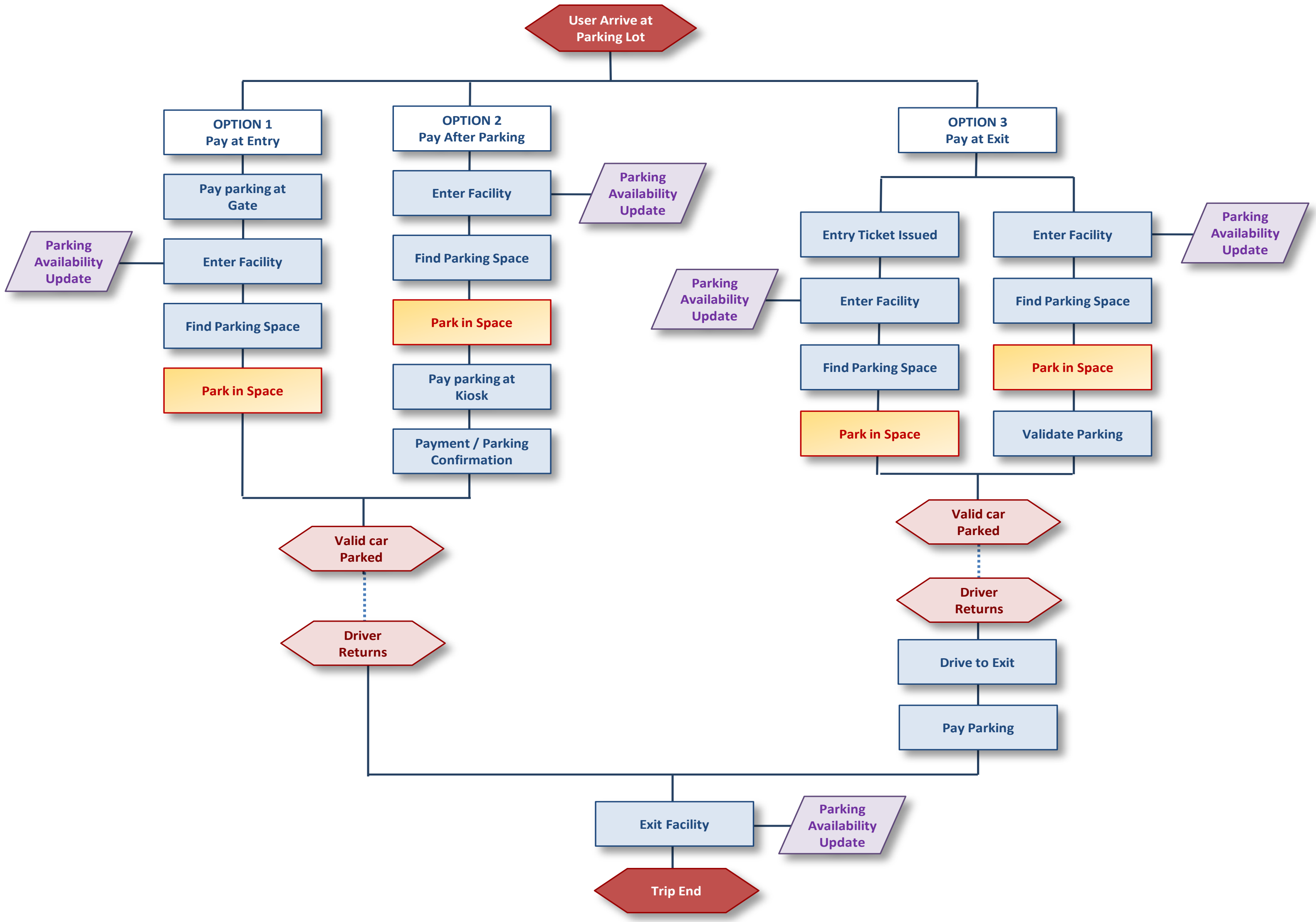

Figure 4 – In-Lot System Interactions: Non-registered Users

5. **Location of an empty parking space in lot and parking of vehicle** – After having entered a parking facility, a traveler then proceeds to find an open parking stall and parks his vehicle in it. Here, we do not assume anything about the parking rules, whether spaces are differentiated or not. Similarly, we do not distinguish between a reserved or non-reserved user. Such specific rules are part of the operational parameters discussed later in this chapter. The assumption here is that the user finds an available space based on prior knowledge about availability.

6. **Validation of transactions** – Registered users who have set up an account may identify themselves with the means provided by the system by:

    - Using their cell phone to confirm that they have parked, by either calling or sending a text message.
    - Scanning their smart card or RFID key fob at a kiosk.
    - Scanning their RFID tag at the parking entrance (in this case, the transaction is chronologically concurrent with step 2).

    Unregistered users can make a transaction in one of the following ways, depending on how the system is set up:

    - Using their cell phone and credit card, or send a paid SMS.
    - Using a cash machine or kiosk in the parking lot or in the transit station.
    - Paying at the entrance of the lot, if access is controlled (in this case, the transaction is chronologically concurrent with step 2).

    The various options outlined above are a mix of different operational concepts and technology choices. These options are sorted out in the section describing operational parameters.

7. **Exit of parking lot at end of trip** – Upon their return, travelers go back to their car and drive out of the parking lot. As they leave the lot, a traffic sensor detects their car. The detection event is then transmitted to the parking management system and used to update the inventory of available spaces

7.2. OPERATIONAL CONSIDERATIONS

Potential constraints affecting how users may interact with a Smart Parking system or perceive such a system include the following:

- Travelers generally expect that reliable and reasonably accurate parking availability information is provided to them. The provision of inaccurate data carries the risk of creating negative perception of the system and may push travelers to ignore the information provided.
- The displaying of parking availability information for lots that are nearing capability requires special considerations. A situation to avoid is one in which travelers are presented with information on advanced road signs or website indicating that space is still available when there is a high likelihood that all available spaces may be gone by the time they reach the facility.
- In undivided lots with reserved and general parking spaces, a method must exist to ensure that users of the facility use appropriate spaces.

- The imposition of parking fees deemed unreasonable by travelers, particularly in relation to fees charged at neighboring non-transit lots and on-street parking options, may push travelers to seek parking elsewhere.
- Travelers who were accustomed to parking for free or pay a very low parking rate may negatively see increases in parking fees, even though these increases are based on sound rational elements.
- The provision of free parking or heavily subsidized parking rates without proper entry control may entice non-transit users to park in park-and-ride lots.
- While CMSs help motorists make informed travel decisions, their true effectiveness in affecting travel mode choices is not clear due to complex interactions between factors affecting travel decisions.
- While advanced, automated payment may be offered, due considerations must be given on how casual parking lot users may pay for parking fees, if such users are allowed. I many cases, this will mean retaining the ability to pay with cash or with a credit card.
- The demographic makeup of commuters in a corridor may put into question the utilization of the new technologies for the deployment of Smart Parking systems, particularly technology that may affect their privacy.

7.3. MAIN SYSTEM FUNCTIONS

Full-featured Smart Parking systems typically implement the basic functionalities shown in Figure 5 and described below.

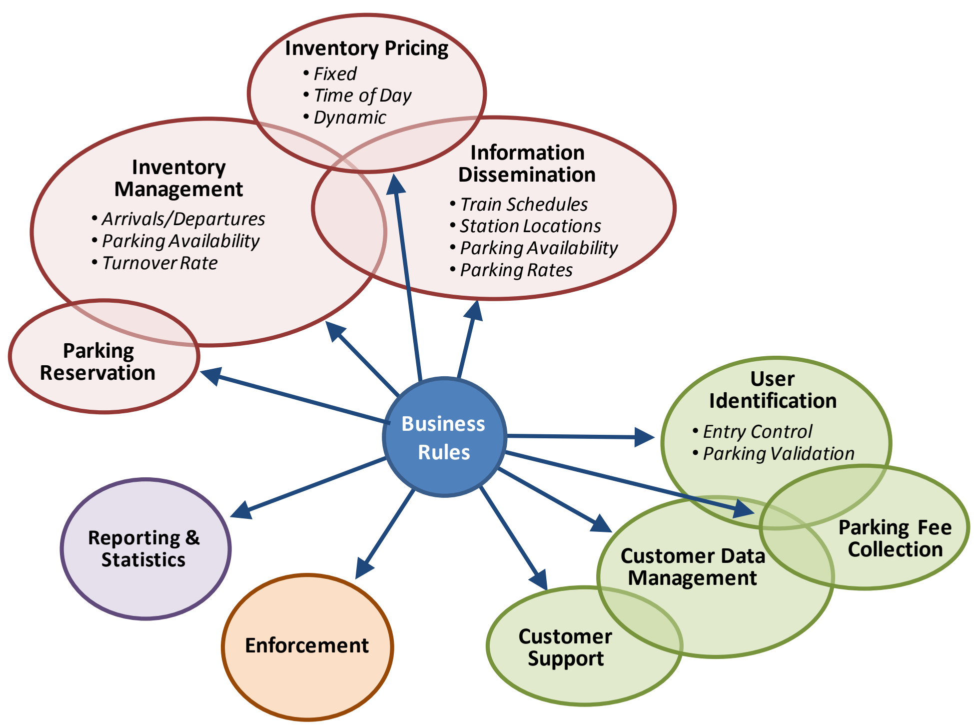

Figure 5 – Smart Parking Key System Functions

1. **Inventory Management** – The role of this module is to keep track of the number of parking spaces that are available at any given time. It must track of the number of spaces physically occupied by a vehicle, the number of spaces currently unoccupied but for which there is currently a reservation, and the number of unoccupied spaces that are truly available for new patrons. The module may determine parking lot utilization using entry and exit detection events or information provided by sensors installed into each parking space. It may also use the collected information to identify trend and predict near-future availability for dissemination by advanced information systems.

2. **Inventory Pricing** – This module, closely linked to the Inventory Management, is only required if a dynamic pricing scheme is implemented. Its role is to determine what fee should be charged for each parking space given the current number of spaces available, time of day, day of week, and possibly short-term parking demand projections.

3. **Information Dissemination** – The Information Dissemination module is responsible for information delivery to users through a variety of channels. Information distributed by this module may include:
    - Real-time parking availability;
    - Parking pricing and programs information;
    - Stations and parking lots information;
    - Train schedules and trip planning tools.

    At a minimum, Smart Parking systems should inform travelers seeking to enter a parking facility of the number of spaces available within using CMSs located at or near the entrance of each facility. Distribution channels in more advanced systems may include internet web sites, SMS- and Web-enabled hand-held devices such as cell phones and PDAs, highway signage, satellite radio, and automotive navigational displays (such as GPS). Ideally, the Smart Parking information dissemination system should be tightly integrated with existing transportation information systems, such as regional 511 services, online trip planners and highway CMS. Within the San Diego region, this leads to a requirement to integrate information dissemination functions with the IMTMS network of the Regional ITS Architecture.

4. **Parking Reservation** – This module is responsible for generating, managing and cancelling parking space reservations from parking lot users.

5. **User Identification** – This module is responsible for identifying vehicles entering a facility, validating parking activities, control access to the facility or specific sections of the facility if physical gates are used. Activities conducted by this module typically involve collecting information from parking facility patrons and comparing this information against a database of registered users. User identification data may be collected either when a vehicle seeks entry into a parking facility, as part of an entry control system, or by requiring that travelers register their vehicle at a kiosk or through their mobile phone after having parked their vehicle.

6. **Parking Fee Collection** – This module is responsible for the collection of parking fees. In many systems, this module is likely to be integrated with the User Identification module. For instance, the smart card system used to identify travelers may also be used to automatically debit parking fees from a registered account linked to the card. In addition to collecting parking fees, this module may also provide accounting and fee distribution functions through a linkage to financial

institutions. Revenue generated from parking activities may for instance be shared between lot operators, transit agencies and other entities.

7. **Customer Data Management** – This module holds a database that is used to store and manage data about Smart Parking users. Specific functions that may executed by this module include creation of new user accounts, management of existing user profiles, tracking of user transactions, and implementation of Customer Relationship Management functions such as communications and direct marketing.

8. **Customer Support** – This module provides assistance to Smart Parking users who may have questions about parking availability, payment methods or other system operations. At a minimum, this module should support the operation of a phone line where Smart Parking customers could reach a customer service representative. To reduce the volume of calls that must be answered by the service representative, a voice IVR system may be used to provide automated answers to common questions. In systems using web-based information outlets, the Customer Support module may also support online assistance functions, such as the ability for travelers to submit queries via emails or through an online chat window.

9. **Enforcement** – This module provides support to parking enforcement activities. In the simplest systems, this module may only be used to enter parking citations in the system used by the transit agency of city parking department for managing public parking facilities. In more advanced Smart Parking systems, this system may be tasked to periodically prepare lists of vehicles for which parking activities have been validated and distribute these lists to PDAs that enforcement officers carry with them. In addition to managing parking citations, the Enforcement module may also be used to offer parking lot users a mechanism to contest parking citations if they feel they have been cited in error.

10. **Data Gathering and Reporting** – This module is responsible for gathering business intelligence data about system operations. Such data is essential to parking lot owners and operators to keep track of system operations and revenue streams (if parking fees are charged). The implications are financial, operational and commercial. Proper reporting should therefore be available to the relevant authorities. More elaborate systems may enable user-input queries and custom reporting.

As shown in Figure 5, several modules may need to interface with other modules. For instance, the Parking Reservation, Inventory Pricing and Information Dissemination modules all need to draw parking availability information from the Inventory Management module. The Inventory Pricing module also needs to interact with the Information Dissemination module to enable up-to-date parking fees to be displayed on appropriate information outlets.

7.4. PHYSICAL SYSTEM ELEMENTS

Figure 6 illustrates a potential Smart Parking system setup. The diagram illustrates many of the physical elements that would normally comprise a Smart Parking system. These include:

- Parking lots
- Entrance/exit control system
- Parking lot monitoring system

- Traveler information/guidance systems
- Parking validation/payment system
- Enforcement system
- Supporting computer and communication infrastructure

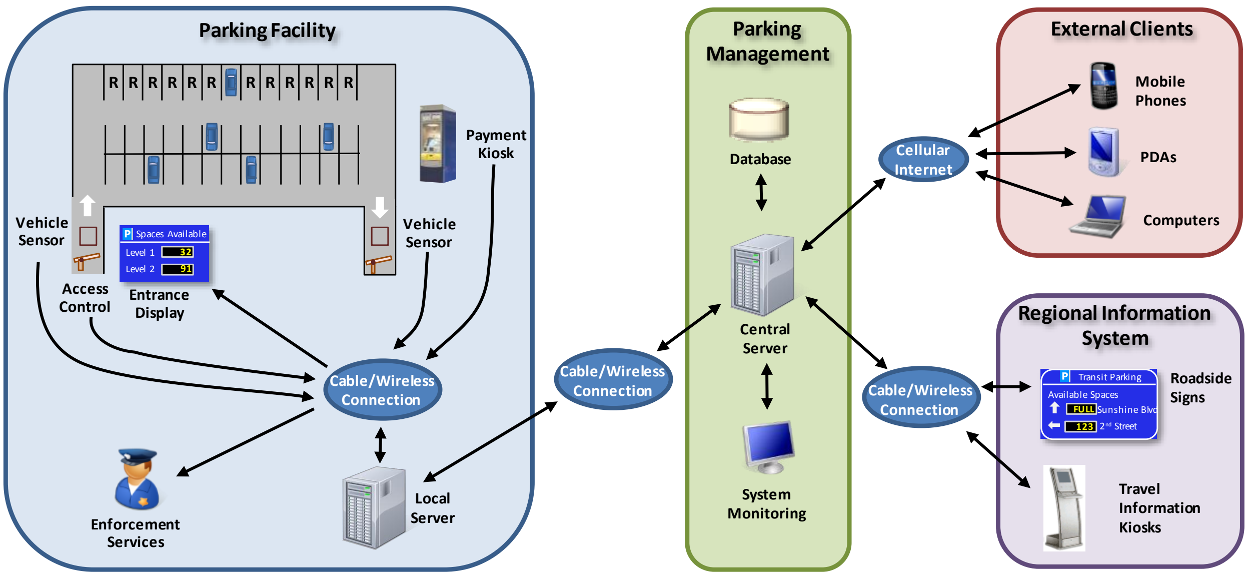

Figure 6 – Example Smart Parking System Setup

7.4.1. Parking Lots

Park-and-ride lots are the central element of Smart Parking systems. Two types of parking lots can essentially be distinguished:

- Surface lots: Lots on one single level, usually at ground level.
- Garages: Structures offering parking spaces on multiple levels.

In each case, parking lots can be characterized based on the following features:

- Total number of available parking spaces
- Number of parking spaces reserved for special permit holders (monthly pass, carpool status, etc.) or individual holding ad hoc reservations.
- Number of segregated areas, i.e., areas reserved for specific types of vehicles.
- Number of entries and exists
- Parking fee structure
- Hours of operations
- Entry control policy

7.4.2. Entrance/Exit Control System

Access control refers to the mechanisms used for regulating access to, and in some cases exit from, parking lots. Access control may be used for various reasons:

- To ensuring that parking fees are paid or that an accurate parking start time is set before a vehicle enters a facility.

- To restrict access to a particular facility only to legitimate users.
- To discourage drivers from entering a lot within which no spaces are available.

Overall, up to four options can be outlined:

- **Open lot** – There is no control and vehicles are free to enter and exit parking lots.
- **Physical entrance gate** – Vehicles must pass a gate to enter a given parking lot. This prevents free access to the lot. Premium or reserved users may enter by using a smart tag or a registration code. For non-registered users, this option is equivalent to a conventional gated lot. They may have to get a ticket or pay at the gate.
- **Virtual gate** – A virtual gate is basically a mechanism to bar access to the lot without a physical implement. A virtual gate may be implemented by requiring payment upon entrance of the lot. In this scheme, vehicles equipped with an electronic vehicle identification device may be able to dash through the gate without stopping. Non-registered users may still enter the facility but must subsequently register their vehicle to validate their entry and avoid a parking citation. Another implementation of a virtual gate may be to display a count of empty drive-in spaces on dynamic signs at the entry of the facility, with the understanding that access may only be allowed if spaces are available. This will divert most drivers and spare them the time and emotional distress of having to look for an empty space.
- **Exit gate** – An exit gate is needed to enforce payment when parking fees are charged by the hour. In the majority of parking lots at commuter train stations, users are expected to leave their cars for the whole day and are charged a daily rate. It is unlikely that Smart Parking scenarios would require exit gates, but this is dependent upon parking rules and policies.

7.4.3. Parking Lot Monitoring System

The number of available parking spaces needs to be actuated each time a space is occupied or liberated so that accurate information could be disseminated to travelers. Where dynamic pricing is used, this information may also be used to adjust parking fees.

Various methods exist for determining parking availability. All of these methods rely on information collected by vehicle sensors placed either at the entrance and exit of parking facilities or directly in parking spaces. Below is a brief description of the various approaches that can be used to determine parking lot utilization. To a large extent, the type of parking availability monitoring system will depend on the type of control used to grant vehicle access to the parking facility and method selected for the payment of parking fees. More than one method may be used at a given facility.

- **Entry/Exit vehicle sensors** – Vehicle sensors are installed on parking lot entries and exits to count the number of vehicles that have entered and exited the facility. Sensors may be traditional loop detectors, RFID tags or other technology allowing counting vehicles. The number of spaces available determined by the subtracting the difference between the number of entering and exiting vehicles from the total number of parking spaces available. This method of determining parking availability can be fairly accurate as long as vehicle sensors are able to correctly detect every entering and exiting vehicle. To account for missed detections, recalibration of the rolling count of available parking spaces may have to be done periodically.
- **Parking space sensors** – Sensors are installed on each parking space to determine if it is occupied or not. In this case, the number of available parking spaces is directly determined by

the number of spaces reported being open. While this method provides more detailed information about available parking spaces, it is also more costly due to the need to install and maintain a large number of vehicle sensors.

- **Indirect assessment** – In this approach, parking lot utilization is determined by compiling parking validation records entered by users at kiosks, payment machines or through their cell phone. A particular advantage of this method is that it allows parking space availability to account for spaces that are not yet occupied for which a reservation has been placed. Since there is no direct determination of whether a parking space is truly occupied, the accuracy of this parking lot utilization monitoring method will strongly depend on the provision of correct parking information by users. Users entering incorrect parking stall number or intentionally avoiding validating their parking may result in some inaccuracies in reported availability.

7.4.4. Information/Guidance System

Traveler information systems include elements used to inform travelers of parking space availability at park-and-ride lots, and potentially, to guide motorists to an open or specific parking space within a given facility. The most common practice for disseminating parking availability information is through the use of dynamic signs displaying the number of available spaces or whether a garage is open or full.

Depending on parking lot and system configuration, installation of dynamic signs may be considered for the following locations:

- **Individual parking spaces** – Signs indicating whether a particular parking stall is open or not.
- **In-lot guidance signs** – Signs installed within parking facilities to help direct motorists to an available space. These could be signs informing motorists of the number of spaces available on each floor of a garage or signs placed at the start of each aisle indicating whether there are spaces available on the aisle.
- **Entry signs** – Signs located at the entrance of a facility indicating whether the parking lot is open or full or the number of spaces available.
- **Roadside guidance signs** – Signs located on nearby streets or at key decision points in a network indicating the number of spaces available in nearby lots. These signs are typically used to help travelers decide which facility they should travel to.

Alternative methods of information dissemination seeking to leverage the increasing ubiquity of internet services are also rapidly gaining in popularity:

- **Agency websites** – This data dissemination method allows anyone who has access to the internet to query parking availability. Information could be accessed from a home computer, an office computer, dedicated kiosks installed at key locations, or smart phones with Internet search capabilities.
- **Smart phone applications** – While smart phones typically provide their users with Internet search capabilities, special purpose applications, or “apps”, may be developed to automate data query. For instance, an application may be developed to query at a given interval the number of parking spaces available at parking lots within a given region and display this information in a user-friendly format.

- **Vehicle navigation systems** – This dissemination method allows real-time parking space availability to be displayed by onboard vehicle navigation systems. While still not common, such a method would only require the development of applications within vehicle navigation systems using emerging vehicle communication systems, such as General Motor's cellular-based OnStar system, to query upon demand parking lot information.

7.4.5. Parking Validation / Fee Collection System

Where parking fees are charged or reserved spaces are used, a system is required to validate parking activities and, if necessary, collect fees from parking lot users. As outlined below, validation may be accomplished using different approaches. To a large extent, the method used will be strongly influenced by the physical layout of a lot and the method used for access control.

Available options for validating parking activities and collecting parking fees include:

- **Entry/exit ticketing machines** – Ticket issuing and/or credit card reading machines may be installed at the entrances and exits of parking facilities. Where fixed parking fees are charged, credit card readers may be installed at the parking lot entrances to facilitate payment. A receipt that must be displayed on the vehicle's windshield may then be generated to show proof of payment and validate the presence of a vehicle in the facility. Where time-based fees are charged, a common approach is to issue a ticket registering a vehicle's time of arrival upon entry into a parking facility. Upon exit, the ticket is scanned by a reader located at the exit and the appropriate parking fee calculated. Instead of issuing tickets, more advanced systems simply ask motorists to scan a credit card. The same card must then be used upon exit. In this case, fees are automatically based on the recorded entry and exit times. More advanced systems may further rely on automated vehicle identification systems, such as smart cards, RFID tags, or license plate recognition systems to detect vehicle entry and exits and calculate appropriate parking fees.
- **Payment machines / kiosks** – Instead of conducting transactions at entrances and exits, parking lot users are required to pay fees at machines located at key locations within a facility or in nearby buildings (for instance, inside transit terminals to prevent non-transit users to use the parking facility). Upon paying, a validation ticket may then be issued for the traveler to place in his car. Instead of requiring a ticket to be displayed inside their vehicle, parking lot users may instead be asked to enter the number of the stall where they have parked their vehicle. This avoids the need to walk back to the car, which can be viewed as an inconvenience by travelers.
- **Remote transactions** – This approach allows parking lot users to pay for parking while not physically at the facility. It is typically used with a reservation option. Depending on the technology used, various systems may be used to enable remote payments, each requiring their own setup:
    - <u>Cell phone payment</u>: In this approach, a user calls a designated number to inform the parking management system where he has parked his vehicle. Depending on the system used, the user may then be required to provide a method of payment or a pre-registered account automatically billed.
    - <u>SMS text-messaging</u>: Similar to the cell-phone registration approach, a user sends a short text message to a given phone number or internet address to inform the parking management system where he has parked his vehicle. Upon reception of the message,

a pre-registered account may then automatically be billed or instructions be sent to the user on how to pay any parking fee.

- Internet transactions: In this approach, a user accesses an Internet site, either through a smart-phone or Internet-connect device, to inform the parking management system where he has parked his vehicle. Depending on the system used, a method of payment may then be requested from him or a pre-registered account automatically billed.

Since one of the main goals of Smart Parking systems is to improve convenience, methods automating transactions should be privileged to the extent possible. While various technologies may help attain such goals, the benefits provided by a specific validation/payment system must however be carefully weighed against its deployment and operating costs. Compatibility with other systems used by other agencies or private parking lot operators may also be considered.

Depending on the facility, more than one method of validation/payment may be used. For instance, smart cards or RFID tags may be used to facilitate parking transactions for registered parking lot users. However, parking lot attendants or kiosks may also be used to collect fees from casual, non-registered users, if such individuals are allowed to use the facility.

7.4.6. Enforcement System

Wherever reserved parking is offered or fees charged for parking, a system for enforcing parking rules and regulations must be used to avoid unauthorized use of parking facilities. In the context of Smart Parking, enforcement typically refers to the task of verifying the validity of a vehicle occupying a given parking space at a given time. Parking lot enforcement can typically be accomplished in two ways:

- **Entry control** – Vehicles are only allowed to enter a facility after having showed proper identification and/or paid the required parking fee. This approach is usually applied at facilities where entry and exit is controlled by physical gates or parking attendants. In this case, the presence of physical gates ensures that only valid users are within the facility. The only exception may be for undivided parking lots with reserved spaces. In such a case, while motorists may gain valid entry into a facility, the potential still exists for them to illegally park in reserved spaces for which they are not authorize to do so. Such a situation would require the use of an in-lot enforcement system, as described below.
- **In-lot enforcement** – Validation of parking activities is done by individuals checking whether each vehicle is parked in an authorized stall. This verification can be done by requiring each user to display a valid parking permit or valid parking ticket issued upon entry into the lot or by a nearby kiosk in their windshield or dashboard. More advanced methods may also rely on automated vehicle identification technologies. For instance, smart card readers, RFID tag readers, or a license plate recognition system could be used to uniquely identify each vehicle entering a facility. Enforcement would then consist of checking whether each vehicle present in a facility is authorized to be there based on a list of recorded entries. Such verification can easily be done by providing enforcement officers patrolling the parking lot with Personal Digital Assistants (PDAs) wirelessly connected to the central parking management system.

Depending on the operational setup, a Smart Parking enforcement system may include one or more of the following elements:

- **Signs** – Signs displaying parking regulations and rules must be installed to inform parking lot users of existing rules and regulation. To be effective, these signs must be placed at locations easily visible by motorists, preferably near the entrance of parking lots. Additional signs may also be placed along the paths taken by travelers to walk in and out of a facility.
- **Entry gates** – Physical or virtual gates may be used to control access to a parking facility. To gain access, motorists may be required to show a valid permit or reservation. Smart cards, RFID tags or license plate readers may also be used to identify each vehicle.
- **Parking space sensors** – Sensors may be installed in each parking space to read RFID tags or other device installed onboard vehicles and determine whether a specific vehicle is authorized to use the space.
- **Enforcement officers** – Individuals tasked to patrol a parking facility for checking whether each vehicle is parked in a valid space.
- **Parking citation tracking system** – If parking citations are to be issued for violators of parking rules, a system will be required to track the citations that have been produced, check whether citations have been paid, and adjust access privilege for repeated offenders if desired.
- **Unauthorized vehicle removal** – Contracts signed with towing companies to remove vehicles parked in authorized spaces.

7.4.7. Supporting Computer and Communication Infrastructure

To provide efficient parking management, Smart Parking systems require that the various systems elements described above cooperate with each other and exchange various types of data. For instance, the data collected by vehicle sensors at the entrances and exits of parking lots will typically need to be provided to the module responsible for tracking available parking spaces. Once determined, information about parking availability will then be forwarded to variable message signs located at the entrance of parking facilities or at key decision points along nearby roads. The information could also be sent to web servers or databases used by information service providers.

Typical data processing elements that may need to be considered include:

- **Local computer servers** – Servers installed within a parking facility, generally for managing data coming from and to a given facility. These servers may be used as local data collection and communication hubs. They may be tasked to retrieve data generated by vehicle sensors and other local systems and to subsequently send the collected information to a central parking management server. Local servers may be tasked to manage communications with information systems installed within a facility. Some servers may also be given some data processing capabilities.
- **Central parking management server** – Computer on which the parking management software is ran. In Smart Parking systems consisting of a single lot, the central server may correspond to the local server. In systems covering multiple lots, the parking management server is likely to be a different computer installed at a convenient central location.
- **Parking management database** – A database should be set up to store the raw and processed data generated by various Smart Parking system components. This database could be used to support various reporting and analysis functions.

Linking the above data processing elements may require the deployment of the following communication capabilities:

- **Local communication network** – Serial or Ethernet cables are needed to allow information collected by the various systems operating within a parking lot to flow to and from a local base station. Wireless communication technologies, such as Wi-Fi or Bluetooth, may also be used in addition or instead of physical cables.
- **Regional communication network** – A regional communication network is required to support data flows between parking lots, a central parking management server, variable message signs installed along roadways, and other regional systems that may use the collected operational data. Ideally, the Regional ITS communication infrastructure should be used to support regional data communications.
- **Third party access** – To increase the dissemination, and value, of collected data, methods may be provided for external service providers to access parking availability data collected by Smart Parking systems. This information could be either sent directly to external communication systems via automated feed or stored in a service database for which external access privilege may be granted.

7.5. SUPPORTING TECHNOLOGIES

Depending on implemented functionalities, Smart Parking systems may involve the use of the following supporting technologies:

- Vehicle sensors
- Dynamic signs
- Electronic identification technologies
- Electronic transaction technologies
- Enforcement tools
- Communication technologies

7.5.1. Vehicle Sensors

Smart Parking systems require that information be continuously collected about the number of vehicles present within a parking facility. This typically requires placing vehicle sensors at each entrance and exit to track the number of vehicles present within the facility, or sensors within each parking stall to detect whether it is occupied.

A variety of vehicle detection technologies can adequately support Smart Parking operations. Depending on the intended sensing location, a key requirement of the selected technology will be an ability to detect either vehicle presence within the device's sensing field or count the number of vehicles crossing the sensing field. The efficiency and cost effectiveness of each technology may also be an important selection consideration, particularly if a large number of sensors need to be installed.

Vehicle sensors that can be used to support Smart Parking systems fall within two broad categories:

- **In-pavement sensors** – Sensors that need to be installed in the ground, below the location where vehicles are detected. Many types of sensors in this category have been used for several decades and have well-understood operations.

- **Non-intrusive sensors** – Sensors that can detect vehicles from a roadside or overhead location.

Below is a summary of available in-pavement detection technologies (Mimbela and Klein, 2007):

- **Inductive loops** – Inductive loops are the most common type of vehicle sensors in use today. This is a mature technology that is well understood. When a vehicle stops or passes over the loop, its metallic mass creates a decrease in the inductance of the loop. This decreased inductance increases the loop's oscillation frequency, which then causes an electronic unit to send a pulse to the loop controller to indicate the presence of a vehicle within the loop's sensing field.
- **Magnetometers** – Magnetometers detect vehicle presence by monitoring perturbations in the Earth's magnetic field created by the metallic mass of vehicles passing over the sensor. While this technology can distinguish vehicles that are spaced by as little as one foot, magnetic sensors cannot detect stopped or slow moving vehicles (typically, vehicles with speeds less than 5 mph) unless a mechanism exists that allow a vehicle to change its magnetic signature characteristics with respect to time. Detector operations also require placement directly in the path of vehicles. This creates some constraints on where such detectors can be placed within parking lots, particularly to monitor traffic at locations where wide vehicle paths are available.
- **Piezoelectric sensors** – Piezoelectric sensors detect vehicles through the use of material that generates electrical energy when subjected to mechanical impact or vibration. This electrical charge then induces a voltage that is proportional to the force or weight of the vehicle, which allows detecting vehicle presence and counting vehicles when processing signal changes over time. Because they can generate electrical pulses that are proportional to the weight of a vehicle, these sensors are often used to classify vehicles by axle count or axle spacing and measure vehicle weight. Similar to inductive loops, these sensors are also subject to failure when installed in poor road conditions and as a result of traffic stresses. They have been known to be sensitive to pavement temperature and vehicle speed.

Available non-intrusive vehicle sensing technologies further include:

- **Microwave Radars** – Microwave radar sensors detect vehicles by transmitting energy toward an area of the roadway. When a vehicle passes through the energy beam, a portion is reflected back towards the emitting antenna, which allows the sensor to determine vehicle presence. While radar sensors are increasingly used to monitor traffic along roadways, particularly to measure vehicle speeds, these sensors cannot detect stopped vehicles unless equipped with an auxiliary sensor. This creates potential constraints on where such detectors can be used.
- **Infrared sensors** – Infrared sensors can be categorized as either active or passive. Active infrared sensors illuminate detection zones with low power infrared energy and detect vehicle presence by monitoring the energy that is reflected from vehicles traveling through the sensing zone. Passive sensors do not transmit energy. They detect the energy that is normally emitted from vehicles, road surfaces and other objects in their field of view. Vehicle presence is detected by monitoring changes in energy readings that result from a vehicle entering the sensing field. Infrared sensors are generally reliable when used to detect vehicles in close proximity of the sensors. However, care should be exercised to ensure that glint from sunlight does not cause unwanted and confusing signals and to minimize impacts from atmospheric particulates and inclement weather such as rain, snow, smoke and dust.

- **Ultrasonic sensors** – Ultrasonic sensors transmit pressure waves of sound energy at frequencies above the human audible range (25-50 kHz). These sensors use the portion of energy that returned after bouncing on a surface to measure the distance of objects from the sensor. In the absence of vehicles, a sensor installed above the road surface will measure the distance to the road surface. When a vehicle enters the sensing field, a change a shorter distance will be measured, thus triggering a vehicle presence signal to be generated.
- **Acoustic sensors** – Acoustic sensors detect vehicles by monitoring the acoustic energy or audible sounds that are produced by vehicles, such as noise from the engine and interactions between the tires and road surface. When a vehicle passes through the detection zone, an increase in sound energy is recognized and a vehicle presence signal is generated. When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold and the presence signal is terminated. Existing sensors generally include functions to attenuate sounds from locations outside the detection zone. Cold temperatures have been reported as affecting the accuracy of the data from acoustic sensors. Some models may also have difficulties accurately detecting slow moving vehicles.
- **Video Image Processing Systems** – Video image processor systems detect vehicles by analyzing changes in captured images across successive frames. Detections result from the identification of significant changes in successive images, after factoring background variations caused by weather conditions, shadows, and daytime or nighttime artifacts. While video imaging is increasingly used to detect traffic, this technology remains vulnerable to a variety of elements that can affect captured images, such as viewing obstructions, occlusions, inclement weather, shadows, vehicle projections into adjacent lanes, and contrast between vehicle and road. Some models are also susceptible to camera motion caused by strong winds. Another important consideration is the high level of energy and data communication bandwidth required.

Table 2, extracted from a recent report on vehicle sensing technologies (Mimbela and Klein, 2007), summarizes the capabilities of available technologies. For each technology, the table lists the types of data provided, coverage area, communication bandwidth, and typical purchase cost. While most technologies are shown to provide vehicle presence and counts, their use must be viewed in the context of sensing vehicles within parking facilities. Such an operating environment is characterized by slow moving vehicles and vehicles that may not follow well-defined paths. This create potential issues for technologies having difficulty detecting slow moving vehicles or requiring detectors to be placed directly in the path of vehicles. The constrained physical environment of parking garages (for instance, low overhead height, low light) may also affect the accuracy of some sensing technologies. Of paramount importance in this case is a need to select a sensing technology providing accurate vehicle counts, as the provision of inaccurate availability data may lead travelers to ignore the information provided and reduce the benefits that could obtained from the implementation of a Smart Parking system.

The range of purchase costs shown for a particular sensor technology reflects cost differences among specific sensor models and capabilities. Actual costs can vary significantly depending on the type and features of the specific sensor model used. If multiple lanes are to be monitored and a sensor is capable of only single lane operation, then the sensor cost must be multiplied by the number of monitored lanes. Direct purchase cost is not the only cost associated with a sensor. Installation, maintenance, and repair should also be factored in. Installation costs include the costs for technicians to prepare the road surface or subsurface for the sensor and mounting structure (if one is required) and costs to verify proper functioning of the device after installation. Maintenance and repair estimates must also be considered.

Table 2 – Typical Characteristics of Commercially Available Traffic Sensors

Sensor Technology	Output Data: Count	Output Data: Presence	Output Data: Speed	Output Data: Occupancy	Output Data: Classification	Multiple Lane, Multiple Detection Zone Data	Communication Bandwidth	Sensor Purchase Cost[a] (each in 1999 U.S. $)
Inductive loop	✓	✓	✓[b]	✓	✓[c]		Low to moderate	Low[i] ($500 to $800)
Magnetometer (Two-axis fluxgate)	✓	✓	✓[b]	✓			Low	Moderate[i] ($900 to $6,300)
Magnetic (Induction coil)	✓	✓[d]	✓[b]	✓			Low	Low to moderate[i] ($385 to $2,000)
Microwave radar	✓	✓[e]	✓	✓[e]	✓[e]	✓[e]	Moderate	Low to moderate ($700 to $3,300)
Active infrared	✓	✓	✓[f]	✓	✓	✓	Low to moderate	Moderate to high ($6,500 to $14,000)
Passive infrared	✓	✓	✓[f]	✓			Low to moderate	Low to moderate ($700 to $1,200)
Ultrasonic	✓	✓		✓			Low	Low to moderate (Pulse model: $600 to $1,900)
Acoustic array	✓	✓	✓	✓		✓[g]	Low to moderate	Moderate ($3,100 to $8,100)
Video image processor	✓	✓	✓	✓	✓	✓	Low to high[h]	Moderate to high ($5,000 to $26,000)

[a] Installation, maintenance, and repair costs must also be included to arrive at the true cost of a sensor solution as discussed in the text.
[b] Speed can be measured by using two sensors a known distance apart or estimated from one sensor and the effective detection zone and vehicle lengths.
[c] With specialized electronics unit containing embedded firmware that classifies vehicles.
[d] With special sensor layouts and signal processing software.
[e] With microwave radar sensors that transmit the proper waveform and have appropriate signal processing.
[f] With multi-detection zone passive or active mode infrared sensors.
[g] With models that contain appropriate beamforming and signal processing.
[h] Depends on whether higher-bandwidth raw data, lower-bandwidth processed data, or video imagery is transmitted to the traffic management center.
[i] Includes underground sensor and local detector or receiver electronics. Electronics options are available to receive multiple sensor, multiple lane data.

Source: Mimbela and Klein, 2007

7.5.2. Dynamic Signs

Dynamic signage is a key feature of Smart Parking systems. Such signs enable real-time information dissemination to motorists in the vicinity of parking lots and on nearby roadways. Such signs can be installed at the entrance of parking lot or along freeways and arterials. They can also be used within parking lots to display current availability, and potentially guide drivers to open spaces.

Available technologies that could be used to provide dynamic signage include:

- **Prism-based signs** – These signs use rotating prisms to display messages. This only allows the displaying of three messages if a triangle is used, such as whether a parking lot has space available, is full or is closed. Four messages could be displayed if a square rotating element is used. A particular benefit of this technology is its low power requirement, as energy is only required when changing the message, which makes them suitable for solar powered applications.
- **Light Emitting Diodes (LED) signs** – Sign displaying current parking space situations using green, yellow or red light-emitting diodes placed in matrix arrays. LED arrangements can be realized to show specific words, such as “Free”, “Full” or “Closed”, or to offer freely programmable options. A particular advantage of LED displays is their high visibility at night, durability, and low maintenance needs.

- **LCD signs** – LCD technology permits the display of current parking situation using highly legible, reflecting LCD characters. Additional informative text using highly legible proportional fonts is also easy to implement. Night time illumination of LCD displays can further be realized by back lighting (white LEDs, or fluorescent tubes).

7.5.3. Electronic Identification Technologies

Electronic vehicle identification technologies may be used to support the operation of physical and virtual gates, mainly to automate the identification of vehicles, as well as the payment of parking fees. The most commonly considered technologies for parking applications include:

- **Smart cards** – Smart cards are pocket-size devices with embedded integrated electronic circuits. While these cards are extensively used in Europe and Asia, they are only starting to gain in popularity in North America. Smart cards typically hold information that uniquely identifies the card. This allows each card to be uniquely linked to a database record identifying the owner of the card or a bank account from which payments could be charged. Smart card readers could be installed at the entrance and exit of parking lots to control entry into the facility and exit from it, as well as to automatically collect parking fees. Alternatively, travelers may be asked to validate their parking or pay fees by scanning their card at kiosks located at key locations within a facility. A particular advantage of smart cards in the context of Smart Parking systems is the potential for using the same payment system for both parking fees and transit fares if local transit agencies also adopt smart cards as a method of payment.
- **RFID tags** – RFID systems uses radio waves to exchange data between a reader and an electronic tag attached to an object. This type of identification has long been used by toll authorities to enable the automated collection of tolls. They are similar in concept to a smart card (which can in many cases be using RFID technology for communication). In the context of parking facilities, RFIP readers may be used to scan vehicle entering a lot. Vehicles for which a valid tag is detected would then be granted access of registered as having entered the facility. If each tag is linked to a specific account, parking fees could then automatically be debited from the account upon entry in the case of fixed fees, or upon exit in the case of time-based fees.
- **License plate recognition systems** – License plate recognition systems uniquely identify vehicles by using image processing software to extract the license plate number of vehicles. In most parking lot applications, a CCTV camera is mounted above the road surface to monitor the entrance. A light source may also be installed to illuminate the license plate. An inductive loop is also commonly installed in the pavement to sense the arrival of vehicles and allow the image processing software to operate only when needed. When a vehicle arrives, it is detected by the inductive loop, which then sends a signal to the image processing software to capture an image of the vehicle’s license plate and start extracting characters. Once extracted, the license plate number is sent to a database where it is checked against a list of permitted vehicles. An access granted or access denied flag is then returned depending upon the result of the check. In more advanced systems, the access control application may also pass relevant data, such as date and time of entry to store it an access diary.

7.5.4. Electronic Transaction Technologies

A convenient Smart Parking features is the possibility to use personal mobile devices to execute parking transactions. While most operators will elect to keep a cash payment option on the premises, an array of technological options exists for validating parking activities and collecting parking fees:

- **Automated gate ticketing** – Ticketing machines placed at the entry of parking lots may be used to issue a parking ticket upon entry. Wherever time-based parking fees are charged, these tickets may then be used upon exit to calculate the exact fee to pay. If fixed fees are charged and paid at the entrance, these tickets may then be used to show proof of payment and parking validity. Many systems further offer the ability to scan a credit card upon entry, which then conveniently allows parking fees to be automatically charged from the card's account upon exit.
- **Payment machines / kiosks** – In this approach, parking lot users are required to pay parking fees at machines located at key locations within a facility or nearby buildings. Upon paying, a validation ticket is issued for the traveler to place in his car. Alternatively, parking lot users may be directly asked to enter the stall number where they parked their vehicles, thus removing the need to place validation ticket in the vehicle.
- **Smart cards** – Smart cards are pocket-size cards embedded with electronic circuits that allow them to store some information. These cards can provide identification, authentication, data storage and application processing capabilities. Smart Parking registered users may for instance be provided with the opportunity to use smart cards to validate parking and pay parking fees. Motorists may for instance be required to have the card scanned at the entry of a parking lot to gain access to the facility or to register their entry in the parking management system. Scanners installed at both entry and exits may also be used to determine time or arrival, time of departure, and the resulting parking fee. As an alternative to using entry/exit scanners, motorists may instead be asked to scan their card at kiosks and provide their stall number to validate and pay for parking. In the context of Smart Parking, smart cards notably offer an opportunity for a shared parking fee / transit fare payment system.
- **RFID tags** – RFID tags have long been used by toll authorities to enable the automated collection of tolls. In the context of Smart Parking systems, they may be used to scan vehicle entering a lot. Vehicles for which a valid tag is detected would then be granted access to the facility or registered as having entered. If a tag is linked to a debit account, parking fees could automatically be debited from the account, either upon entry if fixed fees are charged or upon exit if time-based fees are charged.
- **Cellular phone transactions** – In this approach, users call a designated number to inform the parking management system that they are parked, and if required, where they have parked. Depending on the system used, a method of payment may then be requested from the user or a pre-registered account automatically billed upon receiving the call.
- **SMS messaging** – SMS messaging is a standardized communication protocol used by phones, web application and mobile communication systems that allows the exchange of short text messages between fixed line or mobile phone devices. This enables to operate selected banking and identification services over mobile devices. Similar to the cell-phone registration approach, users would send short text messages to a given phone number or internet address to inform the parking management system that they are parked, and if required, where they have parked. Upon reception of the message, a pre-registered account may then automatically be billed or instructions may be sent back on how to pay parking fees.
- **Internet transactions** – In this approach, users access an Internet site through a home computer, office computer, Internet-connected kiosk, smart-phone, or personal mobile device, to inform the parking management system that they are parked, and if required, where they have parked. Depending on the system used, a method of payment may then be requested or a pre-registered account automatically billed.

7.5.5. Communication Systems

Traditionally, advanced parking management systems have focused on solutions employing closed systems using dedicated resources to generate and display parking space availability in real time (FHWA, 2007). To this end, many of the systems that have been implemented in recent years have privileged solutions relying on fiber optic lines to support communication between various system physical components. A particular advantage of this technology is its ability to deliver large quantity of high-quality data in real-time. However, fiber optics may be relatively expensive to deploy, particularly when trying to retrofit existing facilities. Many of the advanced parking management systems that now rely on fiber optics were implemented at the same time a new facility was built. Because not all Smart Parking deployments may involve new constructions, use of fiber may thus not always be a practical choice, despite its technical capabilities.

An alternate approach to retrofit existing facilities may be to rely on devices using RF communications as such devices may allow data to be retrieved by local hub without having to run cables to each device with which communication is desired. Devices relying on owned or leased microwave systems operating under Federal Communications Commission (FCC) guidelines may also be used. While cellular communications represent another alternative, this type of communications is not generally considered a practical communication medium for Smart Parking systems due to the almost continuous need for data updates, particularly regarding parking availability.

When deciding upon using a communication technology for a given facility or group of facilities, the following elements must be considered:

- Are the facilities being equipped new constructions or retrofits?
- Are the facilities subject to periodic repaving? Frequent repaving creates a need to try to avoid running cables under the pavement.
- Is the parking configuration likely to change over time? If so, a communication system that could easily accommodate changes should be privileged.
- What are the power needs of each device?
- How will power be provided to the devices?
- In what environment each device is expected to operate?

No specific, fit-all solution can be provided without a detailed analysis of the operating need and environment. However, as outlined in Section 6.4.7, a key desired featured of any developed communications solution should be compatibility with the Regional ITS architecture.

7.5.6. Enforcement Tools

Tools that may be considered to support enforcement activities within Smart Parking systems include:

- **Personal Digital Assistants** – PDAs may be given to enforcement officers to allow them to benefit from the real-time information that the Smart Parking system provides. With such a tool, officers in the field may then be able to cross-reference occupied spaces with users in real-time, without having to resort to cumbersome print-outs.

7.6. OPERATIONAL ENVIRONMENT

This section describes the operational environment of Smart Parking systems. Elements described herein include:

- Facilities
- Equipment
- Computing hardware
- Software
- Communication system
- Power and environmental control
- System maintenance
- Enforcement
- Customer support
- Personnel
- Training
- Marketing and outreach

7.6.1. Facilities

Smart Parking systems revolve around the operations of parking facilities. A system may cover a single or multiple facilities. Facilities may be surface lots or multi-level garages, facilities with or without entry gates, and facility with or without segregated areas for reserved and non-reserved users.

In systems covering multiple parking lots, a central location may be used as a data storage facility and to host system-wide parking management functionalities. This may be a room within one of the parking facilities, a room within the office of the parking lot operator, or a room within a regional traffic or transit management center. The last option is generally preferred if a regional management center exists as it would facilitate the integration of the Smart Parking system with other ITS applications and facilitate coordination of operations among various systems. The central facility would host a computer server, and potentially some personnel, tasked with collecting data from all the individual facilities and performing general parking management tasks such as collecting and storing parking availability data from individual facilities, disseminating parking availability information to CMSs located along roadways and other information outlets, managing reservation requests, determining parking prices if dynamic pricing is used, and generating performance reports.

7.6.2. Equipment

At each parking facility, the type of equipment deployed as part of a Smart Parking system will depend on the characteristics of the facility and the desired system functionalities. Key types of equipment that may be deployed include:

- **Vehicle sensors** – Sensors may be installed at the entrances and exits of a parking facility to keep track of the total number of vehicles present within the facility, or within each parking stall to obtain direct count of the number of occupied stalls. As outlined in Section 7.5.1, various technologies may be used to detect vehicles, each imposing its own specific placement and operational requirements.

- **Entry/exit gates** – Physical entry and exit gates may be used to control access to a parking facility. In most systems using physical gates, sensors must be installed to detect the presence of a vehicle waiting to end, and in some cases, to detect when a vehicle has fully passed the location of the gate. The same sensors may also be used to track the number of vehicles present within the facility.
- **Vehicle identification systems** – Smart card, RFID tags or license plate readers may be installed at the entrance of parking facilities as part of a virtual gate system to identify vehicles and/or individuals seeking entrance into the facility. Some systems may include readers at facility exits to check out vehicles leaving the facility.
- **Changeable message signs** – CMSs are used to inform motorists of the number of parking spaces available within a given facility and, if dynamic pricing is employed, the fee currently charged for parking. Signs may be located at the entrance of parking facility, within the facility, and on nearby roadways.
- **Static signs** – Static signs are used to post parking regulations, identify authorized users of specific parking spaces, etc.
- **Payment/validation kiosks** – Kiosks may be installed within a parking facility to allow travelers to pay for parking or validate their parking.

Depending on the facility considered, many of the above equipment may already exist prior to the deployment of a Smart Parking system. For instance, a parking lot may already be equipped with access gate or payment kiosks. In such a case, evaluations will need to be made to determine whether the existing equipment can be integrated within the proposed Smart Parking system or may need to be upgraded or replaced entirely.

Depending on the institutional framework, equipment considered for Smart Parking systems may need not only to provide some specific functionalities but also to satisfy requirements set up by the department of agency responsible for the operation and maintenance of the equipment. For instance, to facilitate data communications between field equipment and a central data server, the department of agency responsible for information technologies may require that all new equipment be IP addressable. For systems that are to be integrated with a regional ITS architecture, there may be requirements that installed equipment be compatible with the architecture.

7.6.3. Computing Hardware

Smart Parking systems covering multiple facilities may require the installation of a two-level computing system. At the bottom level, local computer servers are required to process the data collected within each parking facility and to perform management tasks pertaining to each specific facility. Local computer servers may for instance be tasked to compile parking availability within each parking lot, manage access to the facility, and support local enforcement activities. At the upper level, a central computer server would be able to collect data from all parking facilities and perform system-wide management tasks. This computer may for instance be tasked with compiling system-wide statistics, determining which information to display on CMSs spread throughout the road network, and producing operational reports.

The servers installed at each parking facility should have enough computing capacity to process the volume of data expected to be generated by the various systems operating within the facility. Similarly, the central server should have enough capacity to handle the expected data communication volumes between it and all parking facilities, in addition to communications with roadside signs and other information outlets. A key operational requirement in developing the computing system will be the need to provide at both levels queried information and requested analyses without significant delay to ensure that the system truly operates with real-time data.

In addition to providing adequate computing capacity, the central computer server should provide enough storage space to allow operational data to be archived. The storage capacity needed will depend on specific system needs and needs of the parking lot operators. The needs of other ITS applications using the data collected by the Smart Parking system may also be considered.

7.6.4. Software

Smart Parking systems use of software to collect, process, analyze and manage the data collected by system components. This includes, among other things, the implementation of algorithms to:

- Extract parking availability information from vehicle sensors
- Record parking validation/payment transactions
- Process reservation requests
- Correlate user identification data with a database of registered users
- Adjust parking rates based on available supply if dynamic pricing is used
- Management of data communication between the central parking management system and individual parking lot computer server.
- Manage the operations of variable message signs
- Manage the archival of data
- Monitor the operation and health of various instrumentation used
- Generate operational reports upon request or at fixed intervals

In many cases, software modules implementing some of the desired features may already exist, either as part of an existing parking management system or a package offered by an equipment vendor. For instance, many vendors of vehicle detection systems offer software designed to process and analyze the sensor data. Where possible, explorations should be conducted to determine whether existing software could be integrated within the Smart Parking system. Such integration could provide significant cost savings. However, integration should come at the expense of system functionalities or capabilities to expand system functions.

Ideally, all Smart Parking modules should be integrated into a single system providing a user-friendly interface to the Smart Parking operators. This interface should also provide portals enabling other ITS applications and external information service providers to retrieve data from the system.

Another important software element is the design of a webpage or online application that travelers can access from their mobile phone. This webpage or online application should display the latest parking availability information, or at least the time at which the displayed availability was observed. It should also permit travelers to make a reservation.

7.6.5. Communications System

Smart Parking systems require various systems to communicate with each other, first within a given parking facility, and then between each facility and a site hosting the central parking management system. This will require the development of local communication networks (LANs) within each parking facility, and of a wide-area network (WAN) to enable data transfers between each parking facility and the central parking management system as well as with roadside signs and various information outlets.

A key requirement of Smart Parking systems is the ability to provide information to travelers in real time. This requires use of a communication system having the capability to handle the data volumes expected to occur between each system component. In this case, the highest data bandwidth requirement is likely to be between each parking facility and the central parking management system. This will likely require the use of communication cables to link equipment installed at individual parking facilities with the central parking management system. Such capability could be developed using either proprietary or leased lines. Within each parking facility, either cable-based or wireless communication may be used, depending on the capabilities of the various types of equipment used and the expected communication needs. A local router would then be used to provide connection with the wide area communication network.

The extent to which Smart Parking systems will require the installation of new communication equipment will depend on existing systems. For instances, communication links with a central facilities may already exist at facilities with existing monitoring or electronic payment systems. In this case, the need will be to determine whether the existing communication system could handle the additional volume of data, and if not, what communication method would provide adequate bandwidth.

7.6.6. Power and Environmental Control

All equipment installed at parking facilities must be provided with adequate power supply. This may require installing electrical cables providing power to equipment installed at the entrances and exits of a parking facility, as well as to individual parking spaces within a facility if individual vehicle sensors are used. Access to a power source will also be required at for all CMSs that are to be installed along roadways. To the extent possible, existing power sources should be used to support the additional equipment required by the implementation of a Smart Parking system.

Backup power supply should be used to sustain system operations in the event of a power failure. This may require the installation of backup systems both at individual parking facilities and at the location where the central computer server is hosted. At a minimum, backup power supply at each facility should maintain the operation of physical gates, if such gates are used, to avoid trapping motorists inside a parking lot. Additional backup power supply may also be provided to maintain the operation of vehicle sensors, display signs and payment systems. At the site hosting the central computer server, backup power would be required to maintain overall system functionalities. The extent of backup power needed will depend on the probability of power failures and assessed operational risks. Systems providing at least 20 minutes of backup power may for instance be sufficient to sustain operations in 95% of power failures occurring in urban environments.

Within each parking facility, all computing hardware that is not designed to be exposed to inclement weather should further be housed in a restricted access, environmentally control area. This may be a room built within a parking structure or a standard cabinet installed at a convenient location on the parking groups.

7.6.7. Maintenance

Equipment and data maintenance considerations are critical for any ITS system deployment. A proper maintenance plan must address roles and responsibilities for system maintenance through its life. Equipment maintenance could be contracted to a vendor or done with internal resources. Elements that should be covered in the maintenance plan include:

- Description of system used to monitor the health of the various instruments used. This may include algorithms checking for faulty data being produced by the various instruments or systems initiating periodic equipment diagnostics.
- Schedule for routine system checks.
- Procedures defining system operations when specific components are taken down due to maintenance or repair.
- List of equipment suppliers and individuals that may be contacted to obtain technical support when specific problems are detected.

Maintenance costs can be a significant component of Smart Parking systems and must be carefully considered in the budgeting process.

7.6.8. Enforcement

How enforcement is executed largely depends on the operational setup of each parking facility. Physical entry gates provide a form of automated enforcement. If virtual gates are used or no gate is present, enforcement is then typically be done by officers patrolling each facility. Officers can be individuals from the transit police, city parking enforcement office, or a private firm.

Officers may tasked to assess the validity of a vehicle parked in a given stall by either verifying that a valid permit is displayed or consulting a list of parked vehicles provided by the Smart Parking system. Citations may be issued for vehicles illegally parked. However, enforcement does not stop when a citation or warning is used. There must be proper follow-up to ensure that motorists are not tempted to disregard the rules. This includes verifying that individuals who were issued a citation have paid the fine, offering an appeal process, and establishing a process for debt collection.

7.6.9. Customer Support

While Smart Parking systems seek to provide convenience by automating many tasks, a customer support center must still be offered to address questions and issues that travelers may have. The ability for travelers to talk to a live person generally contributes to increasing the positive perception of a system. Individuals working at the customer support center, which may well be a single person, should:

- Have a detailed knowledge of all parking facilities.
- Have knowledge of all parking procedures and regulations.
- Have the ability to retrieve from the Smart Parking system information regarding parking availability at a specific facility for a given day and time period.
- Have the ability to access the database of Smart Parking users, to perform management tasks on their user account.
- Understand how fares are being determined, if dynamic pricing is used.
- Be able to process reservation requests from callers.

7.6.10. Personnel

Smart Parking systems will typically require the employment of the following professionals:

- **Parking manager** – Individual responsible for monitoring the operation of the system and making operational decisions.
- **IT specialist** – Individual responsible for the operation of computers and communication equipment.
- **Customer support specialists** – Individuals responsible for handling questions that may be asked by parking lot users regarding parking available, parking, the reservation process, etc.
- **Enforcement officers** – Individuals responsible for enforcing parking rules.

The implementation of Smart Parking systems does not necessarily translate into additional staffing requirements. Since automated functionalities are provided, Smart Parking operations may be handled by a relatively small core of individuals. In many cases, existing agency staff or contractors involved in the operation and management of the existing parking facilities could fulfill the required staffing needs.

7.6.11. Training

To achieve full system potentials, individuals working with Smart Parking systems must be provided adequate training on how to use the various system elements. At a minimum, training should include sessions on the following topics:

- Smart Parking goals and objectives.
- Smart Parking system elements.
- Smart Parking system functions.
- Parking availability information provided to travelers.
- How to use the software interfacing with the Smart Parking system.
- How to query parking availability at a given facility for a given day and time.
- How to create a parking reservation request.
- How to push information updates to traveler information outlets.
- How to collect operational statistics.
- How to generate performance reports.
- How to identify system malfunctions.
- How to contact individuals who may assist with troubleshooting.

Individuals having to interact with Smart Parking customers should be provided additional training on the following topics:

- How to create and access Smart Parking user profiles.
- How to address typical customer inquiries about the system.
- How to explain dynamic pricing principles (if used).
- How to forward grievances and issues to the proper individuals.

Parking enforcement officers must be given adequate training and clear guidelines on how to enforce parking rules. It should be emphasized during training that they should be friendly, considerate, and strive to be perceived as helpful community ambassadors.

7.6.12. Marketing and Outreach

Marketing and outreach is an important component of Smart Parking systems. While the displaying of parking availability data on roadside signs and websites offering trip planning tools may help provide some visibility, the system's full potential may only be achieved if there are concerted efforts to publicize the new features offered by the Smart Parking system to individuals who may not normally use the park-and-ride lots, travel by the roadside signs displaying the parking availability data or use online trip planners. Examples of marketing and outreach efforts that may be considered include:

- Publication of press releases.
- Placement of advertising material onboard transit vehicles.
- Purchase of advertising space on billboards along roadways or key pedestrian pathways.
- Placement of recorded information messages on the transit agency's main phone line.
- Mail documents to information pamphlets to residents of a service area.
- Adding a link to the Smart Parking webpage to the online trip planning application offered by transit agencies.
- Enticing event organizers to include a link to the Smart Parking website on the event's webpage.
- Executing special radio or television promotion events.
- Operating information booths at fairs and community events.
- Organizing on-site outreach at colleges

7.7. DESIGN CONTROL ELEMENTS

Parameters affecting how a Smart Parking system operates and interacts with its users can be grouped as follows:

- Lot layout / Parking space differentiation
- Access control
- Parking regulations
- Pricing scheme
- Parking space reservation
- Transaction methods
- Enforcement methods

7.7.1. Lot Layout / Parking Space Differentiation

Lot layout and space differentiation define how a parking lot is divided and spaces within the lot distributed among various groups of users:

- **Space differentiation** specifically refers to the physical allocation of parking spaces to specific types of users, such as spaces specifically reserved for monthly permit holders, carpools, or for non-registered delay users. Differentiation can be implemented with markings of different colors, by placing signs delimiting specific use areas, or by physically separating the parking lots used by specific types of users.
- **Lot layout** specifically refers to the physical and logical organization of parking spaces within a lot when differentiation is employed. Examples of lot layout options include placing spaces reserved from registered users on different floors of a parking garage, along specific aisles on a parking lot, or closest to the transit station entrance.

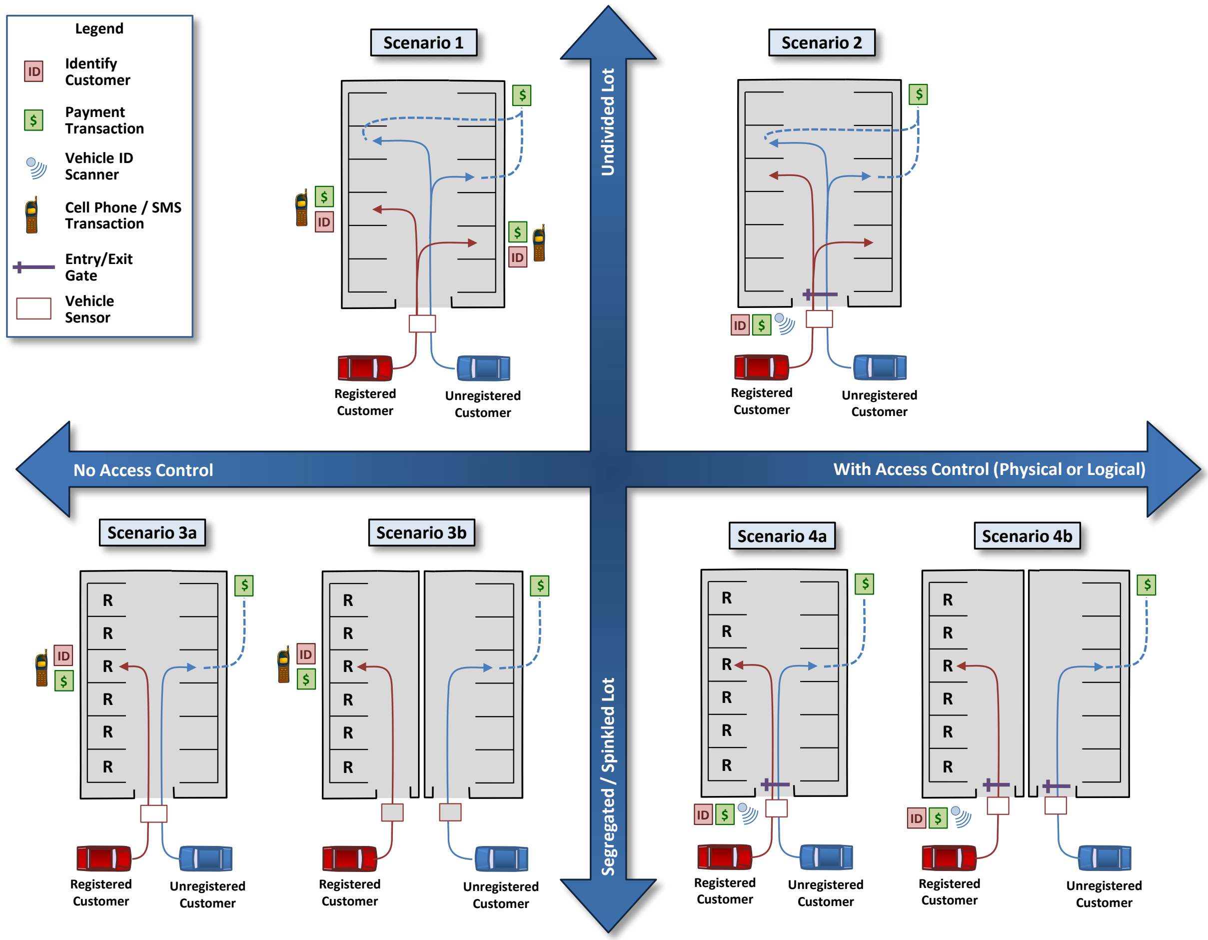

Figure 7 – Parking Facility Options

Figure 7 summarizes the types of parking facilities that can be considered by combining various space differentiation and lot layout options. As shown, three basic layout possibilities exist:

- **Undivided lot** – Parking facility with no distinction between spaces assigned to specific types of users (Scenarios 1 and 2)
- **Sprinkled lot** – Parking facility with common entrances and exits, but within which spaces reserved for different types of users are distinctly marked (Scenarios 3a and 4a).
- **Segregated lots** – Parking facility with completely separated parking areas for each type of users, each with its own entrances and exits (Scenarios 3b and 4b).

Options regarding space differentiation further include:

- **Common use spaces** – A single category of spaces is employed for both reserved and non-reserved users. Parking lot users, whether holding a reservation or not, can park on any open space. This is the situation illustrated in Scenarios 1 and 2.
- **Categorized spaces** – Spaces to be used by individuals holding day reservations or monthly permits and by drive-in users are clearly marked. Motorists belonging to a specific category are typically required to park in the spaces assigned to their category. Space categorization may restrict the utilization of parking stalls to a specific category of users or to groups of users.

Differentiation is most critical when parking spaces must be held to fulfill reservation requests. If a specific number of spaces are marked for reservation holders, the inventory of spaces that can be reserved is then well defined. However, a fixed number of reserved spaces also make the management of parking supply less flexible. If the inventory is too high, some spaces will go unreserved and cannot be used by drive-in users. On the other hand, if the inventory is too low the reservation feature is not exploited to its full benefits.

The other possibility is to not differentiate parking spaces. In this case, other mechanisms have to be implemented to hold reservations. One option is to only grant reservation requests or allow entry to a facility if there is available space at the time of the reservation or when entry into the facility is sought. However, dynamically managing reservations based on available supply will require methods to verify the identity of vehicles seeking access to a parking lot. Another option to manage reservations is to use stall numbers. When an individual would make a reservation, it would be provided with a stall number where to park his vehicle. This approach would allow the number of reserved parking spaces to grow or shrink with the demand. However, it can also be hard to implement.

7.7.2. Access Control

Access control refers to the mechanisms regulating access to and exit from the parking lots. Access control may be used as a way of enforcing payment, as is the case of most gated lots. Access control may also be used to discourage drivers from entering a lot if no space is available. This will enhance the user experience while limiting undue traffic in the lot. Overall, up to four options can be outlined:

- **Open lot** – There is no access control in this case.
- **Entrance gate** – The gate prevents free access to the lot. Premium or reserved users may enter by using a smart tag or a registration code. For non-registered users, this option is equivalent to a conventional gated lot. They may have to get a ticket or pay at the gate. This presents some clear disadvantages because it can slow down access considerably. Moreover, gates are easily vandalized.
- **Virtual gate** – A virtual gate bars access to a facility without any physical element. A virtual gate may be implemented by requiring payment upon entrance of the lot. In this scheme, premium users may be able to dash through if they are equipped with a Smart Tag, while non-registered users may still have the option of a cash or credit card machine. Another implementation of a virtual gate may be to display counts of empty drive-in spaces on dynamic signs, with the understanding that access may only be allowed if spaces are available. This will divert most drivers and spare them the time and emotional distress of having to look for an empty space.
- **Exit gate** – An exit gate is needed to enforce payment when parking fees are charged by the hour. In the majority of parking lots at commuter train stations, users are expected to leave their cars for the whole day and are charged a daily rate. It is unlikely that Smart Parking scenarios would require exit gates, but this is dependent upon parking rules and policies.

7.7.3. Parking Regulations

Hours of operations and local parking rules, whether inherited from the past or entirely new, will affect the design of the system. Key elements to consider include:

- **Hours of operations** – The parking management system has to consider whether lots are open 24/7 or only at certain hours. Overnight or multiple-day parking options have to be factored in.

- **Usage** – Specific rules may apply to determine who can park where and under what conditions. Transit agencies may want to insure that only transit patrons use the lot. Yet, such rules may be dependent on the day of the week or time of the day. Also, there may be legacy users to take into account.
- **Fees** – Whether or not fees are collected is obviously a key decision. If that is the case, rules may vary widely. Fees may be collected on a daily or hourly basis. In the latter case, it implies that the duration of stay is tracked for each user, which may severely complicate the transaction process. In addition, only certain hours of the day may be paid while others are free.
- **Reservation rules** – The ability to reserve parking spaces give users the possibility to plan their arrival time without having to worry about space availability. However, while reservations may be issued, a number of “no-shows” may occur. While “no-shows” take a parking spot out of the available supply for nothing, they do not necessarily result in a loss of parking revenue if parking fees are collected ahead of time. However, a space that remains empty can be equated to a lost customer. A possible measure “no-shows” is to overbook parking spaces, as is done in the airline industry. This approach would however require addressing the problem of what to do when all reservation holders show up. A more practical alternative is to open up unclaimed spaces after a set grace delay. This requires that specific rules will need to be developed to govern the reassignment of parking spaces. Such rules will notably need to be developed in conjunction with other lots regulations, while considering operational parameters such as space differentiation and lot layout.

7.7.4. Pricing Scheme

Various types of parking pricing strategies may be used to influence the demand for parking at park-and-ride facilities. The most basic strategies include:

- **Removal of free parking** – Users of parking lots that are currently free are asked to start paying for the privilege of parking. Such strategies may be implemented to reduce non-transit use of the facility, or to reduce the overall demand for parking. Parking fees may also be implemented simply to better cover facility operating costs.
- **Parking fee increase** – Existing parking rates a facility are increased to better reflect market conditions. Similarly to the imposition of new fees, these increases may be imposed with the goal of reducing non-transit use of the parking facility, reducing the overall demand for parking, or generating revenues to better cover operating costs.
- **Parking fee decrease** – Parking rates charged at a facility are reduced from a pre-existing level. Such a reduction may be implemented to make use of parking facility more attractive and incite transit ridership increases.

Besides establishing or modifying parking fees, there are other actions that can change the costs of parking to users:

- **Differential rates for short-term and long-term parking** – With this strategy, the fee structure is shaped to favor either short-term or long-term users by applying a discount to the group from which more patronage is sought. To attract commuters, who tend to park for continuous periods of 8 hours or more, most park-and-ride facilities offer discounts to long-term parking users. These discounts can take the form of a daily maximum fee or the ability to purchase a monthly pass at a cost significantly lower than the equivalent sum of daily parking fees.

- **Differential rate for single-occupancy and rideshare/carpool vehicles** – This strategy generally shapes the pricing structure to reward individuals who rideshare by offering them lower parking rates than individuals who drive alone. This strategy not only helps reduce the overall demand for parking but may also contribute to reducing traffic congestion on surrounding roads.
- **Elimination of employer parking subsidies** – Many employers provide their employees with free or subsidized parking. While these subsidies often only apply to privately own parking lots near office buildings, such subsidies may be eliminate to increase the cost of the driving alternative and makes the transit options more attractive, even if some park-and-ride fees must be paid.
- **Premium fees** – Under this strategy, higher parking fees may be charged for certain privileges. For instance, higher fees may be charged for lots, or areas within a lot, closer to the entrance of a transit station. Most parking reservation systems fall within this strategy, as a higher fee is often charged for guaranteeing the availability of a parking space at a given lot and given time.

To retain a competitive advantage over other modes of transit, transit parking fees should ultimately be less than the total cost of commuting by automobile. In other words, the cost of traveling to a park-and-ride facility by car, paying the parking fee (if there is any), and paying the transit fare to go to a destination and return from it should be less than the cost of driving and parking a car to the same destination from the same origin. In addition, park-and-ride fees should also compare reasonably to the fees charged at nearby private parking lots.

7.7.5. Parking Space Reservation

The possibility to reserve a parking space in advance is generally considered as an optional feature. However, such a capability can have important implications. For travelers, the ability to reserve parking spaces ahead of time can significantly alter how they may interact with the system. For system operators, a parking reservation system adds a level of complexity that may significantly increase system deployment costs, in addition to affecting enforcement requirements.

7.7.6. Transaction Method

Whether parking fees are charged, parking transactions need to be actuated each time a space is occupied. To a large extent, where and when a transactions take place is determined by the physical layout of each parking facility, the method used for access control, and the technology used for enabling transactions. Operational elements to consider include:

- **On-site transactions** – Equipment must be installed within each facility if parking fees are to be collected or if validation is required for the privilege to park in reserved or specially designed area. For convenience, the same payment technology than the one used by travelers to pay transit fare should ideally be used. If advanced transactions systems are used, such as systems using smart cards, RFID tags or cellular phones, proper consideration should then be given on how occasional parking lot users may pay for parking or validate their use of the facility.
- **Prepaid users** – Users placing reservations from their home, office or mobile phone will likely have paid any required parking fees before reaching the facility. Mechanisms must therefore be implemented to enable these individuals to be recognized by the modules controlling access to each facility and implementing enforcement.

7.7.7. Enforcement Methods

The mechanisms set to enforce the parking rules will depend in large part on the access control and transaction methods. Technology may also bring significant changes in how enforcement is conducted. For instance, depending on the transaction methods employed, the system may have information on each space supposed to be occupied at a given time. If that is the case, enforcement officers may then limit their inspection to those spaces that should not be occupied.

Enforcement methods that may be considered for Smart Parking systems include:

- **Entry/Exit control** – Access to a facility is only granted to vehicles having adequate credentials to do so. If physical gates are used, vehicles may only be allowed to enter a facility after having shown a permit, scanned a smart card, or after a valid license plate number has been read. There would then be no need for enforcement officers to continuously patrol a parking facility to determine whether each parked vehicle is a legitimate user. If virtual gates are used, vehicles entering the parking facility without authorization could be identified by taking a picture of their license plate. A list of unauthorized vehicles would then be provided to enforcement officers, who would then be tasked to find the vehicles and issue a parking citation or warning.
- **Manual cross-referencing** – Cross-referencing refers to the task of verifying the association between a vehicle and a parking space as a legitimate transaction. This approach implies that vehicles can be identified. Identification may be enabled requiring users to display a valid permit, reservation ticket or parking receipt on their dashboard, or by matching the vehicle’s license plate with a list of authorized users. The operational question is whether transactions have to be associated with a specific stall number, i.e., whether it is required to ensure that each vehicle is correctly parked in a space specifically assigned to it. Such verification can be done by having the stall number where the vehicle should be parked on the dashboard ticket or by checking on a list produced by the parking management system whether each identified vehicle is in its assigned place.
- **Automated cross-referencing** – More advanced systems using vehicle sensors in individual parking spaces could be set up to scan an RFID tag or other device installed onboard a vehicle to determine whether a vehicle is authorized to park in a given space.

7.8. INTEGRATION WITH SAN DIEGO REGIONAL ITS ARCHITECTURE

Key systems currently defined within the San Diego Regional ITS Architecture are summarized Table 3. For each system, the table describes some of the basic functional services offered, major types of data processed by the system, and the types of agencies likely to share these functions and data. For Smart Parking system implementations within the San Diego area, integration within the Regional ITS Architecture primarily translates into a need to develop interfaces with the Intermodal Transportation Management System (IMTMS) network, and to enable data exchanges with the Transit Management, Traveler Information, Arterial Management and Freeway Management systems.

The IMTMS network is the system tying together the various transportation management systems. This communication network enables the sharing of data and functional capabilities across individual systems. Figure 8 provides a high-level view of how various management systems are integrated within the IMTMS Network, as well as the basic types of information that are being shared across the various systems.

Table 3 –Key Management Systems of San Diego Regional ITS Architecture

System	Description	Basic Functional Services / Data Types	Stakeholders
IMTMS Network	Regional communications network, including leased and agency-owned communications resources that form the backbone for the exchange of information between ITS systems in the region.	**Services –** System integration, security, communications, regional network management, etc. **Data –** All types of data, including both data exclusive to a particular project and data shared between multiple ITS projects.	All agencies
Freeway Management System	ATMS 2005, deployed by Caltrans District 11, is the core of the management system. It includes control of cameras, CMSs, and vehicle detection sensors. The RMIS sub-system further controls ramp metering signals.	**Services –** Field device (cameras, CMSs, vehicle detection stations), freeway traffic control/management, incident/event management, incident response, resource management, etc. **Data –** Freeway speeds, incidents, video, sign messages, etc.	Caltrans, CHP, cities, transit, emergency services
Regional Arterial Management System (RAMS)	Comprised of two basic tiers: 1. Inter-jurisdictional signal coordination 2. Freeway and arterial operational coordination Tier 1 is in evaluation phase and will include a regional server to provide system-wide real-time data for IMTMS. Tier 2 provides a browser-based integrated workstation.	**Services –** Signal timing/control, inter-jurisdictional signal timing, regional timing plan implementation, field device (cameras, CMSs, vehicle detection stations) control/ management, incident/event management, incident response, resource management, etc. **Data –** Signal status, timing, local incidents/ events, arterial cameras, vehicle sensors, and message signs.	Cities, Caltrans, local law enforcement, and transit agencies
Transit Management System	Comprised of the Regional Transit Management System (RTMS) deployed by Metropolitan Transit System (MTS) and North County Transit District (NTCD) for the purpose of providing fleet management, enhanced schedule performance, improved fare payment, and improved interagency coordination.	**Services–**Fleet management, vehicle tracking, emergency alerts, transit schedule and arrival information, transit traveler information, automated fare payment, etc. **Data–**Transit vehicle locations, vehicle status, schedule adherence, real-time information displays at stops, dispatch/vehicle text messages, transit incidents.	Transit agencies, some local cities, and emergency services during safety related incidents
Traveler Information Management System	SANDAG has contracted for a regional 511 system that is provided by a single information service provider.	**Services–**Portal for public sector transportation information on IMTMS network to private sector information providers, data translation, data filtering. **Data–** Freeway/roadway speeds, incidents, travel times, announcements, transit schedule information, and next stop arrival, etc.	Private sector traveler information providers

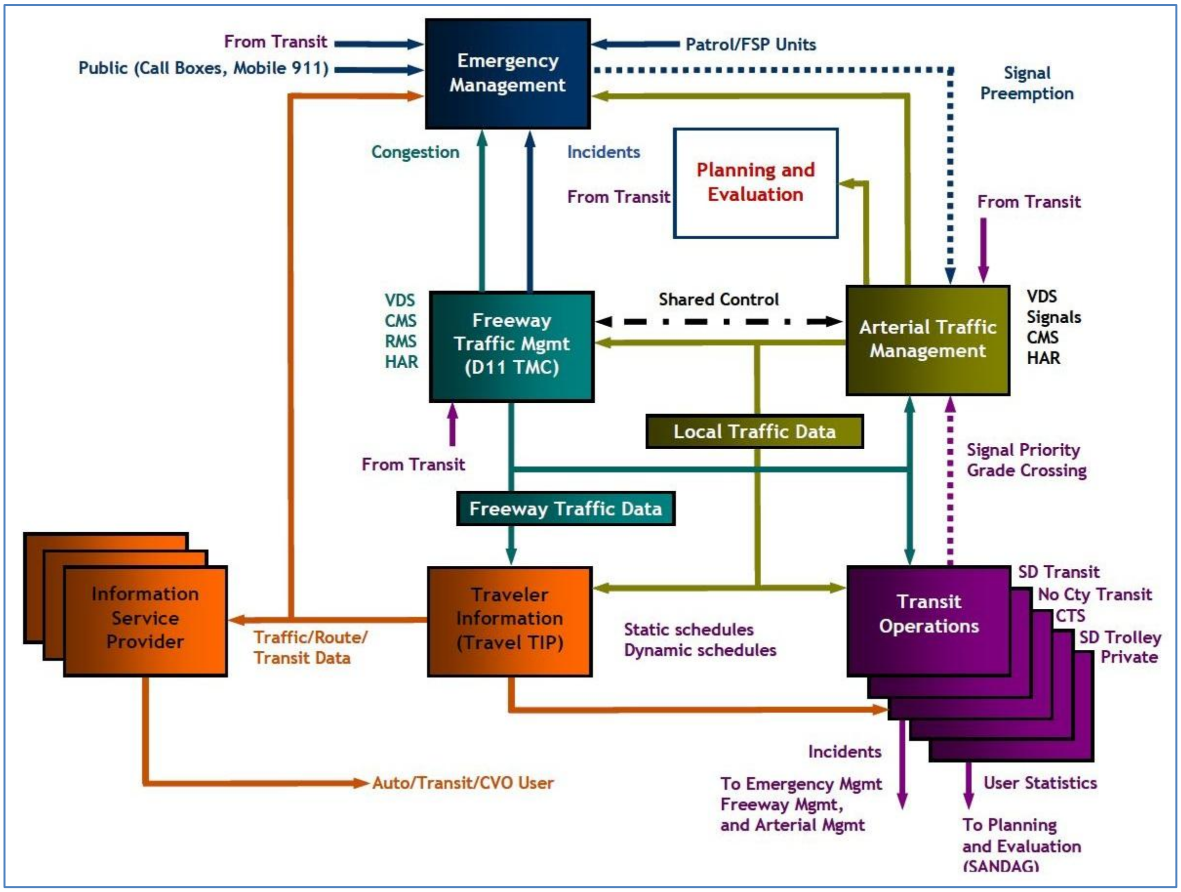

Figure 8 – San Diego IMTMS Logical Architecture

Within the IMTMS Network, communications between system elements occur at two basic levels:

- **Communications between agencies within a specific management system** – At this level, the IMTMS Network is used to link together various agencies utilizing a common system. For example, the network may be used to enable cities to communicate information used by the Regional Arterial Management System and share signal timing coordination data with other agencies. Data exchanges at this level may be in a format specific to the system generating or using the data, in addition to be being restricted to the users of the specific systems.
- **Communications between different modal management systems** – At this level, the IMTMS network is used to communicate information and share functionality between different management systems for instance, to enable data to flow from the Traffic Management System to the Transit Management System and vice versa. The IMTMS network also provides data to a SANDAG-operated information "portal" known as the Advanced Traveler Information Management System (ATIMS) server. Through this server, private sector providers of traveler information can access a vast array of data characterizing transportation system operations, such as transit schedules, bus arrival times, freeway speeds, lane closures, and incidents. To facilitate data and function sharing across systems, XMS data standards are generally being used to the data being processed at this level.

Physical elements composing the IMTMS network include physical communication devices and software enabling communication between various ITS applications:

- **Physical Communications Devices** – The IMTMS network establishes communication between various ITS systems through fiber optic and various high-capacity communications networks that are being deployed by Caltrans, cities, and transit agencies. Leased communication lines are used to reach locations where agency-owned communications are not practical or available. While the network currently primarily consists of leased communication lines, it is anticipated that the balance of connections will gradually shift to a predominance of agency-owned communications over time.
- **Integration/Management Software and Systems** – The IMTMS network implements data communication functions through a suite of browser-based services based on standard XML data architectures and industry web services standards. These functions were designed to enable IMTMS functionalities to be easily expanded to new clients or include new functionality. Since the communication services are browser-based, the only equipment needed for deploying a new functionality is a standard computer connected to the Internet.

The physical architecture of the IMTMS network is illustrated in Figure 9. Within this architecture, the primary role of the IMTMS communication devices is to establish a link between various agency data servers (ADS) and regional host servers (RHS). Each participating data provider, such as Caltrans, SANDAG, cities and transit agencies, has a direct or indirect connection to the network via a dedicated agency server. These servers are used to collect data supplied by local applications, convert data into standardized XML formats when required, and relay the resulting XML data to a set of Web servers for dissemination to other services.

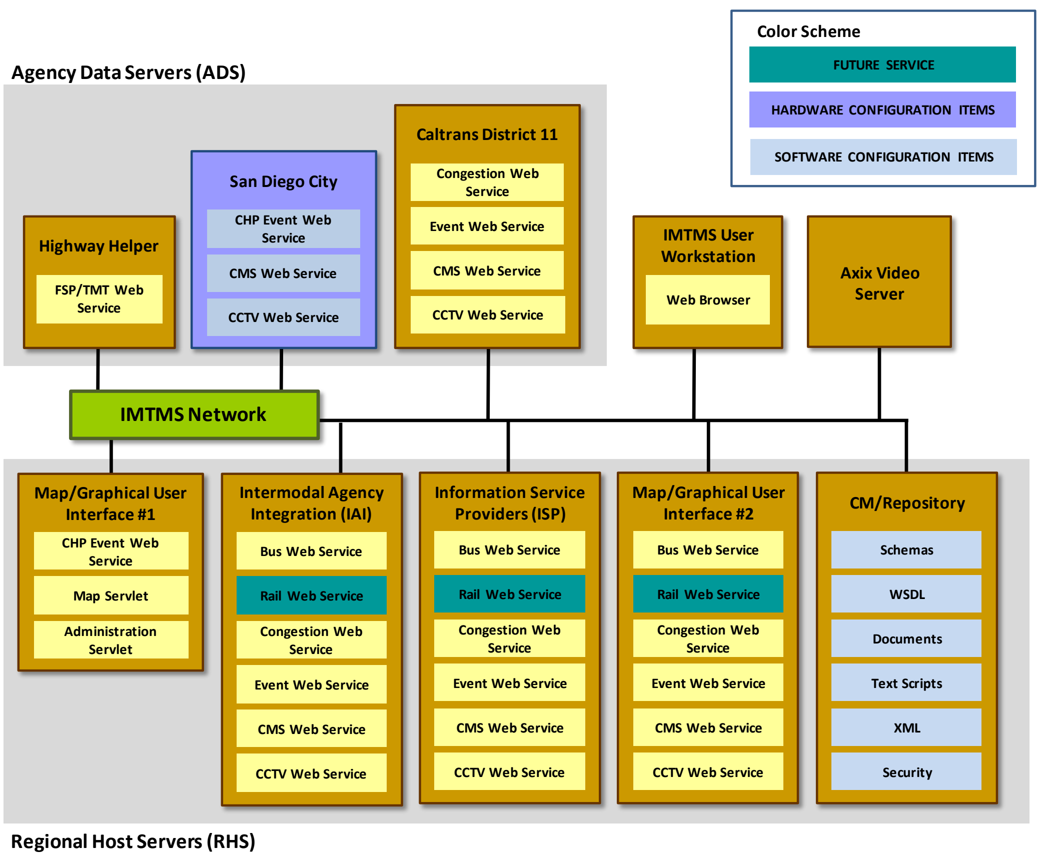

Figure 9 – Physical Deployment of IMTMS Elements
(Adapted from SANDAG sources)

The IMTMS network is implemented as a distributed Service-Oriented Architecture using off-the-shelf web service development technologies. Collectively, the IMTMS web servers provide an XML-based Web service platform that can disseminate data either as HTML map pages for browser display or as direct XML data streams. One or more map servers are further used to provide HTML-based, interactive maps to browser-based Regional Integrated Workstations, with one or more additional servers providing real-time field element data to populate the maps. An Intermodal Agency Integration (IAI) server also provides XML data streams for third-party applications, while one or more Information Service Provider (ISP) servers provide data to the provider that has been contracted by SANDAG to provide regional 511 services. Browser-based workstations needing no special software or installation are finally used as Regional Integrated Workstations to provide real-time intermodal data to potential client users, ranging from 911 dispatch centers to city traffic engineers and transit managers.

Within the IMTMS architecture, new data suppliers can be added by simply adding new Agency Data Servers (ADS) and defining new XML schemas for the new data elements that need to be processed. Integrating a new Smart Parking system within the IMTMS architecture should therefore be a relatively straightforward process. Using a variety of distribution servers, the IMTMS network would take data collected from various Smart Parking system components and provide raw or fused data to other systems or participants as either HTTP web pages or XML data feeds.

7.9. SYSTEM PACKAGES

Of the seven categories of design control parameters defined in Section 7.7, the **Lot Layout/Parking Space Differentiation**, **Access Control** and **Parking Space Reservation** options have generally the most conceptual significance. The **Parking Regulations** parameters typically only provide additional details regarding how a facility is expected to operate, while the **Transaction** and **Enforcement** parameters primarily define technological variations on the implementation of basic functionalities.

Table 4 through Table 7 present examples of sets of operational parameters associated with each of the four lot layout / access control scenarios illustrated in Figure 7:

- Undivided lot without access control (Scenario 1)
- Undivided lot with access control (Scenario 2)
- Divided lot without access control (Scenarios 3a and 3b)
- Divided lot with access control (Scenarios 4a and 4b)

Each of these four cases represents a base scenario upon which further variations can be constructed depending on choices made regarding other parameters.

Table 4 – Operational Parameters: Undivided Lot without Access Control

Parameter	Options
Lot Layout	• Undivided, undifferentiated.
Access Control	• No access control – Entry governed by parking rules only.
Parking Rules	• Undetermined.
Reservations	• Not possible. A reservation system requires some form of control to preserve empty spots for reserved users, which is not possible here.
Transaction Methods	• Registered users: - Mobile devices - RFIDs / Smart cards - Online transactions with printout • Unregistered users: - Payment machine within parking lot
Enforcement	• Undetermined.

Table 5 – Operational Parameters: Undivided Lot with Access Control

Parameter	Options
Lot Layout	• Undivided lot. • Reserved spaces can be sprinkled or differentiated, with varying consequences on access control and transaction methods.
Access Control	• Physical or virtual gate.
Parking Rules	• Undetermined.
Reservations	• Optional.
Transaction Methods	• Registered users: - RFIDs / Smart cards - Mobile devices - Dialed code • Unregistered users: - Payment machine at lot entrance - Payment machine within parking lot
Enforcement	• Physical gates may be used to prevent unauthorized access. • Virtual gates can be combined with payment machines configured not to sell tickets to unauthorized users. • Parking enforcement personnel is required to ensure that motorists park in appropriate spaces

Table 6 – Operational Parameters: Divided Lot without Access Control

Parameter	Options
Lot Layout	• Divided lots or segregated: ○ Without a reservation system, the lot can be segregated into specific areas for registered and unregistered users. ○ With a reservation system, the lot can be segregated into areas for registered or non-registered users, or into areas for reserved and non-reserved users.
Access Control	• No access control – Entry governed by parking rules only.
Parking Rules	• Undetermined.
Reservations	• Optional.
Transaction Methods	• Registered users: - RFIDs / Smart cards - Mobile devices - Online transaction with printout • Unregistered users: - Payment machine at lot entrance - Payment machine within parking lot
Enforcement	• Undetermined.

Table 7 – Operational Parameters: Divided Lot with Access Control

Parameter	Options
Lot Layout	• Divided lots or segregated: ○ Without a reservation system, the lot can be segregated into specific areas for registered and unregistered users. ○ With a reservation system, the lot can be segregated into areas for registered or non-registered users, or into areas for reserved and non-reserved users.
Access Control	• Physical gate or virtual gate.
Parking Rules	• Undetermined.
Reservations	• Optional
Transaction Methods	• Registered users: - RFIDs / Smart cards - Mobile devices - Dialed code • Unregistered users: - Payment machine at lot entrance - Payment machine within parking lot
Enforcement	• Physical gates prevent unauthorized access. • Virtual gates can be combined with payment machines that are configured no to sell tickets to unauthorized users.

8. USER OPERATIONAL SCENARIOS

This section presents several scenarios illustrating how a Smart Parking system may operate and interact with its users and external interfaces under given sets of circumstances. Its objective is to allow readers to walk through the tasks that would be performed by a Smart Parking system and to gain an understanding of how the various parts of the proposed system may function and interact.

The scenarios presented in this section include:

1. Stand-alone parking management system
2. Parking management system with advanced notification
3. Parking management system with advanced notification and reservation option
4. Parking management system integrated into the Regional ITS Architecture featuring advanced notification and reservation option.
5. Parking management system integrated with the Regional ITS Architecture featuring advanced notification, reservation option and dynamic pricing.

To help compare differences between the above alternatives, each scenario is developed for the same implementation context. All the scenarios consider a Smart Parking system aiming to improve the management of park-and-ride lots at train stations located along the COASTER commuter rail corridor in San Diego, California. COASTER is a transit service operated by the North County Transit District agency linking San Diego with Solana Beach, Encinitas, Carlsbad, and Oceanside. This service mainly runs parallel to Interstate 5 north of San Diego along the coast of the Pacific Ocean. During the week, its primary customers are individuals traveling to downtown San Diego from the North County suburbs. Many individuals further travel significant distance by car, typically along Interstate 5, before reaching one of the COASTER stations.

The above commuter rail system was selected to develop the operational scenarios based on the fact that it recently participated in a pilot deployment of a Smart Parking system. While the actual system simply added the ability for COASTER riders to reserve parking spaces, the scenarios considered in this document also consider the use of sensing technologies to demonstrate the potential operation of more comprehensive Smart Parking systems. For instance, all scenarios assume that vehicle sensors are installed within each parking space to monitor its utilization. Parking lot utilization could also be derived from a system counting vehicles entering and exiting a parking facility, albeit not at the same level of details as with the use of individual space sensors. All scenarios further assume that registered Smart Parking users can identify themselves and pay parking fees using a smart card. This option is based on the current ability of San Diego travelers to use COMPASS smart cards to pay for transit fares. The provision of alternate payment options, such as the ability to pay parking through a phone system or SMS text messaging would not change the basic system operations, just the mechanism by which some of the operations are implemented.

8.1. STAND-ALONE PARKING MANAGEMENT SYSTEM

This scenario considers a Smart Parking system offering the following capabilities:

- Ability to monitor in real time parking space use at each facility.
- Ability to guide motorists to open parking spaces within parking facilities.

- Ability for travelers to obtain real-time parking availability and fees from online traveler information services (San Diego 511).
- Ability for registered Smart Parking users to have the $1 fee charged for daily parking automatically debited from their COMPASS smart card account.

This scenario does not provide travelers with advanced parking availability information. The primary goals of the Smart Parking system are simply to help the parking operator monitor parking space utilization and to reduce unnecessary traffic within each parking facility by informing motorists reaching a facility when no parking space remain available. The scenario further considers a system that remains contained within each facility. There is no central computer server collecting and managing data from the various parking facilities. Each Smart Parking system typically operates as a stand-alone unit.

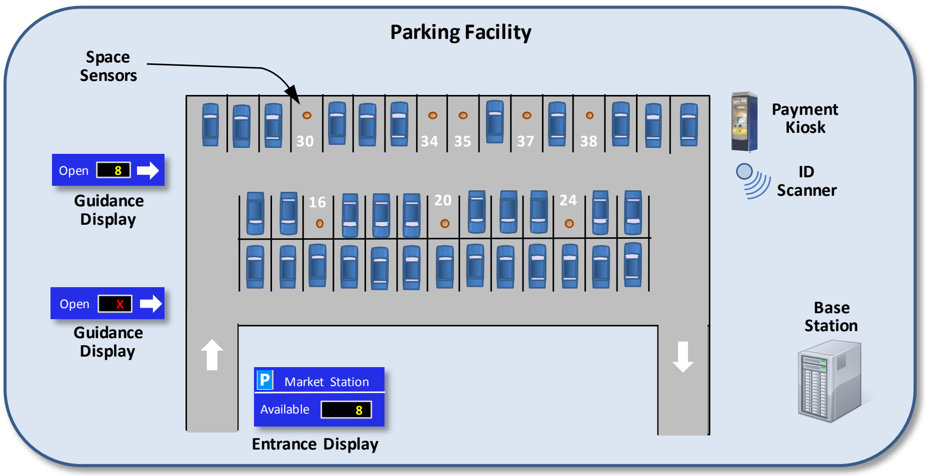

Figure 10 – Stand Alone Smart Parking System

Figure 10 illustrates the various elements of the Smart System considered in this scenario:

- Individual parking space sensors.
- Numbering of parking stalls, to allow the unique identification of each parking space.
- CMS at entrance of facility indicating how many open spaces are available.
- CMS at the start of each aisle indicating how many spaces are open within the aisle.
- COMPAS smart card reader located along pedestrian exit of facility to enable registered user to pay the $1 parking fee.
- Payment machines accepting cash and credit/debit cards, to enable non-registered users of the facility to pay for parking.
- Computer services managing the data flows within each parking facility

For this scenario, the primary participants are:

- **Parking lot users:** Individuals who seek to board a COASTER train and need to park their vehicle at one of the transit stations.

- **North County Transit District (NCTD) agency:** Transit agency operating the COASTER commuter rail system and responsible for managing the park-and-ride lots at each station.

- **Parking enforcement staff:** Staff from the transit agency, local police departments or contracted firms tasked with enforcing parking rules.

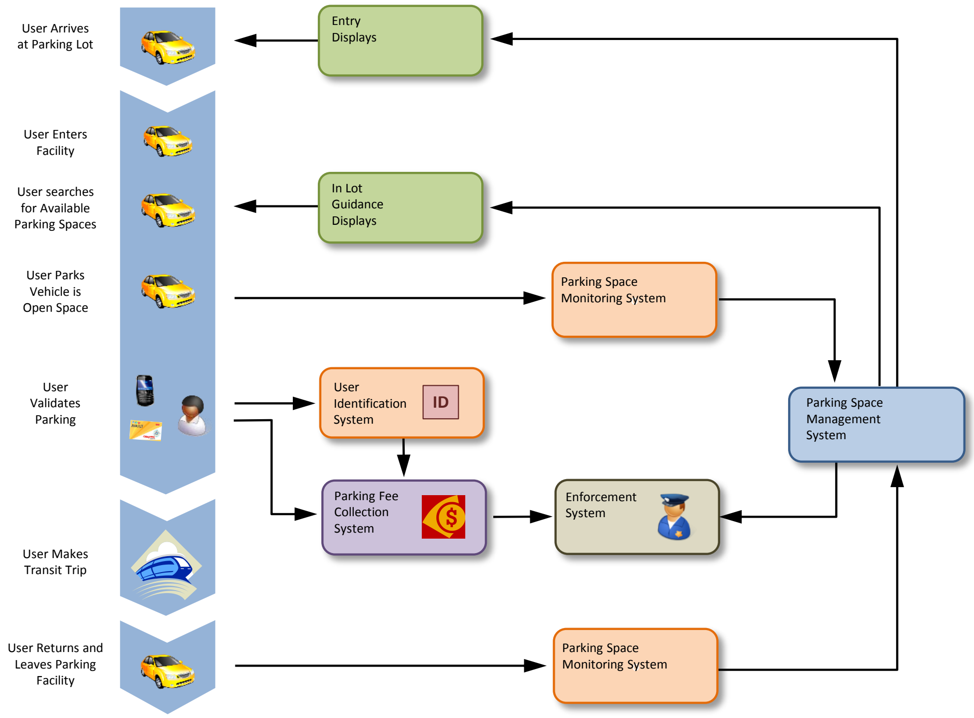

Figure 11 – Key Interactions for Stand Alone Smart Parking System

Figure 11 illustrates how the stand-alone Smart Parking system would be used to manage the available supply or parking spaces, facilitate the payment of parking fees, and ensure that enacted parking rules are respected. Key events for this scenario include:

1. Upon reaching a parking facility, signs located at or near the entrances would inform motorists wishing to enter whether spaces are still available within. In the absence of available space, a motorist may then elect to seek parking elsewhere.

2. After entering the facility, motorists are guided to an open space by CMSs located at the start of each aisle. These signs may show parking availability by displaying a green arrow or the total number of open space on the aisle.

3. After finding an open space, motorists would park their vehicle in the stall. A sensor within the stall would then detect the vehicle and change its status from “open” to “occupied”. This change in status results in a “Parking Event Record" being created and sent to the Inventory Management module, which then uses the information contained within the record to update the CMSs at the entrance of the facility and, if needed, guidance signs within the facility.

4. After having parked their vehicle, all motorists proceed to pay the parking fee. All facility patrons walk to a kiosk where they are asked to provide the stall number where they have parked their vehicle. Registered Smart Parking then scan their COMPASS smart card to have the parking fee automatically debited from their user account. Users without a COMPAS card are further provided with the option to use cash or a credit card. Upon completion, all validation and payment transactions are logged by the Parking Transaction and Payment module for future management, enforcement and reporting tasks.

5. Upon returning from their trip, travelers simply walk to their vehicle and drive away. When the vehicle sensor in parking stall detects the space being vacated, it sends a “Departure Record” to the Inventory Management module indicating the time at which a particular parking space was sensed to have become available. Reception of these departure records then triggers the Inventory Management module to update the list of open parking spaces. Updated parking availability information is subsequently sent to the CMSs located at the entrance of the facility, and guidance signs within the facility.

6. Throughout the day, the Smart Parking Inventory Management module maintains a list of occupied parking stalls and provides this list upon request to the parking enforcement officers patrolling each parking facility with PDAs. For each stall, the list would indicate whether a vehicle is being sensed by the parking space sensor and whether a parking fee or validation has been registered for the space.

8.2. PARKING MANAGEMENT SYSTEM WITH ADVANCE NOTIFICATION

This scenario considers a Smart Parking system similar to one of Section 8.1, except for the addition of capabilities to provide parking availability information to travelers before they reach a parking facility. The operational features of the parking management system being considered include:

- Ability to monitor in real time parking space use at each facility.
- Ability to guide motorists to open parking spaces within parking facilities.
- Displaying of real-time parking availability and parking fee data on CMSs located at key decision points along Interstate 5, which runs parallel to the COASTER rail line, as well as along key urban arterials bringing traffic to COASTER stations.
- Ability for travelers to obtain real-time parking availability and fees from online traveler information services (San Diego 511).
- Ability for registered Smart Parking users to have the $1 daily parking fee automatically debited from their COMPASS smart card account.

The primary goals of the deployed Smart Parking system are to:

- Help reduce unnecessary traffic within each parking facilities by informing travelers whether open spaces are still available and where such spaces may be.
- Help reduce unnecessary trip to parking facilities that may already be full or nearing capacity by providing travelers with the ability to obtain up-to-the-minute parking availability information prior to reaching a parking facility.
- Help increase the demand for parking at underutilized facilities to the dissemination of information highlighting space availability.

Figure 12 illustrates the various system elements considered:

- Individual parking space sensors.
- Numbering of parking stalls, to allow the unique identification of each parking space.
- CMSs at entrance of facility indicating how many open spaces are available.
- Changeable signs at the start of each aisle indicating how many spaces are open within the aisle.
- CMSs installed along nearby Interstate 5 and indicating the number of parking spaces available at nearby stations (operated by Caltrans).

- CMSs installed along arterials leading to the parking facilities and indicating the number of parking spaces available at nearby stations (operated by the San Diego County Department of Public Works).
- Process to disseminate parking availability information to regional traveler information services (San Diego 511, transit agency websites).
- COMPASS smart card readers placed at key locations within each parking facility to enable registered users to pay the $1 daily fee charged for parking spaces.
- Payment machines accepting cash and credit/debit cards placed at key locations within each parking facility to enable non-registered users to pay for parking (may be combined with COMPASS smart card readers).
- Optional base station within each parking facility used to manage the data coming in and out of each facility.
- Central computer server providing system-wide data management and reporting capabilities.

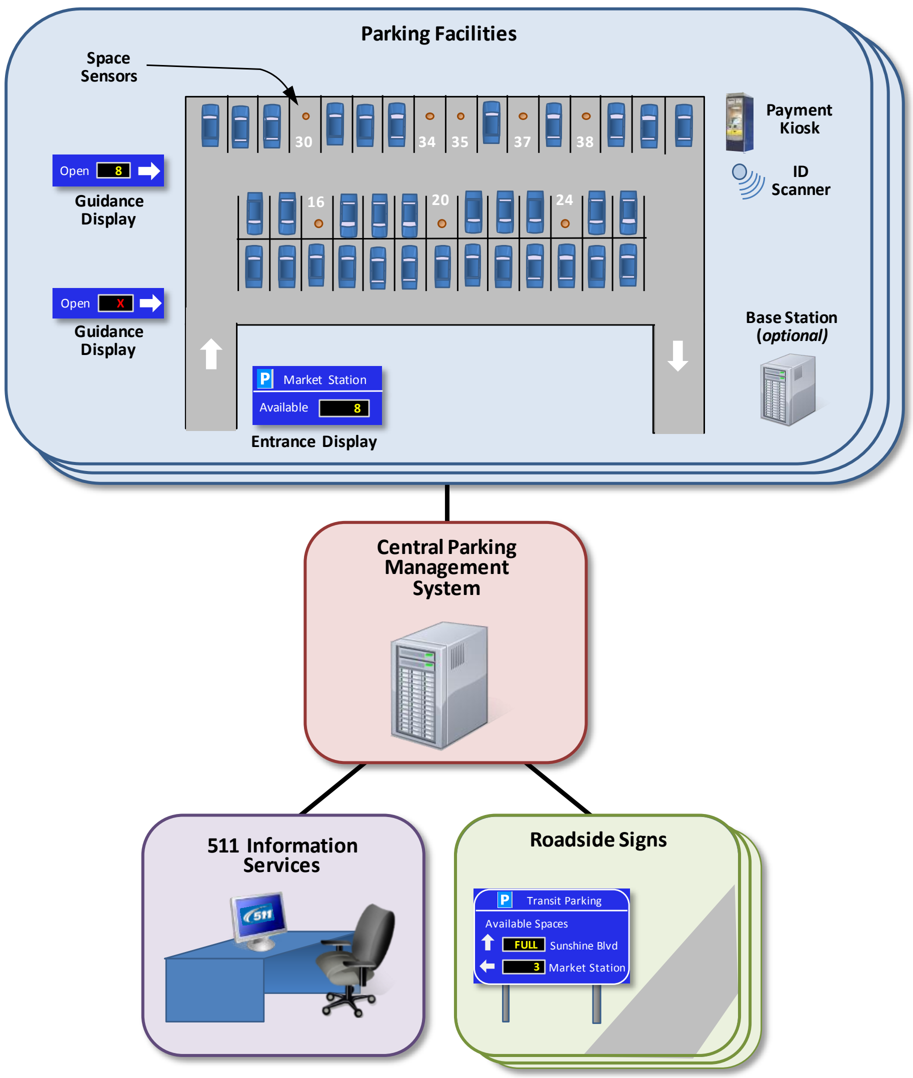

Figure 12 – Smart Parking System with Advanced Notification

For this scenario, the primary participants are:

- **Parking lot users** – Individuals who seek to board a COASTER train and need to park their vehicle at one of the transit stations.
- **North County Transit District (NCTD) agency** – Transit agency operating the COASTER commuter rail system and responsible for managing the park-and-ride lots at each station. The agency may also be responsible for displaying parking availability information on its website.
- **San Diego Association of Governments (SANDAG)** – Regional planning agency responsible for operating the regional 511 information system.
- **California Department of Transportation (Caltrans)** – Agency responsible for managing traffic along interstates and state highways and operating CMSs installed along these roadways.
- **San Diego County Department of Public Works** – Agency responsible for managing traffic along urban arterials in San Diego County and which would be responsible for operating CMSs installed along these roadways.
- **Parking enforcement staff** – Staff from the transit agency, local police departments or contracted firms tasked with enforcing parking rules.

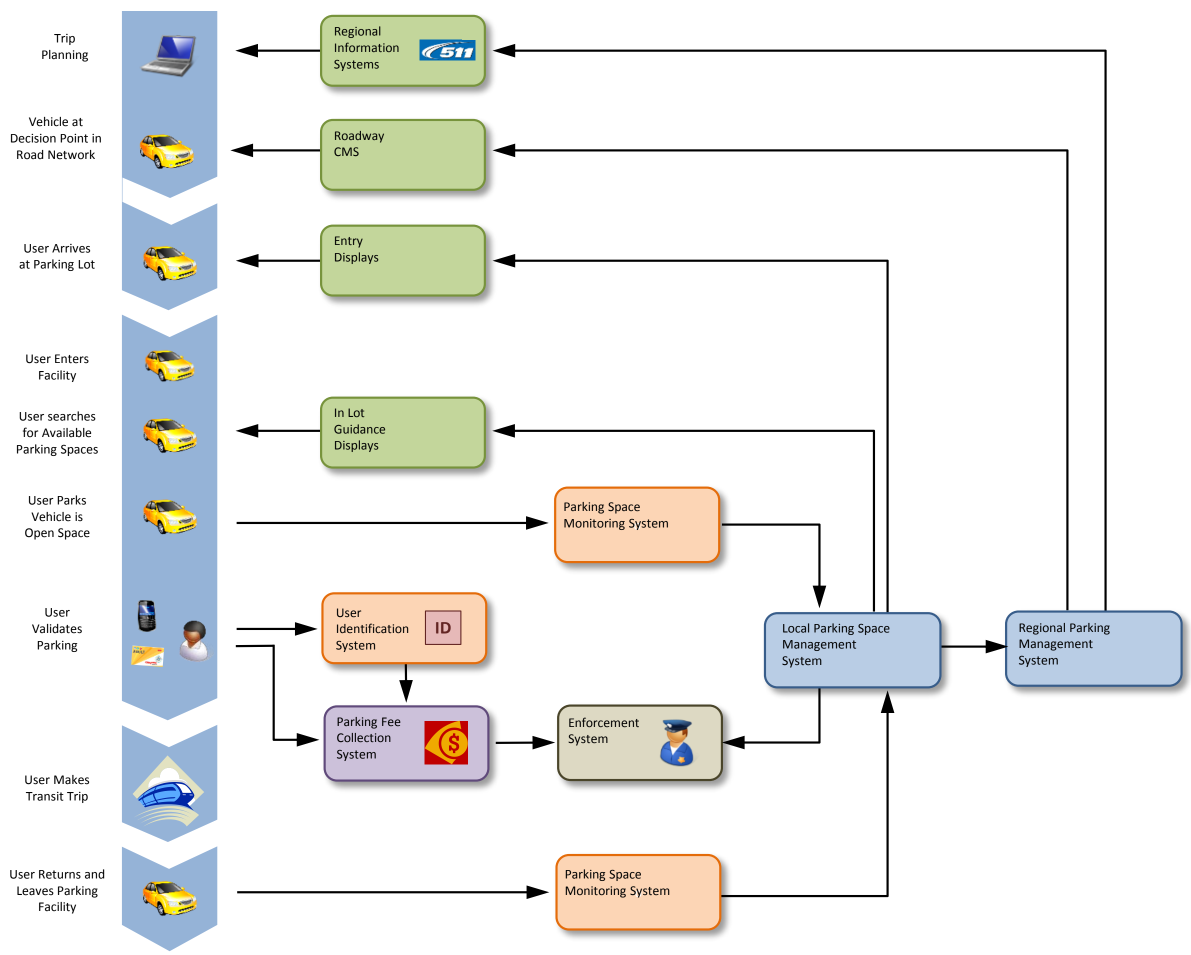

Figure 13 – Key Interactions for System with Advanced Notification

Figure 13 illustrates how the Smart Parking system would be used to manage the available supply or parking spaces, provide advance availability information, facilitate the payment of parking fees, and ensure that enacted parking rules are respected. Key events for this scenario include the following:

1. Before initiating a trip, travelers consult SANDAG's 511 website or ParkingCarma's website to assess parking availability and parking fees at the COASTER station where they wish to park. Both websites display information that is provided to them by the Smart Parking's central Inventory Management module via dedicated communication channels. Prospective travelers assessing that parking may not be available by the time they would reach the facility may then decide to alter their travel plans to avoid an unnecessary trip.

2. At key decision points along the regional road network, CMSs inform travelers about the number of non-reserved parking spaces still available at nearby COASTER stations. This information is sent to the agencies operating the CMSs (Caltrans, San Diego County Department of Public Works) by the Inventory Management module via dedicated communication channels. It is provided to help travelers without reservation confirm that there is still space available at their intended destination and, if not space remains available, help them determine at which alternate stations parking is still available.

3. Upon reaching a parking facility, signs located at or near the entrances would inform motorists wishing to enter whether spaces are still available within. In the absence of available space, a motorist may then elect to seek parking elsewhere.

4. After entering the facility, motorists are guided to an open space by CMSs located at the start of each aisle. These signs may show parking availability by displaying a green arrow or the total number of open space on the aisle.

5. After finding an open space, motorists would park their vehicle in the stall. A sensor within the stall would then detect the vehicle and change its status from "open" to "occupied". This change in status results in a "Parking Event Record" being created and sent to the Inventory Management module, which then uses the information contained within the record to update the CMSs at the entrance of the facility and, if needed, guidance signs within the facility. Parking availability updates would also be sent, through dedicated communication channels, to CMSs operated by Caltrans along I-5 and signs operated by the San Diego County Department of Public Works s along regional arterials.

6. After having parked their vehicle, all motorists proceed to pay the parking fee. All facility patrons walk to a kiosk where they are asked to provide the stall number where they have parked their vehicle. Registered Smart Parking then scan their COMPASS smart card to have the parking fee automatically debited from their user account. Users without a COMPAS card are provided with the option to use cash or a credit card. Upon completion, all validation and payment transactions are logged by the Parking Transaction and Payment module for future management, enforcement and reporting tasks.

7. Upon returning from their trip, travelers would simply walk to their vehicle and drive away. The vehicle sensor installed within each parking stall would detect the space being vacated and send a "Departure Record" to the Inventory Management module indicating the time at which a vehicle was sensed to leave and the stall number where the departing event occurred. Reception of these departure records would trigger the Inventory Management module to

update the list of open parking spaces. Updated parking availability information would subsequently be sent to the CMSs located at the entrance of the facility, guidance signs within the facility, CMSs operated by Caltrans along I-5, CMSs along urban arterials operated by the San Diego County Department of Public Works, and regional 511 services.

8. When the vehicle sensor in the parking stall detects the space being vacated, it sends a "Departure Record" to the Inventory Management module indicating the time at which the parking space became available. Reception of these departure records then triggers the Inventory Management module to update the list of open parking spaces. Updated parking availability information is subsequently sent to the CMSs located at the entrance of the facility and guidance signs within the facility. Information is also sent to CMSs operated by Caltrans along I-5, signs located along urban arterials operated by the San Diego County Department of Public Works, and regional 511 services via dedicated communication channels.

9. Throughout the day, the Inventory Management module maintains a list of occupied parking stalls and provides it upon request to the parking enforcement officers patrolling each parking facility with PDAs. For each stall, the list would indicate whether a vehicle is being sensed occupying it and whether a parking validation and/or fee has been registered for the vehicle.

8.3. PARKING MANAGEMENT SYSTEM WITH ADVANCE NOTIFICATION AND RESERVATION

This scenario considers a Smart Parking system that is similar to the one described in the scenario of Section 8.2 but that adds the ability for travelers to reserve parking spaces prior to reaching a parking facility. The specific capabilities considered in this scenario include:

- Ability to monitor in real time parking space use at each facility.
- Ability to guide motorists to open parking spaces within parking facilities.
- Displaying of real-time parking availability and parking fee data on CMSs located at key decision points along Interstate 5, which runs parallel to the COASTER rail line, as well as along key urban arterials bringing traffic to COASTER stations.
- Ability for travelers to obtain real-time parking availability and fees from online traveler information services (San Diego 511, ParkingCarma).
- Ability for registered Smart Parking users to have the \$1 non-reserved daily parking fee or \$2 reserved parking fee automatically debited from their COMPASS smart card account.
- Ability for travelers to reserve a parking space at a given facility for a given day and time using online traveler information services (San Diego 511, ParkingCarma).

The primary goals of the Smart Parking system described in this scenario are to:

- Help reduce unnecessary traffic within each parking facilities by informing travelers whether open spaces are still available and where such spaces may be.
- Help reduce unnecessary trip to parking facilities that may already be full or nearing capacity by providing travelers with the ability to obtain up-to-the-minute parking availability information prior to reaching a parking facility.
- Help increase the demand for parking at underutilized facilities to the dissemination of information highlighting space availability.
- Enable travelers who wish to do so to reserve ahead of time a parking space at one of the COASTER park-and-ride lots.

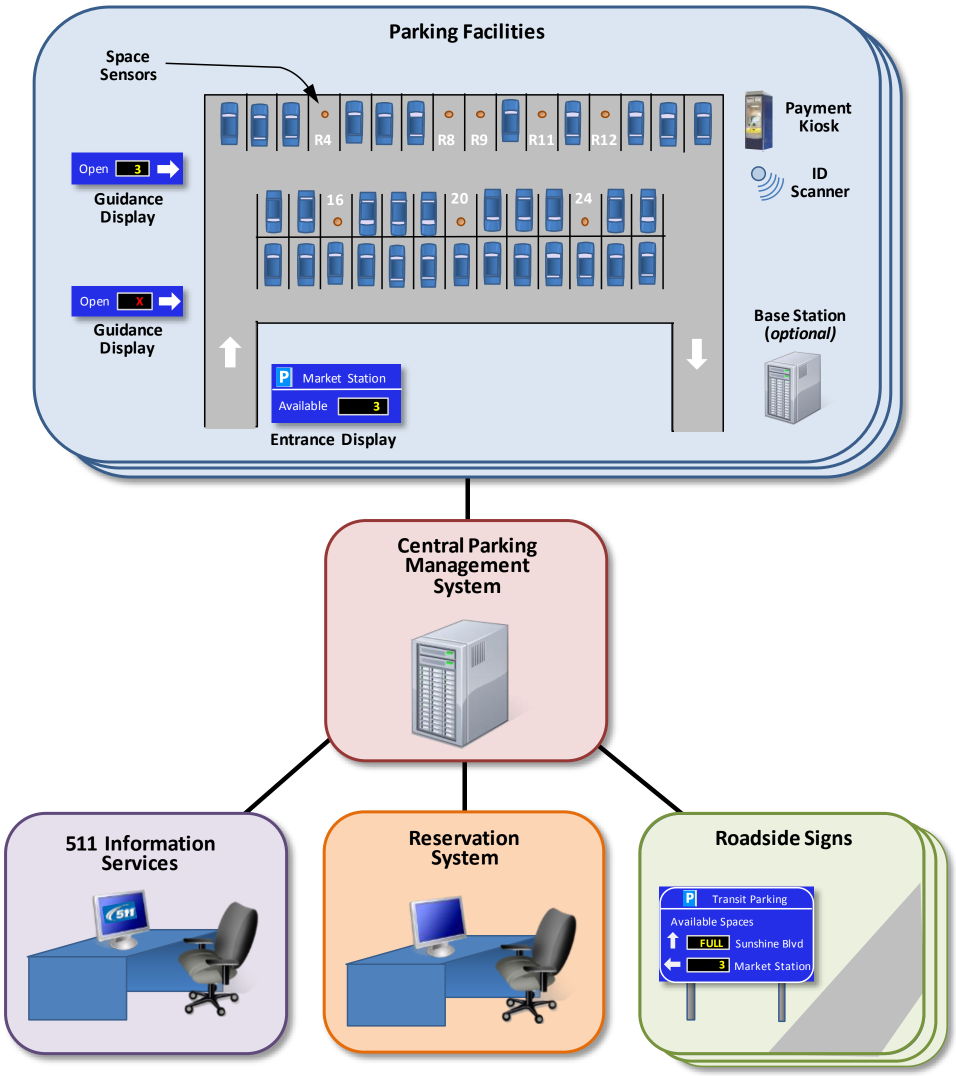

Figure 14 – Smart Parking System with Advanced Notification and Reservation Option

Figure 14illustrates the various elements considered:

- Separation of parking lot in reserved and non-reserved spaces.
- Individual parking space sensors.
- Numbering of parking stalls, to allow the unique identification of each parking space.
- CMS at entrance of facility indicating how many open spaces are available.
- Changeable signs at the start of each aisle indicating how many spaces are open within the aisle.
- CMSs installed along nearby Interstate 5 and indicating the number of non-reserved parking spaces available at nearby stations (operated by Caltrans).
- CMSs installed along arterials leading to the parking facilities and indicating the number of non-reserved parking spaces available at nearby stations (operated by the San Diego County Department of Public Works).
- Process to disseminate parking availability information to regional traveler information services (San Diego 511, transit agency website).
- Interface with an internet-based parking reservation system operated by ParkingCarma.

- COMPASS smart card readers placed at key locations within each parking facility to enable registered users to pay the $1 daily fee charged for non-reserved parking spaces.
- Payment machines accepting cash and credit/debit cards placed at key locations within each parking facility to enable non-registered users to pay for parking (may be combined with COMPASS readers).
- Optional base station within each parking facility used to manage the data coming in and out of each facility.
- Central computer server providing system-wide data management and reporting capabilities.

For this scenario, the primary participants are:

- **Parking lot users** – Individuals who seek to board a COASTER train and need to park their vehicle at one of the transit stations.
- **North County Transit District (NCTD) agency** – Transit agency operating the COASTER commuter rail system and responsible for managing the park-and-ride lots at each station. The agency may also be responsible for displaying parking availability information on its website.
- **California Department of Transportation (Caltrans)** – Agency responsible for managing traffic along interstates and state highways and operating CMSs installed along these roadways.
- **San Diego County Department of Public Works** – Agency responsible for managing traffic along urban arterials in San Diego County and which would be responsible for operating CMSs installed along these roadways.
- **San Diego Association of Governments (SANDAG)** – Regional planning agency responsible for operating the regional 511 traveler information system used to disseminate parking availability information. In this scenario, the 511 system is also used to enable travelers to place parking reservations in addition to the service offered by ParkingCarma.
- **ParkingCarma** – Operator of the Smart Parking reservation system. Responsible for disseminating parking availability data, managing reservations, and collecting parking fees.
- **Parking enforcement staff** – Staff from the transit agency, local police departments or contracted firms tasked with enforcing parking rules.

Figure 15 illustrates how the Smart Parking system would be used to manage the available supply or parking spaces, provide advance availability information, enable the reservation of parking spaces, facilitate the payment of parking fees, and ensure that enacted parking rules are respected. For this scenario, key events include the following:

1. Before initiating a trip, travelers consult SANDAG's 511 website or ParkingCarma's website to assess parking availability and parking fees at the COASTER station where they wish to park. Both websites display information that is provided to them by the Smart Parking's central Inventory Management module via dedicated communication channels.

2. Travelers assessing that parking availability may be an issue at their intended time of travel may elect to reserve a parking space prior to starting their trip. To do so, they must access a website operated by ParkingCarma providing a user-friendly interface with the central Inventory Management module, either directly or through links placed on the regional 511 website or websites of transit agencies. Once on the website, travelers would indicate for which station, day, and time they wish to place a reservation. The Reservation module would then check

whether a space is available and what the fee is for the space, and then display this information onscreen. Individuals who wish to proceed with a reservation are then invited to log in to their Smart Parking account to complete the reservation. After logging in and specifying which vehicle they are planning to use, a reservation request tied to the identified vehicle is created and sent to the Inventory Management module. Following confirmation that a space can be reserved, the parking fee is automatically debited from the user's COMPASS account or charged to the credit card linked to his Smart Parking user profile, followed by the issuance of a reservation ticket clearly identifying a confirmation number, the vehicle to be parked, the parking facility for which the reservation was made, and the day and time of the reservation. Individuals without an existing Smart Parking account are first invited to create a new account before proceeding with the reservation. Individuals who opt to not create a new account are then offered the choice to secure instead a reservation by providing an existing COMPASS smart card or credit card number, in addition to information describing the vehicle they will using. Upon completion, all parking reservations and fee payment transactions are logged by the Parking Transaction and Payment module for future management and reporting tasks.

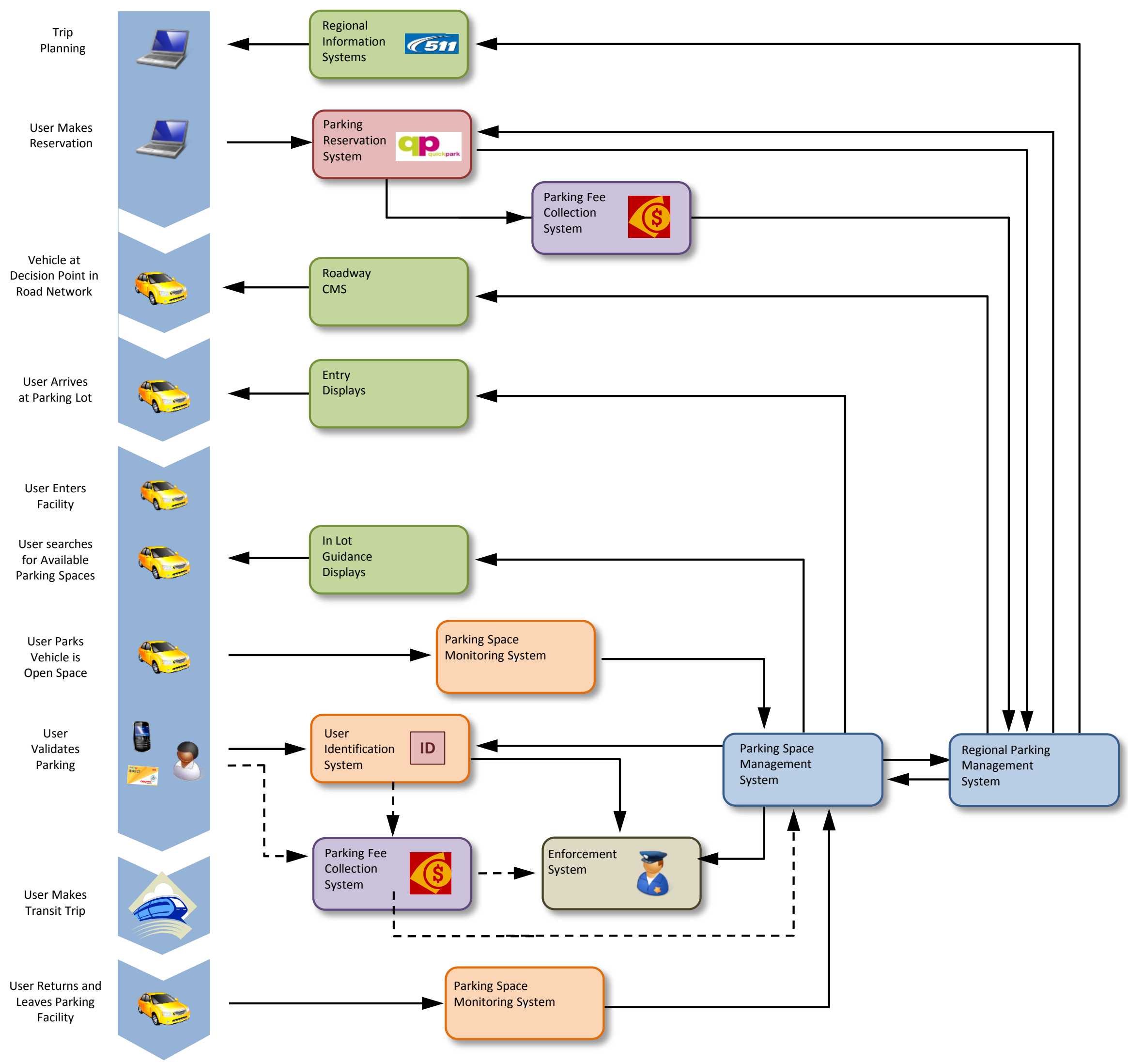

Figure 15 – Key Interactions for System with Advanced Notification and Reservation

3. A new reservation triggers the Inventory Management module to update the number of parking spaces that can be reserved. Notifications of changes in the number of available spaces are then sent to the regional 511 services, ParkingCarma, and other information providers

4. At key decision points along the regional road network, CMSs inform travelers about the number of non-reserved parking spaces still available at nearby COASTER stations. This information is sent to the agencies operating the CMSs (Caltrans, San Diego County Department of Public Works) by the Inventory Management module via dedicated communication channels. It is provided to help travelers without a reservation confirm that there is still space available at their intended destination and, if not space remains available, help them determine at which alternate stations parking is still available.

5. Upon reaching a parking facility, signs located at or near the entrances would inform motorists wishing to enter whether spaces are still available within. In the absence of available space, a motorist without reservation may then elect to seek parking elsewhere. Similar to the information displayed on roadside signs, motorists with a reservation could ignore the availability information if they reach the facility within the validity period of their reservation, as they would already have a guaranteed parking space available.

6. After entering the facility, motorists are guided to an open space by CMSs located at the start of each aisle. These signs may show availability by displaying a green arrow or the total number of open space on the aisle. To account for the fact that motorists with and without a reservation may need to look for parking spaces in different areas within a parking facility, specific directions are provided for patrons with and without a reservation.

7. After finding an open space, motorists would park their vehicle in the open stall. A sensor within the stall would then detect the vehicle and change its status from “open” to “occupied”. This change in status results in a “Parking Event Record" being created and sent to the Inventory Management module. A vehicle moving into a reserved parking space would not trigger an update of the number of available open spaces displayed on traveler information outlets. Only parking events affecting the supply on non-reserved spaces would trigger an update. Each time a non-reserved space becomes occupied, the Inventory Management module would update the CMSs at the entrance of the facility and, if needed, guidance signs within the facility. Parking availability updates would also be sent through dedicated communication channels to CMSs operated by Caltrans along I-5 and signs operated by the San Diego County Department of Public Works s along regional arterials.

8. After having parked their vehicle, motorists proceed to validate their parking. Only individuals without a reservation pay the parking fee at this time. Users with reservation only need to validate their parking since they pay the parking fee when they make their reservation. All facility patrons validate their parking by entering the number of the parking stall where they parked at a validation kiosk on their way out of the facility. Reservation holders identify themselves by simply scanning their COMPASS smart card. Registered Smart Parking users without a reservation may also scan their COMPASS card to have the parking fee automatically debited from their user account. Finally, Users without a COMPASS card are provided with the option to use cash or a credit card to pay for parking. Upon completion, all validation and parking fee payment transactions are logged by the Parking Transaction and Payment module for future management, enforcement, and reporting tasks.

9. When the vehicle sensor in the parking stall detects the space being vacated, it sends a "Departure Record" to the Inventory Management module indicating the time at which the parking space became available. Reception of these departure records then triggers the Inventory Management module to update the list of open parking spaces and/or spaces available for reservation. Updated parking availability information is subsequently sent to the CMSs located at the entrance of the facility and to the guidance signs within the facility. Information is also sent to CMSs operated by Caltrans along I-5, signs located along urban arterials operated by the San Diego County Department of Public Works, and regional 511 services via dedicated communication channels.

10. Throughout the day, the Inventory Management module maintains a list of occupied parking stalls and provides this list upon request to the parking enforcement officers patrolling each parking facility with PDAs. For each stall, the list would indicate whether a vehicle is being sensed occupying it and if a parking fee or validation has been registered for the space.

8.4. FULLY INTEGRATED PARKING MANAGEMENT SYSTEM

This scenario considers a Smart Parking system fully integrated with San Diego's regional ITS Architecture. The capabilities considered in this scenario include:

- Ability to monitor in real time parking space use at each facility.
- Ability to guide motorists to open parking spaces within parking facilities.
- Displaying of real-time parking availability and parking fee data on CMSs located at key decision points along Interstate 5, which runs parallel to the COASTER rail line, as well as along key urban arterials bringing traffic to COASTER stations.
- Ability for travelers to obtain real-time parking availability and fees from online traveler information services (San Diego 511, ParkingCarma).
- Ability for registered Smart Parking users to have the $1 non-reserved daily parking fee or $2 reserved parking fee automatically debited from their COMPASS smart card account.
- Ability for travelers to reserve a parking space at a given facility for a given day and time using online traveler information services (San Diego 511, ParkingCarma).

The primary goals of the Smart Parking system are identical to the example of Section 8.3:

- Help reduce unnecessary traffic within parking facilities by informing travelers whether open spaces are still available and where such spaces may be.
- Help reduce unnecessary trips to parking facilities that may already be full or nearing capacity by providing travelers with the ability to obtain up-to-the-minute parking availability information prior to reaching a parking facility.
- Help increase the demand for parking at underutilized facilities by the dissemination of information highlighting space availability.
- Enable travelers who wish to do so to reserve a parking space ahead of time at one of the COASTER park-and-ride lots.

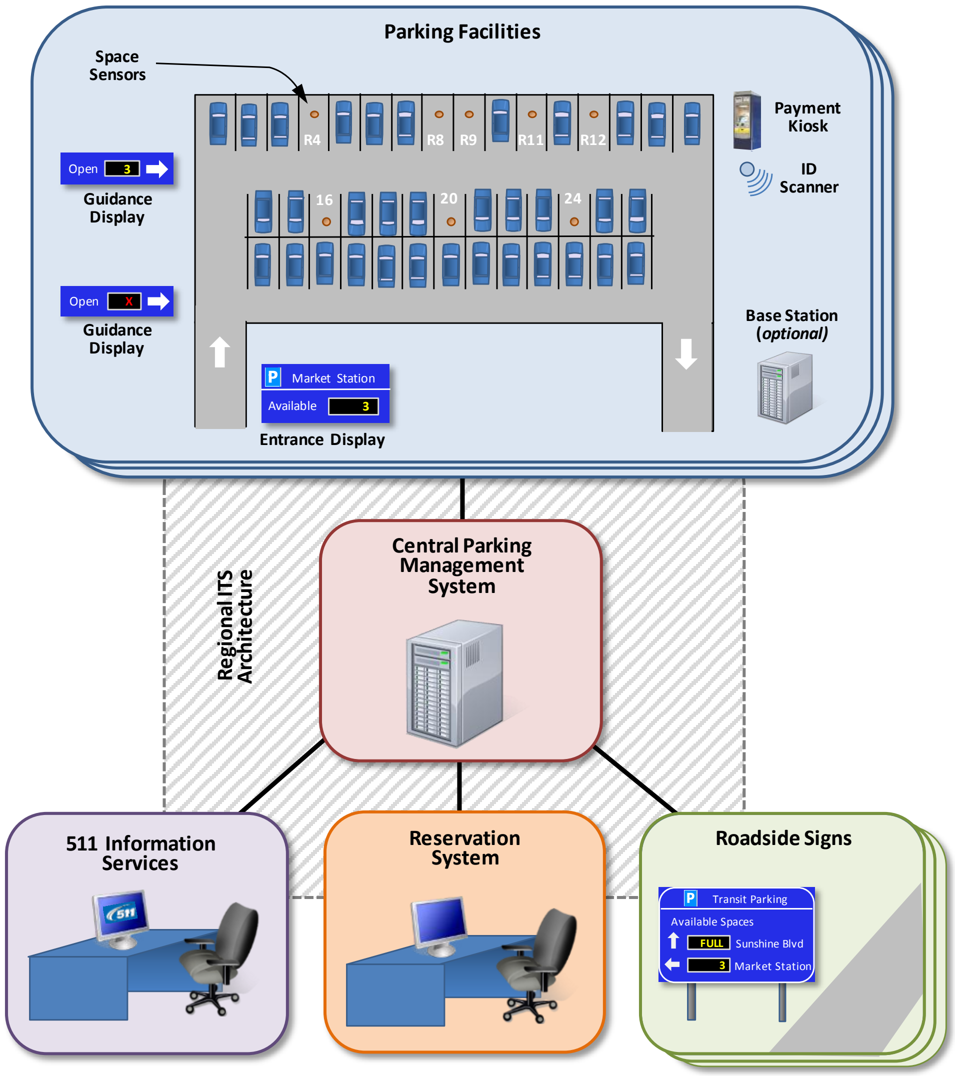

Figure 16– Smart Parking System Fully Integrated with Regional ITS System

Figure 16 illustrates the various system elements considered:

- Separation of parking lot into reserved and non-reserved spaces
- Individual parking space sensors.
- Numbering of parking stalls, to allow the unique identification of each parking space.
- Changeable sign at entrance of facility indicating how many open spaces are available.
- Changeable signs at the start of each aisle indicating how many spaces are open within the aisle.
- CMSs installed along nearby Interstate 5 and indicating the number of non-reserved parking spaces available at nearby stations (operated by Caltrans).
- CMSs installed along arterials leading to the parking facilities and indicating the number of non-reserved parking spaces available at nearby stations (operated by the San Diego County Department of Public Works).
- Process to disseminate parking availability information to regional traveler information services (San Diego 511, transit agency website).
- Interface with an internet-based parking reservation module operated by ParkingCarma.

- COMPASS smart card readers placed at key locations within each parking facility to enable registered users to pay the $1 daily fee charged for non-reserved parking spaces.
- Payment machines accepting cash and credit/debit cards placed at key locations within each parking facility to enable non-registered users to pay for parking (may be combined with the COMPASS smart card readers).
- Optional base station within each parking facility used to manage the data coming in and out of each facility.
- Central computer server providing system-wide data management and reporting capabilities.

The primary difference with preceding scenarios is that communications between various system elements not physically located in the same facility are implemented using the regional ITS architecture. Some of the parking management functions are also assumed to be hosted in a central computer server. For a system implemented in the San Diego area, this means interfacing with the IMTMS network, as well as various ITS services.

For this scenario, the primary participants are:

- **Parking lot users** – Individuals who seek to board a COASTER train and need to park their vehicle at one of the transit stations.
- **North County Transit District (NCTD) agency** – Transit agency operating the COASTER commuter rail system and responsible for managing the park-and-ride lots at each rail station. The agency may also be responsible for displaying parking availability information on its website.
- **California Department of Transportation (Caltrans)** – Agency responsible for managing traffic along interstates and state highways and operating CMSs installed along these roadways.
- **San Diego County Department of Public Works** – Agency responsible for managing traffic along urban arterials in San Diego County and which would be responsible for operating CMSs installed along these roadways.
- **San Diego Association of Governments (SANDAG)** – Regional planning agency responsible for operating the regional 511 traveler information system used to disseminate parking availability information. In this scenario, 511 services are also used to enable travelers to place parking reservations in addition to the service offered by ParkingCarma.
- **ParkingCarma** – Operator of the Reservation module. Responsible for disseminating parking availability data, managing reservations, and collecting parking fees.
- **Parking enforcement staff** – Staff from the transit agency, local police departments, or contracted firms tasked with enforcing parking rules.

Figure 17 illustrates how the Smart Parking system would be used to manage the available supply of parking spaces, provide advanced availability information, enable the reservation of parking spaces, facilitate the payment of parking fees, and ensure that enacted parking rules are respected. For this scenario, key events include the following:

1. Before initiating a trip, travelers consult SANDAG's 511 website or ParkingCarma's website to assess parking availability and parking fees at the COASTER station where they wish to park. Both websites display information provided by the Smart Parking's central Inventory Management module and disseminated via the IMTMS network through an interface with the ITS Transit Management System. It is also possible for the data to reach prospective travelers

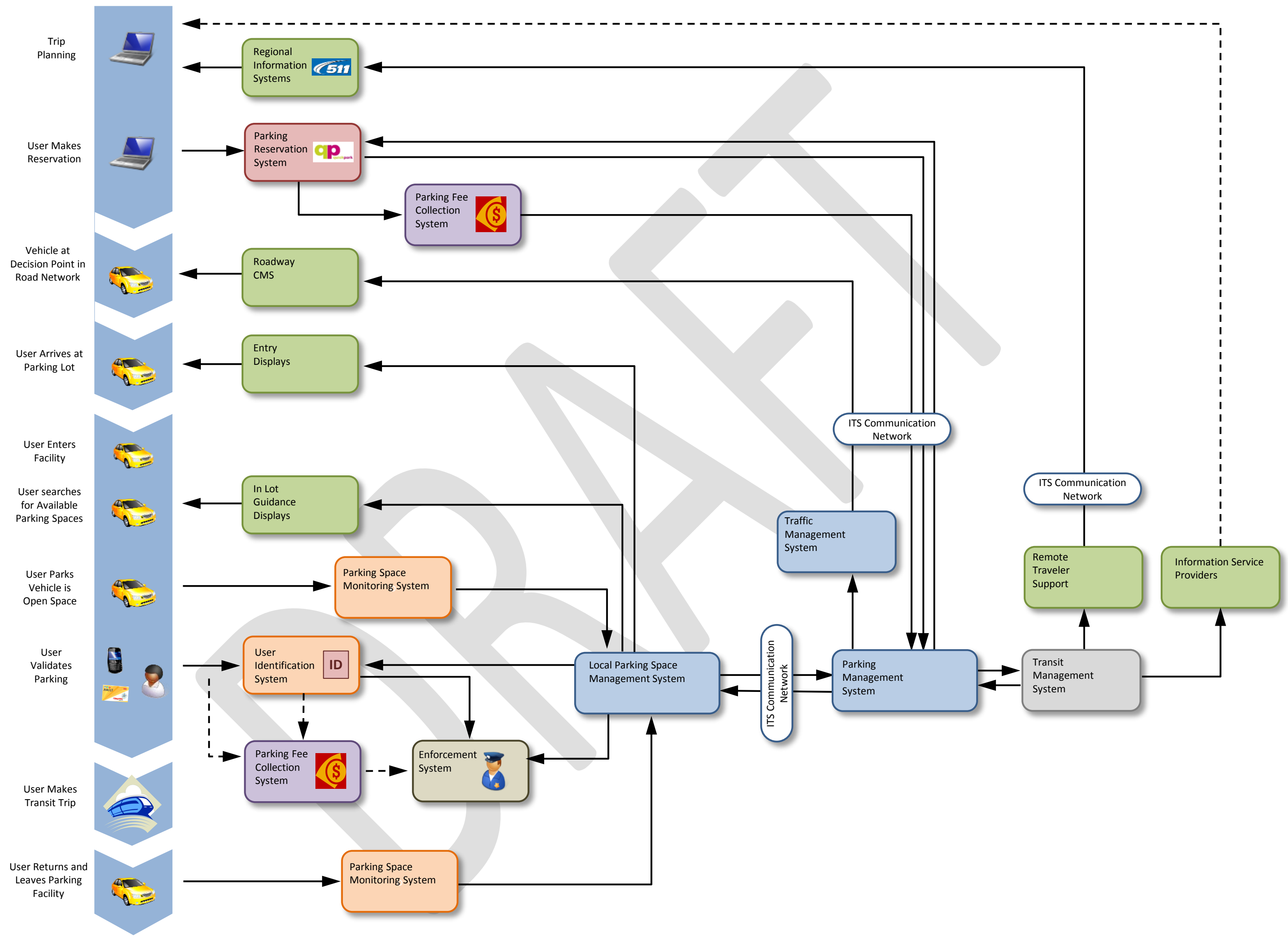

Figure 17 – Key Interactions for System Fully Integrated with Regional ITS Architecture

through online services offered by private information service providers who also retrieve parking information and fee data from the ITS Transit Management System. In this case, though, information is retrieved through Information Provider Service portals and disseminated through private communication networks.

2. Travelers assessing that parking availability may be an issue at their intended time of travel may elect to reserve a parking space prior to starting their trip. To do so, they must access a website operated by ParkingCarma providing a user-friendly interface with the central Inventory Management module, either directly or through links placed on the regional 511 website or websites of transit agencies. Once on the website, travelers would indicate for which station, day, and time they wish to place a reservation. The Reservation module would then check whether a space is available and what the fee is for the space, and then display this information onscreen. Individuals who wish to proceed with a reservation are then invited to log in to their Smart Parking account to complete the reservation. After logging in and specifying which vehicle they are planning to use, a reservation request tied to the identified vehicle is created and sent to the Inventory Management module. Following confirmation that a space can be reserved, the parking fee is automatically debited from the user's COMPASS account or credit card linked to his user profile, followed by the issuance of a reservation ticket clearly identifying a confirmation number, the vehicle to be parked, the parking facility for which the reservation was made, and the day and time of the reservation. Individuals without an existing Smart Parking account are first invited to create a new account before proceeding with the reservation. Individuals who opt to not create a new account are then offered the choice to secure instead a reservation by providing an existing COMPASS smart card or credit card number, in addition to information describing the vehicle they will use. Upon completion, all reservations and fee payment transactions are logged by the Parking Transaction and Payment module for future management and reporting tasks.

3. A new reservation triggers the Inventory Management module to update the number of parking spaces that can be reserved. Notifications of changes in the number of available spaces are then sent to the regional 511 and ParkingCarma websites, as well as other information providers displaying parking availability information.

4. At key decision points along the regional road network, CMSs inform travelers about the number of non-reserved spaces still available at nearby COASTER stations. This information is sent to the agencies operating the CMSs (Caltrans, San Diego County Department of Public Works) by the Inventory Management module via the IMTMS network. It is provided to help travelers without a reservation confirm that there is still space available at their intended destination and, if not space remains available, help them determine at which alternate stations parking is still available. Travelers with a reservation would not need to pay attention to this information as long as they are expected to reach the parking facility where they hold a reservation during the validity period of their reservation.

5. Upon reaching a parking facility, signs located at or near the entrances would inform motorists wishing to enter whether spaces are still available within. In the absence of available space, a motorist without reservation may then elect to seek parking elsewhere. Similar to the information displayed on roadside signs, motorists with a reservation could ignore the availability information if they reach the facility within the validity period of their reservation, as they would already have a guaranteed parking space available.

6. After entering the facility, motorists are guided to an open space by CMSs located at the entrance of each aisle. These signs may show parking availability by displaying a green arrow or the total number of open space on the aisle. To account for the fact that motorists with and without a reservation may need to look for parking spaces in different areas within a parking facility, specific directions are provided for patrons with and without a reservation.

7. After finding an open space, motorists would park their vehicle in the open stall. A sensor within the stall would then detect the vehicle and change its status from “open” to “occupied”. This change in status results in a “Parking Event Record" being created and sent to the Inventory Management module. A vehicle moving into a reserved parking space would not trigger an update of the number of open spaces available displayed on traveler information outlets. Only parking events affecting the supply on non-reserved spaces would trigger an update. Each time a non-reserved space becomes occupied, the Inventory Management module would update the CMSs located at the entrance of the corresponding facility and, if needed, the guidance signs within the facility. Parking availability updates would also be sent to CMSs operated by Caltrans along I-5, signs operated by the San Diego County Department of Public Works along regional arterials, and regional 511 traveler information system via the IMTMS network.

8. After having parked their vehicle, motorists proceed to validate their parking. Only individuals without a reservation pay the parking fee at this time. Users with reservation only need to validate their parking since they pay the parking fee when they make their reservation. All facility patrons validate their parking by entering the number of the parking stall where they parked at a validation kiosk on their way out of the facility. Reservation holders identify themselves by simply scanning their COMPASS smart card. Registered Smart Parking users without a reservation may also scan their COMPASS card to have the parking fee automatically debited from their user account. Finally, users without a COMPASS card are provided with the option to use cash or a credit card to pay for parking. Upon completion, all validation and parking fee payment transactions are logged by the Parking Transaction and Payment system for future management, enforcement, and reporting tasks.

9. Upon returning, travelers simply walk to their vehicle and drive away. When the vehicle sensor in the parking stall detects the space being vacated, it sends a “Departure Record” to the Inventory Management module indicating the time at which the parking space became available. Reception of these departure records then triggers the Inventory Management module to update the list of open parking spaces and/or spaces available for reservation. Updated parking availability information is subsequently sent to the CMSs located at the entrance of the facility and to the guidance signs within the facility. Information is also sent to CMSs operated by Caltrans along I-5, signs located along urban arterials operated by the San Diego County Department of Public Works, and regional 511 traveler information system via the IMTMS network.

10. Throughout the day, the Inventory Management module maintains a list of occupied parking stalls and provides this list upon request to the parking enforcement officers patrolling each parking facility with PDAs. For each stall, the list would indicate whether a vehicle is being sensed occupying it and whether a parking fee or validation has been registered for the space.

8.5. FULLY INTEGRATED PARKING MANAGEMENT SYSTEM WITH VARIABLE PRICING

This scenario is identical to the one presented in Section 8.4, except for the addition of a module dynamically assessing the price for parking based on space availability. The specific capabilities assumed in this scenario include:

- Ability to monitor in real time parking space use at each facility.
- Ability to guide motorists to open parking spaces within parking facilities.
- Displaying of real-time parking availability and parking fee data on CMSs located at key decision points along Interstate 5, which runs parallel to the COASTER rail line, as well as along key urban arterials bringing traffic to COASTER stations.
- Ability for travelers to obtain real-time parking availability and fees from online traveler information services (San Diego 511, ParkingCarma).
- Ability for travelers to reserve a parking space at a given facility for a given day and time using online traveler information services (San Diego 511, ParkingCarma).
- Ability to automatically adjust up or down the price charged for parking based on availability of parking spaces and observed parking demand.
- Ability for registered Smart Parking users to have the $1 non-reserved daily parking fee or $2 reserved parking fee automatically debited from their COMPASS smart card account.

The primary goals of the Smart Parking system considered here are to:

- Help reduce unnecessary traffic within parking facilities by informing travelers whether open spaces are still available and where such spaces may be.
- Help reduce unnecessary trips to parking facilities that may already be full or nearing capacity by providing travelers with the ability to obtain up-to-the-minute parking availability information prior to reaching a parking facility.
- Help increase the demand for parking at underutilized facilities by the dissemination of information highlighting space availability.
- Enable travelers who wish to do so to reserve a parking space ahead of time at one of the COASTER park-and-ride lots.

Figure 18 illustrates the various system elements considered:

- Separation of parking lot into reserved and non-reserved spaces
- Individual parking space sensors.
- Numbering of parking stalls, to allow the unique identification of each parking space.
- CMS at entrance of facility indicating how many non-reserved spaces are available and the parking fee charged for these spaces.
- CMSs at the start of each aisle indicating how many parking spaces are open within the aisle.
- CMSs along nearby Interstate 5 indicating the number of non-reserved parking spaces available at nearby stations and the parking fee charged (operated by Caltrans).
- CMSs installed along arterials leading to the parking facilities indicating the number of non-reserved parking spaces available at nearby stations and the fee charged for these spaces (operated by the San Diego County Department of Public Works).
- Process to disseminate parking availability information to regional traveler information services (San Diego 511, transit agency website).
- Interface with an internet-based parking reservation system operated by ParkingCarma.

- COMPASS smart card readers placed at key locations within each parking facility to enable registered users to pay the $1 daily fee charged for non-reserved parking spaces.
- Payment machines accepting cash and credit/debit cards placed at key locations within each parking facility to enable non-registered users to pay for parking (may be combined with the COMPASS smart card readers).
- Optional base station within each parking facility used to manage the data coming in and out of each facility.
- Central computer server providing system-wide data management and reporting capabilities.
- Module determining parking fees based on information about available parking prices provided by the Smart Parking management system.

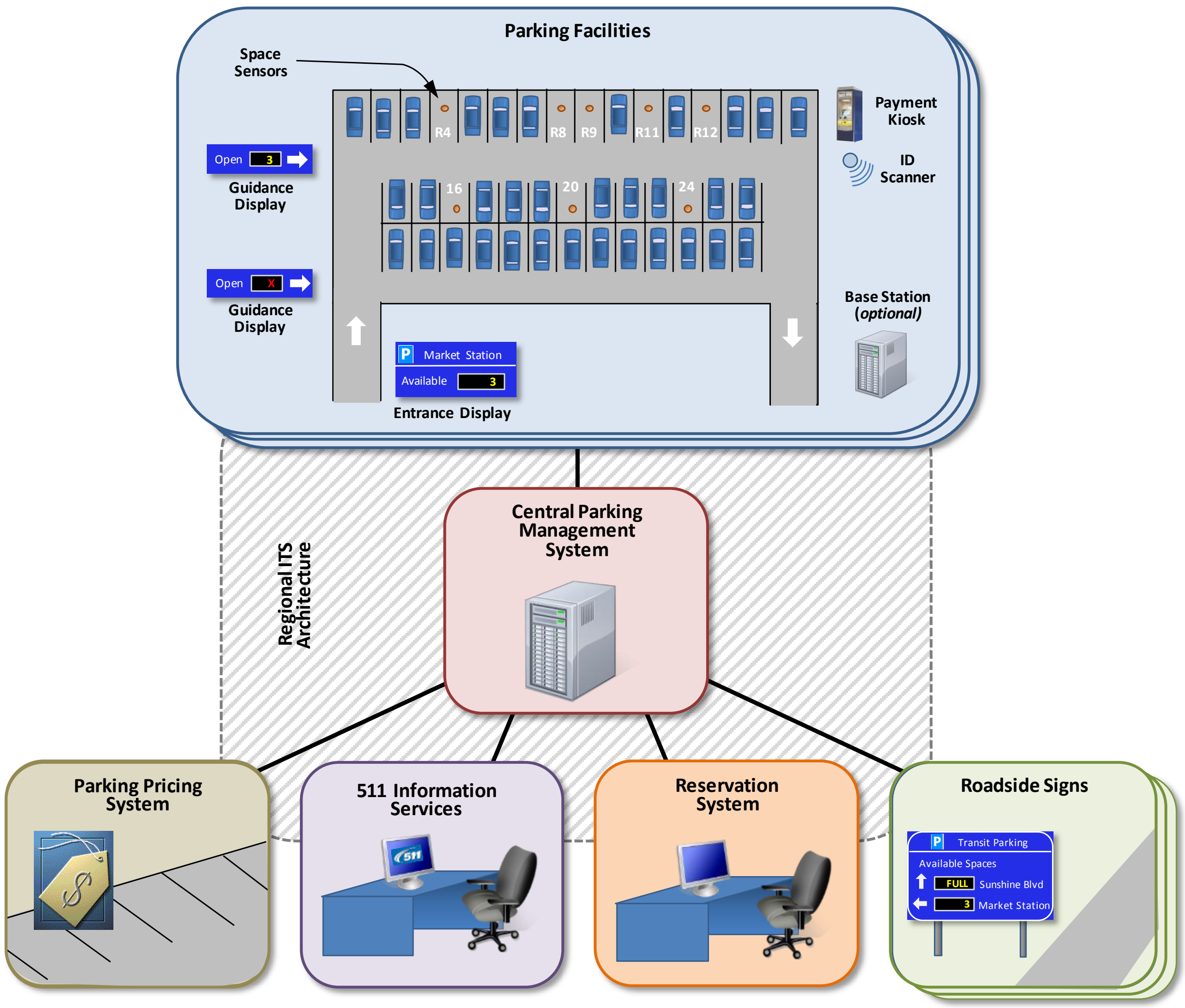

Figure 18 – Smart Parking System Fully Integrated with Regional ITS System with Variable Pricing

For this scenario, the primary participants are:

- **Parking lot users** – Individuals who seek to board a COASTER train and need to park their vehicle at one of the transit stations.

- **North County Transit District (NCTD) agency** – Transit agency operating the COASTER commuter rail system and responsible for managing the park-and-ride lots at each rail station. The agency may also be responsible for displaying parking availability information on its website.
- **California Department of Transportation (Caltrans)** – Agency responsible for managing traffic along interstates and state highways and operating CMSs installed along these roadways.
- **San Diego County Department of Public Works** – Agency responsible for managing traffic along urban arterials in San Diego County and which would be responsible for operating CMSs installed along these roadways.
- **San Diego Association of Governments (SANDAG)** – Regional planning agency responsible for operating the regional 511 traveler information system used to disseminate parking availability information. In this scenario, the 511 system is also used to enable travelers to place parking reservations in addition to the service offered by ParkingCarma.
- **ParkingCarma** – Operator of the Smart Parking reservation system. Responsible for disseminating parking availability data, managing reservations, and collecting parking fees.
- **Parking enforcement staff** – Staff from the transit agency, local police departments, or contracted firms tasked with enforcing parking rules.

Figure 19 illustrates how the Smart Parking system would be used to manage the available supply of parking spaces, provide advanced availability information, enable the reservation of parking spaces, facilitate the payment of parking fees, and ensure that enacted parking rules are respected. For this scenario, key events include the following:

1. Before initiating a trip, travelers consult SANDAG's 511 website or ParkingCarma's website to assess parking availability and parking fees at the COASTER station where they wish to park. Both websites display information provided by the Smart Parking's central Inventory Management module and disseminated via the IMTMS network through an interface with the ITS Transit Management System. It is also possible for the data to reach prospective travelers through online services offered by private information service providers, who also retrieve parking information and fee data from the ITS Transit Management System. In this case, though, information is retrieved through Information Provider Service portals and disseminated via private communication networks.

2. Travelers assessing that parking availability may be an issue at their intended time of travel may elect to reserve a parking space prior to starting their trip. To do so, they must access a website operated by ParkingCarma providing a user-friendly interface with the central Inventory Management module, either directly or through links placed on the regional 511 website or websites of transit agencies. Once on the website, travelers would indicate for which station, day, and time they wish to place a reservation. The reservation system would then check whether a space is available and what the fee is for the space, and then display this information onscreen. Individuals who wish to proceed with a reservation are then invited to log in to their Smart Parking account to complete the reservation. After logging in and specifying which vehicle they are planning to use, a reservation request tied to the identified vehicle is created and sent to the Inventory Management module. Following confirmation that a space can be reserved, the parking fee is automatically debited from the user's COMPASS account or a credit card linked to his Smart Parking profile. Upon completion of the transaction a reservation

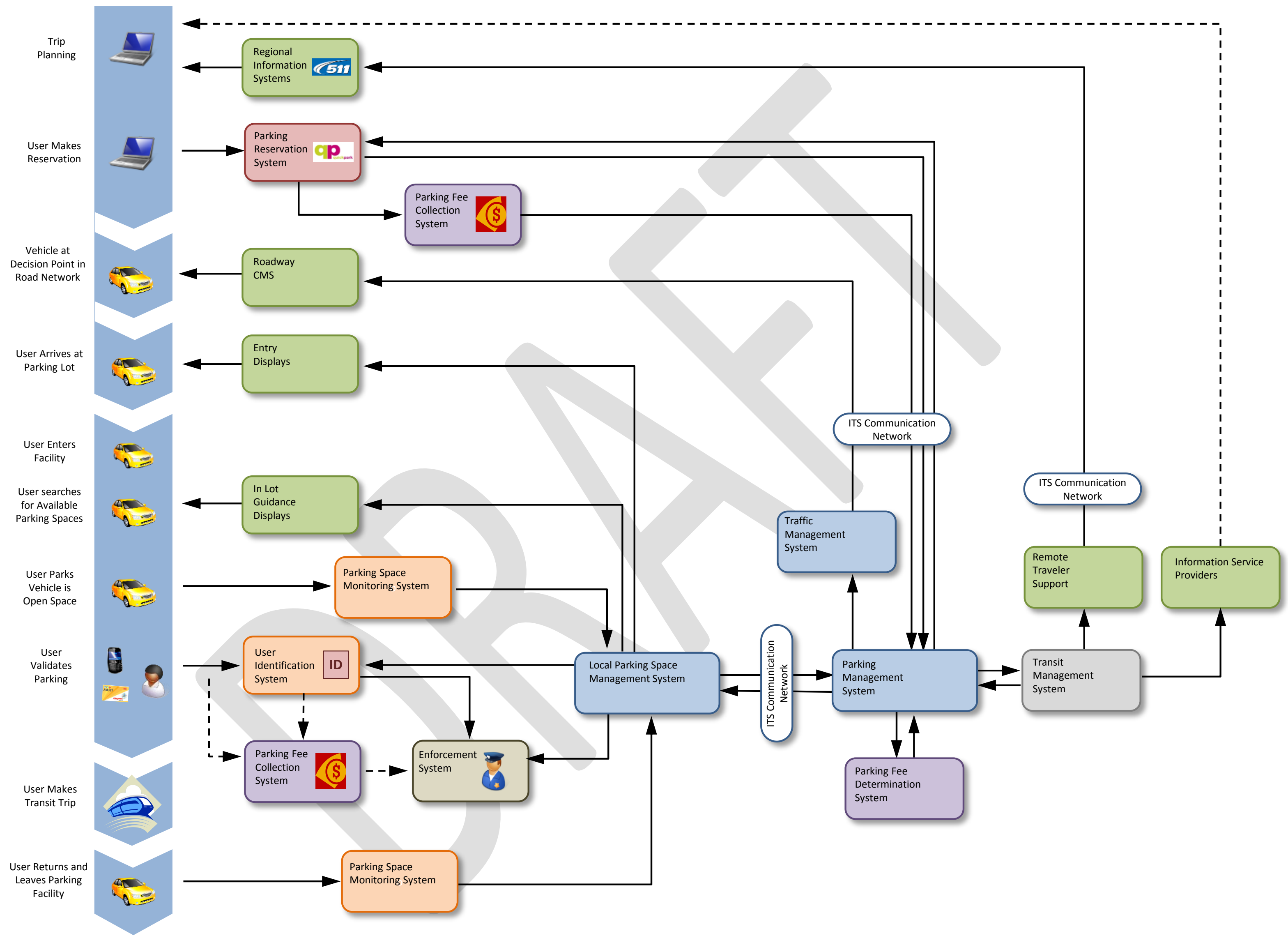

Figure 19 – Key Interactions for System with Advanced Notification and Reservation Option

ticket clearly identifying a confirmation number, the vehicle to be parked, the parking facility for which the reservation is made, and the day and time of the reservation is issued. Individuals without an existing Smart Parking account are first invited to create a new account before proceeding with the reservation. Individuals who opt to not create a new account are then offered the choice to secure instead a reservation by providing an existing COMPASS smart card or credit card number, in addition to information describing the vehicle they will use. Upon completion, all parking reservations and fee payment transactions are logged by the Parking Transaction and Payment system for future management and reporting tasks.

3. A new reservation triggers the Inventory Management module to update the number of parking spaces that can be reserved. Notifications of changes in the number of available spaces are then sent to the regional 511 and ParkingCarma websites, as well as other information providers. New reservations also trigger the Smart Parking Inventory Pricing module to reassess the fee charged for parking reservations. For each facility, the reservation fee to charge is determined based on the number of remaining spaces, ratio of remaining open spaces to parking capacity, rate at which the supply of parking spaces has been diminishing, and/or predictions of near-future parking occupancy rates based on recent turnover rates and historical data.

4. At key decision points along the regional road network, CMSs inform travelers about the number of non-reserved spaces still available at nearby COASTER stations. This information is sent to the agencies operating the CMSs (Caltrans, San Diego County Department of Public Works) by the Inventory Management module via the IMTMS network. It is provided to help travelers without a reservation confirm that there is still space available at their intended destination and, if not space remains available, help them determine at which alternate stations parking is still available. Travelers with a reservation would not need to pay attention to this information as long as they are expected to reach the parking facility where they hold a reservation during the validity period of their reservation.

5. Upon reaching a parking facility, signs located at or near the entrances would inform motorists wishing to enter whether spaces are still available within. In the absence of available space, a motorist without reservation may then elect to seek parking elsewhere. Similar to the information displayed on roadside signs, motorists with a reservation could ignore the availability information if they reach the facility within the validity period of their reservation, as they would already have a guaranteed parking space available.

6. After entering the facility, motorists are guided to an open space by CMSs located at the entrance of each aisle. These signs may show parking availability by displaying a green arrow or the total number of open space on the aisle. To account for the fact that motorists with and without a reservation may need to look for parking spaces in different areas within a parking facility, specific directions are provided for patrons with and without a reservation.

7. After finding an open space, motorists would park their vehicle in the open stall. A sensor within the stall would then detect the vehicle and change its status from “open” to “occupied”. This change in status results in a “Parking Event Record" being created and sent to the Inventory Management module. A vehicle moving into a reserved parking space would not trigger an update of the number of open spaces available displayed on traveler information outlets. Only parking events affecting the supply on non-reserved spaces would trigger an update. Each time a non-reserved space becomes occupied, the Inventory Management module would update the

information displayed on the CMSs at the entrance of the corresponding facility and, if needed, the guidance signs within the facility. Parking availability updates would also be sent to CMSs operated by Caltrans along I-5 and signs operated by the San Diego County Department of Public Works s along regional arterials via the IMTMS network.

8. Following a change in the number of open non-reserved parking spaces, the Smart Parking Inventory Pricing module would reassess the fee charged for the remaining open spaces. This assessment would not be done for vehicles moving into reserved spaces since occupancy of theses space is factored in at the time a reservation is made. Depending on the specific system setup, the price to charge for the remaining open spaces may be assessed based on the number of remaining spaces, the ratio of remaining open spaces to parking capacity, the rate at which the supply of parking spaces has been diminishing, and/or predictions of near-future parking occupancy rates based on turnover rates and historical data.

9. After having parked their vehicle, motorists proceed to validate their parking. Only individuals without a reservation pay the parking fee at this time. Users with reservation only need to validate their parking since they pay the parking fee when they make their reservation. All facility patrons validate their parking by entering the number of the parking stall where they parked at a validation kiosk on their way out of the facility. Reservation holders identify themselves by simply scanning their COMPASS smart card. Registered Smart Parking users without a reservation may also scan their COMPASS card to have the parking fee automatically debited from their user account. Finally, users without a COMPASS card are provided with the option to use cash or a credit card to pay for parking. Upon completion, all validation and parking fee payment transactions are logged by the Parking Transaction and Payment system for future management, enforcement and reporting tasks.

10. When the vehicle sensor in the parking stall detects the space being vacated, it sends a “Departure Record” to the Inventory Management module indicating the time at which the parking space became available. Reception of these departure records then triggers the Inventory Management module to update the list of open parking spaces and/or spaces available for reservation and the Inventory Pricing module to reassess the price for reserved or non-reserved parking spaces. Updated parking availability and pricing information is subsequently sent to the CMSs located at the entrance of the facility and guidance signs within the facility. Information is also sent to CMSs operated by Caltrans along I-5, signs located along urban arterials operated by the San Diego County Department of Public Works, and regional 511 traveler information systems via the IMTMS network.

11. Throughout the day, the Inventory Management module maintains a list of occupied parking stalls and provides this list upon request to the parking enforcement officers patrolling each parking facility with PDAs. For each stall, the list would indicate whether a vehicle is being sensed occupying it and whether a parking fee or validation has been registered for the space.

9. SUMMARY OF IMPACTS

This section provides a summary of potential system impacts, performance metrics that could be used to assess the success of a Smart Parking system, and elements that may constrain the development of such systems.

9.1. SUMMARY OF POTENTIAL IMPROVEMENTS

As previously noted, Smart Parking systems have the potential to provide significant improvements in the management and park-and-ride facilities. These systems have the potential to:

- Provide parking lot operators with the ability to monitor parking lot utilization in real time.
- Provide parking lot operators with a rich source of data that could be used to analyze parking activities.
- Provide travelers with advanced information about parking availability, through the use of roadside CMSs and/or traveler information websites.
- Save travelers unnecessary trips to parking facilities where no parking space remains available.
- Increase parking availability for transit riders by reducing, if not eliminating, unauthorized park-and-ride lot utilization by non-transit users.
- Increase parking availability on streets surrounding park-and-ride facilities that frequently reach their capacity through a reduction of spillover effects.
- Provide a mechanism to better balance the demand for parking across multiple facilities by enticing motorists traveling to a parking facility reaching capacity to seek parking at an alternate location.
- Increase utilization of, and potentially revenue collection from, underused parking facilities by better informing travelers when and where parking is available.
- Reduce accident risks within parking facilities. This is a result of a reduction of the number of unnecessary trips to full parking facilities. However, some systems may also contribute to this effect by providing motorists with dynamic guidance to open parking spaces within a given facility.
- Provide travelers with the ability to reserve a parking space ahead of time to guarantee that a parking space is available at the time of a projected trip.
- Provide parking lot operators with the tools to develop more refined parking management strategies, including the ability to dynamically adjust parking prices based on available supply, turnaround and other elements.
- Implementation of more cost effective parking transaction methods, such as paying parking fees using smart cards or other electronic identification technologies.
- Implement more effective parking enforcement methods.
- Integrate the payment fees with the same system used for paying transit fares.
- Integrate parking management functions within a regional ITS data collection system.

- Increase the positive perception of the park-and-ride service offered by transit agencies.
- Reduce environmental impacts of transit activities by reducing the number of unnecessary trips to full parking lots and circling activities within parking lots.

9.2. POTENTIAL SYSTEM METRICS

Success of Smart Parking systems could be measured in multiple ways. Key metrics that may be used to assess system impacts include:

- Reduction in amount of time that a given parking facility is completely full.
- Increase in utilization ration of individual parking facilities.
- Increase in average utilization ratio across all managed facilities.
- Increase in transit ridership from stations adjacent to park-and-ride lots.
- Increase in overall parking revenues.
- Increase in parking space turnaround rate.
- Reduced traffic within parking facilities.
- Reduced accidents/conflicts within parking facilities.

9.3. DEVELOPMENT CONSTRAINTS

While Smart Parking systems only rely on existing technologies, some elements may constrain the ability of a transit agency or parking lot operator to deploy an envisioned system. Among the most prevalent constraints are:

- Budget constraints may prevent investments in new technologies that are central to the effectiveness of Smart Parking systems.
- The imposition of parking fees at facilities where parking is currently free may not be well accepted by motorists and create some political backlash, particularly if the proposed fees are substantial increases. The implementation of variable parking pricing schemes may be considered a political risk due to the equity issues raised by such schemes.
- Some system elements may require cooperation from other agencies or entities. Without such cooperation, some system elements may not be fully realized.

10. REFERENCED DOCUMENTS

The following documents are referenced throughout the system descriptions that follow:

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APPENDIX A: COST-BENEFIT ANALYSIS

Smart Parking systems generally seek to improve management of the existing supply of park-and-ride spaces at transit stations through the provision of real-time parking availability information to potential transit customers. The extent to which Smart Parking systems will truly be beneficial will depend on their ability to generate benefits to system stakeholders, primarily parking lot users and operators, exceeding the deployment and operating costs of these systems.

The potential usefulness of a proposed Smart Parking system can be gauged by conducting a break-even analysis, i.e., by attempting to determine the minimum number of people who would need to be affected by a system to allow its expected deployment and operational costs to be compensated by its anticipated benefits. To perform such an analysis, both a reasonable cost model and reasonable benefit model must be available. The following subsections detail elements of a benefit/cost evaluation methodology that can be used to evaluate the potential benefits of a proposed Smart Parking system. A partial application of the methodology to a case study is also provided. Elements described in the following subsections include:

- Evaluation scenarios
- Underlying assumptions
- Cost elements
- Benefits estimation model
- Case study: Implementation of Smart Parking at six COASTER stations along the I-5 corridor in the San Diego metropolitan area

A.1. EVALUATION SCENARIOS

A-1. Because of the nature of Smart Parking projects, two different scenarios must be considered for a cost/benefit analysis:

- **Scenario 1** – Park-and-ride lots where the demand for parking routinely exceeds the number of spaces available
- **Scenario 2** – Park-and-ride lots where the demand for parking is well below capacity

The above two scenarios must be considered due to the differing objectives of Smart Parking systems in each case. In the first scenario, the objective is to reduce the demand for parking to a point where it could be accommodated by the existing supply of parking spaces. In the second scenario the opposite objective exists: the goal is to increase parking lot utilization by enticing more travelers to use transit services to reach their destination.

A.2. ASSUMPTIONS

The benefit/cost analysis conducted in this section is based on the following general assumptions:

- **Actors** – The two main actors are individuals commuting from home to work (consumers) and the transit agency offering a travel service to the commuters (producer). Consumers are assumed to be regular commuters, i.e., individuals who commute on average 20 times per month. This number of trips per month is just a multiplier within the model. If it is determined that existing or new users commute less regularly, the analysis must then simply consider that more users must be attracted by a Smart Parking system for the deployment and operation of such a system to break-even.

- **Parking supply** – The supply of parking spaces is assumed to be fixed, i.e., not affected by a change in the price of parking. The analysis does not entertain the possibility of increasing the size of parking lots or their capacity in any way.
- **Initial parking price** – The reference scenario is a situation in which parking is initially available at no cost to transit riders. Such a situation corresponds to what prevails at many park-and-ride stations across the country.
- **Parking price increase** – Smart Parking projects usually involve some sort of price increase with respect to a given reference situation. In the analysis, new parking fees are implemented as an attempt to (1) distribute surplus between consumers and producer (the higher the price, the greater the producer surplus and the smaller the consumer surplus) and (2) influence how many new users will be attracted to the system (elasticity of demand with respect to price).
- **Demand elasticity** – Because the primary concern of the analysis is to determine the number of persons who need to be affected by a proposed system to break even, the effect of price on customer behavior is ignored.

A.3. COST ELEMENTS

Cost elements for the evaluation of a Smart Parking system cover three primary categories:

- System implementation
- System operations and maintenance
- Traveler costs

The breakdown of costs associated with system implementation leads to the following categories of cost elements based on the nature of the tools or activities associated with each one of them:

1. **Engineering Costs** – Costs for any engineering design, consultancy or contracting needed for the launch or implementation of a particular project. This cost category includes both fixed and recurring cost components. Fixed elements include costs associated with the development of initial engineering plans prior to implementation of the project, while recurring costs typically relate to the continuous monitoring, reviewing, and evaluation of a project implementation.
2. **Construction and Infrastructure Costs** – Costs for construction activities needed to build a new parking facility or to modify existing infrastructures. Most cost items in this category can be classified as fixed/initial implementation costs.
3. **ITS Tools** – Costs for the purchase, installation, and integration of ITS technologies supporting desired system functionalities. This category includes potential costs for deployment of vehicle sensors, electronic identification devices, and/or CMSs. The magnitude of costs associated with this category is likely to vary based on the degree of advancement or innovation associated with the proposed Smart Parking system.
4. **Information Technologies** – Costs needed for the deployment of communication capabilities and computer systems supporting the operation of the Smart Parking systems. Elements in this category include costs for the purchase and installation of necessary hardware, integration of

data processes among various system components, and the development of suitable user interfaces.

5. **Software Licenses** – Costs for the initial purchase of licenses for the use of proprietary software tools developed by third-party vendors, which support parking management functions or the operations of various Smart Parking system components.
6. **Training** – Cost for the training of personnel that will be tasked with the operation and maintenance of the system.
7. **Marketing/Public Outreach** – Costs for marketing and public outreach campaigns that may be conducted following the launch of a Smart Parking system to inform the traveling public of the new features provided by the system, highlight system benefits, and entice desired behavioral changes.

System operations and maintenance costs include yearly or periodic expenses necessary to ensure the continuing operation of Smart Parking systems. Typical operations and maintenance cost categories include:

1. **Infrastructure Maintenance** – Annual or periodically recurring costs incurred to ensure the health and safety of parking infrastructures.
2. **ITS Tools** – Costs associated with the maintenance and periodic upgrade of ITS tools.
3. **Information Technologies** – Recurring charges for the lease or operation of communication lines or wireless channels, maintenance and upgrade of computer systems, and necessary upgrades of user interfaces.
4. **Software Licenses** – Costs of annual maintenance fees associated with software licenses. These fees typically provide software users access to technical support and, depending on the particularities of each license, the ability to receive software updates when fixes or new versions are released.
5. **Personnel** – Costs associated with the employment of individuals responsible for the operation and maintenance of the Smart Parking system, as well as customer service functions.
6. **Enforcement** – Costs associated with the employment of individuals or contracting of external firms for the enforcement of parking rules.
7. **Marketing/Public Outreach** – Costs for the execution of periodic marketing campaign designed to boost awareness and utilization of the system.

Smart Parking systems should be evaluated not solely based on their deployment, operations and maintenance costs, but also on the benefits they provide to parking lot users. In this context, system costs should also include the impacts that such systems may have on the travel costs incurred by travelers. These costs typically include:

1. **Vehicle operating Costs** – Costs associated with the operation of a motor vehicle. These include costs associated with fuel consumption and various non-fuel vehicle operating costs, such as vehicle wear-and-tear and depreciation.
2. **Parking Costs** – Fees that must be paid for the privilege of parking at a given location.
3. **Transit Fares** – Costs associated with trips made by bus, commuter rail, or some other public transport vehicle.

4. **Travel Time** – Value of the time spent traveling from one location to another.
5. **Environmental Effects** – Value associated with the release of air pollutants by motor vehicles.

A.4. BENEFITS ANALYSIS MODEL

The potential benefits provided by Smart Parking systems can be evaluated using macroeconomic principles. Benefits to parking lot users (customers) and parking lot operators (producers) can be assessed by analyzing changes in the supply and demand for parking resulting from the implementation of a Smart Parking system, and using the concepts of consumer surplus and producer surplus as indicators of potential system benefits.

A.4.1. Underlying Concepts

The analysis uses the two following macro-economic concepts to assess the benefits that can be derived from Smart Parking systems:

- **Consumer Surplus** – Consumer surplus measures the benefits that consumers derive from an exchange of goods and services. It is essentially the difference between the maximum price that consumers are willing and able to pay for a good or service and the price they actually pay for it.
- **Producer Surplus** – Producer surplus measures the benefit that a producer receives for selling services in the market. This parameter essentially is a measure of the difference from the market price that was received for an item or service and the minimum price for which the producer would have been prepared to supply the good or service to the market.

Figure A-1 illustrates how consumer surplus and producer surplus are estimated from a typical demand-supply graph. Consumer surplus is represented by the area below the demand curve and above the market price for a good or service, while producer surplus is represented by the area above the supply curve and below the market price for the good or service.

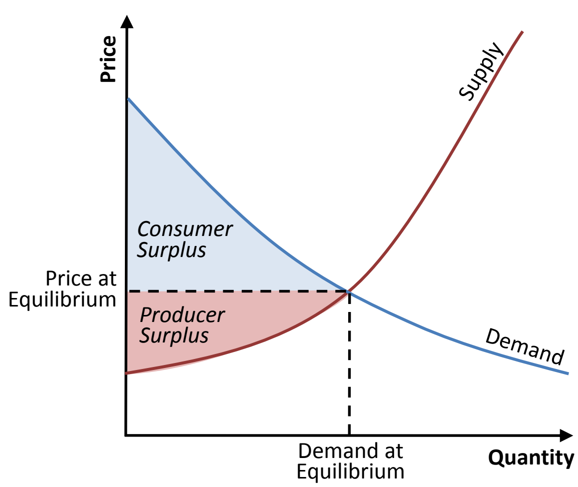
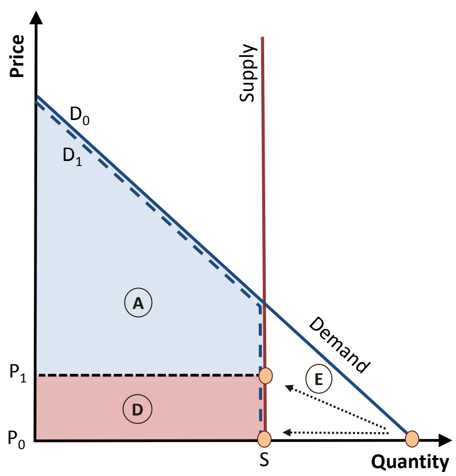


Figure A-1 – Consumer Surplus and Producer Surplus Concepts

A.4.2. Parking Lot at Capacity Scenario

This scenario assumes that a parking lot reaches capacity relatively early in the day prior to the implementation of a Smart Parking system. This results in a number of individuals traveling to the parking lot only to find it full. These individuals may then subsequently attempt to find parking at another station or simply elect to drive directly to their work location.

Figure A-2 shows from a demand-supply perspective the effect that a Smart Parking system would have on a facility with excess demand for parking. The line $\mathbf{D_0}$ represents the original demand function, the vertical line S represents the fixed supply of parking spaces, while the horizontal lines P_0 and P_1 represent the fees charged for parking before and after the introduction of Smart Parking, respectively. The existence of an excess demand for parking is indicated by the fact that the demand function $\mathbf{D_0}$ meets the horizontal line representing the current parking price P_0 to the right of the supply function S.



$P_1 > P_0$ (P_0 = \$0.00)

Parameter	Before (P_0, S)	After (P_1, S)	Change
Consumer Surplus	A + D	A	-D
Producer Surplus	Ø	D	+D
		Net Change	Ø (-Externalities)

$P_1 = P_0$ = \$0.00

Parameter	Before (P_0, S)	After (P_1, S)	Change
Consumer Surplus	A + D	A + D	Ø
Producer Surplus	Ø	Ø	Ø
		Net Change	Ø (-Externalities)

Figure A-2 – Consumer and Producer Surplus Analysis: Parking Lot at Capacity

The illustrated analysis assumes that parking is initially free (P_0 = \$0.00). This is a situation characterizing many transit park-and-ride lots. For this situation, the consumer surplus is the area delimited by the demand curve D_0 and the initial parking price P_0. This corresponds to the area comprised of sectors A and D. The consumer surplus is represented by the area between the supply curve S and initial parking price P_0. Since parking is initially free, there is in this case no consumer surplus (P_0 x S = 0) before the implementation of Smart Parking, i.e., no benefit to parking lot operators.

In systems in which supply could be adjusted, an excess demand would usually lead producers to increase the quantity of goods offered (here, parking spaces) and establish a new equilibrium between demand and supply. However, since supply is assumed fixed, no such readjustment is possible. The excess demand is thus simply wasted and not considered in the consumer or producer surplus analysis.

The goal of Smart Parking systems is to affect the parking demand so that it does not exceed the available supply of parking. This goal is represented by the dotted line D_1, which caps the demand at the supply line S. This change is ideally implemented by informing travelers when parking spaces are no longer available. Upon receiving this information, travelers faced with the potential that no parking space maybe available at their intended park-and-ride destination will then either attempt to find parking at another facility or simply elect to drive to their final destination.

Assuming a nominal change in parking price from P_0 to P_1 (e.g., from \$0 to \$1 per day), the consumer surplus after Smart Parking system deployment is given by the area between the demand curve and the horizontal line representing the new parking price P_1. This corresponds to sector A. As indicated earlier, the analysis takes a short-term view and assumes that the deployment of a Smart Parking system does not change the overall demand for travel. Individuals who elect to switch to a park-and-ride option are simply removed from the pool of individuals electing to drive to their destination.

The producer surplus following the implementation of Smart Parking is determined by the area between the supply curve and the horizontal line representing the new parking price P_1. This area corresponds to sector D. In this case, the producer surplus can then simply be calculated by multiplying the change in parking fee by the number vehicles using park-and-ride lots following system implementation.

As shown in the tables next to the demand-supply graph, the introduction of Smart Parking results no apparent overall system benefits for scenarios in which demand for parking exceeds capacity. Increases in producer surplus (higher benefits to system operations) are typically compensated by reductions in consumer surplus (reduced benefits to parking lot users). No net change would also be determined if the initial parking price is retained ($P_1 = P_0 = \$0$).

Individuals who elect not to travel to a parking lot because of a lack of available space are not counted as a loss since they were already lost to the system before the Smart Parking implementation. However, indirect benefits may be compiled from the fact that Smart Parking systems enable travelers to avoid unnecessary trips to determine whether parking is available at a given facility. In Figure A-2, the shaded area E can be viewed as representing external costs that existed prior to the Smart Parking implementation, such as time spent, vehicle wear-and-tear, fuel consumption and air pollutant emissions resulting from circling in a parking lot to find an open space or from wasted trips made from nearby freeways to check whether parking spaces may be available. Any reduction in these externalities would thus provide a benefit to the system that should be considered in a benefit/cost analysis.

Table A-1 identifies externalities that can be associated with scenarios involving excess parking demand. For each parameter, the table indicates the stakeholders primarily affected and how the parameter can be estimated. The parameters most likely to be considered include change in vehicle miles traveled (VMT), travel time savings, reduced vehicle operating costs (fuel consumption, wear and tear), and reduced environmental impacts (vehicle emissions). Reduction of stress associated with travel, impacts on the social image of the transit agency, or impacts on accident risks can also be considered. However, estimating these parameters' impacts can be relatively difficult due to the high number of potentially impacting factors or their subjective nature. Only parameters for which reasonably reliable estimates can be obtained should therefore be considered.

The degree to which the externalities can be abated will largely depend on the reliability and the timeliness of the parking information provided to travelers. If information is inaccurate, particularly when a lot is nearing capacity, individuals may still be enticed to travel to a park-and-ride lot under the false perception that some space will still be available. For this scenario, the greatest reduction in externalities would be achieved by minimizing the number of persons unsuccessfully traveling to a park-and-ride lot.

Table A-1 – External Benefits: Parking Lot at Capacity

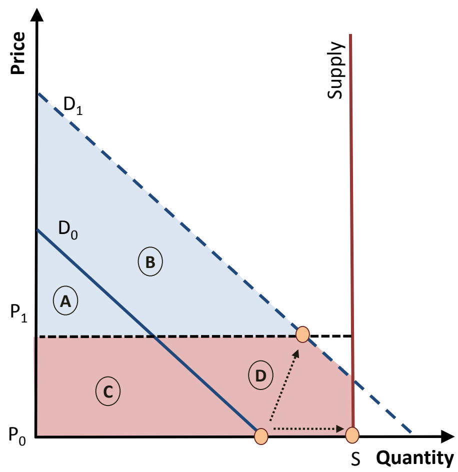
Benefit	Benefit to Whom?	Estimation Method(s)
Reduction in vehicle miles traveled (VMT)	Users	• Distance associated with avoided trips to full parking lots (distance to park-and-ride lot from nearby freeway/highway along path to final destination). • Reduction in circling activities within parking lots (reduction in average distance traveled while searching for a space within a parking lot).
Reduced travel time	Users	• Time savings associated with avoided trips (trip to parking lot and circling within the lot).
Reduced vehicle wear and tear	Users	• Multiply reduction in VMT by a distance-based factor representing average vehicle wear and tear.
Reduced fuel consumption	Users	• Multiply reduction in VMT by distance-based average fuel consumption rate. • Input changes in VMT and average travel speeds into a fuel consumption estimation model.
Reduced pollution from vehicle emissions	Community	• Multiply reduction in VMT by distance-based average vehicle emission rates. • Input changes in VMT and average speed into a fuel consumption estimation model.
Increased traffic safety	Users	• Analysis of accident trends within parking lots and on roads leading to facilities.
Enhanced agency image	Transit agency	• Survey of park-and-ride users, other transit users, and motorists.
Reduced road congestion	Community	• Measurement of changes in traffic volumes and/or average travel times along roadways leading to park-and-ride lots.

A.4.3. Parking Lot below Capacity Scenario

In this scenario, parking is below capacity on a regular basis. Smart Parking systems thus present an opportunity to increase parking lot utilization by attracting more travelers to use transit services. In addition to increased ridership, an increase in new parking users could also provide an increase in revenue for the transit agency if fees are charged for parking.

To evaluate the benefits provided by a Smart Parking system, a model using consumer surplus as the primary indicators of benefits is used. Figure A-3 presents the demand-supply analysis. Similar to Figure A-2, the initial demand for parking is indicated by the line D_0, the demand after introduction of the Smart Parking system by the line D_1, the fixed parking supply by the vertical line S, and the price charged for parking before and after Smart Parking implementation by the horizontal lines P_0 and P_1, respectively. An initial lower-than-capacity demand for parking is represented by the fact that the demand curve D_0 crosses the horizontal line P_0 to the left of the supply line S.

In this scenario, the introduction of Smart Parking is expected to create new demand for parking, but not excess demand. Similar to the previous scenario, it is assumed that the introduction of Smart Parking produces no short-term change in the overall demand for travel. Increases in parking demand are simply the result of a change in preferred travel mode from individuals who would have otherwise traveled by car. In Figure A-3, the new equilibrium that results from the introduction of Smart Parking can be represented by the point marking the intersection of the new demand curve D_1 with the new price P_1. If no parking price increase is imposed, the new equilibrium would then correspond instead to the location where the horizontal line P_0 meets the supply curve S.



$P_1 > P_0$ (P_0 = $0.00)

Parameter	Before (P_0, S)	After (P_1, S)	Change
Consumer Surplus	A + C	A + B	-C + B
Producer Surplus	Ø	C + D	+C + D
		Net Change	+B + D (-Externalities)

$P_1 = P_0$ = $0.00

Parameter	Before (P_0, S)	After (P_1, S)	Change
Consumer Surplus	A + C	A + C + B + D	+B + D
Producer Surplus	Ø	Ø	Ø
		Net Change	+B + D (-Externalities)

Figure A-3 – Consumer and Producer Surplus Analysis: Parking Lot below Capacity

The tables shown in the right side of Figure A-3 indicate that the introduction of Smart Parking systems has positive net impacts on the combined benefits obtained by parking lot users (consumers) and lot operators (producers). Whether the benefits obtained by lot users exceed the benefits obtained by lot operators, or vice versa, will depend on specific factors, particularly the change in parking price.

Estimating changes in consumer surplus for this scenario is relatively hard since an exact calculation requires knowledge of the slope of the demand curve. Where parking is initially offered at no cost, there is no basis for estimating demand elasticity. Elsewhere, the multitude of factors affecting demand elasticity often only allow developing crude estimates of the shape of the demand curve. To circumvent this problem, cost-benefit studies involving demand elasticity effects often use an average willingness-to-pay value to estimate consumer surplus. For park-and-ride facilities, a willingness-to-pay value may be estimated by calculating the cost of driving to a downtown destination and parking there. At a minimum, this estimate should consider travel time and basic vehicle operating costs (fuel consumption, wear-and-tear, vehicle depreciation), as well as the cost of parking at downtown facilities. Other cost elements may also be included if a method exists to quantify them. Once a willingness-to-pay value has been established, consumer surplus may then be estimated by calculating the overall cost savings associated with the park-and-ride option when factoring all driving and transit costs, and by subsequently multiplying the resulting cost differential by the number of users affected.

Similar to the previous scenario, elements external to the demand-supply analysis may produce system benefits. In this case, external benefits primarily stem from reductions in trip costs associated with individuals switching from a drive-only to a park-and-ride option. Table A-2 lists the various external parameters that may be considered, the stakeholders affected, and how each parameter may be estimated. Again, the parameters most likely to be considered are changes in vehicle miles traveled (VMT), travel times, vehicle operating costs (fuel consumption, wear and tear), and environmental impacts (vehicle emissions). Other parameters may also be considered if adequate methods exist to produce reasonable estimates.

Table A-2 – External Benefits: Parking Lot below Capacity

Benefit	Benefit to Whom?	Estimation Method(s)
Reduction in vehicle miles traveled (VMT)	Users	• Differential in distance traveled by car between the drive-only and park-and-ride options.
Reduced travel time	Users	• Differential in origin-to-destination travel times between the drive-only and park-and-ride options (likely to show as benefit for drive-only option, except perhaps along heavily congested corridors).
Reduced fuel consumption	Users	• Multiply reduction in VMT by distance-based average fuel consumption rate. • Input changes in VMT and average travel speeds into a fuel consumption estimation model.
Reduced vehicle wear and tear	Users	• Calculable based on decreased VMT.
Reduced parking cost	Users	• Difference in hourly parking rate between park-and-ride and CBD parking facilities.
Increased traffic safety	Users	• Analysis of accident trends (likely to show negligible impacts given the small overall magnitude of changes in traffic along traffic corridors).
Reduced pollution from vehicle emissions	Community	• Multiply reduction in VMT by distance-based average vehicle emission rates. • Input changes in VMT and average speed into a fuel consumption estimation model.
Reduced road congestion	Community	• Change in intersection flow counts, roadway average travel times along major corridors.
Enhanced agency image	Transit agency	• Survey of park-and-ride users, other transit users, and motorists.

A.5. CASE STUDY: COASTER COMMUTER RAIL IN SAN DIEGO

This section presents the result of an analysis that was conducted to determine the potential benefits associated with the implementation of a full-featured Smart Parking system at the six of COASTER commuter rail stations that were part of a pilot partial system deployment in 2008.

A.5.1. Implementation Environment

The COASTER commuter rail is a transit service provided by the North County Transit District (NCTD) to serve the coastal communities north of San Diego. Figure A-4 provides a map of the service. COASTER trains mainly operate during weekday peak periods, with limited weekday midday, Friday evening and Saturday service. Seasonal Sunday service is also provided, as well as special evening service when the San Diego Padres baseball club plays evening home games during the week.

Stations of interest to the analysis are the stations at the north end of the corridor: Oceanside, Carlsbad Village, Carlsbad Poinsettia, Encinitas, Solano Beach and Sorrento Valley. As shown in Figure A-5, these stations are all located along Interstate 5, typically within 1 mile of a freeway exit. Table A-3 further indicates that these stations are set in varying environmental contexts. While some stations are close to a local downtown area, others are not. Residential density around the stations further ranges from low to very high, while employment density ranges from low to medium. Some stations also feature good pedestrian access and connectivity to local transit services, which other do not.

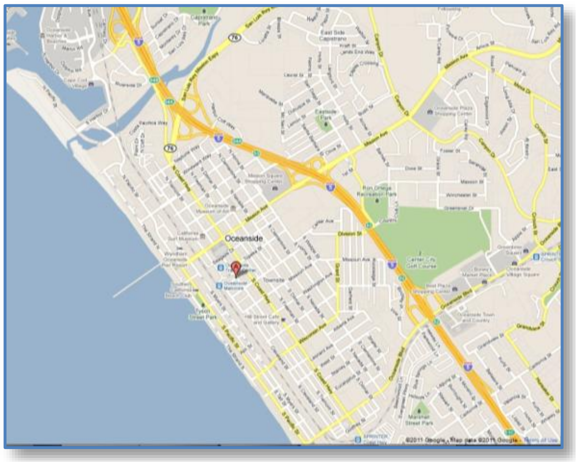
Figure A-4 –COASTER Commuter Rail Line

Table A-3 – Location Characteristics of COASTER Stations

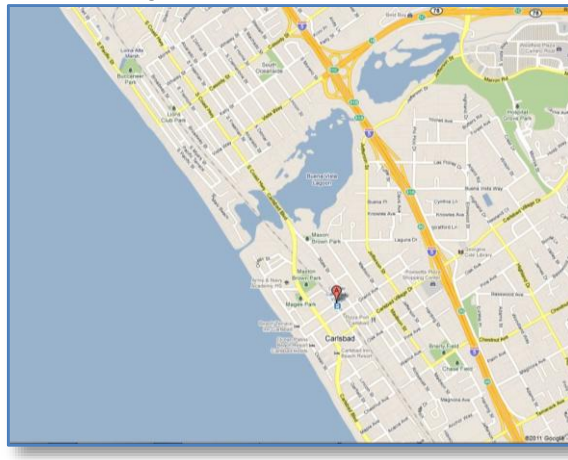
Characteristic	Station					
	Oceanside	**Carlsbad Village**	**Carlsbad Poinsettia**	**Encinitas**	**Solana Beach**	**Sorrento Valley**
Adjacent to downtown	Yes	Yes	No	Yes	Yes	No
Residential density within 1 mile	Medium	Medium	Low-Medium	Medium-High	Low-Medium	Very High
Employment density within 1 mile	Medium	Medium	Low	Medium	Low	Low
Pedestrian Accessibility	Moderate	High	Poor	High	Moderate	Poor
Connectivity to other transit	Very High	Moderate	Low	Moderate	High	Moderate
Other transit available	BREEZE SPRINTER Amtrak Metrolink Greyhound Riverside Transit Agency	BREEZE	BREEZE COASTER Connection	BREEZE	BREEZE Amtrak	BREEZE COASTER Connection MTS Buses

Source: Rodier *et al.*, 2010

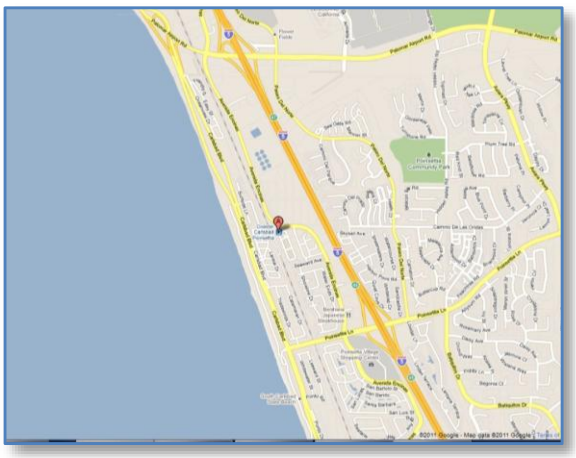
Oceanside



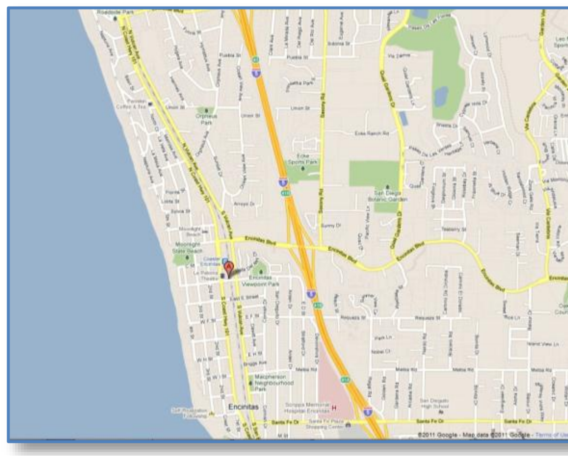
Carlsbad Village



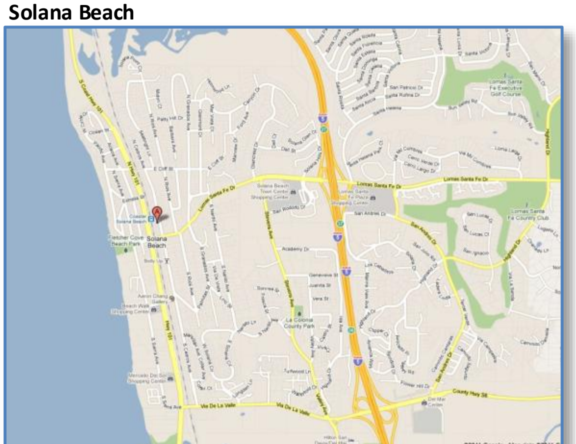
Carlsbad Poinsettia



Encinitas



Solana Beach



Sorrento Valley

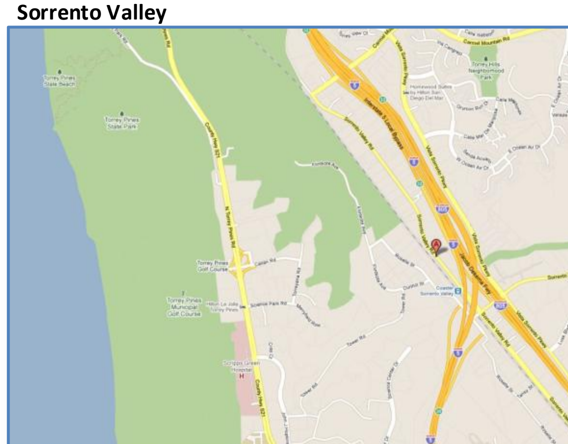


Figure A-5 –COASTER Stations with Pilot Smart Parking Deployments

Table A-4 summarizes the issues that were identified to affect the parking facility associated with each COASTER station in the fall of 2008, before the recession hit and caused a significant drop in overall parking demand. A lack of parking capacity was found to be either an existing problem or a likely near-term issue at all stations. The relative scarcity of parking often resulted in spillover parking activities on nearby streets at three stations. Non-COASTER use and overnight utilization were also identified as common problems, in part due to a lack of enforcement.

Figure A-6 shows the results of an analysis on the utilization of park-and-ride lots at the various COASTER stations that was conducted in late 2007 and early 2008. The analysis indicates that the parking facilities at the Carlsbad Poinsettia and Encinitas stations had utilization rates exceeding their stated capacity. This situation was due to motorists parking their vehicles in unmarked spaces as a result of these lots regularly filling up before 8:00 AM, causing significant difficulty for individuals wishing to take trains running later in the morning. The parking lot at the Carlsbad Village station further had an average occupancy of 95%, which caused IT to periodically become full in late morning. The remaining stations had occupancy rates hovering around 90% and generally did not fill up completely, except during the summer period.

Table A-4 –Identified Problems at COASTER Stations based on 2008 Parking Demand

Station	Overcapacity	Overnight Parking	Non-COASTER Parking	Neighborhood Spillover	Lack of Enforcement
Oceanside		X	X		X
Carlsbad Village	X	X	X	X	X
Carlsbad Poinsettia	X	X	X	X	X
Encinitas	X	X	X	X	X
Solana Beach	X	X	X		X
Sorrento Valley	X	X	X		X

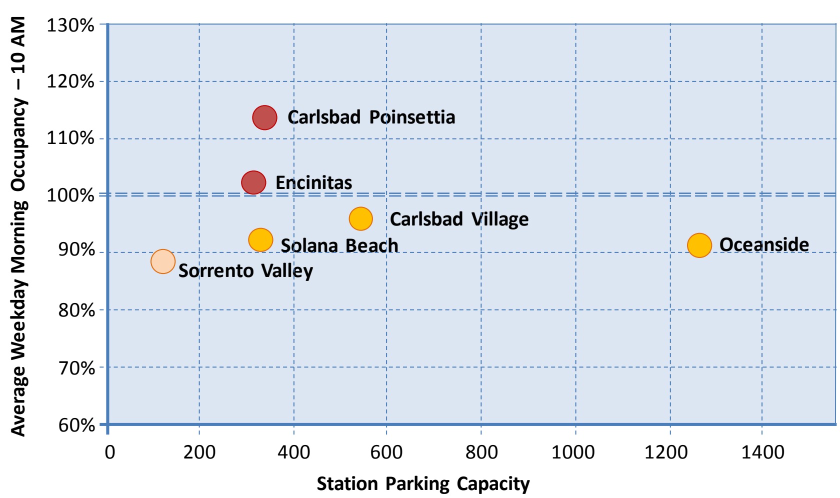


Figure A-6 – 2008 COASTER Park-and-ride Lot Utilization Rates
(Source: Rodier *et al.*, 2010)

Observational analysis further showed that long-term and non-transit users typically occupied between 5% and 60% of parking spaces at the various stations during commute hours. At the Oceanside and Solana Beach stations, the majority of non-COASTER users were found to be daily commuters using

Amtrak or Metro Link transit services. A 2006 study further determined that 48% of individuals parking at Solana Beach were Amtrak riders (Wilson & Company, 2006).

While overnight parking is not technically permitted, most parking lot users were not aware of this policy due to poor signage and lack of enforcement. Some overnight parking was the result of travelers using "station cars". These travelers would keep a car parked at the station to enable them to get from their end station to their destination. Since these vehicles would usually only be parked overnight, they generally had a relatively minor impact on ridership. However, Amtrak riders, airport passengers, and other individuals often parked for multiple days. Long-term and overnight parking activities were an issue at all stations except Carlsbad Village. Overall, these activities were assessed to take away 15% of available COASTER parking spaces. A comparison with an earlier study conducted by SANDAG (SANDAG, 2002) further indicated that overnight parking was a growing problem.

The lack of enforcement at COASTER parking lots along with crowded and restricted street parking were found to encourage use of the parking facilities by individuals not traveling by train. Four COASTER stations are adjacent to a downtown area and had local employees and shoppers regularly parking there. Five stations further lie within a quarter mile of a beach and were frequently used by recreational users, mainly because of the free parking they offered. Field observations also showed non-public transit parking to be a significant issue at Oceanside, Solana Beach and Encinitas. The 2006 parking study mentioned earlier found that 11% of people parking at Solana Beach on a weekday were not using public transit. While the parking lots at Oceanside and Solana Beach usually had excess parking available, these facilities were fast approaching their capacity. At the Encinitas station, which experienced parking overcrowding, observations suggested that non-public transit users with nearby destinations could take between 5% and 10% of the lot's capacity on a typical weekday.

The location of every station within a half-mile of Interstate 5 further enticed commuter vanpools in using the lots as a pickup point. Multiple non-public transit vanpools were observed to make pickups at Oceanside, Carlsbad Poinsettia, Encinitas, and Solana. This affected parking availability as many vanpool riders simply left their car in the COASTER parking lots for the day.

A.5.2. Analysis Parameters

Two separate analyses are conducted: the first analysis looking at the benefits that could be obtained when parking lots are full, and the second at the benefits associated with underutilized lots. In both cases, the analysis focuses on benefits that could be obtained by travelers seeking to travel to the last COASTER station in downtown San Diego. Benefits to system operators and other potential stakeholders are also considered through the macroeconomic analysis principles defined in Section A.4.

Table A-5 and Table A-6 list the parameters used to estimate and monetize system benefits. Specific notes associated with these parameters include:

- The $26.00 daily parking fee for downtown San Diego reflects the average fee charged in 2010.
- The $4.47 per gallon represents the average cost for regular gasoline across California in April 2011.
- The value of time ($12.07), non-fuel vehicle operating cost ($0.25/mile), and costs for individual air pollutants are the life-cycle benefit/cost analysis economic values for 2010 that have been published by the Economic Analysis Branch of the Division of Transportation Planning of

Caltrans. For the air pollutant costs, the values used in the analyses are those published for the Los Angeles/South Coast region.

- Vehicle fuel consumption and emissions rates are estimated using the California Air and Resource Board's EMFAC 2007 model (version 2.3). The model was used to obtain average annual rates for a 2011 fleet of passenger cars operated in the San Diego area.
- Distances and travel times were estimated using Google Maps, without considering traffic congestion effects.

Table A-5 – COASTER Case Study: General Parameters

Parameter	Value
Daily parking fees	
COASTER stations prior to Smart Parking system	$0.00
COASTER stations with Smart Parking system	$1.00
Downtown San Diego	$26.00
Travel time	
Value of time in automobile	$12.07/hr
Value of time in transit vehicle	$12.07/hr
Average speed – Freeways	55.0 mph
Average speed - Local streets	25.0 mph
Vehicle operating costs	
Cost of gasoline	$4.16/gal
Fuel consumption	EMFAC 2007
Vehicle emissions	EMFAC 2007
Non-fuel vehicle operating costs	$0.25/mi
Vehicle emissions costs	
Carbon monoxide (CO)	$135/ton
Carbon dioxide (CO_2)	$34/ton
Nitrogen oxides (NOx)	$55,700/ton
Coarse particulate matter (PM_{10}):	$456,500/ton
Sulfur oxides (SOx):	$171,500/ton
Volatile organic compounds (VOC):	$3,465/ton

Table A-6 – COASTER Case Study: Station Trip Parameters

	Oceanside	Carlsbad Village	Carlsbad Poinsettia	Encinitas	Solana Beach	Sorrento Valley
Distance to downtown San Diego (mi)	37.2	34.0	29.5	25.5	21.2	15.8
Distance from I-5 (mi)	0.9	0.8	1.0	0.8	1.3	1.6
Circling distance within lot (mi)	0.6	0.6	0.7	0.6	0.7	0.35
Average speed on I-5 (mph)	55	55	55	55	55	55
Average speed on local streets (mph)	25	25	25	25	25	25
Average speed in parking lot (mph)	10	10	10	10	10	10
COASTER round-trip transit fare ($)	11.00	11.00	11.00	11.00	11.00	10.00
COASTER travel time to San Diego (min)	61.0	56.0	50.0	44.0	37.0	27

A.5.3. Single Trip Benefits – Parking lots at Capacity

The primary benefits for overcrowded parking lots are linked to the ability of travelers to avoid unnecessary trips to facilities with no available space. As explained in Section A.4.2, the net benefits associated with this situation only include externalities to the macroeconomic analysis since a Smart Parking system only affects individuals who would not park at a COASTER station whether the system is present of not. These externalities include:

- Reduced time spent driving to a parking lot and circling within it to look for an open space.
- Reduced fuel consumption.
- Reduced vehicle emissions.
- Reduced non-fuel vehicle operating costs.

Table A-7 – Benefits Associated with Reducing Unnecessary Trips to Overused COASTER Stations

Station	Travel Time to Parking Lot (min/trip)	Circling Time within Lot (min/trip)	Value of Time ($/trip)	Fuel Costs ($/trip)	Other Vehicle Costs ($/trip)	Net Out-of-pocket Benefits ($/trip)	Vehicle Emissions Costs ($/trip)	Net Trip Benefits ($/trip)
Oceanside	4.3	3.8	1.72	0.56	0.42	2.06	0.08	2.14
Carlsbad	3.8	3.5	1.57	0.51	0.38	1.87	0.07	1.94
Carlsbad Poinsettia	4.8	4.0	1.86	0.61	0.46	2.23	0.09	2.32
Encinitas	3.8	3.5	1.57	0.51	0.38	1.87	0.07	1.94
Solana Beach	6.2	4.0	2.16	0.72	0.56	2.63	0.10	2.73
Sorrento Valley	7.7	2.1	2.07	0.73	0.61	2.59	0.10	2.69
Average	**4.6**	**3.5**	**1.82**	**0.58**	**0.47**	**2.21**	**0.08**	**2.29**

Table A-7 summarizes for each of the COASTER stations the benefits obtained from eliminating unnecessary trips from nearby I-5. Based on the assumptions of Table A-5 and the station characteristics of Table A-6, eliminating such trips would save between 3.8 and 7.7 min in travel time to the station, and between 2.1 and 4.0 min in circling time depending on the station considered. This translates into average travel time and circle time reductions of 4.6 min and 3.5 min respectively, for an overall trip travel time reduction of 8.1 min. When factoring the value of time, fuel consumption and vehicle operating costs, an average out-of-pocket trip cost saving of $2.21 is obtained for each unnecessary trip eliminated, with station-specific benefits ranging between $1.87 and $2.63 per trip. When also considering vehicle emissions costs, which are not normally paid by travelers, an overall system benefit of $2.29 per trip is obtained, with station specific values ranging from $1.94 to $2.73. To break even in this situation, a Smart Parking system must be able to reduce the total number of unnecessary trips made to all stations by an amount that would yield cumulative benefits matching or exceeding the anticipated life-cycle costs of the system over the same period.

A.5.4. Single Trip Benefits – Underutilized Parking Lots

The primary benefits of the Smart Parking systems for underutilized parking lots is the ability to entice motorists to use the COASTER trains to reach downtown San Diego instead of driving. As discussed in Section A.4.3, the net benefits associated with this situation include both operator and user benefits:

- Operator benefits directly result from the ability to collect additional parking and transit revenues. Additional parking revenues may be collected from existing park-and-ride users if parking fees are imposed or increased. Additional parking and transit revenues may also be collected if the system results in increased transit ridership. In the macroeconomic analysis model, these benefits are represented by the producer surplus.
- User benefits result from the ability to reduce their net travel expenditure by switching to transit. These benefits are represented by the consumer surplus. In this case, consumer surplus can be estimated by simply considering the cost differential with the driving and transit options with respect to travel time, fuel consumption, parking, and transit costs.

Similarly to the scenario considering overcrowded facilities, additional benefits are also obtained through factors that do not directly affect parking lot operators or users. In this case, external factors primarily include societal benefits associated with reduced vehicle emissions.

Table A-8 – Benefits Associated with Change from Driving to Riding COASTER Trains

Station	Travel Time (min/trip)	Value of Time ($/trip)	Fuel Costs ($/trip)	Other Vehicle Costs ($/trio)	Downtown Parking Costs ($/trip)	Park-and-ride Fee ($/trip)	Transit Fare ($/trip)	Out-of-Pocket Benefits ($/trip)	Vehicle Emissions ($/trip)	Net Trip Benefits ($/tri)
Oceanside	(47.2)	(10.02)	10.57	12.23	26.00	(1.00)	(11.00)	26.78	1.07	27.85
Carlsbad	(43.3)	(9.19)	9.70	11.22	26.00	(1.00)	(11.00)	25.73	0.98	26.71
Carlsbad Poinsettia	(42.6)	(9.03)	8.21	9.52	26.00	(1.00)	(11.00)	22.70	0.82	23.52
Encinitas	(38.0)	(8.06)	7.12	8.26	26.00	(1.00)	(11.00)	21.32	0.72	22.04
Solana Beach	(36.9)	(7.84)	5.48	6.42	26.00	(1.00)	(11.00)	18.06	0.54	18.60
Sorrento Valley	(30.7)	(6.51)	3.67	4.36	26.00	(1.00)	(10.00)	16.52	0.36	16.88
Average	**(39.8)**	**(8.44)**	**7.46**	**8.67**	**26.00**	**(1.00)**	**(11.00)**	**21.85**	**0.75**	**22.60**

Table A-8 summarizes the benefits that can be obtained by motorists deciding to reach downtown San Diego using COASTER trains instead of driving there directly. The benefits are estimated assuming that a $1 fee would be charged for parking at each COASTER station. The analysis shows that an average benefit of $22.60 per trip could be obtained for each travelers electing to travel by train, with station-specific benefits ranging from $27.86 for individuals boarding trains at the Oceanside station (farthest to downtown San Diego) to $16.87 for individuals boarding trains at the Sorrento Valley station (closest to San Diego). In this case, longer travel times by train and the need to paid a $10 or $11 transit fare and 1$ for parking at park-and-ride lots (all shown by negative numbers in parentheses in the table) are entirely compensated by reductions in fuel consumption, vehicle emissions, and vehicle operating costs, as well as by eliminating the need to paid $26 for parking at a downtown facility. If vehicle emissions costs are ignored, since these are not typically directly paid by travelers, an average out-of-pocket benefit of $21.85 per trip is obtained, with station-specific benefits ranging from $16.52 to $26.79.

As explained in Section A.4.3, overall system benefits are obtained by calculating changes in consumer and producer surplus. Calculations for each COASTER station are shown in Table A-9 for an assumed $1 parking fee increase. For each station, the consumer surplus is calculated from the data of Table A-8 by subtracting the environmental costs from the overall trip benefits, while the producer surplus simply adds the parking fees and transit fares collected from COASTER riders. Externalities finally represent the environmental benefits obtained from a reduction in vehicle emissions. For this scenario, adding the changes in consumer surplus, producer surplus, and externalities yield an overall average system benefit of $34.43 per trip for each traveler electing to take a COASTER train instead of driving to downtown San Diego. Station-specific benefits range between a net benefit of $27.88 for travelers boarding trains at the Sorrento Valley station to $39.85 for individuals boarding train at the Oceanside station.

Table A-9 – System Benefits for Underused COASTER Facilities with 1$ Parking Fee

Station	Consumer Surplus ($/trip)	Producer Surplus ($/trip)	Externalities ($/trip)	System Benefits Rate ($/trip)
Oceanside	26.78	12.00	1.07	39.85
Carlsbad	25.73	12.00	0.98	38.71
Carlsbad Poinsettia	22.70	12.00	0.82	35.52
Encinitas	21.32	12.00	0.72	34.04
Solana Beach	18.06	12.00	0.54	30.60
Sorrento Valley	16.52	11.00	0.36	27.88
Average	**21.85**	**11.83**	**0.75**	**34.43**

Table A-10 – System Benefits for Underused Facilities under Alternate Park-and-ride Fees

	Benefit Rate ($/trip)			
Parking price	**$0**	**$1**	**$2**	**$3**
Consumer surplus	$22.85	$21.85	$20.85	$19.85
Producer surplus	$10.83	$11.83	$12.83	$13.83
Externalities (environmental costs)	$0.75	$0.75	$0.75	$0.75
Net benefits	**$34.43**	**$34.43**	**$34.43**	**$34.43**

Table A-10 further explores system benefits associated with alternative parking pricing schemes. The table shows changes in consumer surplus, producer surplus and externalities associated with a free parking option and scenarios imposing parking fees between $1 and $3. If it is assumed that there is no change in overall parking demand, changes in parking fees would result in no net change in system benefit as the benefit for producers associated with higher parking revenues are negated by higher travel costs for travelers.

A.5.5. Potential Impacts of Parking Fee Increases on Transit Agency Revenues

The benefit evaluations described in Sections A.5.3 and A.5.4 both assume that raising parking fees from $0 to $1 would not significantly affect transit ridership. This may not necessarily be the case. This issue was explored by the Transportation Sustainability Research Center (TSRC) at the University of California, Berkeley, which used a survey of 1,632 COASTER riders to look at the potential effects of raising parking fees on transit demand (Shaheen and Martin, 2011). In this survey, nearly half of the respondents were individuals who regularly park-and-ride at COASTER stations and who would therefore be affected by a Smart Parking system.

Table A-11 compiles the forecasted changes in revenues associated with hypothetical parking fee increases ranging from $1 to $7. The survey results suggest that any increase in parking fee from the current situation (free parking) would result in a decrease of ridership and net loss of revenue for the transit agency operating the COASTER train. For the $1 fee increased that was considered in the previous evaluations, the data notably suggest a modest potential annual loss in revenue of $47,806. Larger price increases results in significantly higher losses as the added revenues from parking are unable to compensate for an increasing loss in transit ridership and fare revenues.

Table A-11 – Forecasted Changes in Parking and Transit Revenues with Various Parking Fees

	Change in Parking and Transit Fare Revenues							
Parking Fee	**$0**	**$1**	**$2**	**$3**	**$4**	**$5**	**$6**	**$7**
Change in Parking Revenue	$0	$135,875	$166,550	$165,450	$152,700	$139,000	$133,350	$145,600
Change in Transit Fare	$0	-$183,681	-$321,129	-$415,879	-$477,750	-$507,700	-$525,003	-$526,687
Net Revenue Change	**$0**	**-$47,806**	**-$154,579**	**-$250,429**	**-$325,050**	**-$368,700**	**-$391,653**	**-$381,087**

The decreasing revenue trends ofA-11 are strongly influenced by the stated influence of parking prices on travel behavior from survey respondents. 34% of all respondents who indicated they would stop using COASTER after a parking fee increase indicated that they would do so following a $1 increase. Most of these respondents notably belonged to a group of individuals who are using COASTER trains regularly and holding monthly passes, particularly a 3-zone pass. Since these individuals contribute significant revenue to the transit agency, the loss of a single of these riders can thus have significant impacts on revenue. At the time of the study, a 3-zone monthly pass could be purchased for monthly fee of $165. Individuals buying this pass every month thus provided $1,980 in revenue annually to COASTER. Under a scenario considering a $1 parking fee increase, 1980 additional parking spaces would then need to be used during the year to compensate for the loss of a single 3-zone pass rider.

While the above results paint a negative picture, it should be emphasized that they are subject to the uncertainty that naturally arise from a stated response survey. It is possible that some respondents would not pay a price they stated they would pay, or that respondents who stated they would stop using COASTER following a parking price increase would in fact keep using COASTER.

A.5.6. System Deployment Costs

Estimating system deployment and operating costs for a generic Smart Parking system is relatively difficult as deployment and operating costs are highly dependent on the characteristics of the parking facilities that are to be included in a proposed system. Examples of elements that may have significant impacts on deployment and operations costs include:

- Lot layout: how many entries and exits, how many rows to equip with guidance signs, how many spaces to be equipped with sensors, how many payment kiosks to provide, etc.
- Ability to integrate existing infrastructure and equipment into a new Smart Parking system.
- Need to upgrade existing equipment and software to support new Smart Parking functionalities.
- Ability to purchase commercial off-the shelf equipment and software, versus the need to develop custom software or equipment.

- Facility with which landline or wireless communications can be established between various systems components.
- Ability to use an existing communication infrastructure to communicate with a central server and remote equipment.
- Installation of equipment to be done by in-house staff of contractors.

While pilot Smart Parking systems were deployed at the six COASTER stations being considered, these deployments only results in limited installation of new equipment as only handfuls of parking spaces at each station were part of the pilot deployments. The sensors that were initially installed were eventually abandoned and removed, leaving no current capability to track daily parking lot utilization. Furthermore, while an advanced reservation system was implemented, this system currently only covers the distribution of free monthly parking permits. In addition, CMSs were not used to provide advanced availability information.

The partial system deployment and subsequent system changes make it very high difficulty to use deployment costs for the pilot deployments as a true reflection of typical Smart Parking system costs. General preliminary ball-park figures could however be obtained by considering both data from related parking management projects and typical equipment retail and operations costs to fill the information gaps. Such an analysis is provided below for the 5 systems listed in Table A-12, which correspond to the five operational scenarios discussed in Section 8 of the ConOps.

Table A-12 – Cost Evaluation Scenarios

	Parking Monitoring	Gated Entry/Exit	Advanced Notification	Reservation Option	Integrated with Regional ITS Architecture	Variable Pricing
Stand-alone system	X	X				
System with advance notification	X	X	X			
System with advance notification and reservation	X	X	X	X		
System integrated with Regional ITS Architecture	X	X	X	X	X	
Full-featured Smart Parking system	X	X	X	X	X	X

The cost analyses for each scenario are presented in Table A-13 to Table A-22. These analyses are based on the following assumptions:

- **Number of reserved spaces** – Similar to current practice at park-and-ride lots along the San Francisco's Bay Area Rapid Transit (BART) lines it is assumed that one third of all parking spaces within each lot are set aside for reservation holders.
- **Equipment costs** – All equipment costs are rough estimates. Most of the estimates are based on inflation-adjusted unit costs for ITS equipment retrieved from the cost database maintained by the Research and Innovation Technology Administration (RITA) of the U.S. Department of Transportation (www.itscosts.its.dot.gov/its/benecost.nsf/CostHome). Where possible, actual costs from published parking management system deployment reports or vendor documentation were also used. All estimates include the cost of installing the equipment in addition to its retail cost. Annual recurring costs further account for power charges and the need for periodic inspection and maintenance. For equipment for which no operation and

maintenance cost estimate was available, a recurring annual cost corresponding to 5% of its initial deployment cost was arbitrarily used.

- **Parking monitoring system** – Within each parking lot, parking availability is assumed to be determined by a system monitoring the cumulative number of vehicles that have entered and exited the facility. For comparison purposes, an alternative using wireless sensors installed within each parking stall instead of vehicle counters at entrances and exits is also considered. This alternative is similar to what was done for the COASTER pilot deployments.
- **Computing support** – In addition to a host server, it is assumed that a base station will be installed within each parking lot to help collect data generated by the sensors installed within the facility and manage other local equipment. Base stations may not be necessary if all equipment can be effectively controlled and data collected from a remote location.
- **Traveler information system** – All scenarios with advanced information assume that 4 changeable message signs would be installed at key locations along nearby freeways. This includes signs installed on I-5 as well as potentially on the SR-78 and SR-56 freeways near their respective interchange with I-5. Roadside signs are also assumed to be installed along key arterials leading to each park-and-ride lots where travelers might have an opportunity to alter their travel plan. The assumption is that 2 signs would be installed on arterials around each station. At each lot, signs indicating the number of parking spaces within the lot, and potentially the parking fee, are to be installed near each lot entrance. Finally, small guidance signs helping travelers to find an open space are assumed to be installed only within the parking structure at the Oceanside station, as all other lots are surface lots.
- **Payment/identification system** – It is assumed that park-and-ride users are offered the opportunity to use the regional COMPASS smart card to pay for parking. Since COMPASS cards can already be used to pay for COASTER train tickets, it is assumed that no additional vending machine will be needed. However, a new compass card reading machine is assumed to be installed at each station to process parking fees. To enable occasional travelers without a smart card to pay for parking, it is finally assumed that payment kiosks would be installed within each parking facility.
- **Enforcement system** – Enforcement is assumed to rely on the use of gates to control entry and exit from each parking facility.
- **Reservation system** – In relevant scenarios, it is assumed that an existing parking reservation system offered by a third-party company can be used to implement the desired reservation capability. The system deployment activities thus primarily consist in customization efforts to adapt an existing reservation system to the need of the parking lot operators. The customization costs used in the calculations are those that were incurred by ParkingCarma for the implementation of the COASTER reservation system. The cost of maintenance is derived based on information provided by ParkingCarma regarding the maintenance of the BART reservation system.
- **Integration with the Regional ITS Architecture**. In relevant scenarios, it is assumed that interfaces will be developed to enable the Smart Parking system to use the IMTMS network to communicate data with a remote Smart Parking server, information service providers, and other ITS applications.
- **Dynamic pricing module** – The scenario involving dynamic pricing assumes that new software would need to be developed to determine the parking fee to charge based on space availability

and parking demand. The scenario also assumes that slightly more complex CMSs would need to be installed to enable the displaying of parking fees in addition to available spaces.

- **Staffing needs** – It is assumed that the implementation of a Smart Parking system will only require the hiring of new personnel to handle new parking management functionalities that would not exist prior to system implementation. All scenarios assume that a system administrator would be hired, as well as a new technician to handle the maintenance of the Smart Parking equipment. The hiring of parking revenue manager is based on the assumption that parking is currently free (as is the case with the COASTER stations). For the customer support staff, experience from ParkingCarma suggests that additional staff may be only required for a period of two months or less to handle a temporary increase in call volume following a system launch.
- **Other costs** – Other costs reflect the expenses that may be incurred for planning the deployment of a Smart Parking, as well as for training personnel and developing operations manual and equipment documentation.

Table A-13 – Cost Evaluation – Stand-alone System with Entry/Exit sensors

	Unit Cost	Annual Operation and Maintenance Cost	Stations						Total Units	Initial Deployment Cost	Annual Recurring Cost
			Oceanside	Carlsbad Village	Carlsbad Poinettia	Encinitas	Solana Beach	Sorrento Valley			
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	12	8	4	10	8	2	44	$220,000	$17,600
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	0	0	0	0	0	0	0	$0	$0
Wireless Repeaters	$500 /repeater	$25 /repeater	0	0	0	0	0	0	0	$0	$0
Communications Charges		$1,000 /lot	0	0	0	0	0	0	0	$0	$0
Computing Support											
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Traveler Information System											
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								0	$0	$0
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$1,120,850	**$463,000**

Table A-14 – Cost Evaluation – Stand-alone System with Stall Sensors

	Unit Cost	Annual Operation and Maintenance Cost	Stations: Oceanside	Carlsbad Village	Carslbad Poinettia	Encinitas	Solana Beach	Sorrento Valley	Total Units	Initial Deployment Cost	Annual Recurring Cost
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	0	0	0	0	0	0	0	$0	$0
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	571	448	332	306	322	118	2097	$629,100	$31,455
Wireless Repeaters	$500 /repeater	$25 /repeater	3	3	2	5	4	2	19	$9,500	$475
Communications Charges		$1,000 /lot	1	1	1	1	1	1	6	$0	$6,000
Computing Support											
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Traveler Information System											
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								0	$0	$0
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$1,759,450	**$500,930**

Table A-15 – Cost Evaluation – System with Advance Notification and Entry/Exit Sensors

	Unit Cost	Annual Operation and Maintenance Cost	Stations: Oceanside	Carlsbad Village	Carslbad Poinettia	Encinitas	Solana Beach	Sorrento Valley	Total Units	Initial Deployment Cost	Annual Recurring Cost
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	12	8	4	10	8	2	44	$220,000	$17,600
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	0	0	0	0	0	0	0	$0	$0
Wireless Repeaters	$500 /repeater	$25 /repeater	0	0	0	0	0	0	0	$0	$0
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	0	0	0	0	0	0	0	$0	$0
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$37,500 /sign	$2,000 /sign	2	2	2	2	2	2	12	$450,000	$24,000
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								0	$0	$0
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$100,000 /unit								1	$100,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$2,060,850	**$542,800**

Table A-16 – Cost Evaluation – System with Advance Notification and Stall Sensors

	Unit Cost	Annual Operation and Maintenance Cost	Stations						Total Units	Initial Deployment Cost	Annual Recurring Cost
			Oceanside	Carlsbad Village	Carslbad Poinettia	Encinitas	Solana Beach	Sorrento Valley			
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	0	0	0	0	0	0	0	$0	$0
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	571	448	332	306	322	118	2097	$629,100	$31,455
Wireless Repeaters	$500 /repeater	$25 /repeater	3	3	2	5	4	2	19	$9,500	$475
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	1	1	1	1	1	1	6	$0	$6,000
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$37,500 /sign	$2,000 /sign	2	2	2	2	2	2	12	$450,000	$24,000
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								0	$0	$0
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$100,000 /unit								1	$100,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$2,699,450	**$580,730**

Table A-17 – Cost Evaluation – System with Advance Notification, Entry/Exit Sensors and Reservation

	Unit Cost	Annual Operation and Maintenance Cost	Stations						Total Units	Initial Deployment Cost	Annual Recurring Cost
			Oceanside	Carlsbad Village	Carslbad Poinettia	Encinitas	Solana Beach	Sorrento Valley			
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	12	8	4	10	8	2	44	$220,000	$17,600
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	0	0	0	0	0	0	0	$0	$0
Wireless Repeaters	$500 /repeater	$25 /repeater	0	0	0	0	0	0	0	$0	$0
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	0	0	0	0	0	0	0	$0	$0
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$37,500 /sign	$2,000 /sign	2	2	2	2	2	2	12	$450,000	$24,000
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Enforcement Devices (PDAs)	$300 /PDA	$200 /PDA							0	$0	$0
Enforcement Support (Subcontract)		$2,000 /lot	0	0	0	0	0	0	0	$0	$0
Reservation System											
Development of new Reservation System	$208,000 /unit								0	$0	$0
Customization of Existing Software	$4,800 /unit								1	$4,800	$0
Operations and Maintenance		$282 /year							1	$0	$282
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								2	$7,973	$93,840
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$2,123,623	$636,922

Table A-18 – Cost Evaluation – System with Advance Notification, Stall Sensors and Reservation

	Unit Cost	Annual Operation and Maintenance Cost	Stations: Oceanside	Carlsbad Village	Carlsbad Poinettia	Encinitas	Solana Beach	Sorrento Valley	Total Units	Initial Deployment Cost	Annual Recurring Cost
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	0	0	0	0	0	0	0	$0	$0
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	571	448	332	306	322	118	2097	$629,100	$31,455
Wireless Repeaters	$500 /repeater	$25 /repeater	3	3	2	5	4	2	19	$9,500	$475
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	1	1	1	1	1	1	6	$0	$6,000
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$37,500 /sign	$2,000 /sign	2	2	2	2	2	2	12	$450,000	$24,000
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Enforcement Devices (PDAs)	$300 /PDA	$200 /PDA							0	$0	$0
Enforcement Support (Subcontract)		$2,000 /lot	0	0	0	0	0	0	0	$0	$0
Reservation System											
Development of new Reservation System	$208,000 /unit								0	$0	$0
Customization of Existing Software	$4,800 /unit								1	$4,800	$0
Operations and Maintenance		$282 /year							1	$0	$282
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								2	$7,973	$93,840
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$2,762,223	$674,852

Table A-19 – Cost Evaluation – System with Advance Notification, Entry/Exit Sensors and Reservation Integrated with Regional ITS Architecture

	Unit Cost	Annual Operation and Maintenance Cost	Stations: Oceanside	Carlsbad Village	Carslbad Poinettia	Encinitas	Solana Beach	Sorrento Valley	Total Units	Initial Deployment Cost	Annual Recurring Cost
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	12	8	4	10	8	2	44	$220,000	$17,600
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	0	0	0	0	0	0	0	$0	$0
Wireless Repeaters	$500 /repeater	$25 /repeater	0	0	0	0	0	0	0	$0	$0
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	0	0	0	0	0	0	0	$0	$0
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$37,500 /sign	$2,000 /sign	2	2	2	2	2	2	12	$450,000	$24,000
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Enforcement Devices (PDAs)	$300 /PDA	$200 /PDA							0	$0	$0
Enforcement Support (Subcontract)		$2,000 /lot	0	0	0	0	0	0	0	$0	$0
Reservation System											
Development of new Reservation System	$208,000 /unit								0	$0	$0
Customization of Existing Software	$4,800 /unit								1	$4,800	$0
Operations and Maintenance		$282 /year							1	$0	$282
Integration with Regional Architecture											
IMTMS System Integration	$100,000 /unit								1	$100,000	$0
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								2	$7,973	$93,840
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$2,223,623	$636,922

Table A-20 – Cost Evaluation – System with Advance Notification, Stall Sensors and Reservation Integrated with Regional ITS Architecture

	Unit Cost	Annual Operation and Maintenance Cost	Stations: Oceanside	Stations: Carlsbad Village	Stations: Carslbad Poinettia	Stations: Encinitas	Stations: Solana Beach	Stations: Sorrento Valley	Total Units	Initial Deployment Cost	Annual Recurring Cost
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	0	0	0	0	0	0	0	$0	$0
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	571	448	332	306	322	118	2097	$629,100	$31,455
Wireless Repeaters	$500 /repeater	$25 /repeater	3	3	2	5	4	2	19	$9,500	$475
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	1	1	1	1	1	1	6	$0	$6,000
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$37,500 /sign	$2,000 /sign	2	2	2	2	2	2	12	$450,000	$24,000
CMS - Lot Entrances	$37,500 /sign	$2,000 /sign	3	3	2	4	2	1	15	$562,500	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Enforcement Devices (PDAs)	$300 /PDA	$200 /PDA							0	$0	$0
Enforcement Support (Subcontract)		$2,000 /lot	0	0	0	0	0	0	0	$0	$0
Reservation System											
Development of new Reservation System	$208,000 /unit								0	$0	$0
Customization of Existing Software	$4,800 /unit								1	$4,800	$0
Operations and Maintenance		$282 /year							1	$0	$282
Integration with Regional Architecture											
IMTMS System Integration	$100,000 /unit								1	$100,000	$0
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								2	$7,973	$93,840
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
										$2,862,223	$674,852

Table A-21 – Cost Evaluation System with Advance Notification, Entry/Exit Sensors, Reservation and Dynamic Pricing Integrated with Regional ITS Architecture

Item	Unit Cost	Annual Operation and Maintenance Cost	Stations: Oceanside	Carlsbad Village	Carlsbad Poinettia	Encinitas	Solana Beach	Sorrento Valley	Total Units	Initial Deployment Cost	Annual Recurring Cost
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	12	8	4	10	8	2	44	$220,000	$17,600
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	0	0	0	0	0	0	0	$0	$0
Wireless Repeaters	$500 /repeater	$25 /repeater	0	0	0	0	0	0	0	$0	$0
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	0	0	0	0	0	0	0	$0	$0
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$40,000 /sign	$2,000 /sign	2	2	2	2	2	2	12	$480,000	$24,000
CMS - Lot Entrances	$40,000 /sign	$2,000 /sign	3	3	2	4	2	1	15	$600,000	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Enforcement Devices (PDAs)	$300 /PDA	$200 /PDA							0	$0	$0
Enforcement Support (Subcontract)		$2,000 /lot	0	0	0	0	0	0	0	$0	$0
Reservation System											
Development of new Reservation System	$208,000 /unit								0	$0	$0
Customization of Existing Software	$4,800 /unit								1	$4,800	$0
Operations and Maintenance		$282 /year							1	$0	$282
Integration with Regional Architecture											
IMTMS System Integration	$100,000 /unit								1	$100,000	$0
Dynamic Pricing Module											
Dynamic Pricing Software	$25,000 /unit	$1,500 /year							1	$25,000	$1,500
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								2	$7,973	$93,840
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
									Total	$2,316,123	$638,422

Table A-22 – Cost Evaluation System with Advance Notification, Stall Sensors, Reservation and Dynamic Pricing Integrated with Regional ITS Architecture

Item	Unit Cost	Annual Operation and Maintenance Cost	Stations: Oceanside	Carlsbad Village	Carlsbad Poinettia	Encinitas	Solana Beach	Sorrento Valley	Total Units	Initial Deployment Cost	Annual Recurring Cost
Station Characteristics											
Parking Spaces			571	448	332	306	322	118			
Reserved Spaces (pilot project)			7	6	7	6	7	7			
Reserved Spaces (analysis)			190	149	111	102	107	39			
Entries			6	4	2	5	4	1			
Exits			6	4	2	5	4	1			
Parking Monitoring System											
Entrance/Exit Vehicle Counters	$5,000 /entry	$400 /entry	0	0	0	0	0	0	0	$0	$0
Vehicle Sensors - Individual Stalls	$300 /sensor	$15 /sensor	571	448	332	306	322	118	2097	$629,100	$31,455
Wireless Repeaters	$500 /repeater	$25 /repeater	3	3	2	5	4	2	19	$9,500	$475
Communication Gateway	$2,000 /gateway	$100 /gateway	1	1	1	1	1	1	6	$12,000	$600
Communications Charges		$1,000 /lot	1	1	1	1	1	1	6	$0	$6,000
Computing Support											
Smart Parking Central Server	$4,000 /server	$400 /server							1	$4,000	$400
Parking Lot Base Stations	$4,000 station	$400 /station	1	1	1	1	1	1	6	$24,000	$2,400
Communication to Central Site	$4,000 /lot	$1,800 /lot	1	1	1	1	1	1	6	$24,000	$10,800
Traveler Information System											
CMS - Freeways	$125,000 /sign	$5,000 /sign	1	1	0	1	0	1	4	$500,000	$20,000
CMS - Arterials	$40,000 /sign	$2,000 /sign	2	2	2	2	2	2	12	$480,000	$24,000
CMS - Lot Entrances	$40,000 /sign	$2,000 /sign	3	3	2	4	2	1	15	$600,000	$30,000
CMS - In-lot Guidance	$1,000 /sign	$100 /sign	6	0	0	0	0	0	6	$6,000	$600
Data Processing Software	$15,000 /system	$1,500 /system							1	$15,000	$1,500
Communication Charges - Remote Signs		$1,500 /sign	3	3	2	3	2	3	16	$0	$24,000
Payment / Identification System											
Smart Card Readers	$2,000 /reader	$200 /year	1	1	1	1	1	1	6	$12,000	$1,200
Payment Kiosk	$15,000 /kiosk	$1,500 /year	1	1	1	1	1	1	6	$90,000	$9,000
Smart Card Vending Machine	$30,000 /machine	$1,500 /year	0	0	0	0	0	0	0	$0	$0
Database and Software for Billing	$15,000 /system	$1,500 /year							1	$15,000	$1,500
Enforcement System											
Entry/Exit Gates	$4,000 /gate	$200 /gate	12	8	4	10	8	2	44	$176,000	$8,800
Small Static Signs	$25 /sign	$0 /sign	190	149	111	102	107	39	698	$17,450	$0
Medium Static Signs	$50 /sign	$0 /sign	16	11	6	12	10	3	58	$2,900	$0
Enforcement Devices (PDAs)	$300 /PDA	$200 /PDA							0	$0	$0
Enforcement Support (Subcontract)		$2,000 /lot	0	0	0	0	0	0	0	$0	$0
Reservation System											
Development of new Reservation System	$208,000 /unit								0	$0	$0
Customization of Existing Software	$4,800 /unit								1	$4,800	$0
Operations and Maintenance		$282 /year							1	$0	$282
Integration with Regional Architecture											
IMTMS System Integration	$100,000 /unit								1	$100,000	$0
Dynamic Pricing Module											
Dynamic Pricing Software	$25,000 /unit	$1,500 /year							1	$25,000	$1,500
Staffing											
System Administrator	$125 /hour								1	$0	$255,000
Parking Revenue Manager	$40 /hour								1	$0	$81,600
Software Engineer	$60 /hour								0	$0	$0
Equipment Technician	$35 /hour								1	$0	$71,400
Customer Support Staff	$23 /hour								2	$7,973	$93,840
Enforcement Personnel	$20 /hour								0	$0	$0
Other Cost Items											
System Planning and Design	$150,000 /unit								1	$150,000	$0
Training and Documentation	$50,000 /unit								1	$50,000	$0
									Total	**$2,954,723**	**$676,352**

Table A-23 summarizes the estimated deployment and annual operating costs associated with the various scenarios and alternatives considered:

- For systems using entry/exit gate sensors to monitor parking availability, estimated deployment costs for the 6-parking lot COASTER system used as a case study would vary between $1.1 and $2.3 million. Most of this range is associated with the assumed cost to deploy four CMSs along nearby freeways ($500,000) and 12 additional CMSs along arterials ($450,000 to $480,000). Estimated annual operating costs would further vary between $463,000 and $638,000. When annualized over a 5-year period, total system costs would range between $3.3 and $5.3 million.
- The cost for systems replacing the entry/exit vehicle counters with individual stall sensors would ranges between $1.8 and 3.0 million. In this case, the estimated annual operating costs would vary between $500,000 and $676,000. When annualized over a 5-year period, total system costs would range between $4.1 and $6.1 million.

Table A-23 –Estimated Deployment and Operating Costs for COASTER Scenarios

	Deployment Cost	Annual Cost	5-Year Cost*
System Using Entry/Exit Gates for Monitoring			
Stand-alone system	$1,120,850	$463,000	3,261,559
System with advance notification	$2,060,850	$542,800	4,570,519
System with advance notification and reservation	$2,123,623	$636,922	5,068,470
System integrated with Regional ITS Architecture	$2,223,623	$636,922	5,168,470
Full-featured Smart Parking system	$2,316,123	$638,422	5,267,905
System Using Space Sensors for Monitoring			
Stand-alone system	$1,759,450	$500,930	4,075,530
System with advance notification	$2,699,450	$580,730	5,384,490
System with advance notification and reservation	$2,762,223	$674,852	5,882,441
System integrated with Regional ITS Architecture	$2,862,223	$674,852	5,982,441
Full-featured Smart Parking system	$2,954,723	$676,352	6,081,877

** Annualized with a 4% interest rate and monthly interest compounding*

Table A-24 – Stall-based Estimated Deployment and Operating Costs for COASTER Scenarios

	Deployment Cost	Annual Cost	5-Year Cost*
System Using Entry/Exit Gates for Monitoring			
Stand-alone system	$535	$221	$1,555
System with advance notification	$983	$259	$2,180
System with advance notification and reservation	$1,013	$304	$2,417
System integrated with Regional ITS Architecture	$1,060	$304	$2,465
Full-featured Smart Parking system	$1,104	$304	$2,512
System Using Space Sensors for Monitoring			
Stand-alone system	$839	$239	$1,944
System with advance notification	$1,287	$277	$2,568
System with advance notification and reservation	$1,317	$322	$2,805
System integrated with Regional ITS Architecture	$1,365	$322	$2,853
Full-featured Smart Parking system	$1,409	$323	$2,900

** Annualized with a 4% interest rate and monthly interest compounding*

To provide a scaling ratio, deployment and operating costs can be estimated on a per parking space basis. If it is considered that that the system being analyzed covers 2097 parking spaces, estimated deployment cost per parking space would vary between $535 and $1,409 (see Table A-24). Annual operations and maintenance cost would further vary between $221 and $323 per stall, while the total 5-year system costs would vary between $1,555 and $2,900 per stall.

Once again, it is emphasized that the above cost estimates are rough calculations and are only provided as a discussion starting point. Actual system deployment costs could be lower or higher depending on lot layout, instrumentation already in place, discounts offered by vendors for sizeable equipment purchases, number and type of CMSs that are to be installed, the ability to use existing staff to support Smart Parking functions, site-specific constraints, etc. Unit deployment costs will also vary based on the number of spaces covered by the system as some cost elements would be fixed. A more formal and detailed cost analysis should therefore be performed as part of any proposed system deployment.

A.5.7. Break-even Analysis

Despite the difficulty to provide exact cost estimates, it is possible to conduct break-even and cost/benefit analyses for hypothetical system deployments. To break even, a Smart Parking system needs to generate enough cumulative benefits over a given period across all covered facilities to at least match, and ideally exceed, the anticipated life-cycle costs of the system over the same period. For scenarios considering parking facilities operating at capacity, a Smart Parking system would need to reduce a sufficient number of unnecessary trips to cover the system implementation and operation costs. For scenarios considering underutilized facilities, the system would instead need to generate enough new parking and/or transit revenues, as well as travel cost reductions for parking lot users, to cover implementation and operating costs.

Table A-25 – Station-Specific Benefits Rates for COASTER System

Station	Status	Primary Source of Benefits	Benefit Rate
Oceanside	Under capacity	New transit riders / Parking revenues	$39.85/trip
Carlsbad Village	Near capacity	New transit riders / Parking revenues	$38.71/trip
Carlsbad Poinsettia	Over capacity	Reduction of unnecessary trips	$2.32/trip
Encinitas	Over capacity	Reduction of unnecessary trips	$1.94/trip
Solana Beach	Near capacity	New transit riders / Parking revenues	$30.60/trip
Sorrento Valley	Near capacity	New transit riders / Parking revenues	$27.88/trip

** Annualized with a 4% interest rate and monthly interest compounding*

For many parking systems, benefits are likely to be generated from the management of a group of facilities that are operating both under and over capacity. For the COASTER system, the expected benefit rate, and source of benefits for each park-and-ride lot would correspond to the system characteristics listed in Table A-25. Based on this data, between 15 and 20 unnecessary trips would need to be avoided at over utilized stations to provide the same benefits obtained by attracting a single new transit rider at parking lots with spare capacity. This indicates a preferred bias in using Smart Parking systems to help increase use of underutilized facilities. However, it should be kept in mind that the low benefit rates for overused facilities associated with this analysis is heavily linked to the fact that the COASTER stations are typically located within 1 mile of an I-5 exit. Higher benefits could therefore be expected for parking facilities requiring longer trips on local arterials.

Table A-26 – Estimated System Benefits

Station	10 Travelers Affected			20 Travelers Affected			50 Travelers Affected		
	Daily	Annual	5-year*	Daily	Annual	5-year*	Daily	Annual	5-year*
Oceanside	$399	$101,618	$469,835	$797	$203,235	$939,669	$1,993	$508,088	$2,349,173
Carlsbad Village	$387	$98,711	$456,394	$774	$197,421	$912,788	$1,936	$493,553	$2,281,970
Carlsbad Poinsettia	$23	$5,916	$27,353	$46	$11,832	$54,706	$116	$29,580	$136,765
Encinitas	$19	$4,947	$22,873	$39	$9,894	$45,746	$97	$24,735	$114,364
Solana Beach	$306	$78,030	$360,776	$612	$156,060	$721,553	$1,530	$390,150	$1,803,882
Sorrento Valley	$279	$71,094	$328,707	$558	$142,188	4657,415	$1,394	$355,470	$1,643,537
System-wide	**$1,413**	**$360,315**	**$1,665,938**	**$2,2826**	**$720,630**	**$3,331,876**	**$7,065**	**$1,801,575**	**$8,329,691**

** Annualized with a 4% interest rate and monthly interest compounding*

Using the data of Table A-25, Table A-26 provides estimates of the benefits that may be obtained by a system affecting on average 10, 20 and 50 travelers at each COASTER station. Assuming that there are 255 working days per year, annual benefits of $360,000, $720,000 and $1.8 million are obtained for each scenario. Over a 5-year period, these benefits further translate into total annualized benefits of $1.7 million, $3.3 million and $8.3 million, respectively.

For the above scenarios, a break-even situation occurs when net system benefits exactly match the system's net deployment and operating costs. For the scenario assuming that 20 individuals are affected on average per station, a break-even situation occurs for a system costing slightly over $3.3 million over 5 years. Fir the scenario assuming that 50 individuals are affected on average at each station, the break-even point is then for a system costing slightly over $8.3 million over 5 years.

The break-even point defines the maximum system deployment and operating costs to generate benefits. Depending on system functionalities, Table A-23 shows net deployment and operations costs for a COASTER Smart Parking system ranging between $3.3 and $6.1 million over a 5-year period. When these costs are compared to the estimated benefits of Table A-26, a full-featured system projected to benefit at least 50 persons per station would then generate net societal benefits. In this case, $8.3 million in benefits would be obtained for a system costing $6.1 million to deploy and operate. This corresponds to a benefit/cost ratio of 1.36. For a system affecting only 20 persons per station, no net benefits would be obtained, as the expected annualized deployment and operations costs of the simplest possible system ($3.3 million for the stand-alone system with entry/exit gates) would then almost exactly match the estimated net potential benefits ($3.3 million).

While the above analysis yields no benefits for a system affecting only 20 individuals per station, it is possible for benefits to be obtained with a similar level of influence when considering a different set of parking facilities. For the COASTER stations used in the analysis, enticing drivers take transit to reach their destination carries significantly higher benefits than eliminating unnecessary trips to transit stations since each station lies relatively close to a regional major thoroughfare. Higher benefit rates could for instance be obtained by restricting system deployments to underutilized facilities or by considering facilities necessitating longer access trips from a major road.

APPENDIX B: POTENTIAL FINANCING MECHANISMS

The constrained funding environment in which many transportation and planning agencies operate may impose a significant challenge to the implementation of Smart Parking systems. While there may be interest in such systems, financial constraints may prevent some agencies to agree to launch or participate in a deployment projects. Such financial obstacles could however be surmounted by utilizing alternative financial instruments, such as Public-Private Partnerships (PPPs) and Public-Public Partnerships (PuPPs). This appendix explains the nature of each type of partnership, presents examples of how partnerships have been used to finance transportation projects, and briefly discusses how these types of partnerships can affect Smart Parking projects.

10.1. PUBLIC-PRIVATE PARTNERSHIPS (PPPS)

Public-Private partnerships (PPPs) are contractual agreements formed between a public agency and a private sector entity that allow for greater private sector participation in the delivery and financing of transportation projects. Such partnerships have grown in popularity in recent years as they allow transportation agencies to access sources of financing for the development of new infrastructure that may not be available otherwise.

Figure B-1 illustrates various types of PPPs that are commonly considered. For the building of new facilities, commonly considered options include:

- **Design Build** – Project delivery method that combines two, usually separate, services into a single contract. In this type of procurement, owners of private companies execute a single, fixed-fee contract for both architectural/engineering services and construction. The design-build entity may be a single firm, a consortium, a joint venture or some other organization assembled for a particular project.
- **Design Build Operate** – Integrated partnership that combines the design and construction responsibilities of design-build procurements with operations and maintenance. Such a partnership allows the listed project components to be procured from the private sector in a single contract with financing secured by the public sector. This project delivery approach is practiced by several governments around the world and is known by a number of different names, including "turnkey" procurement and build-operate-transfer (BOT).
- **Design Build Finance Operate** – In this partnership approach, the responsibilities for designing, building, financing and operating are bundled together and transferred to private sector partners. Partnerships within this category tend to be either partly or wholly financed by debt leveraging revenue streams dedicated to the project, such as toll revenues. Typically, future revenues are leveraged to issue bonds or other debt that provide funds for capital and project development costs. They are also often supplemented by public sector grants in the form of money or contributions in kind, such as right-of-way.

For project focusing on existing facilities, the following options are often considered:

- **Operations and Maintenance** – Operations and maintenance concessions are used to transfer responsibility for asset operation and management to the private sector. These comprehensive agreements involve both service and management aspects and can be useful in encouraging enhanced efficiencies and technological sophistication. Contractors can be paid either on a fixed fee basis or on an incentive basis, in which they receive premiums for meeting specified service levels or performance targets.

- **Long-term Lease** – This model involves the long term lease of existing, publicly-financed toll facilities to a private sector concessionaire for a prescribed concession period during which they have the right to collect tolls on the facility. In exchange, the private partner must operate and maintain the facility and in some cases make improvements to it. The private partner must also pay an upfront concession fee. Long term leases are typically procured on a competitive basis, with awards going to the qualified bidder making the most attractive offer to the sponsoring agency.

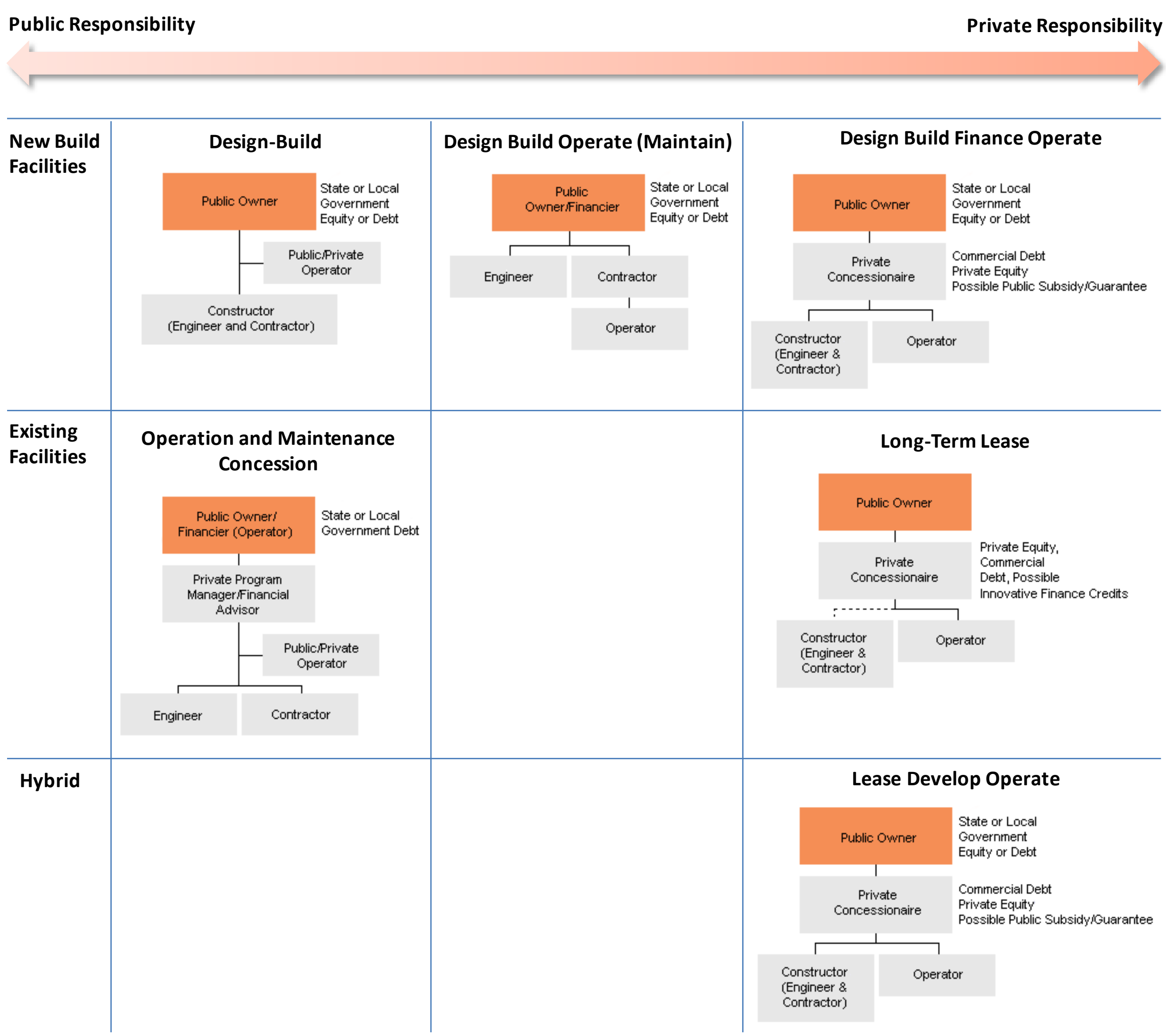


Figure B-1 – Public Private Partnership (PPP) Options

For the expansion or upgrade of existing facilities, the following option also exists:

- **Lead-Develop-Operate** – In this arrangement the project sponsor grants a private operator/developer a long-term lease to operate and expand an existing facility. The private party agrees to invest in facility improvements, and can recover the investment plus a reasonable return over the term of the lease.

Given that the long-term goal of private entities is profit maximization, public interests must be protected from unfair financial agreements. This generally leads to the inclusion of revenue control terms or specific generation in partnership agreements. Examples include:

- **Revenue Sharing** – In the case of Texas Highway 130, the revenue share received by the state increases as the return on the investment increases. In this way the government agency controls the revenue generated by the private partner.
- **Toll rate limitation** – The Chicago and SR-125 projects are examples of government entities setting a maximum allowed toll, without actually sharing any revenue.
- **Shadow Toll** – In a shadow tolling scheme, the public sector pays the "toll" instead of the motorist. The DC Streets initiative is an example of shadow tolling. In this case, a private partner provides a service following established criteria after which a toll (i.e., lump payment) is paid by the public agency.

Tables B-1 to B-6 provide various examples in which government agencies within the United States used PPPs to finance projects along with the private sector.

Table B-1 – SR 125 / South Bay Expressway

Year	1991
PPP Type	Design Built Finance Operate
Brief Description	In 1991 Caltrans signed a franchise agreement with CTV to design and build SR 125, a 12.5 mile highway alignment near San Diego. Construction began in 2003 and the highway opened in late 2007. South Bay Expressway (SBX) Ltd, with CTV as its general partner, is tasked with operating and maintaining the toll road until 2047. Both companies are owned by the US subsidiary of Macquarie Infrastructure Group.
Duration	35 years
Institutional Arrangement	The project was divided into two segments: a non-tolled freeway segment funded by SANDAG and FHWA and a tolled segment financed by private entities. The same contractor built both segments and CTV functioned as the general partner, managing the project and administering the contracts. The first stage of the project resulted in the building of a 9.5-mile toll facility, with an additional 2 miles funded by SANDAG. Besides receiving private loans to build the toll facility, the SBX/CTV group received a Federal TIFAI loan. The latter stages of the project were funded by Federal and SANDAG funds. During the 35 year franchise, SBX will collect all the toll revenue. A fraction of these revenues will be destined for loan payment and operations costs. SBX is also allowed to set market rate tolls. The franchise agreement stipulates a maximum return on total investment of 18.5% with additional allowed incentive return for implementing strategies that increase vehicle occupancy. If the revenues exceed the establish maximum, the excess is considered a franchise fee payable to Caltrans.

Table B-2 – Washington DC's Streets Initiative

Year	2000
PPP Type	Operate & Maintain Concession
Description	Partnership between the District of Columbia Department of Public Works (DCDPW) and VMS, Inc. to maintain and preserve 75 miles of roadway and associated elements making up the District's portion of the National Highway System (NHS). This was a five-year contract worth $69.6 million.
Duration	5 years
Institutional Arrangement	DCDPW and VMS had a performance based contract. In the contract, DCDPW did not specify the materials or methods to be used by VMS. The contract outlined instead the expected outcomes, leaving the contractor free to use whatever methods or materials to achieve them. DCDPW was also responsible for monitoring VMS operations.

Table B-3 – Texas State Highway 130 Development Agreement

Year	2002
PPP Type	Design Build with an option for long term lease
Description	Highway 130, a 49-mile toll way near Austin, was designed and built as part of an agreement between the Texas DOT and Lone Star Infrastructure (LSI).
Duration	Completion of project
Institutional Arrangement	LSI was selected in a competitive procurement process to design and build Highway 130. This initial agreement established separate deadlines for 4 highway segments; the developer was paid lump sums in monthly installments based on the progress achieved in accordance to the agreement schedule. In 2006 the Texas DOT signed a toll concession agreement with another company, SH 130 Concession Company, LLC. This venture group agreed to design and build segments 5 and 6 of Highway 130 and to continue operating and maintaining the toll facility for 50 years (long term concession agreement). To protect the public interests the concession revenues are shared on the basis of an annual return on investment. For example, if the annual return on investment is equal to or below 11 percent, the share of the state would be 5 percent. Higher returns on investment means a higher revenue shares for the state (GAO 2008).

Table B-4 – Chicago Skyway Concession Agreement

Year	2005
PPP Type	Long Term Lease
Description	The Chicago Skyway is a 7.8 mile toll road that runs through the city's South side towards the Indiana boarder. In October 2004, the city of Chicago transferred operations and maintenance responsibility of the toll road to the Skyway Concession Company after the payment of a $1.83 billion concession fee.
Duration	99 years
Institutional Arrangement	The Skyway Concession Company is responsible for all the operation and maintenance costs of the toll road. The company also has the right to establish, collect, and enforce payment of tolls, in addition to the rights to all the toll revenue. While the agreement indicates that the city of Chicago surrendered its right to intervene in the setting of toll rates, it also specifies the maximum tolls that the company can collect over a given time interval. After 2017, the leasing company is for instance required to determine the tolls on the basis of a formula that considers the Consumer Price Index (CPI) and the Gross Domestic Product (GDP) per person.

Table B-5 – Chicago Downtown Parking System Concession Agreement

Year	December 2006
PPP Type	Long Term Lease
Description	Leasing of four parking garages previously operated by the city of Chicago to Morgan Stanley and its associates. This contract, which covered a total 9,178 parking spots, had a value of $563 million.
Duration	99 years
Institutional Arrangement	Morgan Stanley is responsible for the maintenance and rebuilding of the garages, when necessary, over the duration of the lease. The estimated cost of rebuilding the parking garages was estimated to be $550 million over the duration of 99-year lease. By the end of the lease period, the garages must be transferred back to the city of Chicago in a condition “not materially worse” than at the beginning of the lease.

Table B-6 – Chicago On-Street Parking Concession Agreement

Year	December 2008
PPP Type	Long Term Lease
Description	The city of Chicago leased 36,000 on-street parking spots to Chicago Parking Meters (CPM) for the amount of $1.157 billion.
Duration	75 years
Institutional Arrangement	Prior to selecting CPM, the city negotiated with several bidders to establish the duration of the lease, the type of meter technological improvements that had to be implemented, the hours of operations and the rights that the city would retain. The city also gave bidders a proposed meter rate increase schedule that was later enacted as part of the concession agreement. According to signed agreement, CPM is responsible for the maintenance and operations of the entire network. Maintenance provisions also stipulate that CPM has to periodically upgrade the coined-based meter system. The city of Chicago further reserved the right to intervene in on-street parking system in the following ways: • Revise meter rates, locations and hours of operation • Add additional on-street parking or eliminate parking spaces • Restrict metered parking due to exceptional situations If the city intervenes, the contract stipulates the city must then reimburse any loss of revenue that may result from its intervention. The city also has the responsibility to establish, maintain, and undertake procedures for the enforcement of parking rules and regulations designed to deter parking violations, although CPM also has the right to issue tickets in accordance to the city’s standards.

10.2. PUBLIC-PUBLIC PARTNERSHIPS (PUPPS)

A Public-Public partnership (PuPP) is a partnership between a government body or public authority and another such body or a non-profit organization to provide services and/or facilities. Similar to Private-Public Partnerships, Public-Public Partnerships are usually developed to facilitate access to funds required for the development of new infrastructure or operation of existing infrastructures.

The following are examples of transportation projects in which government entities used PuPPs to finance project needs:

- **I-80 Lease, Pennsylvania** – In 2007, the General Assembly of Pennsylvania passed an act to bridge a transportation funding gap. The act increased tolls on the Pennsylvania Turnpike and leased Interstate-80 to the Pennsylvania Turnpike Commission, an independent agency of the Commonwealth of Pennsylvania. In returned for the lease, the Commission requested and obtained the approval of the FHWA to toll I-80, with the intent to use the tolls collected to pay the lease to PennDOT and maintain and reconstruct the facility as needed.

- **Texas State Highway 121** – In 2007, the Texas DOT (TxDOT) entered into a tentative Private-Public Partnership with Cintra, a Spanish-based company, which was supposed to design, build and operate the remaining segments of Texas State Highway 121. In exchange for the toll collected, Cintra was supposed to make an upfront payment of $2.1 billion and a $700 million payment over the life of the contract. However, the deal was cancelled due to political opposition. Following this cancellation, the legislature pushed for a deal with the North Texas Tollway Authority (NTTA), which had previously expressed interest in the project but had withdrawn from the consideration. This case is noteworthy due to the level of involvement from members of the political spectrum, and the fact that the Texas Senate passed a bill that created favorable conditions for regional toll authorities to enter into agreement with TxDOT to construct and operate regional toll projects in their respective counties.

- **10th Street Connector Project, Greenville, North Carolina** – This project featured a partnership between the North Carolina Department of Transportation (NCDOT), City of Greenville, Pitt County Memorial Hospital, and East Caroline University. Initially, NCDOT was going to be the sole source of funding for the construction of the connector. However, the proposed connector was too narrow in comparison to the one envisioned by the City which, along with multimodal features and streetscape, would serve as the gateway to Greenville. With the help of the hospital and the university, the City funded a study that justified a wider cross-section and funded the subsequent planning, design, additional right-of-way acquisition, and streetscape elements required for the expanded project. Construction is set to begin in 2013. Upon completion of the project, the roadway will come under NCDOT jurisdiction. Prior to that date, Greenville will be responsible for the roadway's maintenance and operations.

10.3. POTENTIAL INFLUENCE OF PARTNERHIPS ON SMART PARKING SYSTEM FEATURES

Table B-7 indicates how PPPs and PuPPs can influence the components of a Smart Parking system. The table highlights impacts based on the type of entities seeking a partnership. The goal here is not to assess the legitimacy or appropriateness of a hypothetical PPP agreement, but simply to present how such agreements may affect a particular project. For transit-based Smart Parking projects, the most likely sought partnerships are those involving partnership between a public lot owner and public partner or public lot owner and private partner.

Table B-7 – Potential Impacts of Partnership Agreements on Smart Parking Projects

	Public Partner	Private Partner
Public Lot Owners	• A PuPP agreement could give transit agencies access to right of way needed to display CMS information. Such access could influence the number or features of the signage system deployed as part of a Smart Parking project	• Public agencies owning parking facilities could partner with private companies to provide services that they could not otherwise. For example, a public agency could provide real-time parking availability information to a private company in return for the company providing a reservation, online payment, or other relevant services. In this case, the partnership would essentially entail the transferring of information between different types of entities.
Private Lot Owners	• Enforcement methods available to private companies are often limited in comparison to methods available to state agencies. States typically have a more extensive enforcement apparatus and the ability to access information often off-limits to private companies such as license plate records, a type of information highly relevant for license plate recognition systems. In this context, a PPP could broaden the enforcement system alternatives available to the private sector and improve the effectiveness of operation of a particular Smart Parking project. • By partnering with public agencies, private lot operators may get access to public spaces where they could display parking availability information. This could influence the signage system configuration. • Public agencies may be interested in integrating facilities owned and operated by private companies into the regional ITS architecture to create a Smart Parking system.	