Title

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Final Report for Task Order 6116

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Abstract

This report summarizes a field evaluation project involving investigation of the feasibility of using RFID technology to record vehicle and traveler activities at transit parking lots and at the station entrance. The report presents the field test results collected at a Bay Area Rapid Transit (BART) station, the analyses on the reliability RFID technologies for correlating parking events to station entries and observations on whether travelers accept RFID concept. The study concluded that, under certain design constraints, RFID can be utilized for parking management applications. The report also made recommendations for further investigations.

Keywords: RFID, Advanced Parking management

Executive Summary

Radio Frequency Identification (RFID) technologies can be used for vehicle identification, which had great potential for automated parking management. Under the sponsorship of the California Department of Transportation (Caltrans), the California PATH Program, in partnership with SoftLogistics, ParkingCarma and the Bay Area Rapid Transit District (BART), conducted a small field test to investigate the feasibility of using RFID technology to record vehicle and traveler activities at passenger train parking lot and at the station entrance. The focus of this project was to evaluate through field testing whether RFID technologies can reliably correlate parking events to station entry and to observe whether travelers accept RFID concept. We have selected the Lafayette BART station in the East Bay as the test site.

The testing system includes vehicle detectors consisting of a RFID reader placed at either the entrance of the parking lot or above the ticket machine at the BART entrance and a data acquisition computer. A total of 20 pairs of RFID tags are distributed. The 'vehicle tags' are to be placed at the front bumpers and the travelers are advised to hold the 'people tags' when passing through the BRT entrance.

Two sets of tests were conducted, including verification tests conducted at the University's Richmond Field Station and field test at Lafayette BART station. The verification tests were conducted under a controlled environment to validate the performance characteristics of the tested RFID system using two different types of tags for both vehicle detection as well as rider identification for transit parking application. The field testing facilitated a good understanding about the application issues of the RFID system. The test results are reported in the report. We have concluded that RFID technology using passive tags can meet the needs of parking management when tags are chosen properly based on the characteristics of the parking entrances.

Further development efforts are recommended to (1) define the requirement specifications for passive RFID reader/tag system for meeting the needs of various parking management applications, including the consideration of a wide range of characteristics of various parking entrance layouts, (2) investigate available RFID tags to determine which types of RFID types are appropriate for which applications, and (3) conduct larger scale field operational testing to validate the reliability of the RFID system and to seek ways to improve the reliability to an acceptable level by transit agencies.

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1. Introduction

Automated administration and management of transit parking facilities are of interest by many. In transit stations, drivers demand fast and convenient transition in and out of parking facilities. In university campuses and medical facilities, various parking privileges are assigned to students, faculty, patients, and doctors. In downtowns and other activity centers, drivers want to quickly find an available space in congested traffic. Parking operators want to efficiently manage the parking facility in order to maximize the revenue and facility utilization.

Despite the advancement of automated vehicle detection technologies, management of parking facilities today is to various degrees done manually. For example, at BART stations, transit patrons need remember their space number and either pay or register this number at a ticket machine inside the station. The parking management relies on the parking number entry. Often transit patrons forget to remember the parking number, and would have to go back to the parking location again to obtain the parking space number. Transit riders may also forget to enter the parking space, which would cause inaccurate parking occupancy statistics until enforcement personnel validates the occupancy. Not entering the parking space number also would result in issuing a violation citation to those who actually use transit. If vehicle identification technologies are used, this extra step to the process can be removed. It not only helps to reduce the complexity of the parking process for patrons but also makes the parking management system more reliable. A comprehensive parking management system can increase the efficiency of parking facilities and encourage drivers from the car to public transit.

Radio Frequency Identification (RFID) technologies can be used for vehicle identification. A more detailed description of RFID technologies is provided in Appendix II. One of the important features that distinguish different RFID technologies is the tags. Examples of RFID tags are active tags such as those that are used for highway toll collections and the passive tags. The RFID tags could provide a viable alternative for passenger identification until the EasyRider cards are in full operation. We chose to use passive RFID tags for its low cost and ease for widespread applications.

This small scale field testing project is conducted by the California PATH Program under the sponsorship of California Department of Transportation (Caltrans), in partnership with SoftLogistics, ParkingCarma and BART, to investigate the feasibility of use of state-of-the-art

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RFID technology to track and manage a parking facility. The focus of this project is to evaluate through field testing whether RFID technologies can reliably correlate parking events to station entry. As part of this feasibility study, as RFID is in essence a short range communication system (from tag to reader) and the tags plays a key role in the overall performance, the project team intended to evaluate the appropriateness of selected RFID tags and to determine the detection range using these tags. BART expressed interest in RFID as an interim technology to correlate patrons parking in BART parking lots to those actually entering the station and taking the trains. We have selected the Lafayette BART station in the East Bay as the test site, which provided a more viable use of the technology in a real application.

2. RFID Field Testing

2.1Test Site at BART Lafayette Station

In order to test the ability of the RFID to identify cars entering the parking facility and individuals entering the station, the San Francisco Bay Area Rapid Transit District (BART) was identified. The Lafayette station was selected for the test demonstration. The station contains two parking areas, separated by the elevated platform in the center median (see Figure 1 below). The south parking lot, marked in shade in Figure 2, is a self-contained lot of about 80 spaces and allows for the test to be done in a controlled manner.

Figure 1 BART Lafayette Station

2.2 Business Scenario

The BART parking lots are designated for BART patrons only. BART is consistently working to ensure these spaces are available to BART riders and not adjacent uses. The BART system is currently charging for parking at many of its stations. There are a variety of pricing scenarios from monthly (identified by a sticker on the car) to daily reserved and daily fees.

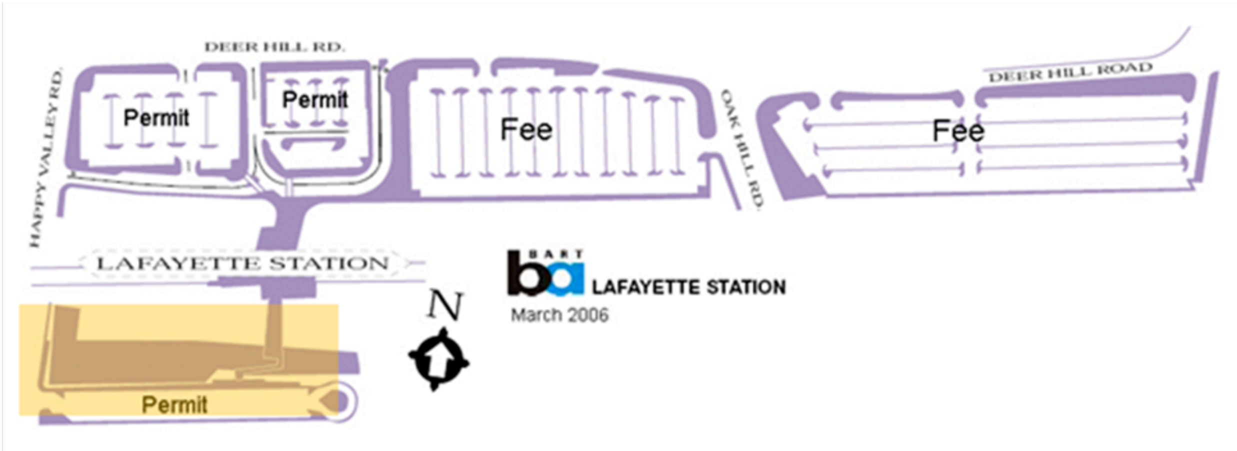


Figure 2 Parking Lots at BART Lafayette Station

The monthly reserved parking permit at Lafayette is $84, which guarantees a space within a designated parking area close to the station Monday through Friday until 10 a.m. The daily parking fee of $1.00 for all spaces is required Monday through Friday from 4:00 a.m. to 3:00 p.m. In order to validate parking, BART patrons must remember the stall number, enter it into the parking validation machine inside the station, and pay using a BART ticket or with cash.

BART is in the process of developing a fare card, EZ Rider, currently in testing by selected riders. In addition, a regional transit card, TransLink is also in test mode. BART is interested in an interim solution that would streamline the parking experience for BART riders while ensuring those parking in the lots are actually riding BART. The current system is time consuming and requires extra steps. The RFID demonstration test addresses the interim parking fee payment for BART.

This research project is designed to identify how the RFID Parking Management System could be used in the BART environment. It tested vehicle identification linked to parking validation. The RFID readers were placed at the entrance to the parking lot and at the entrance to the BART station. Patrons placed identical RFID tags on the vehicle and carried one through the fare gates. The RFID tags are automatically registered through the system. Once the system was actually deployed, parking payment would be linked to the tag in the pre-paid system similar to FasTrak.

2.3 The Testing System

2.3.1 RFID Based Parking Management System

The IDAccess™ RFID Parking Management System developed by SoftLogistics LLC is used in the field testing. The following is a schematic diagram for the installation of the system. The system consists of:

1) Control Station (a PC or Laptop);
2) An RFID reader;
3) One or two RFID antennas; and
4) A vehicle RFID tag on each vehicle and a person RFID tag for each BART patron (see Figure 3 IDAccess™ RFID Parking Management System).

The antenna is connected with the RFID reader with a special cable provided by SoftLogistics. And the Reader and the Control Station will be connected with a standard Ethernet CAT5 cable. Since there is no gate at the parking lot selected for the test at Lafayette station, the access control component is not installed. That is so the system does control the open or close of a gate. There are two readers, one installed at the entrance of the parking lot with an antenna at the side; and the other installed at the BART station with an antenna overhead at the ceiling of the BART station entrance.

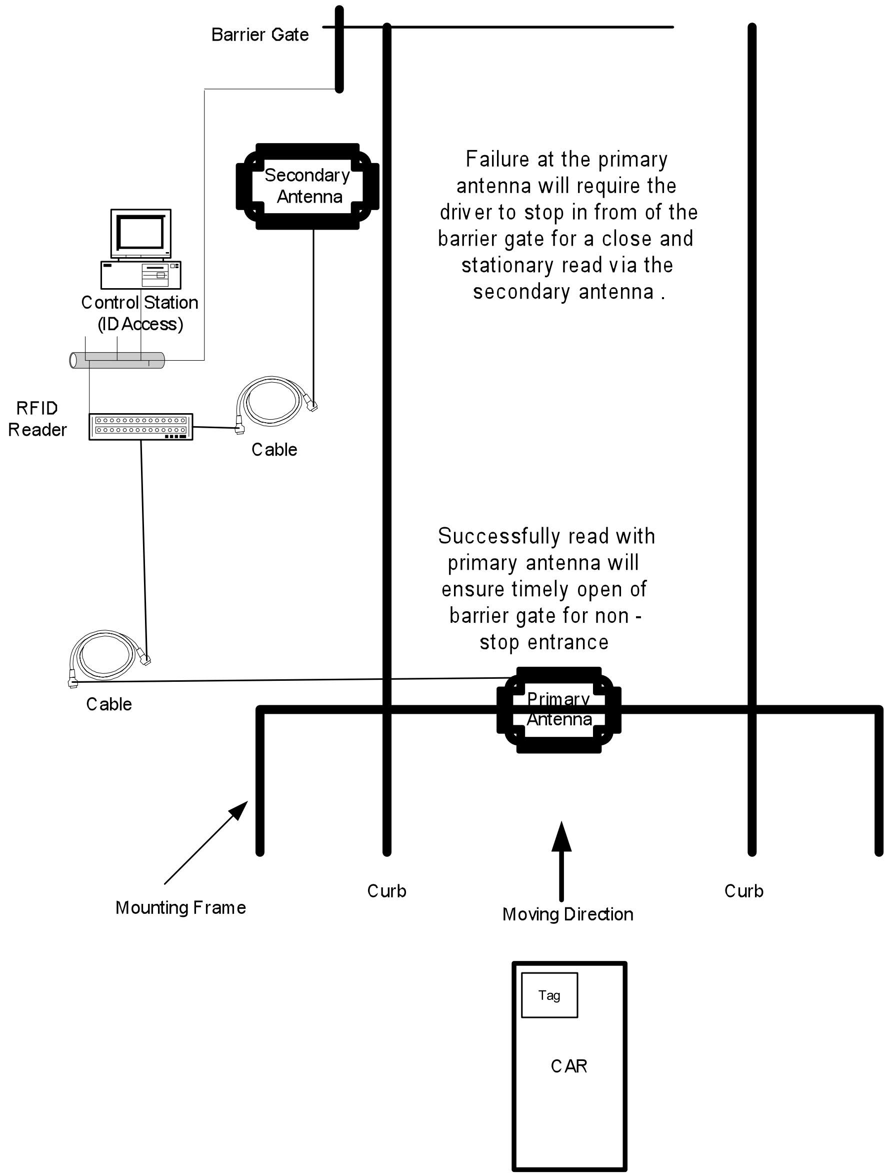


Figure 3 IDAccess™ RFID Parking Management System

2.3.1.1 Reader

The two readers we used for this research are Symbol XR-400 readers. They are EPC GEN2 UHF long range readers (see Figure 4). XR-400 reader reads all EPC GEN2 compliant tags.

Figure 4. Symbol XR 400 RFID Reader

One of the readers is installed at the entrance of the parking lot. The reader and its antenna are mounted on a CMS at the entrance (see Figure 5). The CMS also provides power for the reader and a laptop computer that controls the reader and runs the RFID Parking Management application software. There is only one entrance for that parking lot. All vehicles coming in with a vehicle tag will be read by this reader.

Figure 5. RFID Reader At the Entrance of BART Lafayette Station Parking Lot

The other reader is installed at the entrance of the BART Lafayette station (see Figure 6 below), mounted within a plastic electronic enclosure. The station lighting power is used to supply power for the reader and a laptop computer installed within the enclosure.

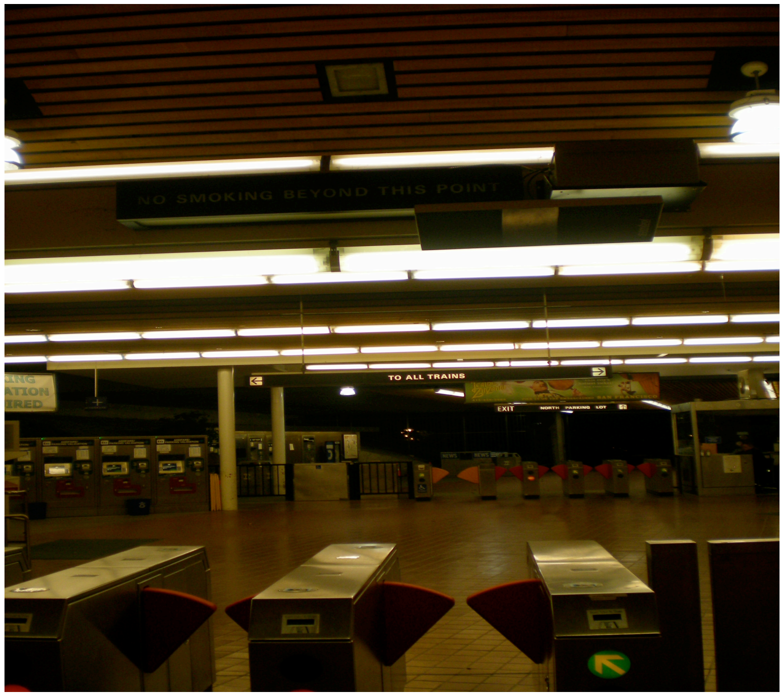


Figure 6. RFID Reader At the Entrance of BART Lafayette Station
(Reader and Its Antenna are mounted on top of the entrance near the ceiling)

This reader reads all BART riders with a person tag as they enter the BART station. Whenever a person tag is read, the system will search for the associated vehicle tag. When the vehicle tag is found, the parking space of the associated vehicle is validated. There is no need to remember the stall number, or go through the process to manually validate the parking space every day.

2.3.1.2 Tags

The test system uses vehicle tags to identify vehicle, and person tag to identify the BART patron. The system will automatically associate the vehicle tag and the person tag, therefore validate the parking at BART parking facilities by BART patrons. Figure 7 (a) shows a vehicle tag. It needs to be placed on the vehicle that a patron drives to the BART station. The recommended location to place the tag is the right side of the front bumper. Figure 7 (b) shows a person tag. A BART patron needs to show this tag whenever she enters the BART station, to validate her parking.

The tag inlay embedded in each vehicle tag or person tags is either an Alien generic EPC Class 1 GEN 2 tag inlay, or Omni-ID specialty tag.

Figure 7. (a) a Vehicle Tag and (b) a Person Tag

The Alien tag inlay used for vehicle and person tags is ALN-9540 - "Squiggle™" tag inlay, manufactured by Alien Technology for EPC Class 1 GEN 2 standard tags (see Figure 8). Its read range is 10 feet or longer depending on the environment. It is widely used in Mal-Mart and DoD RFID deployment, for package and case level asset tracking in the supply chain.

Figure 8 Alien ALN-9540 - "Squiggle™" Passive RFID Tag Inlay

Omni-ID Max, shown in Figure 9, is a tag that is specifically tuned for applications requiring longer read range and with RFID unfriendly materials. Its claimed read range is 40 feet. It can work with metal, so that the tag will work with vehicles with metal bumper. It can also work with water. They can be used as person tags to provide reliably read when placed very close to a human body, a large part of which is water.

Figure 9. Omni-ID Max Long-Range Passive UHF RFID Tags

2.3.1.3 Software

IDAccess™, an RFID Parking Management System, is the software used for this research. It is provided by SoftLogistics LLC, an RFID System Integrator, with customization for person tag and vehicle tag matching to perform automatic parking validation.

Figure 10 shows the high level architecture of the IDAccess™ software. Its lowest layer is the device broker, which talks directly with RFID readers and other devices. On top of the device broker is the RFID framework, which provide infrastructure to quickly develop robust RFID applications. RFID Parking Management System is a specific application developed on top of the RFID framework.

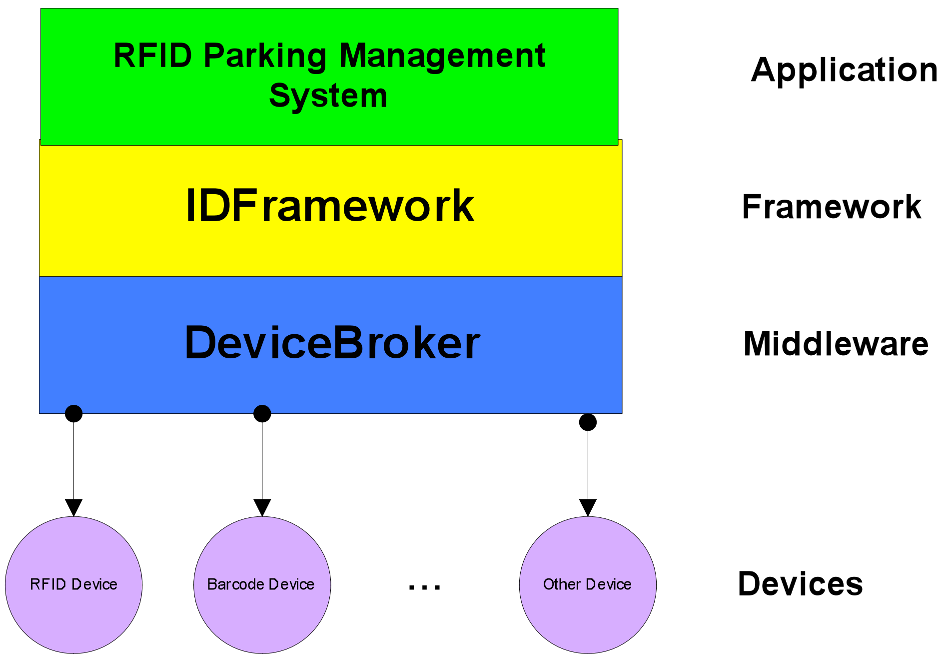
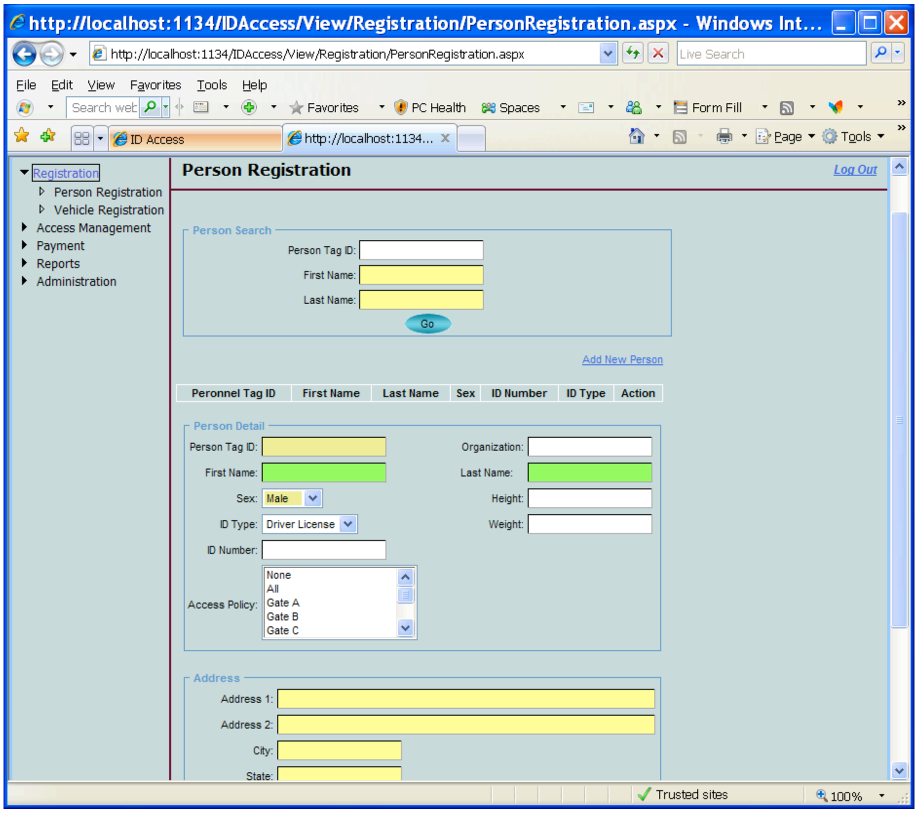


Figure 10 IDAccess RFID Parking Management System Software

IDAccess™ RFID Management System has three major components: 1) A Local Service component, which installed on the local computer and communicate with the reader; 2) A Web Application component, which has a registration module for registering vehicles and persons, an access processing module for validation, and a payment module; and 3) a central database. Figure 11 Shows snapshots of the web interface.



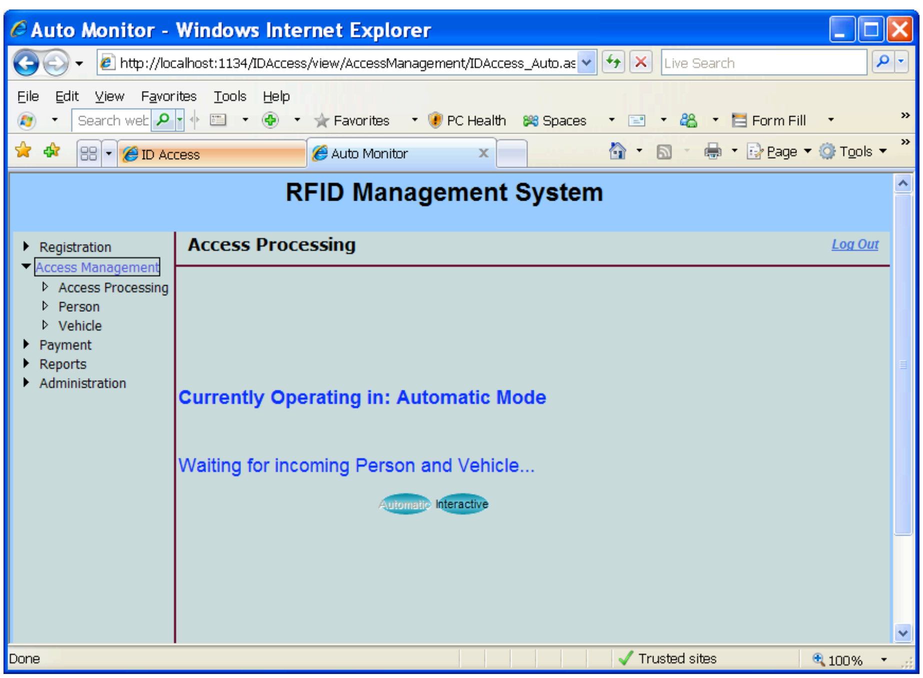


Figure 11 Snapshots of IDAccess™ RFID Management System Web Interface

2.3.2 Vehicle Counters

The Lafayette BART parking lot used for demonstration purposes has approximately 200 spaces, and fills each day by 7 am. In addition, about 150 cars enter and exit the lot each day dropping off riders. There is no overnight parking allowed at this lot.

A sensor-based vehicle counting system was installed at the entrance of the parking lot. While the counting system was not correlated one-to-one with the RFID reader, it provided some insight into how the integrated systems could be used in future applications.

Wireless lane sensors were placed at the entrance of the south Lafayette parking lot to capture vehicle entry and exit information, estimating lot occupancy and fill rates. The vehicle entry and exit information and the lot occupancy information complement the individual vehicle information captured by the RFID reader. The data collected with the vehicle detection sensors can be useful for understanding lots and monitoring behavior. For example, it provides data that can augment the RFID information in lots where parking payment is collected.

The ParkingCarma Parking Information Network (PIN) can be used to communicate with the wireless vehicle detector. The PIN uses an open design which allows quick scalability of data collection and management in different settings with different equipment. The vehicle detectors are just one component of a larger system. Other sensing equipment and a reservation system are also included in the PIN, which were not employed during this demonstration project.

3. Testing Results

Tests were conducted to evaluate the applicability of RFID technology for the parking validation process of an automated parking management system. Two sets of tests were conducted, including verification tests under a controlled environment and field tests at BART stations, in order to determine the performance of the selected tags and to produce design parameters for the RFID based parking management system.

The results of the two sets of tests are reported below. The sensitivity and reliability of the tag/reader system to distance and speed were tested.

3.1 Tests under Controlled Environment

The tests under a controlled environment were conducted at Richmond Field Station, where RFID reader was set up at an angle toward the vehicle path. The instrumented vehicle was driven following a trajectory at various distances between reader and the tag trajectory *d,* as shown in Figure 12.

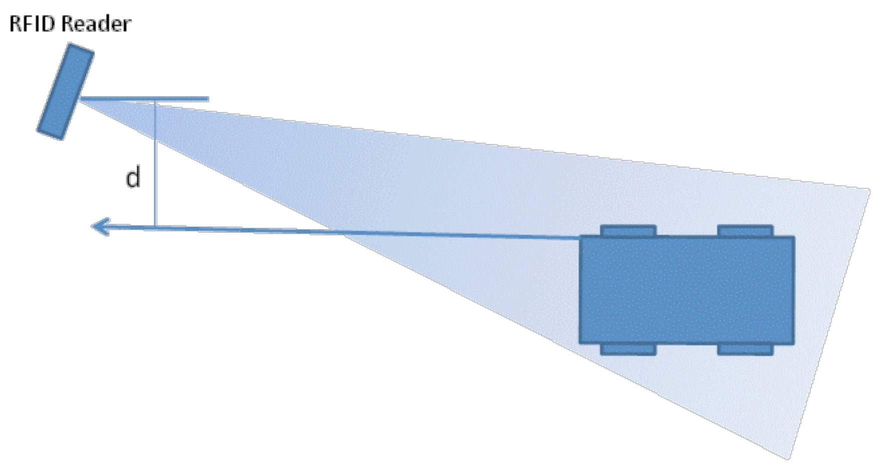


Figure 12 Schematic of the Testing Setup

Tables 1 and 2 show the test results for 100 runs under each case. Reliable readings can be achieved within 5 MPH and 10 ft of distance *d*. With Omni-ID tags, reliable readings can be achieved within 15 MPH and 15 ft of distance *d*.

Table 1. Reading Statistics for Alien Tag

Speed/Distance	4 ft	8 ft	10 ft
5 mph	100%	100%	96%
10 mph	92%	56%	Mostly failed
15 mph	Mostly failed	Mostly failed	Mostly failed

Table 2. Reading Statistics for Omni-ID Tag

Speed/Distance	8 ft	15 ft	20 ft
5 mph	100%	100%	60%
10 mph	100%	100%	Mostly failed
15 mph	100%	100%	Mostly failed
25 mph	100%	95%	Mostly failed

The test results indicate that the performance of the RFID readings depends on the distance between the tag trajectory and vehicle approaching speed, which are very much affected by the entrance types and lane/speed markings. For entrances that vehicle trajectory and speed are constrained by the entrance (e.g., a narrow entrance with speed bumps), low cost tags such as the Alien tag will work fine. However, if the entrance is wider and the entrance speed is higher, better performance tags such as Omni tags are necessary. The tests under a controlled environment concluded that RFID can be designed for parking application by choosing appropriate tags based on the layout of the entrance of a parking lot.

3.2 Tests at BART Lafayette Station

The field tests were conducted at the entrance of the south parking lot of BART Lafayette station. The BART Lafayette station has only one entrance and lane marking is not every visible. The vehicle RFID reader was installed at the entrance of the parking lot. Another RFID reader is installed at the station above the passenger entrance to collect passenger entrance data. As the tests under controlled environment have already provided a quantitative evaluation of how well the system can work, the objective of this field test is to see how well BART riders accept the RFID concept.

RFID tags were distributed by the project team at the entrance of the south parking lot at BART Lafayette station. Because of project is intended to be a feasibility study, no specific goals were set for the number of tags to be distributed or for the types of recipients. During a 3 day period, a total of 20 sets of Alien RFID tags were distributed to BART patrons prior to the test. An instruction sheet was given to the users when the tags were distributed. The tag recipients were advised to adhere vehicle tags onto the right corner of their car bumper. They were also advised to hold the rider tag above their waist as they enter the station. The instruction for how to use the

RFID tags is provided in Appendix I. Due to the nature of this test, how many recipients of these tags actually put them on the vehicle and whether they use both tags in sequence as advised were unknown. It is worth noting that our preferred choice for vehicle tags are the Omni-ID max long-range passive UHF RFID tags, which can work much better than the Alien RFID tags. However, because of the difficulties in obtaining the Omni tags during the planned test period (they were ordered but were received two weeks after the scheduled field test starting date), the Omni option was not viable.

3.2.1 Test Records of Vehicle Tag Readings

Table 3 provides detailed daily reading activities at the entrance of the parking lot. The reader recorded the first vehicle tag read at 23:33 May 21, 2008, and last vehicle read at 18:09, June 24, 2008. During the installation, the system has been trial tested prior to switching to automated mode. The system has been tested during the field testing and again after completing the field tests. The 'prior', middle' and 'after' verification testing show that the system functioned as expected and that the quality of readings were consistent with that obtained from the testing under controlled environment.

Table 3. Read Activities at the Entrance of the Parking Lot

Date	Unique Tags Read	First Read Time	Last Read Time
5/21/08	610345333690	23:33	23:33
5/22 – 5/25			No Activities
5/26/08	2DAD3F846A5E3FDBB2364CE3	4:41	4:41
5/27-5/28			No Activities
5/29/08	610345333280	8:42	8:42
5/30 - 6/1			No Activities
6/2/08	610345333280	8:43	8:43
6/3/08	610345333280	8:48	8:48
6/4 – 6/6			No Activities
6/7/08	E2003411B802011252129347	22:20	22:34
6/8/09			No Activities
6/9/08	0C210531606173972202161F	23:33	23:33
6/10 – 6/13			No Activities
6/14/08	F30DD075DFB4FCE4	16:10	16:10
6/15 – 6/23			No Activities
6/24/08	E2003411B802011311173681	18:09	18:09

The results show that during the entire one month testing period, only 9 records were recorded, among which three entries belong to one vehicle and the additional 6 records were taken for 6 vehicles, with one entry per vehicle. Because the three separate verification tests throughout the testing period show that the system functioned properly for the entire testing period, the analysis of the reason for the low number of the readings pointed toward two application issues:

1) The way that the selected Alien RFID tags are designed is not appropriate for vehicle application. For this temporary field testing, we required drivers to stick a RFID tag onto the right corner of the front bumper. Although the adhesive on the RFID is not of permanent type, many people may not like to put a sticker on the car bumper. Also because of the weak adhesive, if one did not clean the bumper before putting the RFID tag on, it could come off within a matter days.

2) The readability of the Alien tag is such that it works reliably within 8 feet between the trajectory of the right vehicle bumper where the RFID tag locates and the RFID reader and the vehicle traveling speed is within 5 mph. This implies that, assuming the tags are installed at the right corner of the bumper, vehicles must use right side of the entrance at very low speed. However, because the lane marking at the entrance of the south parking lot at Lafayette BART station is not visible, many drivers, particularly those who make a left turn to the parking lot, tend to drive in the middle of the entrance. Furthermore, although we advise drivers to put the RFID tags on the right corner, there is a possibility that the drivers would put it anywhere on the bumper, resulting in a larger distance to the RFID reader. These factors reduce the chance that the tags are reliably read.

These two issues may explain the low numbers of readings at the parking lot entrance. Despite the light reading activities, the field tests combined with the tests under controlled environment show that RFID can work for the parking application. However, the selection of the RFID type will have to be based on the characteristics of the parking entrance. For the two types of the RFID we tested, Alien RFID can work well when parking entrance is narrow and well confined, where Omni RFID tags should be chosen if the parking entrance is open and the variation of the vehicle entering trajectory is large.

3.2.2 Test records at BART Station Entrance

A RFID reader was installed at the south entrance of the Lafayette BART station, above the gate. The detailed installation is provided in section 3.3.1.1. The reader recorded the first successful read at 0:10 on May 22, and the last successful read at 17:47 on July 7, during the pilot period between May 15 and July 7. Table 4 provides detailed daily read activities at the entrance of Lafayette BART station.

Table 4. Read Activities at the Entrance of BART Station

Date	Unique Tags Read	First Read Time	Last Read Time
5/22/08	610345333690	0:10	0:10
5/23 – 5/27			No Activities
5/28/08	610345333661 610345333156 610345333280 610345333283 610345333674	7:57	9:03
5/29/08	610345333157 610345333158 610345333284 610345333289	7:19	10:34
5/30/08	610345333157 320D774D800 (new tag or outside tag)	7:40	12:53
6/1/08			No Activities
6/2/08	610345333155 610345333664 610345333236 34360141E800000800BAD343 34360141E800000800BAD9A0 610345333158	7:57	17:54
6/3/08	610345333158	8:50	8:50
6/4/08	610345333671 610345333158 610345333128	8:04	18:12
6/5/08	610345333158 OC2105777000002202157F	12:37	17:46
6/6/08	610345333155 610345333128	8:00	10:03
6/7/08	E200341138020 610345333347	22:12	22:12
6/8/08			No Activities
6/9/08	6103453333155	8:16	8:16
6/10/08	6103453333155 6103453333158	8:07	8:07
6/12/08	6103453333155 6103453333299	8:06	8:51
6/13/08	6103453333155 6103453333158	7:47	7:47
6/14/08			No Activities

6/15/08			No Activities
6/16/08	6103453333155 6103453333158	8:48	18:23
6/17/08	6103453333155 6103453333158	9:04	9:05
6/18/08	6103453333155	8:34	8:34
6/19-6/23			No Activities
6/24/08	6103453333155 E200341138681	17:21	18:06
6/25/08	6103453333155	7:34	7:34
6/26/08			No Activities
6/27/08			No Activities
6/28/08	0C2105020524292922O2180F	10:50	10:50
6/30/08	0C2105061851024122O2116F	18:37	18:37
7/1/08	0C2105301695420022016700	10:06	10:06
7/2/08	34360141E80000080341065B	13:43	13:43
7/3-7/6			No Activities
7/7/08	495430303030323739363335	17:47	17:47

'Before' and 'after' verification tests indicate that the equipment performs properly during the entire testing period. A total of 47 readings were collected by 16 people. A few BART patrons (such as Person Tag xxx55 and Person Tag xxx58) had been consistently participating in the pilot during the whole pilot period. Note that the numbering of the tags can be either numbers or letters and do not have a specific meaning.

3.2.3 Test records of the Vehicle Counter at BART Station Entrance

The vehicle counter system instrumented by ParkingCarma intends to demonstrate the ability to measure, monitor, and distribute the load occupancy of parking locations. This system is designed to capture real-time vehicle count data over time to support parking pricing decisions. Because of the demonstration nature of the program, the tested system was connected with a communication system therefore the data collection is stored in a computer.

Table 5 and Figure 13 provide one-day sample data set. Because the counter system may not detect bicycles and motorcycles, the total vehicle count (marked in shade) went beyond 100% during the morning commute hours. While the counts are not 100% accurate, they do provide a view of the potential of the vehicle counter system. Combined with reservation technology and the RFID system, they would be able to provide an accounting of the parking lot occupancy.

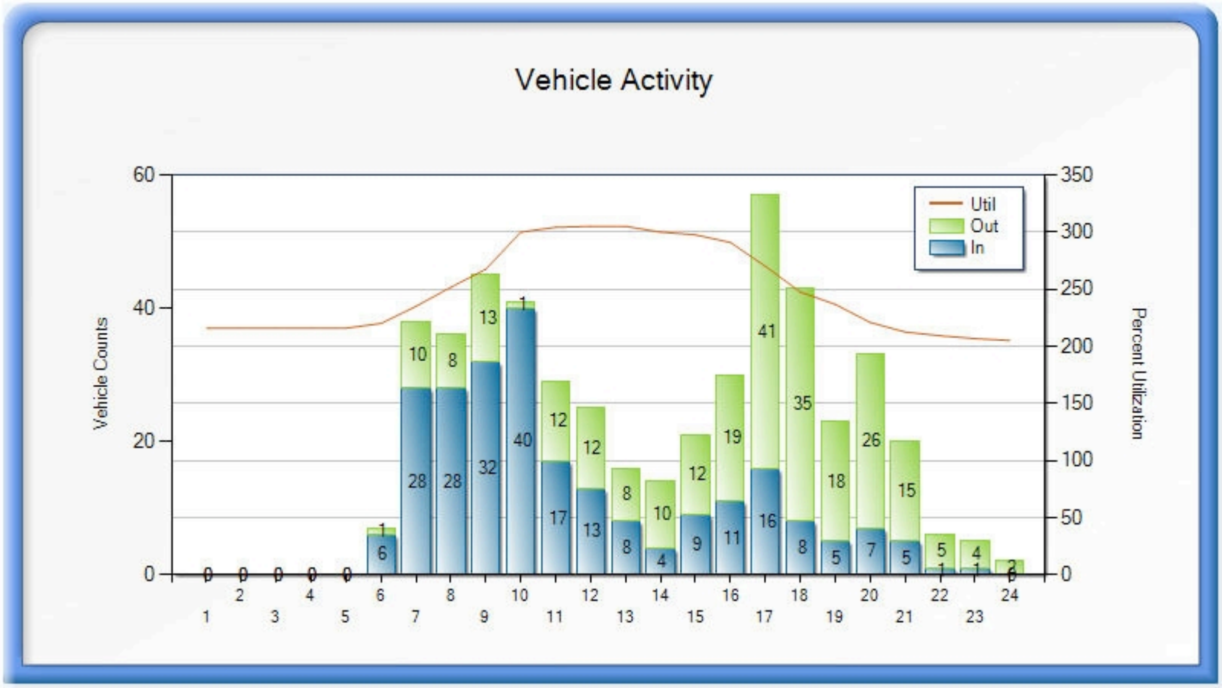


Figure 13 Cumulative Parking Activity

Table 5. Parking Lot Occupancy

Site	Laf		
Space	235		
Train	Net Adds	Occupancy	Fill
4:00	3	3	1%
4:15	35	38	16%
4:30	22	60	26%
4:45	35	95	40%
5:00	25	120	51%
5:15	50	170	72%
5:30	15	185	79%
5:45	5	190	81%
6:00	5	195	83%
6:15	10	205	87%
6:30	20	225	96%
6:45	-	225	96%
7:00	2	227	97%
7:15	-3	224	95%
7:30	5	229	97%
7:45	3	232	99%
8:00	-4	228	97%
8:15	-	228	97%
8:30	2	230	98%
8:45	-3	227	97%
9:00	5	232	99%
9:15	3	235	100%
9:30	-4	231	98%
9:45	-	231	98%
10:00	-	231	98%
10:15	2	233	99%
10:30	-3	230	98%
10:45	5	235	100%
11:00	3	238	101%
11:15	-4	234	100%
11:30	-9	225	96%
11:45	-	225	96%

Train	Net Adds	Occupancy	Fill
12:00	2	227	97%
12:15	-3	224	95%
12:30	5	229	97%
12:45	3	232	99%
13:00	-4	228	97%
13:15	-	228	97%
13:30	2	230	98%
13:45	-3	227	97%
14:00	5	232	99%
14:15	3	235	100%
14:30	-4	231	98%
14:45	-	231	98%
15:00	2	233	99%
15:15	-3	230	98%
15:30	5	235	100%
15:45	3	238	101%
16:00	-4	234	100%
16:15	-	234	100%
16:30	2	236	100%
16:45	-10	226	96%
17:00	5	231	98%
17:15	-30	201	86%
17:30	5	206	88%
17:45	-50	156	66%
18:00	6	162	69%
18:15	-20	142	60%
18:30	-5	137	58%
18:45	-15	122	52%
19:00	-5	117	50%
19:15	-15	102	43%
19:30	-5	97	41%
19:45	7	104	44%

Train	Net Adds	Occupancy	Fill
20:00	-1	103	44%
20:15	2	105	45%
20:30	3	108	46%
20:45	-20	88	37%
21:00	-5	83	35%
21:15	-15	68	29%
21:30	-5	63	27%
21:45	-15	48	20%
22:00	-5	43	18%
22:15	-20	23	10%
22:30	-5	18	8%
22:45	-5	13	6%
23:00	-	13	6%
23:15	-5	8	3%
23:30	-5	3	1%
23:45	7	10	4%
0:00	-1	9	4%
0:15	-5	4	2%
0:30	-5	-1	0%
0:45	-2	-3	-1%
1:00	-2	-5	-2%
1:15	-4	-9	-4%
1:30	-1	-10	-4%
1:45	2	-8	-3%
2:00	-1	-9	-4%
2:15	2	-7	-3%
2:30	3	-4	-2%
2:45	-4	-8	-3%
3:00	-1	-9	-4%
3:15	2	-7	-3%
3:30	3	-4	-2%
3:45	-4	-8	-3%
4:00	-1	-9	-4%

4. Concluding Remarks

The small scale testing conducted under this project has demonstrated the potential of RFID technologies for parking management. The testing under a controlled environment validated the performance characteristics of the tested RFID system using two different types of tags for both vehicle detection as well as rider identification for transit parking application. The field testing, on the other hand, facilitated a good understanding about the application issues of the RFID system. Through this study, we have concluded that RFID technology using passive tags, when tags are chosen properly based on the characteristics of the parking entrances, can meet the needs of parking management.

Further development efforts are recommended to (1) define the requirement specifications for passive RFID reader/tag system for meeting the needs of various parking management applications, including the consideration of a wide range of characteristics of various parking entrance layouts, (2) investigate available RFID tags to determine which types of RFID types are appropriate for which applications, and (3) conduct larger scale field operational testing to seek ways to improve the RFID reliability to acceptable levels by transit agencies and to design RFID applications based on the needs of transit agencies for advanced parking management.

Appendix I Parking RFID Users Guide

RFID Lafayette Parking RFID Demonstration
May 26-June 6, 2008

Thank you for volunteering to test the innovative use of the RFID technology through a University of California Research Demonstration at the Lafayette BART station.

The purpose of the research is to test whether the RFID technology can match a car to a person entering the station. If this works, it may be implemented to allow BART riders to enter the station and pay for parking without remembering specific space numbers. It can also be used to provide parking availability information. The demonstration is sponsored by California Department of Transportation (Caltrans), BART, UC Berkeley, SoftLogistics LLC and ParkingCarma.

Here is how the demonstration works:

In the envelope, there are two tags: one is placed on the car bumper (it is easily removed) and the other is carried into the station.

Installing the vehicle tag

1. Place the vehicle tag on the right side of the front bumper.
2. As you enter the parking lot, the RFID tag is identified by the reader located at the entrance of the parking lot.
3. The sticker is designed to be temporary and will not affect the paint on the car.

Displaying the personal tag

1. The rider tag is displayed as you enter the BART station.
2. Hold the tag above your waist as you enter the station.
3. After inserting the BART ticket and the gate is open, hold the rider RFID and walk through the middle entrance.
4. The tag reader is located near the no-smoking sign above the middle entrance.

About RFID
RFID is an automatic identification technology. An RFID parking management system consists of two readers, one located at the entrance of the parking lot and the other installed at the station entrance. Two types of tags are provided to parking patrons, including a vehicle RFID tag and a rider tag. Identification data stored on the tags can be read by the reader via radio waves transmitted through antennas.

If you have any questions, please contact BART coordinator Alan Lee at alee1@bart.gov.

Thanks so much for your participation in this research project!

Appendix II. RFID Technologies

Radio-frequency identification (RFID) is an automatic identification technology (Auto-ID) using radio waves to transmit information between an interrogator or reader and a storage device, identified as a transponder or tag. Auto-ID technology provides information about the movement of vehicles, people, goods, and products. Due to its advantages over other Auto-ID technologies, RFID technology has found applications in transportation, logistics, manufacturing industries, and service oriented industries. Examples of these applications include product identifications by major retailers such as Wal-Mart and goods verification by US Customs.

II.1 Overview of Automatic Identification Technologies

Various technologies have been developed for Automatic Identification (Auto-ID). The most widely adopted Auto-ID technologies are bar code technology, smart card technology, Optical Character Recognition (OCR) technology and RFID technology.

The Bar Code was invented in the 1950s, and was widely spread in the 1980s. For the last twenty years, barcodes have been the dominant identification system in the market. Barcodes are a binary code comprising a field of bars and gaps arranged in a parallel configuration. They are arranged according to a predetermined pattern and represent data elements that refer to an associated symbol. The sequence, made up of wide and narrow bars and gaps, can be interpreted numerically and alphanumerically. It is read by optical laser scanning, with different reflections of a laser beam from black bars and white gaps. Bar codes provide a simple and inexpensive method of encoding text information that can be easily read by inexpensive electronic readers. However, a barcode scanning laser needs a direct line of sight to the bar code, and the bar code itself needs to be reasonably clean and undamaged for the scanner to read properly.

Optical Character Recognition (OCR) was first introduced in the 1960s. Special fonts were developed for this application that stylized characters so that they could be read both in the normal way by people and automatically by machines. The most important advantage of OCR systems is the high density of information and the possibility of reading data visually in an emergency. Today, OCR is used in the production, service, and administrative fields, and as well as in banks for the registration of checks. However, OCR systems have failed to become universally applicable because of their high prices and complicated readers.

A Smart Card is a detached electronic data storage system. For convenience, it is usually incorporated into a plastic card the size of a credit card. The first smart cards in the form of prepaid telephone smart cards were launched in 1984. Smart cards are placed in a reader, which make a connection to the contact surfaces of the smart card using contact springs. The smart card is supplied with energy and a clock pulse from the reader via the contact surfaces. Data transfer between the reader and the card takes place using a bidirectional serial interface. One of the primary advantages of the smart card is that data stored on it can be protected against undesired read access and manipulation. Smart cards make all applications that relate to personal identity information or financial transactions simpler, safer, and cheaper. However, one major disadvantage of contact-based smart cards is its vulnerability of the contacts to wear, corrosion and dirt. Readers that are used frequently are expensive to maintain due to their tendency to malfunction.

RFID technology was introduced in the 1950s. In 1948, Harry Stockman presented "Communication by Means of Reflected Power" (Proceedings of the IRE, pp 1196–1204, October 1948). Stockman predicted that "…considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored." The first RFID patent (U.S. Patent 3,713,148) was granted to Mario Cardullo in the United States in 1973. The initial device was passive, powered by the interrogating signal, and was demonstrated in 1971 to the New York Port Authority and other potential users and consisted of a transponder with 16 bit memory for use as a toll device. A very early demonstration of reflected power (modulated backscatter) RFID tags, both passive and semi-passive, was done by Steven Depp, Alfred Koelle and Robert Freyman at the Los Alamos Scientific Laboratory in 1973. The portable system operated at 915 MHz and used 12 bit tags. This technique is used by the majority of today's UHF RFID tags.

RFID is the most promising Auto-ID technology for a parking management system. RFID does not require a direct line of sight to a vehicle. RFID enables an automatic and quick read as vehicles pass through the entrance or exit. Compared to Smart Card technology, RFID does not need a direct physical contact between the reader and the tag, thus the RFID tag can be placed on the vehicle and can be read while the vehicle is in motion. The no contact capability also dramatically increases the durability of the readers. RFID is the most promising technology that can provide automatic vehicle identification for parking management.

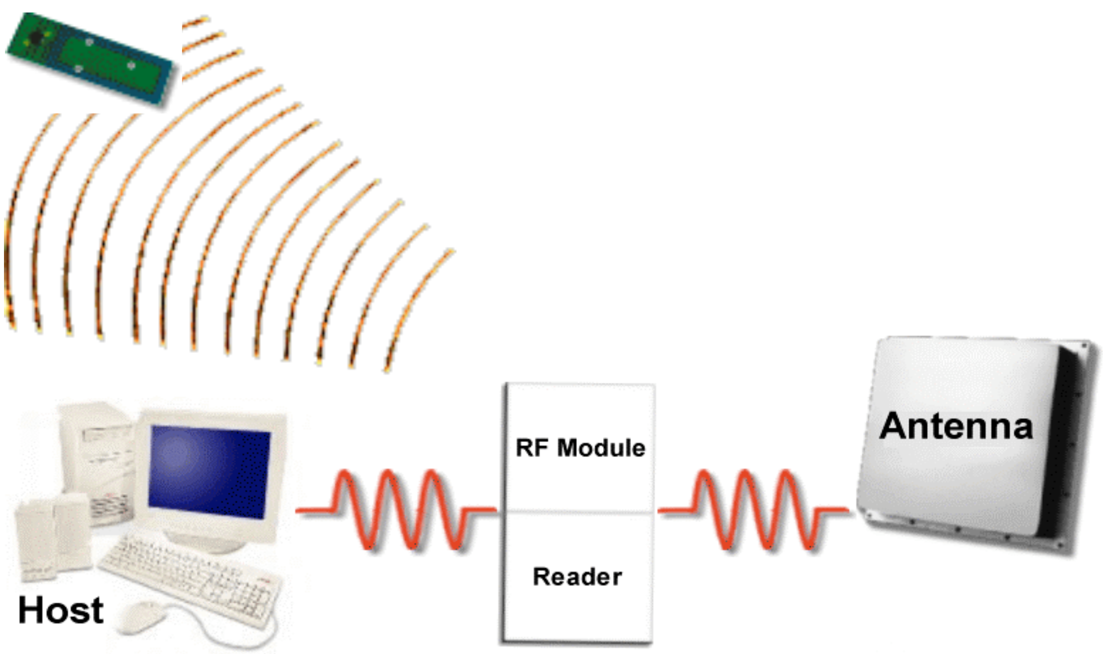


Figure 1 RFID System Components

The RFID system used in the pilot program consisted of three components: 1) a reader, 2) one or more tags, and 3) a controller or host computer. The reader sends out radio frequency signals via its antenna. The signal reaches the tag via radio wave or electromagnetic field. Part of the signal that reaches the tag is absorbed by the tag, and the rest is scattered in many directions with varying intensity. A small portion of the reflected signal finds its way back to the transmitter antenna. This portion of the reflected signal is received by the reader, and further processed by the controller for various Identification purposes (See Figure 1).

II.1.1 Tag

An RFID tag consists of an integrated circuit and an antenna. RFID tags come in three general varieties: passive, active, or semi-passive (also known as battery-assisted). Passive tags require no internal power source, thus being pure passive devices (they are only active when a reader is nearby to power them), whereas semi-passive and active tags require a power source, usually a small battery.

II.1.1.1 Passive Tag

Passive RFID tags have no internal power supply. The minute electrical current induced in the antenna by the incoming radio frequency signal provides just enough power for the CMOS integrated circuit in the tag to power up and transmit a response. Most passive tags signal by backscattering the carrier wave from the reader. This means that the antenna of the tag has to be designed both to collect power from the incoming signal and also to transmit the outbound backscatter signal.

Passive tags have practical read distances ranging from about a few inches (ISO 14443) up to many feet (Electronic Product Code (EPC) and ISO 18000-6), depending on the chosen radio frequency and antenna design/size. But thanks to deep-space technology, that distance is now significantly increased. Due to their simplicity in design they are also suitable for manufacture with a printing process for the antennas. The lack of an onboard power supply means that the device can be quite small: commercially available products exist that can be embedded in a sticker.

Most RFID applications in the supply chain and recent RFID applications in transportation and parking management use passive RFID tags.

II.1.1.2 Active Tag

Unlike passive RFID tags, active RFID tags have their own internal power source, which is used to power the integrated circuits and to broadcast the response signal to the reader.

Communications from active tags to readers is typically much more reliable (i.e. fewer errors) than from passive tags due to the ability for active tags to conduct a "session" with a reader.

Active tags, due to their on board power supply, also may transmit at higher power levels than passive tags, allowing them to be more robust in an "RF challenged" environment with humidity and spray or with dampening targets (including humans/cattle, which contain mostly water), reflective targets from metal (shipping containers, vehicles), or at longer distances: Generating strong responses from weak reception is a sound approach to success. In turn, active tags are generally bigger, caused by battery volume, and more expensive to manufacture, caused by battery price. Frequent read of active tags will significantly reduce the lifetime of the battery, and thus the active tag.

Many active tags today have operational ranges of hundreds of meters, and a battery life of up to 10 years, though frequent reads of an active tag will significantly reduce the lifetime of its battery, and thus the active tag itself. Active tags may also include larger memories than passive tags, and may include the ability to store additional information received from the reader.

Special active RFID tags may include temperature sensors. Temperature logging is used to monitor the temperature profile during transportation and storage of perishable goods as fresh produce or certain pharmaceutical products. Other sensor types are combined with active RFID tags, including humidity, shock/vibration, light, radiation, temperature, pressure and concentrations of gases like ethylene.

The United States Department of Defense (DoD) has used active tags in logistics to trace containers to battlefields to improve the visibility of its supply chain. Many existing toll roads on the East and West coasts use active RFID tags for toll collection.

II.1.2.3 Semi-passive Tag

Semi-passive tags are similar to active tags in that they have their own power source, but the battery only powers the microchip and does not power the broadcasting of a signal. The response is usually powered by means of backscattering the RF signals from the reader, where the signal is reflected back to the reader as with passive tags. An additional application for the battery is to power data storage.

Whereas in passive tags the power level to power up the circuitry must be 100 times stronger than with active or semi-active tags, also the time consumption for collecting the energy is omitted and the response comes with shorter latency time. The battery-assisted reception circuitry of semi-passive tags leads to greater sensitivity than passive tags, typically 100 times more. The enhanced sensitivity can be leveraged as increased range (by one magnitude) and/or as enhanced read reliability (by reducing bit error rate at least one magnitude).

The enhanced sensitivity of semi-passive tags place higher demands on the reader concerning separation in more dense population of tags. Because an already weak signal is backscattered to the reader from a larger number of tags and from longer distances, the separation requires more sophisticated anti-collision concepts, better signal processing and some more intelligent assessment which tag might be where. For passive tags, the reader-to-tag link usually fails first. For semi-passive tags, the reverse (tag-to-reader) link usually collides first.

Semi-passive tags have three main advantages 1) Greater sensitivity than passive tags 2) Longer battery powered life cycle than active tags. 3) Can perform active functions (such as temperature logging) under its own power, even when no reader is present for powering the circuitry. However, it has the similar disadvantages as the active tags, such as expensive to manufacture, relatively larger size, and limited life time.

II.1.2 Reader

A reader typically contains an RF transmitter, an RF receiver, a control unit, and an antenna. In addition, almost all modern readers also contain an additional interface, which usually includes RS 232, RS 485, TCP/IP, Digital I/O, etc. (see Figure 2).

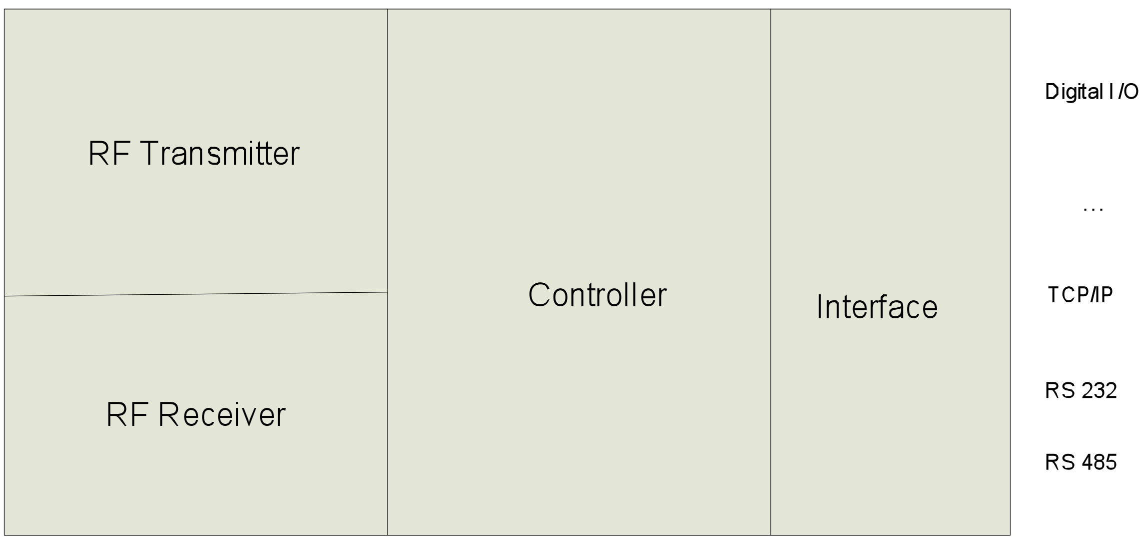


Figure 2 Schematic Diagram of an RFID Reader

The RF transmitter sends RF signals to tags via the antenna. The tag reflects back the signals to the RF receiver. The control unit then converts the RF signal into digital signals and passes them to the external computers or other system via the reader interface.

TCP/IP interface will enable the reader to communicate with external computers or the network directly. Digital I/O allows the reader to control Programmable Logic Units (PLCs), such as the gate or the traffic light.

Just like radio, RFID readers communicate with tags at different frequency ranges. Based on the way the tags and reader are coupled (see Figure 3), the frequency of an RFID system is usually classified as Low-Frequency (LF), ranging 30 kHz - 300 kHz; High-Frequency (HF) , ranging 3 MHz – 30 MHz; or Ultra-High Frequency (UHF), ranging from 300 MHz - 3 GHz.

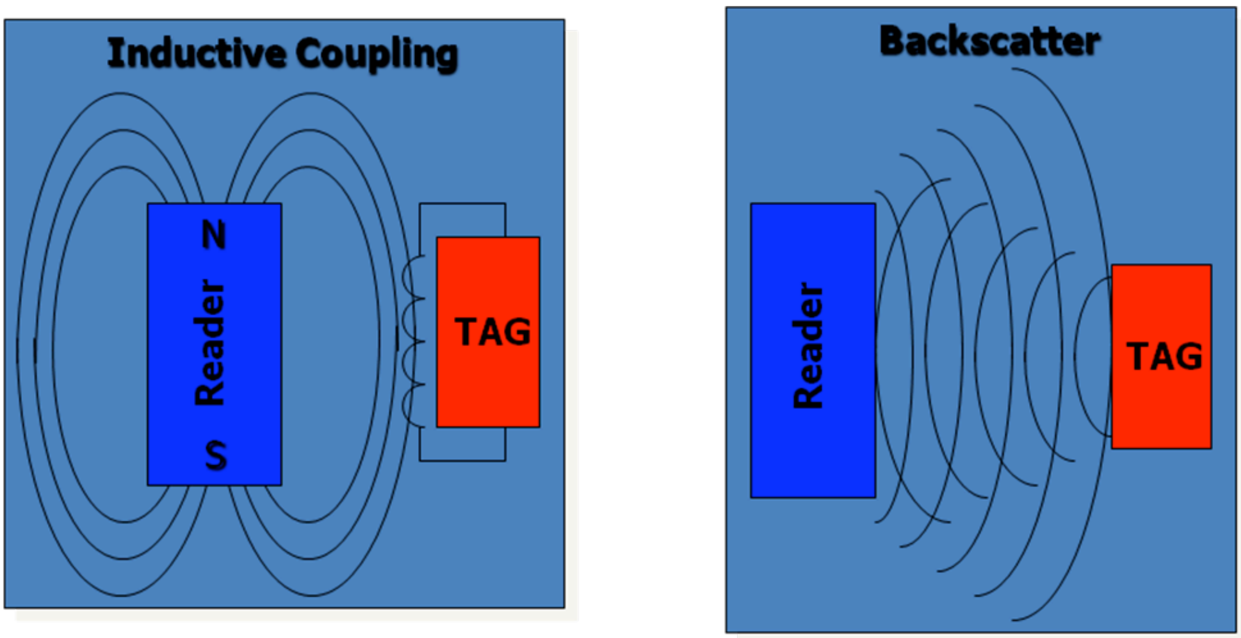


Figure 3 Coupling Mechanisms at Different Frequency

At Low-Frequency (LF), the reader and tags are normally inductively coupled. Since the voltage induced is proportional to frequency, many coil turns are needed to produce enough voltage to operate an integrated circuit. Compact LF tags, like glass-encapsulated tags used in animal and human identification, use a multilayer coil wrapped around a ferrite core

High frequency is with the range of 3 MHz - 30 MHz At 13.56 MHz, a HFID or HF RFID tag, using a planar spiral with 5–7 turns over a credit-card-sized form factor can be used to provide ranges of tens of centimeters. These coils are less costly to produce than LF coils, since they can be made using lithographic techniques rather than by wire winding, but two metal layers and an insulator layer are needed to allow for the crossover connection from the outermost layer to the inside of the spiral where the integrated circuit and resonance capacitor are located.

At Ultra-high frequency (UHF), the tags' antennae are usually coupled to the reader antenna via radio waves and can employ conventional dipole-like antennas. Only one metal layer is required, reducing cost of manufacturing. Dipole antennas, however, are a poor match to the high and slightly capacitive input impedance of a typical integrated circuit. Folded dipoles, or short loops acting as inductive matching structures, are often employed to improve power delivery to the IC. Half-wave dipoles (16 cm at 900 MHz) are too big for many applications; for example, tags embedded in labels must be less than 10 cm (4 inches) in extent. To reduce the length of the antenna, antennas can be bent or meandered, and capacitive tip-loading or bowtie-like broadband structures are also used. Compact antennas usually have gain less than that of a dipole — that is, less than 2 dBi — and can be regarded as isotropic in the plane perpendicular to their axis. Figure 4 below shows the various frequencies, read distances, and application domains.

	Frequency	Distance	Example Application
LF	125khz	A few inches	Contactless smart card, ticketing, access control
HF	13.56Mhz	A few feet	Small item tracking, Pharmaceuticals, anti-theft,
UHF	900Mhz	10 feet or more	Transportation, Supply Chain

Figure 4 Reader Frequencies, Read Distance, and Application Domains

II.1.3 Data Processing Function

The RFID data processing capability is accomplished by software, which typically includes: 1) RFID device drivers, 2) RFID middleware, and 3) RFID application software. The device driver talks with the native RFID reader APIs via TCP/IP or other proprietary protocols. The middleware filters data read from RFID devices, management network and system operations, and interface with the application layer. RFID middleware is also called edgeware. It processes a large amount data emitted directly from readers. It filters and sends only meaningful data to the application and enterprise system. The application software processes and presents all business related workflow, such as parking management, for the end users. Figure 5 below shows the high level architecture of a typical RFID software system.

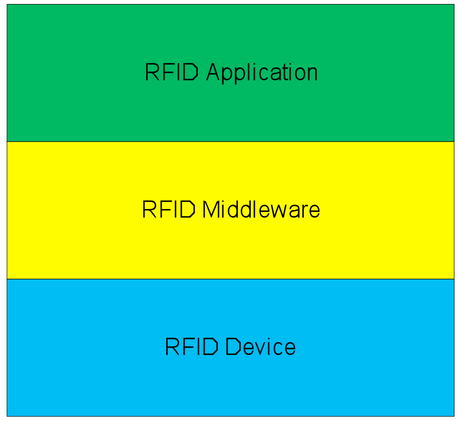


Figure 5 High Level Architecture of an RFID Data processor

II.2 RFID Parking Management System

An RFID Parking Management System is an Advanced Parking Management System (APMS) with an RFID system as its vehicle identification component. In Addition to the RFID vehicle identification component, it usually has an access control component. The access control device could be either a gate or simply a traffic light. The gate will open or the light turns green when the vehicle is identified and access is granted. Optionally, it could also have an automatic payment system based on gate access activities, an online reservation system for the convenience of drivers, and a real time driver information system distributed via onsite displays, Internet, and/or wireless devices.

II.2.1 Vehicle Identification Component

Vehicle identification is a critical component of any advanced parking management system. Inaccurate identification or counting can cause the inventory count to be in error in a positive or a negative direction. Undercounting available spaces means a lost opportunity for a patron and lost revenue for the operator. Over-counting available spaces can result in frustrated patrons and potential loss of future credibility and revenue for the operator. In permit or pre-paid parking lots, inaccurate identification means drivers without a permit or payment may be granted access to the parking facilities, while drivers with permit or payment may be denied access to the parking facilities.

Traditionally, induction loop detector or video detection technology is used for vehicle identification. For example, induction loop counters can be employed as entry/exit counters where surfaces and anticipated weather treatments support their application. In cases where loop detectors are not feasible, video detection technologies similar to those used in actuated traffic signal control may be considered.

Another alternative is the space occupancy detector which is manufactured for installation in the ground under the vehicle, on a post in front of the space, or over the space on garage ceilings. Most occupancy detectors use ultrasonic sensors, such as those used in Baltimore-Washington International Airport.

Compared to loop detectors, RFID technology has a high read accuracy and no restrictions on road surface requirements; and compared to ultrasonic space occupancy detection device, it does not need the expensive communication infrastructure, which usually needs to be included in construction of the facility. These systems may also require purchase or lease of dedicated fiber optic communications capacity; and they need to be tested for its proper functioning periodically, based on experience from BWI.

Furthermore, a defining differentiator of RFID is its ability to identify a specific vehicle by reading the ID data carrying with each RFID tag on a vehicle. This identification ability enables the RFID component to seamlessly integrate with other components, such as an electronic payment system, an online reservation system, etc. Thus, the whole parking management system can be automated, based on identification information.

II.2.2 Access Control Component

A typical access control component is a gate at the entrance and/or exit of a parking facility. For example, if a driver with a parking permit drives to the entrance, the gate opens and lets the vehicle in; if he does not have a parking permit, the gate will not open. In this way, the gate controls the access of vehicle to the parking facility. The gate can be either opened automatically by the APMS system or opened manually by an attendant. In most fee based parking facilities, vehicles will be let in. Then, at the exit, the gate will not open until the appropriate fees have been paid.

The actual physical presence of an access control component can vary significantly. Instead of a gate, many parking facilities may only have a traffic light at the entrance to control access. In some other facilities, there may not be any physical access control device at all. All vehicles are let in and out physically. Parking rules will be enforced manually by police or parking enforcement staff.

An RFID Parking Management System usually has an access control component, such as a gate or a traffic light. As the driver drives close to the gate of the entrance, the RFID reader will read the RFID tag on the vehicle and thus identify the vehicle. The system will then contact the central database for parking information for this specific vehicle, and open the gate or turn on the light automatically if the system grants access to the vehicle.

II.2.3 Electronic Payment Component

An electronic payment is an optional component of an APMS system. More and more APMS systems are implementing an electronic payment component to reduce cost to the facility operator and increase convenience to the driver. Traditional payment component would be a payment station installed inside parking facilities that may take cash or credit. An RFID Parking Management system will link the vehicle ID data stored on the RFID tag to a driver's payment account. This account could be either a credit card account, or cash debt account. When the vehicle approaches the exit, the RFID tag will be read by the RFID reader. The system will use the ID data to check whether the linked account has the appropriate balance. If yes, the fee will be automatically deducted from the balance and the gate will open to let the vehicle out.

II.2.4 Other Components

Some Advanced Parking Management Systems also have an online reservation component and a driver information component. Some even have a navigation system that can provide driver turn-by-turn guidance to an available parking space. An RFID Parking Management System allows a driver to reserve a parking space under his vehicle ID, and the system will be able to identify the vehicle at the parking entrance, and grant access accordingly.

II.2.5 Benefits of an APMS

Research (Fed parking report) shows that an APMS can reduce driver's frustration, increase accessibility, increase facility occupancy, and improve traffic flow, among other benefits.

Direct BWI airport customer feedback gathered by the Maryland Aviation Authority indicates that customers felt the system saved them aggravation leading to very high levels of customer satisfaction with the BWI parking experience. Customer satisfaction became the major factor in the decision to expand from a test of several thousand spaces to deployment across all hourly and daily garage facilities at BWI.

According to the above research, the vacancy rate at the facilities participating in using an APMS system was much lower—17 percent versus 38 percent. The study included an area served by 42 parking facilities—17 of which are participants in the advanced parking management system. The study also shows a 9 percent reduction in travel time after the APMS system was activated.

In addition to all the above benefits for a typical APMS, RFID Smart Parking also provides high accuracy of vehicle counts, high integration and automation to increase driver's convenience and reduce routine operational cost, and less demanding on infrastructure requirements of power and communication to reduce one time investment cost.