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Caroline Rodier, Susan A. Shaheen, Tagan Blake, Jeffrey R. Lidicker, Elliot Martin

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EasyConnect II: Integrating Transportation, Information, and Energy Technologies at the Pleasant Hill BART Transit Oriented Development

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ABSTRACT

Smart growth policy strategies attempt to control increasing auto travel, congestion, and vehicle emissions by redirecting new development into communities with a high-intensity mix of shopping, jobs, and housing that is served by high-quality modal alternatives to single occupant vehicles. The integration of innovative technologies with traditional modal options in transit-oriented developments (TODs) may be the key to providing the kind of high-quality transit service that can effectively compete with the automobile in suburban transit corridors. A major challenge, however, of such an integration strategy is the facilitation of a well-designed and seamless multi-modal connection infrastructure – both informational and physical. EasyConnect II explored the introduction and integration of multi-modal transportation services, both traditional and innovative technologies, at the Pleasant Hill Bay Area Rapid Transit (BART) District station during the initial construction phase of the Contra Costa Centre Transit Village (or TOD) in the East San Francisco Bay Area. The project explored the integration of following in this TOD: 1) shared-use, low-speed vehicles, 2) electronic lockers ("eLockers") with reservation capabilities: smart transit-based parking technology; 3) a protocol for a web-based information system (Mobility Options Protocol or MOP) to obtain information about available modal options and transportation services; and 4) innovative distributed power generation technologies to help meet growing electrical loads associated with the introduction of advanced electronic transportation and information technology systems.

EXECUTIVE SUMMARY

Smart growth policy strategies attempt to diminish increasing auto travel, congestion, and vehicle emissions by redirecting new development into communities with a high-intensity mix of shopping, jobs, and housing that is served by high-quality modal alternatives to single occupant vehicles. The integration of innovative technologies with traditional modal options in transit-oriented developments (TODs) may be the key to providing the kind of high-quality transit service that can effectively compete with the automobile in suburban transit corridors. A major challenge, however, of such an integration strategy is the facilitation of a well-designed and seamless multi-modal connection infrastructure – both informational and physical.

EasyConnect II explored the introduction and integration of multi-modal transportation services, both traditional and innovative technologies, at the Pleasant Hill Bay Area Rapid Transit (BART) District station during the initial construction phase of the Contra Costa Centre Transit Village (or TOD) in the East San Francisco Bay Area.

The report begins by describing the various components of the EasyConnect II project, which included the following:

- Shared-use, low-speed vehicles (electric bicycles, non-motorized bicycles, and Segway Human Transporters) available for commuting from the BART station to area businesses within approximately five miles.
- Electronic lockers ("eLockers") with reservation capabilities located at the station and nearby businesses that are a unique physical and technology design solution to the problem of low-speed mode access to traditional transit.
- Smart parking technology to provide cost-effective and space-efficient solutions to parking at the TOD site.
- A protocol for a web-based information system (Mobility Options Protocol, or MOP) that allows users to reserve, pay, and access travel information, moving seamlessly across a range of available modal options and transportation services.
- Innovative distributed power generation technologies to help meet growing electrical loads associated with the introduction of advanced electronic transportation and information technology systems.

This is followed by a discussion of the results of an on-line survey of current electronic locker users ("eLocker") in California. The survey shows that eLockers are generally used by work-based commuters traveling by bicycle. It is apparent from the data on travel patterns, that the eLockers are almost exclusively serving the access side of the bicycle commute. That is, the vast majority of eLocker users are riding from their homes to a transit station (usually a BART station), and parking their bicycles at the station for the day. A much smaller contingent of eLocker users are leaving their bicycles at a remote transit station and traveling to it to pick up their bicycles to complete the "last mile" of their trip. Hence, eLockers are generally used in the same manner as conventional bike racks. But a fair number of respondents consider eLockers to be essential to completing their commute by bicycle. Roughly 180 respondents (about 40 percent) indicated that they would complete their trip by some mode other than a bicycle, if eLockers were not available. Many respondents said they would shift to other modes; nearly 80 respondents suggested that they would shift to driving alone in an automobile. Hence, it appears that eLockers may be enabling 15 to 20 percent of the sample surveyed to use bicycles instead of automobiles. These results suggest that the eLockers are having some positive environmental impact by facilitating bicycling for people who would otherwise drive. In addition, users expressed considerable satisfaction with their use of the eLockers.

Next, we report the results of in-person interviews with eLocker users who volunteered to beta test the reservation service that was added as part of this research project. The results suggested the following: that reservation capabilities may be an important factor in users' decisions to bike to transit stations, particularly if they use the station during peak demand hours and eLockers are limited; the test period allowed for significant improvement in the user interface provided for the reservation system; and, there was general satisfaction with current eLocker payment options.

The report concludes with a detailed discussion of the mobility options protocol.

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Smart growth policy strategies attempt to diminish increasing auto travel, congestion, and vehicle emissions by redirecting new development into communities with a high-intensity mix of shopping, jobs, and housing that is served by high-quality modal alternatives to single occupant vehicles. The integration of innovative technologies with traditional modal options in transit-oriented developments (TODs) may be the key to providing the kind of high-quality transit service that can effectively compete with the automobile in suburban transit corridors. A major challenge, however, of such an integration strategy is the facilitation of a well-designed and seamless multi-modal connection infrastructure – both informational and physical.

EasyConnect II explored the introduction and integration of multi-modal transportation services, both traditional and innovative technologies, at the Pleasant Hill Bay Area Rapid Transit (BART) District station during the initial construction phase of the Contra Costa Centre Transit Village (or TOD) in the East San Francisco Bay Area. The project explored the integration of the following elements:

- Shared-use, low-speed vehicles (electric bicycles, non-motorized bicycles, and Segway Human Transporters) available for commuting from the BART station to area businesses within approximately five miles.
- Electronic lockers ("eLockers") with reservation capabilities at the station and nearby businesses, which provide a unique physical and technological design solution to the problem of low-speed mode access to traditional transit.
- Smart parking technology to provide cost-effective and space-efficient solutions to parking at the TOD site.
- A protocol for a web-based information system (Mobility Options Protocol, or MOP) that allows users to reserve, pay, and access travel information, moving seamlessly across a range of available modal options and transportation services.
- Innovative distributed power generation technologies to help meet growing electrical loads associated with the introduction of advanced electronic transportation and information technology systems.

This report includes the following sections: 1) a description of the components of the EasyConnect II project; 2) an analysis of surveys of eLocker users; 3) a description of the results of in-person interviews with eLocker reservation users; and 4) a description of the mobility option protocol.

2.0 Project Components

Building on EasyConnect I, a first- and last-mile low-speed mode service, the EasyConnect II project explored the implementation and integration of the following four elements at the Pleasant Hill BART station TOD: 1) electronic bike lockers including reservation capabilities, 2) improved transit parking information, 3) a hydrogen fuel cell power source, and 4) a protocol for a web-based service that provides detailed information on available modal options. Each project component is described in more detail below.

2.1 EasyConnect I

EasyConnect I was a field operational test that introduced shared-use electric bicycles, non-motorized bicycles, and Segway Human Transporters (HTs) (known as "low-speed modes") at the Pleasant Hill BART station, to allow commuters to connect to surrounding employment centers within approximately five miles. Commuters were able to ride the units from the BART station to their offices in surrounding employment centers in the morning and back to the station at the end of the day, i.e. for "commuter use." The devices were also used to run personal and business errands during the day, i.e. for "day use," when stored at the work place. In addition, some units were located directly at employment locations (e.g., the Contra Costa Centre) to provide day-use options for those who commute by vanpool or carpools.

There is an extensive paved trail network in the Pleasant Hill BART area. The East Bay Parks District granted permission to use the electric bike and Segway HT on the Iron Horse and Canal Trails. Access to the trails greatly enhances BART, employment, and shopping connections.

The Contra Costa Centre assumed operation of the day use portion of EasyConnect I at the end of the field operational test.

2.2 eLockers

Traditional bicycle lockers are relatively inefficient because each locker is usually reserved for an individual who has pre-paid for the locker on a yearly basis. As a result, lockers often sit empty and unused. A shared-use, technologically advanced electronic locker system ("eLockers") can increase by approximately five-fold the number of cyclists (and other low-speed mode users) served by traditional lockers. Secure eLockers work like metered curbside parking: users only pay for eLockers when they are using them. The lockers are accessed using specially designed smartcards.

The EasyConnect I program placed electronic eLockers at the Pleasant Hill BART station to enable commuters to travel from the station to places of employment. The lockers were originally secured through donations by the Contra Costa Centre, Contra Costa 511, County of Contra Costa, Metropolitan Transportation Commission, and the Bay Area Air Quality Management District. Half of the 24 lockers were used for the EasyConnect I program, and the other half were available for public use. By the end of the EasyConnect I project, the public eLockers were full most days. At the completion of EasyConnect II, the majority of the eLockers were transferred to BART for public use. Two eLockers were reserved for continued use by Contra Costa Centre employees.

The eLockers are part of a network of bicycle lockers at BART stations across the San Francisco Bay Area. Patrons purchase a BikeLink smart card in order to access the lockers. At the Pleasant Hill BART station, a charge (three cents per hour) was deducted from the card's value. These funds enabled provision of user support services. Within a few months, eLockers were filled by bicycle commuters most days. Initially, all of the eLockers were access on-demand: commuters arrived at the station each morning and accessed the eLockers without prior reservations or information about availability of the eLocker.

The EasyConnect II program added a web-based advanced reservation component to the eLockers. The reservation system, which was linked to the BikeLink care, enabled patrons to reserve an eLocker, ensuring they would have a place to park when they arrived at the station. In addition, this system allowed for remote access of detailed use information.

eLocker reservations could be made on the same day, if space was available, or for dates in the future. The system sent a confirmation to the patron approximately 12 hours before the reservation time, and the reservation was considered completed when the bicycle was parked in the eLocker. If a reservation was not completed within two hours of the reservation, the eLocker reverted to on-demand status.

The operation of the eLocker reservation system, as demonstrated at the Pleasant Hill BART station, allowed for system improvements based on user feedback, including increased efficiency in inputting user and credit card information, reminder notification and confirmation emails, and timeframes for holding reservations.

The reservation system was well received by bicycle commuters at the Pleasant Hill BART station (see discussion in 3.0). However, the field test experience pointed to an upgrade needed for cost-effective implementation of the system in the absence of plug in power sources (i.e., 110 volt). A battery powered eLocker reservation system was installed at the station, which turned out to require frequent and costly battery changes that could not be sustained though existing operational revenues. As a result, the manufacturer has now designed ultra-low power consumption electronic hardware and built-in solar charging for the eLocker reservation systems. These new systems will be deployed in 2010.

2.3 Smart Parking

Closely related to providing multi-modal station access is the need to address station parking demands. Smart parking (broadly defined as the use of advanced technologies to help motorists locate, reserve, and pay for parking) holds the potential to optimize parking services. During EasyConnect II, a smart parking system was installed by the Transit Village developer in an existing parking structure at the Pleasant Hill BART station. However, the system was not fully operational during most of the project period. The system included space sensors and changeable message signs at the garage entrance to indicate if the garage was full so that patrons would not waste time searching in the garage and would seek parking elsewhere at the station. An operational smart parking system was eventually installed at the existing and new parking structure at the station at very end of the EasyConnect II study.

2.4 Hydrogen Fuel Cell

The “CleanCharge” program was designed to demonstrate the ability of hydrogen fuel cells to produce power for remote and emergency back-up use. The fuel cell system works by using hydrogen from cylinders stored in the fuel cell cabinet that react with oxygen in the fuel cell stack to provide electricity. The resulting power source is significantly cleaner and quieter than conventional generators without the longevity issues of battery-based systems. And, to re-fuel, only the cylinders need to be replaced. The system installed at the Pleasant Hill BART station consisted of a mobile hydrogen refueling trailer, a small (five-kilowatt) stationary fuel cell system, and 110-volt electrical outlets for electric vehicle charging. The research team used CleanCharge to charge components of the EasyConnect II project because a power supply was not available at the Pleasant Hill BART station.

CleanCharge was installed on a small area of the surface parking that was not under construction. The system was designed to charge the EasyConnect II units providing connectivity to the Pleasant Hill BART station (Segway HTs and electric bicycles). A neighborhood electric vehicle (NEV) was added to the Contra Costa Transit Village fleet (Segway, HTs, and electric bicycles) and charged using this technology.

The BART permitting process for the operation of the CleanCharge system proved more difficult and time consuming than anticipated. The original plan involved operating the CleanCharge system for one year. Unfortunately, it was operational for only three months, because by the time the system was permitted and installed, construction was beginning in the area around the unit. The CleanCharge unit was moved to Berkeley to continue operation at an electric car dealer.

2.5 Mobility Options Communications Protocol

EasyConnect II included the development of a Mobility Options Communications Protocol (MOP) designed to enable a web-based information system allowing users to reserve, pay, and access travel information online. Through this system, a range of modal options and transportation services could be linked over the Internet in formats accessible to users, vendors and project planners. The MOP addressed the challenges of providing information about multiple modes and connections through a web-based interactive system. Smart parking information was included in the MOP. The MOP research for this study is described in 5.0. See Appendix A for a comprehensive review of numerous technologies and innovative strategies to support the MOP by researchers at the University of California at Riverside. Since the research team had prior experience in smart parking systems, they were able to incorporate this concept into the MOP. See the detailed discussion of the MOP in section 5.0.

3.0 eLocker Evaluation

3.1 Introduction

Over the last decade, a number of forces have united to accelerate a revival in the popularity of non-recreational or utilitarian bicycling in the U.S. (Moritz 1997). Constituencies concerned about climate change view bicycling as a sustainable transport mode capable of displacing many motor vehicle trips. Public health advocates view it as a healthy transport mode enabling people of all ages to lead a more active life. Since the early 1990s, more federal and local funding has been invested in communities to expand bicycle facilities.

Available research indicates that secure bicycle parking at trip destinations may be a key factor in the choice to bicycle for utilitarian travel (Martens 2007; Pucher and Buehler 2008; Taylor and Mahmassani 1996, Hunt and Abraham 2007). In the U.S., Federal Bureau of Investigation crime statistics estimate that a total of 220,000 bicycles were stolen in 2007. The average value of a stolen bicycle was 240 U.S. dollars in 2004, the last year this data was collected, and the overall loss exceeded half a billion dollars (Dept. of Justice 2008).

Recent advances in locker technologies have created new opportunities for transit agencies to address the problem of bicycle theft and cost-effectively expand bicycle access and transit, particularly when ridership is constrained by automobile parking capacity (Taylor and Mahmassani 1996). Automobile parking can cost six to 20 times the cost of secure bicycle lockers (Schneider 2005).

The evaluation of the eLockers includes the results of an on-line survey of users at the Pleasant Hill BART station as well as other transit stations in California. The evaluation begins with a review of the literature. The eLocker parking system is described. The survey data and the results of the analysis of the survey data are presented. Finally, conclusions are drawn from the analysis.

3.2 Literature Review

3.2.1 The Netherlands' Experience

In the Netherlands, bicycling has the highest overall modal share of any developed country: 27 percent of all trips are made by bicycle (Martens 2007). The Dutch experience indicates that often the simplest way of increasing bicycling mode share is to install more and better parking capacity at key destinations (Martens 2007). The Netherlands has invested substantial resources to provide large quantities of bicycle parking at transit stations (Pucher and Buehler 2008). The Dutch transportation agency has set guidelines for bicycle parking at transit stations including type, capacity, location, and design parameters for parking facilities (Martens 2007). Approximately, 91 percent of Dutch citizens have secure bicycle parking at their home stations, and 25 percent of

Dutch commuter trips use a bicycle in conjunction with transit, primarily as an access mode (Brons et al. 2009).

Since commuter trains run at higher speeds than metro or bus lines, they tend to have larger catchment areas and naturally attract more bicyclists (Martens 2004). For Dutch metro stations, more than 60 percent of bicyclists live within 2 kilometers (1.2 mi) of the station, while 70 percent of bicyclists live at least 2 kilometers (1.2 mi) away from the train station they use. In the latter case, bicycles are much more likely to replace a car as the station access mode. In fact several Dutch case studies show that about 50 percent of bicyclists who ride to train or metro stations also own a car. Bicycling to transit is also more popular in suburban areas relative to urban areas, in part because of safer traffic conditions, lower levels of local transit service, and longer station access distances. Netherlands' example shows the potential of bicycles to play an important complementary role with high-speed transit in addition to serving as an important general transportation mode. (Martens 2004)

3.2.2 Availability and Importance of Bicycle Lockers

A number of studies have assessed the availability and importance of bicycle lockers. Moritz's (Moritz 1997) analysis of an internet and mail-based survey of U.S. bicycle commuters (n=2,374) found that only 15 percent of respondents had bicycle lockers available at their travel destinations.

Hopkinson and Wardman's (Hopkinson and Wardman 1996) analysis of surveyed households near bicycling routes in the U.K. (n=513 with a 50 percent response rate) found that secure bicycle parking was the fourth most important factor, after better safety, lower traffic speed and volume, and intersection safety; 63 percent stated that it would increase their bicycling frequency (Hopkinson and Wardman 1996).

Stinson and Bhat (Stinson and Bhat 2004) used an ordered probit choice model to analyze results of an online survey of both bicycle and non-bicycle commuters in the U.S. (n=2,822) to predict the frequency of bicycle-commuting. They found that the presence of bicycle racks or lockers at work, or at least the knowledge of them, has a strong positive effect, one that is equivalent to four miles in distance from a destination and more than five years of bicycle experience (Stinson and Bhat 2004).

Givoni and Rietveld's (Givoni, M. and P. Rietveld 2007), and later Brons et al.'s (Brons et al. 2009), analysis of a Dutch Railway customer satisfaction survey (n=2,542) failed to find a significant relationship between bicycle parking and bicyclists' satisfaction with rail services. However, both studies suffer from problems of endogeneity between satisfaction and mode choice.

Taylor and Mahmassani (Taylor and Mahmassani 1996) developed a choice model based on stated preference surveys (n=814) of Texas Bicycle Coalition members, and showed that high-quality bicycle parking contributes significantly, not only to the likelihood of choosing bike-and-ride to access transit, but also to respondents' likelihood of choosing transit over driving to their final destination. The utility coefficient estimates indicate that the availability of bicycle lockers has greater impact than clothing comfort, lack of a household car, and gender on the biking versus driving (Taylor and Mahmassani 1996).

Hunt and Abraham (Hunt and Abraham 2007) conducted a stated preference paper survey of bicycle commuters in Edmonton, Alberta (n=1128). The authors' logit model indicated that bicycle parking is a much more important factor than showers as a destination amenity. One of their five final models indicated that secure bicycle parking at the rider's destination is worth almost more than 100 minutes of riding in a bicycle lane for all age groups and more than 50 minutes of riding on bicycle paths. This study also investigated the relationship of bicycle cost to demand for secure parking. Dummy variables recorded the effect of bicycle price ranges on secure parking demand and found that even somewhat inexpensive bicycles are highly valued by their owners and the risk of theft or vandalism is considered to be high by most cyclists (Hunt and Abraham 2007).

Wardman et al. (2007) also addressed the role of bicycle parking in mode choice decisions and constructed a hierarchical logit model using data from the British National Travel Survey. The study found that only 35 percent of commuters surveyed currently have secure parking. They estimated that better parking facilities could raise bicycle mode share by nearly a full percentage point (14 percent increase) from the reported 5.8 percent (Wardman et al. 2007).

3.3 Bicycle Parking System

3.3.1 Bicycle Locker Options

Several types of bicycle parking options are available for use at transit stations, and each have relative advantages and disadvantages. Lockers offer higher security and are important in areas with high theft rates or where many people use more expensive bicycles. Lockers are also good for overnight storage. Bicycle racks are less expensive, but are more appropriate for users who only park during the day or for short periods of time. Bicycle cages offer greater parking capacity and are relatively inexpensive to install, but they often require an attendant, and can be less convenient for users who are often in a hurry at transit stations.

New electronic lock systems for lockers allow bicyclists to use any available locker while maintaining the security of the facility by tracking users. These lockers allow operators to implement a payment scheme that discourages extended use of lockers and enables their efficient use. Electronic lockers have the added benefit of better data collection, which can allow better characterization of bicycle parking demand. Lockers do require some cleaning and maintenance, but agencies can often contract with the locker manufacturer or another party to take care of these needs. Experience shows that bicyclists' willingness to pay for the lockers can cover these costs (Schneider 2005). The location of the bicycle lockers relative to the station platform is an important factor in customers' satisfaction and perceptions of convenience. Cyclists want a quick and convenient transfer experience (Martens 2007).

3.3.2 Study Locker System

The BikeLink electronic bicycle storage lockers, also called “eLockers,” were first installed in El Cerrito, California in June 2004 (Pullen 2004). The technology uses a simple, single button interface in conjunction with a smart card to facilitate quick locker rentals at any eLocker location. Users may sign up for an account online and receive their card in the mail. BikeLink typically charges a flat hourly rate for use of the eLockers (between $0.03 and $0.05 per hour). The user reserves a certain amount of time in advance and then begins the rental. If the user returns early, any difference in the cost is debited back to the user. However, if the user overstays his reserved time, then the rate usually rises to a higher level, but the bicycle remains secure. This pricing system encourages users to return promptly, and allows the lockers to become available for others’ use. BikeLink members can add value to their smart cards online at the BikeLink website, or over the phone. Smart card technology for the eLocker enables flexible pricing strategies to: promote short or longer term use depending on the locker location; allow advance rental; differentiate by user group; and, vary pricing policies by time. The company that manufactures the eLockers, eLock Technologies, LLC, has plans to permit greater compatibility with other smart card systems including regional fare cards.

3.4 eLocker Survey Analysis

This analysis is based on data collected from an on-line survey of active eLocker users at transit stations between December, 2008 and April, 2009 in California. The email survey invitation provided a link to an online survey instrument. Of the approximately 1,303 valid email addresses, the survey received 789 responses. Only 620 of these were complete and of those, 454 indicated that they had used the bike lockers and answered a sufficient number of questions to be included in the analysis. The final survey response rate was 35 percent. As can be expected with any voluntary survey, some self-selection bias is expected. But the bias will likely tend towards infrequent users of the bike lockers. The survey also may not be representative of bicyclists in general. Table 3.1 presents the basic demographics of the core respondents.

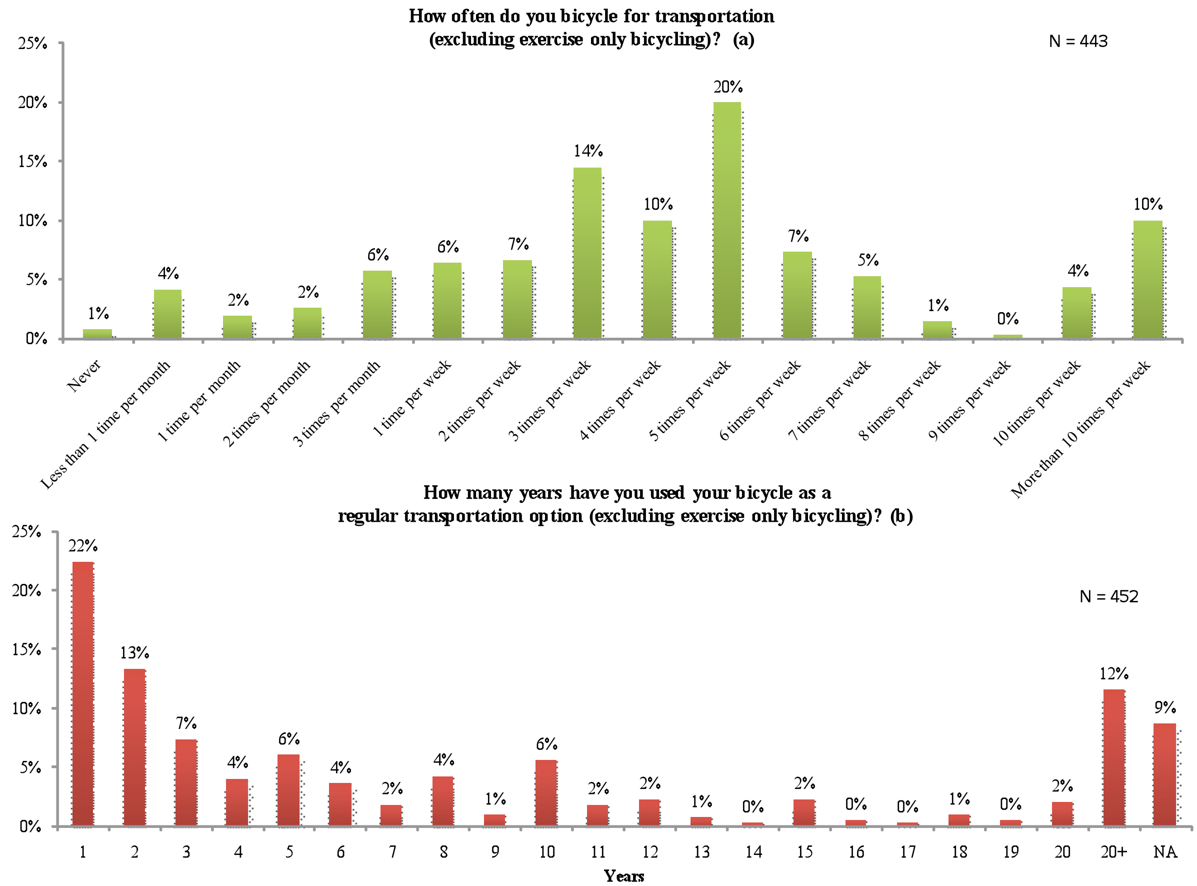
Table 3.1: Demographics of Survey Respondents

Demographic Attribute	Count	Percent	Demographic Attribute	Count	Percent
Gender			**Age**		
Male	302	67%	0 to 20	1	0%
Female	148	33%	20 to 30	87	19%
Total	N = 450		30 to 40	169	37%
			40 to 50	108	24%
			50 to 60	61	14%
			60 to 70	23	5%
Education			70 to 80	2	0%
Grade school	1	0%	Total	N = 451	
Graduated high school	4	1%			
Some college	36	8%			
Associate's Degree	12	3%	**Income**		
Bachelor's Degree	167	37%	Under $15,000	9	2%
Some graduate school	41	9%	$15,000 - $25,000	13	3%
Master's Degree	115	25%	$25,000 - $50,000	40	9%
Law Degree (JD, LLM)	34	8%	$50,000 - $75,000	69	15%
M.D.	4	1%	$75,000 - $100,000	74	16%
Ph.D., Ed.D,	33	7%	$100,000 - $150,000	101	22%
Other. Please specify:	6	1%	$150,000 - $200,000	61	14%
Total	N = 453		$200,000 and over	32	7%
			Decline to state	51	11%
			Total	N = 450	

The data show that eLocker users are relatively educated: roughly 90 percent have a degree beyond high school and about 40 percent have a Bachelor's degree or better. The age distribution suggests that eLocker users are mostly middle-aged, with 60 percent of users between the ages of 30 and 50. The household income of eLocker users is also skewed towards the upper brackets: more than 40 percent were from households that earned over $100,000, while median fell within the $75,000 to $100,000 category.

The bicyclists using the eLockers had a variety of experience riding a bicycle for transportation. This would be natural, in part due to the diversity in the age of respondents. But the eLockers were predominantly utilized most by very new riders and very experienced riders. Figure 3.1 shows the distribution of the weekly or monthly frequency of bicycling for transportation and by the years they have been bicycling for transportation.

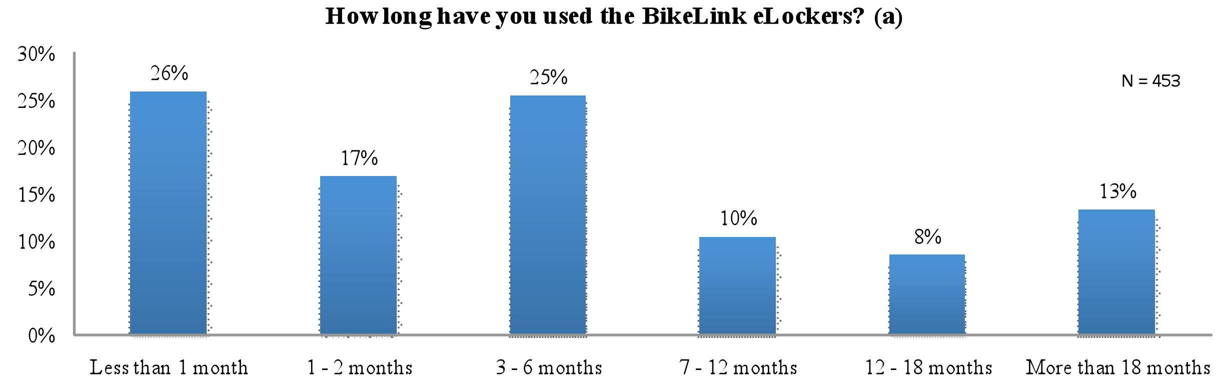
Figure 3.1: Frequency of Bicycling for Transportation and Bicycling Experience



As is apparent in Figure 3.1(a), the majority of respondents are avid users of bicycles for transportation: nearly 50 percent of respondents used the bicycle for transportation five times per week. But many of the respondents were also relatively new to bicycling for transportation. Figure 3.1(b) shows the wide distribution of experience. The first and third largest categories include those who had one year and 20+ years of experience respectively. The "NA" response consists of those who did not use the bicycle as a regular transportation option. Another important characteristic of this sample is that nearly 50 percent of respondents had experienced a bicycle stolen or vandalized at least once in the last 5 years. The other 50 percent had not had any crimes against their bicycle during this time period.

At the time of the survey, respondents had used the eLockers for a wide distribution of tenure. Figure 3.2(a) shows tenure of eLocker use and the means by which users learned about them. More than a quarter of respondents used eLockers for less than one month and more than half had actively used eLockers for 6 months or less. Figure 3.2(b) shows that most respondents learned of eLockers simply by seeing them, while others learned through social contacts or public media.

Figure 3.2: Tenure of eLocker usage and Means of Learning of eLocker



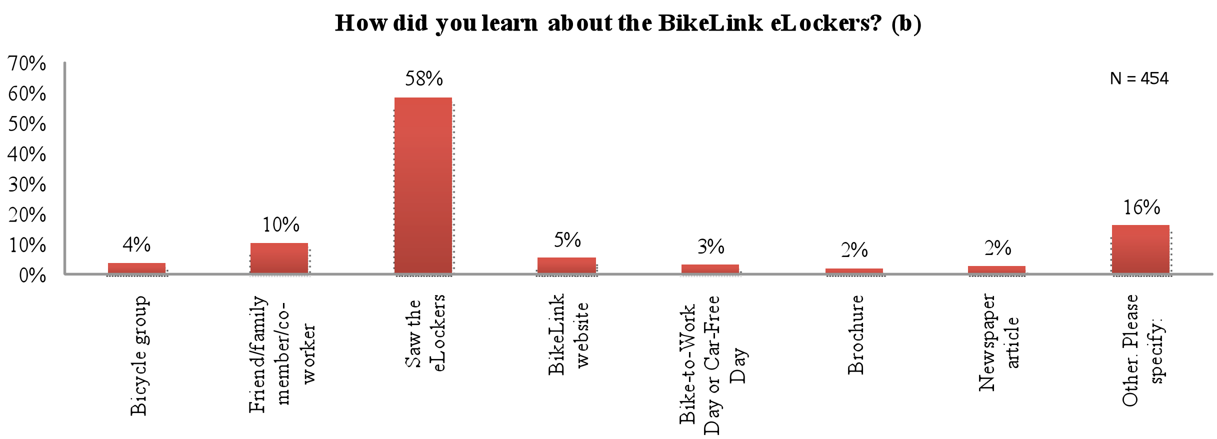
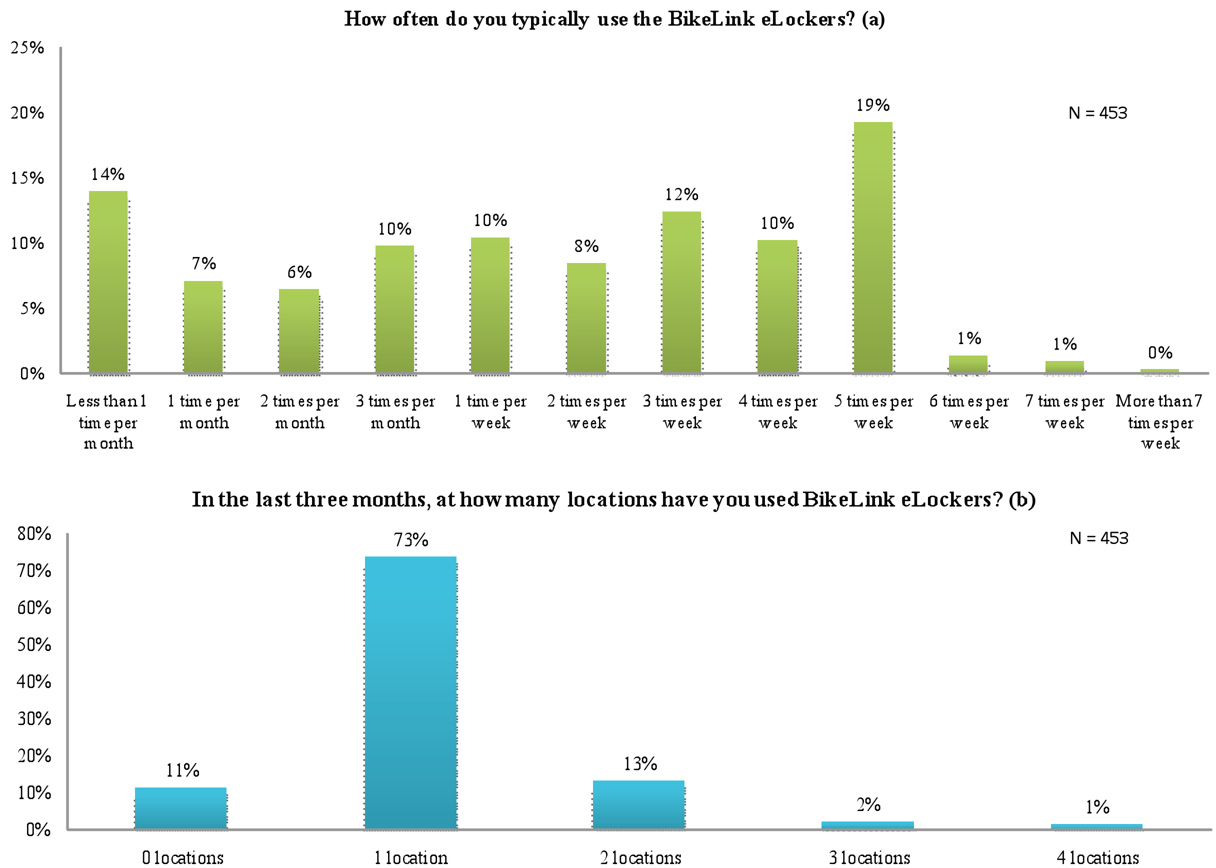


Figure 3.2(b) also shows that a fair share of respondents learned of the eLockers through "Other" means, which most commonly included, "had one of the previous lockers," "was on the waiting list for a bike locker," and "through the East Bay Bicycle Coalition." As shown in Figure 3.3, respondents also demonstrated a similar diversity in the frequency of eLockers use. More than 20 percent of respondents used eLockers five days a week or more. Another 40 percent used eLockers on a weekly, but not daily basis. Twenty-five percent of respondents used eLockers monthly, and the final 15 percent used eLockers less than once per month.

Figure 3.3: Usage Frequency of eLockers



Respondents were asked about the number of different eLocker locations that they used over the course of the past three months. Figure 3.3(b) indicates that nearly three-quarters of respondents used only one eLocker location, while 15 percent used eLockers at multiple locations. Consistent with Figure 3.3(a), 11 percent of respondents had not accessed an eLocker at any location over the past three months.

In terms of travel patterns, the respondents indicated that they overwhelmingly used the eLockers to support home-originating trips to work. That is, most respondents traveled from home to the locker by bicycle before starting the next leg of their commute. Table 3.2 illustrates this dynamic with a cross-tabulation of two key questions.

Table 3.2: Trip Origin by Trip Purpose

Trip Purpose[1] / Trip Origin[2]	Personal errands	Commute to work or school	Social or recreational activities	Business-related activities	Shopping	Other	Total
Home	5% (21)	79% (351)	8% (35)	3% (15)	1% (6)	0% (0)	96% (428)
Work	0% (1)	2% (7)	1% (5)	0% (1)	0% (0)	0% (0)	3% (14)
Other. Please specify:	0% (0)	0% (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (1)
School	0% (0)	0% (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (1)
Total	5% (22)	81% (360)	9% (40)	4% (16)	1% (6)	0% (0)	100% (444)

[1]Which trip purpose below best describes the typical reason you use the BikeLink eLockers?

[2]What is your typical starting place for your trip to the eLockers?

Nearly 80 percent of respondents primarily used the eLockers to begin trips at home for their commute to work. Overall, 96 percent of respondents used eLockers for trips that began at home. This is an expected result given that the commute to work almost always starts from home, except in cases of a second job. But, while Table 3.2 presents important baseline insights, it does not show whether the eLocker is servicing the end of the "first mile" of the commute or the beginning of the "last mile" of the commute. That is, with an eLocker, people may ride their bicycles to take transit, or they may ride transit to pick up their bicycle. The eLocker facilitates the latter especially well compared to a regular bike lock. However Table 3.3, a cross tabulation of trip origin and the mode used immediately before accessing the eLockers, shows that very few respondents are using the eLocker to facilitate traveling the last mile of their trip.

Table 3.3: Travel Mode Preceding eLocker Access by Trip Origin

Trip Origin[1] / Mode of Access to elocker[2]	Home	Work	School	Other	Total
Bicycle	90% (405)	3% (12)	0% (1)	0% (0)	93% (418)
BART	4% (16)	0% (2)	0% (0)	0% (0)	4% (18)
Drive	0% (2)	0% (0)	0% (0)	0% (0)	0% (2)
Bus or Shuttle	0% (1)	0% (0)	0% (0)	0% (0)	0% (1)
Walk	1% (3)	0% (0)	0% (0)	0% (0)	1% (3)
Caltrain	0% (1)	0% (0)	0% (0)	0% (0)	0% (1)
Other Train or Light Rail Transit	1% (4)	0% (0)	0% (0)	0% (0)	1% (4)
Other. Please specify:	1% (4)	0% (0)	0% (0)	0% (0)	1% (4)
Total	97% (436)	3% (14)	0% (1)	0% (0)	100% (451)

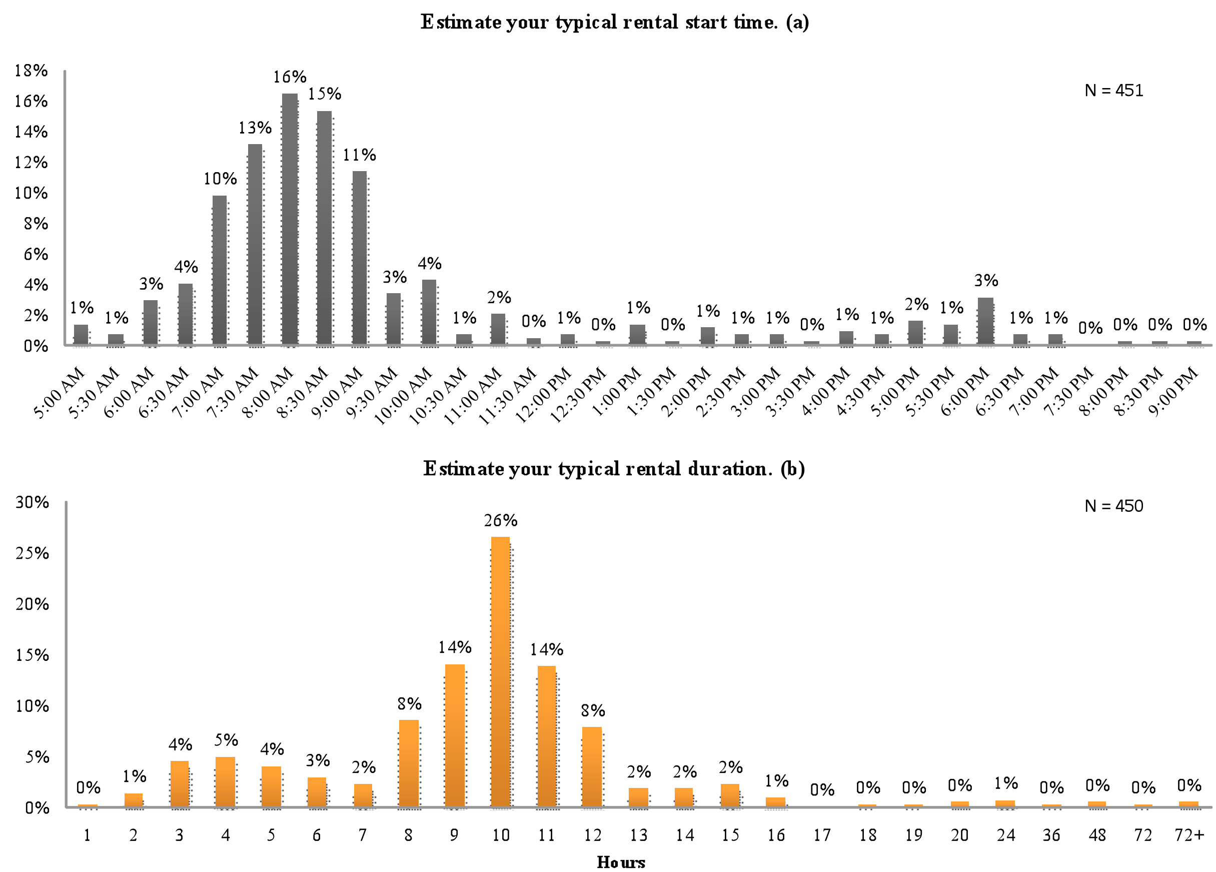
[1]What is your typical starting place for your trip to the eLockers?

[2]What travel mode are you using immediately before you arrive at the BikeLink eLockers from your typical starting place?

Table 3.3 provides a more detailed insight with respect to how respondents are integrating the eLockers with their trips. The results suggest that a vast majority (90 percent) of respondents start their trips from home and access the eLocker on a bicycle. Hence, eLockers are overwhelmingly used as part of the access leg of the trip, serving as the terminal end of a bicycle trip that starts at home. A much smaller share of no more than five percent of all respondents use the eLocker as a part of the egress leg of their trip. Four percent of all respondents accessed the eLocker after riding BART, indicating that the eLocker served as a storage facility for their bicycles closer to their destinations. The remaining share includes those who used Caltrain, bus, or other light rail before reaching the eLockers. Thus, for this small minority of users, eLockers are likely facilitating the use of the bicycle as a "last mile" mode of travel.

In terms of time and duration of use, the eLockers are used in a fashion that is consistent with people commuting to work by bicycle with the support of transit. The eLockers are generally accessed in the morning, and held for the duration of the work day. Figure 3.4 shows the distribution of time accessed and the duration of the rental period.

Figure 3.4: Time of Access and Duration of Rental



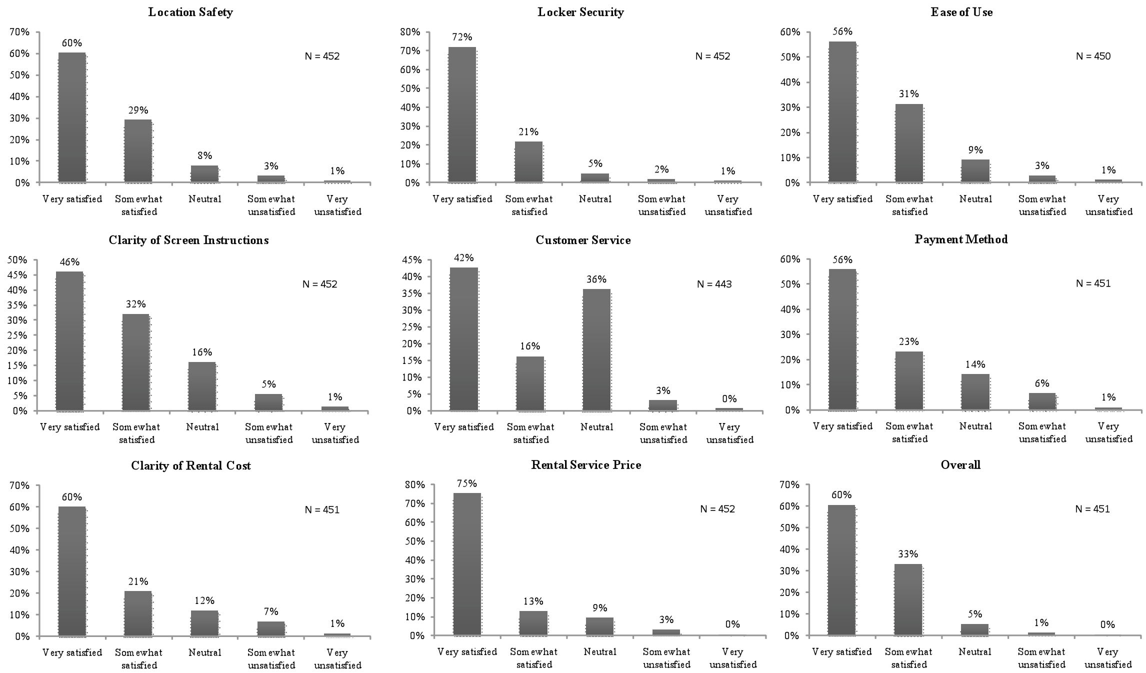
The stated motivations respondents report for using the eLockers vary. But it is important to note that among the population using eLockers, travel by bicycle is more driven by volition and the utility of the bicycle than by stated economic constraint. Table 3.4 shows the distribution of answers respondents gave to a direct question asking them why they use the eLockers.

Table 3.4: Motivation for Using the eLockers

Please select the statement below that BEST characterizes the leading reason why you choose to use the eLockers and bicycle for transportation rather than use…		
Response	Count	Percent
I don't own a car	26	6%
Bicycling is faster and/or more convenient than other available travel modes	147	32%
I want to avoid using a car for environmental reasons	127	28%
To get exercise	53	12%
I want to avoid using a car to save money	36	8%
Other. Please specify:	58	13%
Because of poor or non-existent public transit service	6	1%
Total	453	100%

More than 70 percent of respondents elected reasons that related to personal health, environmental concerns, or the convenience of the bicycle. Roughly 15 percent stated that their choice was related to lack of a car or to avoiding the expense of an existing car. Thus, the survey showed that most people using bicycles and eLockers are driven by non-monetary motivations. Users also expressed a relatively high level of satisfaction with the cost, safety, and operation of the lockers. Figure 5 illustrates the distribution of responses to a series of Likert scale questions that probed the overall satisfaction of users with the system.

Figure 3.5: Respondent Satisfaction with the eLocker system



Specifically, respondents were asked to "Select the responses in the table below that best describe your level of satisfaction with the eLockers in the categories provided." Along most every metric, more than three-quarters of respondents indicated that they were at least somewhat satisfied with the eLocker system. The only exception was customer service, which received a high number of neutral responses, possibly because these respondents never needed customer service.

The survey also asked respondents how they would react if the eLockers were no longer available. That is, they were asked how they would change their travel patterns. The question initially split the respondents into two separate groups. One group used eLockers in conjunction with transit, while the other group did not. The reason for this split was to permit the respective groups to be probed more appropriately given their specific travel circumstances. Among those who integrate eLockers with their transit trip, the results indicate that about half of the respondents would continue to ride their bicycle to the station even if the eLockers were no longer present. Other respondents indicated that they would change their travel in the absence of eLockers. As a follow-up these respondents were asked which mode they would switch to. Table 3.5 offers a cross tabulation of these responses for those that use transit with eLockers.

Table 3.5: How Travel Would Change if eLockers were not Present (Transit Users)

If the BikeLink eLocker service were no longer available, how would your trip to your typical destination place change? Please select the one answer that best describes how your trip would change. "If the BikeLink eLockers were no longer available, I would most likely …"	Please specify which alternate travel mode you would take to or from the transit station (or final destination):							
	Bus or Shuttle	Drive alone	Walk	Pick-up or Drop-off by another driver	Carpool or Vanpool	Bicycle	Other. Please specify:	Total
Use another travel mode to or from the same transit station.	12	41	38	5	2	0	4	102
No longer use the transit station and use a different method of travel to my final destination.	4	13	0	0	4	2	2	25
Use a different transit station.	4	8	6	0	0	7	2	28
Unsure.	NA	NA	NA	NA	NA	NA	NA	10
Continue to access the transit station by bicycle.	NA	NA	NA	NA	NA	NA	NA	137
None of the above, please describe how you would make this trip:	NA	NA	NA	NA	NA	NA	NA	23

Table 3.6: How Travel Would Change if eLockers were not Present (Non-transit Users)

If the BikeLink eLocker service were no longer available, how would your trip to your typical destination place change? Please select the one answer that best describes how your trip would change. "If the BikeLink eLockers were no longer available, I would most likely …"	Please specify which alternate travel mode you would take instead of the bicycle:							
	Bus or Shuttle	Drive alone	Walk	Pick-up or Drop-off by another driver	Carpool or Vanpool	Bicycle	Other. Please specify:	Total
Use a different travel mode instead of bicycling	5	17	14	0	0	0	2	38
Unsure	NA	NA	NA	NA	NA	NA	NA	17
None of the above. Please describe how you would make this trip:	NA	NA	NA	NA	NA	NA	NA	12
No longer make this trip	NA	NA	NA	NA	NA	NA	NA	3

	The same general location as the BikeLink eLockers.	A location closer to my final destination.	Other. Please specify:	Total
Continue to ride my bicycle	37	8	7	52

The results show some interesting modal shifts, as 102, or about 20 percent of total respondents, would use a different mode to get to their transit stations. About half of the respondents would use public transit or walking to access stations, while the other half would use some form of automotive access. The 41 respondents who would drive alone are intriguing because these respondents represented an environmental impact that was avoided as a result of the eLockers. Other respondents indicated that they would no longer use transit, and would drive all the way to their final destinations. Again, roughly half of these respondents indicated that they would do so through some form of automotive travel. Finally, 28 respondents would use a different transit station, with a quarter of respondents selecting automotive travel as their next alternative. Because a follow-up question regarding the alternative mode was irrelevant for the other three initial responses, no question was asked of the other half of respondents selecting one of these three options.

The other group of respondents, those who do not integrate their trip with transit, is smaller (122 respondents). Most of these respondents indicated that they would either continue riding their bicycles or shift to walking or transit. But a few did indicate that they would shift to an automotive mode. The answers to this question are shown in Table 3.6, which shows a cross-tabulation of responses. The table is split into two sections because respondents who stated they would continue bicycling would see the mode-shift question as irrelevant. Instead, these respondents were asked how their bicycle parking would shift if the eLockers were no longer available. Of the 52 that would continue bicycling, most would park in the same location. Overall however, the share of this cohort is roughly 11 percent of the total sample size. Among the cohort that would change modes, a little less than half would shift to an automobile if the eLockers were no longer available.

3.5 Conclusions

In this study, the results of an on-line survey of current electronic locker users (“eLocker”) in California are used to develop models that test the significance of factors contributing to bicycling choice and bicycling frequency. This study is unique in that a consistent set of policy-relevant variables are tested—in both choice and frequency models—to understand their relative importance in different decision contexts.

The survey shows that eLockers are generally used to support work-based commuters traveling by bicycle. Data on travel patterns show that the eLockers are almost exclusively serving the access side of the bicycle commute. That is, the vast majority of eLocker users are riding from their homes to a transit station (usually a BART station), and parking their bicycles at the station for the day. A much smaller contingent of eLocker users are leaving their bicycles at a remote transit station and traveling to it to pick up the bicycle to complete the “last mile” of their trip. Hence eLockers are generally used in the same manner as conventional bike racks. But a fair number of respondents consider the eLocker to be essential to completing their commute by bicycle. Roughly 180 respondents (about 40 percent) indicated that they would complete their trip with some other mode other than a bicycle if eLockers were unavailable. Thus the eLockers are facilitating bicycle travel for a sizeable share of the sample. Many of these respondents would shift to other modes, and nearly 80 respondents suggested that they would shift to driving an automobile alone. Hence, based on these results, the eLockers may be enabling 15 to 20 percent of the sample to use a bicycle instead of an automobile. These results suggest that the eLockers are having some positive environmental impact by facilitating bicycling for people who would otherwise drive. In addition, users expressed considerable satisfaction overall with respect to their use of the eLockers.

4.0 eLocker Reservation Service Evaluation

From December, 2008 to January, 2009, researchers conducted a series of interviews with eLocker users to beta test its reservation service. A total of ten participants in the beta test were interviewed individually, all of whom used the service at least once per month in the time leading up to the interviews.

While most participants were avid cyclists, their use of the eLockers varied: A couple of respondents only used the lockers a couple times per month, while others used it every day. One participant used the service only during warm months, accessing BART three days per week to get to Emeryville. Most of the users interviewed had been biking for utilitarian travel for many years. However, one participant had only begun biking for non-recreational purposes nine months prior to the interview, but used the lockers four days per week to access BART travel to San Francisco. Another began biking for utilitarian purposes four months before the interview and now does so everyday. Most users said eLockers helped them bike more often. Almost all the respondents used the lockers primarily to commute to Oakland, Emeryville, or San Francisco.

4.1 Users' Reservation Behavior

Some users did not perceive any eLocker supply problems, but those who used them at peak hours felt strongly that availability was limited. A regular user, who arrived at the peak hour in the morning, always made a reservation because the lockers were so heavily used at that time. Several indicated they would consider using the nearby Walnut Creek BART station if eLockers were provided there. Many participants said that the occasions when eLockers were not available caused major problems. Several participants avoided biking to the BART station if they did not have an eLocker reservation. It appears that the reliability of finding an available locker may affect users' travel choices. Most users would like to see more eLockers at the station. Several expressed a willingness to pay a higher rate for lockers if necessary.

Another noteworthy trend is that competition for eLockers rises over the summer. Several users said they took more care to make a reservation in the summer months because of higher demand. It was also noted that demand is lower in the wetter and colder months. Even the most committed daily users sometimes balk at bad weather, and several interview participants said their cycling drops off in rainy weather.

Most participants did not consider locking their bikes to a rack an acceptable parking option. The availability of secure parking is a key component to their decision to bicycle. One participant had not experienced any problems getting a locker, but said he would consider driving if he could not be certain of having a secure locker. Another did drive occasionally when he could not reserve a locker. One said that he simply brings a bike lock when he cannot make a reservation, but sometimes he gets a ride to the station from his wife. Usually he brings the bike on board all the way to the office if he can. Another user also said he was dropped off by car when he could not make a locker reservation. Only one respondent seemed unconcerned about having to use the regular bike racks if she could not find an available locker. However, she always checked locker availability first before locking her bike at a rack. She particularly liked the reservation service because it allowed her to leave her heavy bike lock at home. Users who are very concerned about bike security especially appreciate the certainty of a secure parking. These users would not consider leaving their bikes with only a bike lock to secure it. In fact, one respondent's last bicycle was stolen at the Pleasant Hill BART station.

Obviously, bike security is the primary factor driving use of the lockers, but when there is excess demand for the lockers and users cannot bring their bikes onboard BART, they no longer have an acceptable parking option. If there is no possibility of installing additional secure bike parking, locker reservations or at least availability information is a critical necessity for many cyclists.

When asked about using lockers at other locations, the ability to reserve a locker remained a key factor for many respondents. One user said he would not risk biking or traveling farther without being sure of having a secure location to store his bike at his destination. The respondent said he would bike nearly everyday if he were always certain of finding an available locker. For him and other users, having a reservation for a locker would make them more comfortable traveling to more distant locations by bicycle. Most interview participants stated that more locker locations, especially with reservations available, would allow them greater flexibility and increase their frequency of biking. However, most users admitted they would primarily use the lockers only at a single location. In fact, several users said they probably never used the lockers at more than one location. For these users, their bicycles fit a very specific purpose in their overall transportation needs. Many users seem to regard BART stations as a natural location for eLockers and would like to see them at more stations.

4.2 Satisfaction with the Reservation System

While most users who were interviewed used the reservation service frequently, many thought the system had room for improvement. In particular some users wished they could make last-minute reservations when they were certain of their travel plans. Many noted that they experienced some inconvenience waiting for a confirmation email or having to attempt to make a reservation multiple times. The time respondents took to complete a reservation varied. On the high end, one user said it typically took three minutes. One occasional user found the reservation service to be unreliable and often not worth the hassle since it took about two minutes to complete and usually was not successful. Other participants said they usually made reservations in under a minute. Most used home or work computers. The beta testers traveling at peak hours in the morning were most likely to make a point of reserving an eLocker to be assured of an available locker for their bikes. One user said he would reserve a locker for the entire summer if he could. Some of the participants interviewed tried to make multiple reservations at once. Some people reserved their lockers up to a week in advance, while other made a single reservation every day the night before. Several users said they always tried to make a reservation, but often forgot.

Users typically made the locker reservations from their homes or work computers. One respondent said he used a smart phone to reserve an eLocker, and thought the BikeLink website should have better compatibility with smart phones. Two other users also mentioned interest in using a website with better phone compatibility. One respondent said he appreciated the simplicity of the website, and almost all the users indicated they had no problems with the reservation interface.

The survey also asked participants about eTokens, eLock's system to encourage users to honor their reservations and show up. Most participants felt the penalty for missing reservations was fair, but several respondents stated they would like it to be easier to work out misunderstandings and user error. One user noted that buying the eTokens required for a reservation was an annoying process. Several participants noted that the eToken system does not allow for cancellations or early arrivals. These and other users wished the system were "smarter" and could respond flexibly to their travel behavior. For example, a user who showed up early for a reservation was charged an eToken, because he technically did not use his reservation. One participant noted that he preferred making multiple reservations at a time, but without sufficient eTokens, he could not do this. Several users mentioned their interest in reserving specific lockers.

4.3 Payment Options

All interview participants said they were comfortable with the online credit card payment system, but many expressed interest in alternate payment options. Most did not like using credit cards directly with the machines, or worried about forgetting their card. At least one user admitted to having left his smartcard in the locker interface; another suggested a noise reminder if a card is left in the locker interface too long. Many interviewees did like using a Translink, BART EZ Rider card, or other smart cards with the BikeLink system. One pilot participant thought it would be convenient to be able to add value at the eLockers. A couple of users noted that they liked the pay-as-you-use element of the eLockers, because they would never pay for time they did not use.

Although about half of the beta test participants interviewed said that they had experienced serious technical issues with the eLockers on at least one occasion, all expressed a high level of satisfaction with the service. Technical issues included cards not working on wet days and certain lockers not working on the coldest days of the year. Several users expressed concern about difficulties undoing mistakes made using the machine. However, none of these incidents appeared to affect participants' use of the eLockers. Most users appreciated how easily and quickly they could put their bicycles in the lockers and get into the BART station. They were very satisfied with the technology on location.

5.0 Mobility Options Protocol (MOP)

EasyConnect II investigated the integration of multiple strategies designed to enhance transit at the Pleasant Hill BART District station and Contra Costa Centre Transit Village. A central component of this research was the development of the MOP. The MOP addressed challenges of providing information about multiple modes and connections through a web-based interactive system. Researchers at the University of California at Riverside have completed a comprehensive review of numerous technologies and innovative strategies to support the MOP. The full report is provided in Appendix A.

The MOP is a web-based information system that allows users to reserve, pay, and access travel information online. Through this system, a range of modal options and transportation services are seamlessly linked over the Internet in formats accessible to both users and project planners. This system allows various transportation providers to publish information on the web in a format that can be recognized and interpreted by automated agents, such as trip planning applications. The MOP extends traditional trip planning tools beyond fixed-route, fixed-schedule carriers and incorporates real-time status, last-mile providers, and reservations for vehicles, rides, and parking. Essentially, the MOP includes informational infrastructure that facilitates travel options such as walking, bicycling, carsharing, and other supportive transit modes. This system is designed to manage the resulting multi-modal, multi-vendor data in a commercially feasible manner. The specific objective is a system that:

- Provides a seamless experience for end users to view or reserve modal options;
- Attracts new modal choice vendors who may join the information web;
- Requires little administration by the operating agencies; and,
- Offers opportunities to distribute information and data to interested parties.

5.1 Mobility Options Protocol System

The MOP is a fully distributed web protocol. Information is listed by individual vendors and linked together through a central portal rather than a central computer server. But the information is not centrally controlled. Anyone can create a central portal and make it available. Once the information is published using the MOP protocol, it is available publically to any vendor or publisher. This system provides more flexibility in adding or modifying information. After the information about a required trip and mode choices is entered, details about specific connections, modes and routes are presented seamlessly to the traveler.

The MOP includes five levels. They can be implemented together, or individually.

- Level 1: Basic contact information and locations of services provided
- Level 2: Adds real time status
- Level 3: Allows availability of service through queries of future dates
- Level 4: Includes reservation services
- Level 5: Integrates fare payment

Level 1 is the most basic implementation of the system. Data about actual transportation hubs is provided. Tools that display MOP data operate by using the most specific information available. Providers who offer services at fixed locations fill in "point" elements, indicating service availability at each location (e.g. at each bike locker or rental location). The location of a point can be specified in terms of an address, in proximity to a landmark (e.g. a rail station), or via geographic coordinates (latitude/longitude). Providers who pick up or drop off travelers can specify a designated service area by utilizing a list of zip codes, cities, or a set of boundaries that indicate where the service is provided.

Level 2 adds real time status to the basic information provided in Level 1. A user could access the current parking space availability at a garage, or lot, in the system.

Level 3 builds upon the innovations of previous MOP levels by allowing users to inquire about future service availability. These requests typically involve a place and time. For instance, a user would be able to inquire whether a bicycle locker would be available at a specific time and location in the future, such as the Pleasant Hill BART station on May 1 from 5pm to 7pm.

Level 4 incorporates a reservation system whereby users can create, modify and cancel reservations. This level also introduces a process of verifying that a traveler has a pre-existing relationship with a service provider and thus can streamline the process by only presenting a username and password for service use.

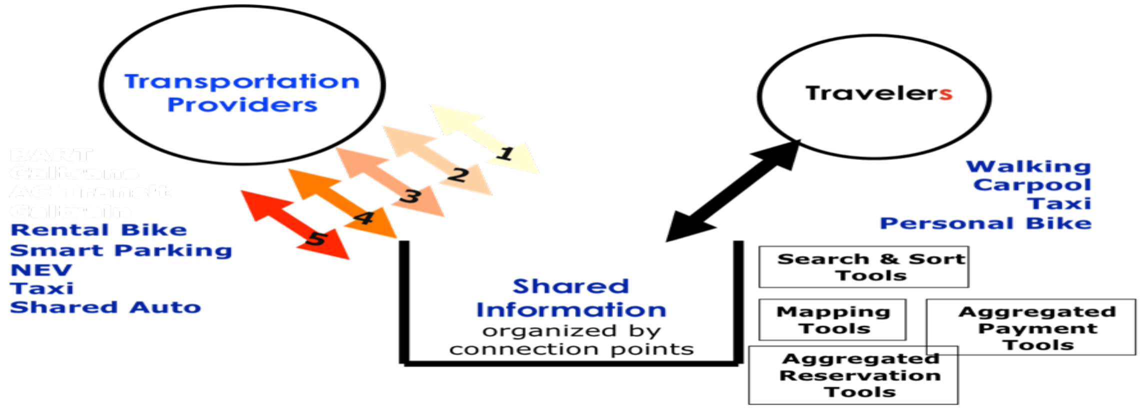
Level 5 is the most complex stage of the system. At this level, the MOP incorporates a scheme for integrated fare payment. Examples of the complexities include maintaining an audit trail, and processing refunds and reconciling corrections. While transit fare integration with different providers is operational, it is more complicated to integrate across services.

5.2 Travel Information Flow

The aim of the MOP is to help travelers combine different modes of transport in a single trip. The ability to make efficient connections requires coordinating schedules, status, reservations, and payment information from different sources. In order to seamlessly facilitate inter-modal access, options, and efficiency, the MOP allows travelers to interact with varying levels of information sharing. At the most basic MOP level, travelers and transportation providers can share contact information and locations of service providers. At its most sophisticated level, the MOP provides travelers and transportation providers with a system that facilitates service reservations. The system is accessible to both travelers and transportation providers. Shared information creates an annotated information platform whereby transportation providers contribute information about services such as bike rentals, smart parking, taxis, and carsharing. Travelers can also contribute transit information that is not necessarily provided by transportation providers, such as walking routes, carpools, taxis, and personal bike usage.

Figure 5.1 provides a visual graphic for travel information flow in a MOP system.

Figure 5.1: Travel Information Flow in a MOP System



5.3 Issues with Integrating Flow

Integrating travel flow is challenging because not all modes can be incorporated easily, or use the same communication mechanisms. The MOP addresses these issues by allowing travelers to share and augment information. Users can provide recommendations for routes, such as walking paths, not available through transportation providers. The ability to add a map with highlighted routes also assists travelers using alternative methods.

5.4 Benefits of Information Sharing and Integrating Multi-Modal Travel

Intermodal travel shifts the emphasis from focusing on route and mode to connection points. Information sharing and multi-modal travel creates a seamless experience where travelers would only have to look up connection point schedules once a destination has been chosen.

The MOP integrates project component technologies into a simplified, web-based interface while seamlessly facilitating inter-modal access, options, and efficiency. The MOP addresses the following types of information components, allowing users to make efficient connections that require coordinating schedules: status, reservations, and payment information from different sources.

5.5 Implementation Considerations

During the EasyConnect II project, the MOP was designed, but did not reach the operation phase. The ability to implement the MOP would require a location where the multiple modes were all in operation, with real-time information and reservation capabilities. The Contra Costa Transit Village services were not advanced enough to launch this project. Furthermore, during the planning it became evident that further programming resources and a more in depth data related to travel across multiple modes and points connecting these transportation options was necessary. The following elements were identified as important considerations to implementing a new MOP or augmenting an existing traveler information system with information collected during the MOP planning process:

- Keep it simple and easy to use;
- Focus on commercial viability, adoptability;
- Conduct review of current (and past) applications;
- Incorporate enough connection points to be useful to users;
- Test the system with actual transportation vendors and portals;
- Maintain vendor neutrality based on open standards (XML, RSS, SOAP);
- Utilize individual portals, not a central information server; and,
- Consider compliance for eventual adoption as a Federal DOT Intelligent Transportation Systems (ITS) standard.

5.6 Beyond the MOP: Current Traveler Information Activity

The MOP introduces an informational infrastructure to effectively link multiple modes of transportation. While the MOP was in development, other traveler information sites began expanding their services to include considerations addressed during the MOP planning process. While these programs do not include all the elements (i.e., reservations), they do include multi-modal trip planning options.

Expanded traveler information services include Google Transit and 511 sites. Google Transit, for example, provides many of the same basic functions for the traveling public as the MOP. Google Transit includes walking, driving, and public transportation (i.e., BART and AC Transit). Google Transit does not include a system that allows users to reserve a future service and does not include an integrated fare payment system (Levels 4 and 5). A number of the 511 systems also are proving traveler information services that include multiple modes and connection points. In the MOP vernacular, these systems currently operate at Levels 1, 2, and partially at Level 3. They do allow users to access information about multiple transportation modes, including real time status information, and allow future queries as to availability of service. But they do not include reservation or payment capabilities.

The MOP is based on an open source system, allowing users to share information as well as access it. This capability enables the expansion of the system with up-to-date information – the basis of the MOP concept. While the EasyConnect MOP was not actually deployed, the investigation resulted in innovative ways of addressing multi-modal trips. These elements can inform future iterations of currently deployed multi-modal travel planning tools.

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Appendix A

EasyConnect II:
Technology and Integrated Systems Review

FINAL REPORT
prepared for
California PATH
September, 2007

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Summary

UCR has completed a comprehensive review of numerous technologies and innovative strategies to support the EasyConnect II program. A Mobility Options Protocol (MOP) is a proposed open source protocol for linking information across a broad range of mobility options to trip planning systems and travel information aggregators across the internet and digital communication networks. The primary focus is on the following systems with respect to MOP integration:

- Communication Hardware;
- Communication Protocols and Standards;
- Electronic Fare Payment and Access Control;
- Reservation Systems and Trip Planners.

The communications hardware section of this report summarizes the common hardware configurations utilized in digital network applications. Special focus is given to wireless network devices suitable for communication with individual MOP integrated devices (e.g. electronic bike lockers). While the MOP will function primarily over Internet compatible hardware devices, several end devices may require specialized hardware and network considerations.

One of the key primary considerations in the development of a MOP is the inherent interoperability. The universal acceptance of a protocol involves the standardization and acknowledged acceptance by the respective experts in the field. The automotive, computing, communications, and electronics industries all possess nationally and internationally recognized bodies for the development, evaluation, approval, publication, and dissemination of protocols and standards. The extensive amount of MOP relevant activity in standardization of communication protocols is addressed in the Protocols and Standards section of the report.

The development of electronic payments and digital access control is allowing a merger of the two technologies for transportation purposes. The evolution of digital keys (e.g.,. proximity cards) and electronic payment (e.g., smartcards) has created an overlap suitable for transportation applications. The electronic fare payment devices are successfully being utilized for access control in transit environments. The associated hardware and software of various combined electronics fare payment and access control applications is discussed.

Interoperability of transit services utilizing a MOP will be fully achieved if the relevant travel information can be shared between *reservation systems* and *trip planners*. This type of interoperability has been achieved in some travel industries. A review of reservation systems, trip planners, and associated standards are discussed in the final section.

The resulting technology review should provide insight into the current conditions within the transportation industry relative to development of a MOP. Portions of the industry have developed compatible hardware, architecture, and standards while others require significant advancement. This review will help select a path for MOP development.

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Introduction

The initial technology implementation at the Pleasant Hill Bart Transit Oriented Development (TOD) is attempting to integrate several mobility options within a single transportation Mobility Options Protocol (MOP). The purpose of the protocol is to create a standard method of integrating mobility options suitable for disseminating transit information, expanding services, and allowing open access to services provided.

The initial architecture proposed for the Pleasant Hill TOD includes a Local Area Network (LAN) which interconnects the hardware technology options, software applications, and provides communication between electronic devices being utilized or accessed for transit purposes and Internet-linked transit oriented applications.

The electronic devices and services being integrated within the LAN may include:

- Informational kiosks and access display terminals;
- Electronic bike lockers;
- Electronic access mechanisms for Segway Human Transporters (HT);
- Smart parking spaces and meters;
- Power station performance interface;
- Reference databases for transit service web portals (e.g. 511.org);
- Electronic reservations and scheduling;
- Transit (bus/train) schedules with arrival/departure tracking; and,
- Carsharing.

The report is organized into the following sections:

Technology Background – provides a review of suitable reference models, technologies, and network architectures upon which network-based applications operate;

Communication Hardware – present MOP-suitable communication methods for interconnecting digital devices;

Communication Protocols and Standards – summarize MOP-relevant protocols and standards for communication devices and integrated systems;

Electronic Fare Payment and Access Control – review MOP-suitable fare payment and access control technologies;

Reservation Systems and Trip Planners – evaluate reservation techniques and trip planners in the context of implementing a MOP;

Conclusions – summary of significant findings from each technology section; and,

Annotated Bibliography – provides keys details regarding relevant references.

This technology review for MOP implementation encompasses numerous communication technologies, systems, methods, and protocols. To properly present the most recent developments in these technology areas, a thorough understanding of previous and current implementations is required.

1. Background

This background section presents the key areas of development which have enabled MOP-style architectures to be proposed, developed, and implemented. The background review discusses the following technology areas:

- Reservation applications and vehicle management;
- Digital communications;
- Fare payment and access control;
- Reference models; and,
- Standards bodies.

Previous applications of mobility-related reservation and vehicle management systems will be reviewed, describing what level of technology has been previously implemented. Additionally, the communications industry has been rapidly evolving and growing. This continued expansion requires a thorough understanding of previous developments. Background for fare payment and access control is presented to clarify evolution of these technologies. The integration of communication methods, protocols, hardware, and applications requires some type of organizational method to describe how the technology components relate within a data-oriented communications network. A suitable reference model is the International Standardization Office (ISO) Open Systems Interconnections (OSI) Reference Model (ISO/IEC 7498, 1994). Details regarding the OSI reference model are provided to allow for presenting relationships of key technology components suitable for MOP related integration. The background review finishes with a presentation of relevant government bodies and agencies responsible for developing standards and protocols which influence the implementation of a MOP for shared-use mobility applications.

1.1 Mobility Reservation Applications and Vehicle Management

In recent years, numerous shared-use vehicle services have developed that reflect different operational models and market segments. A classification system for categorizing different shared-use vehicle system models, ranging from neighborhood carsharing to station car systems, was developed in 2002 (Barth et al., 2002b). The predominant shared-use vehicle model is neighborhood carsharing, where individuals in dense metropolitan areas access shared-use vehicles distributed throughout neighborhood parking lots. Indeed, this is the prevailing approach in Europe and commercial shared-use services in North America. Station car systems are another model, where vehicles are closely linked to transit stations to enhance access. Some of the more innovative shared-use vehicle service providers today are combining elements of both traditional carsharing and station cars, forming what are called "hybrid" models (Barth et al., 2002b). As of January 2007, there were 18 car-sharing programs domestically, boasting 134,094 members, according to Innovative Mobility Research, a group that researches environmentally-friendly transportation alternatives. Those members shared 3,637 vehicles — roughly the equivalent of 37 users per car (Scherzer et al., 2007).

One of the key elements of modern-day shared-use vehicle systems is the application of intelligent transportation system (ITS) technologies. These technologies can enhance shared-use vehicle services by improving their overall efficiency, user-friendliness, and operational manageability. Dispatching and reservation systems so that users can obtain system information, check-out vehicles, and make reservations over the web, by phone, by kiosk, or other remote means, have been widely implemented. Much of this advanced technology has been developed and applied in shared-use vehicle research programs, such as the UCR IntelliShare testbed (Barth et al., 2000) and the Carlink II program (Shaheen, 2000). Evaluation of previous commercial implementations has demonstrated that individual entities have implemented proprietary systems for managing reservations and vehicle usage leading to a segregated customer base.

Commercial carsharing organizations as of 2005 in North America have increased technology penetration in their systems, where 70 percent of U.S. shared-use vehicle organizations have advanced operations and 11.5 percent still utilize manual services (Shaheen, 2006). Previous carsharing technology evaluation (Shaheen, 2002) has shown: manual operations include operator phone services and in-vehicle trip logs; partially automated systems are automated reservations via touch-tone telephone or Internet or both; and advanced operations involve smartcard access, reservations, billing, automated vehicle location, and cellular/radio frequency communications. As shared-use vehicle systems continue to expand and multiply, the penetration of ITS technology is increasing since manually managing larger fleets and more diverse user markets (e.g., one-way trip rentals) becomes more difficult with increased scale. The high initial cost of establishing advanced operations is decreasing relative to the benefits added.

As shared-use vehicle services continue to grow, there will be an increasing need for interoperability among shared-use vehicle systems and providers. This continued push for interoperability has provided significant motivation for development and implementation of a MOP. While development of a MOP is key for interoperability in mobility operations, there are two additional areas where development of standards would be beneficial that are outside the scope of a MOP.

Customer Interface Standards—from the customer’s perspective, it is beneficial for shared-use vehicle system operators to provide a high degree of interoperability and consistency among various shared-use vehicle systems, as well as with transit. A key example in this case would be a single access mechanism (e.g., smartcard and/or key fob) that could be used among many shared-use vehicle systems and other mobility services such as transit and parking management. Billing could also be made uniform across many programs, so that one monthly bill is received rather than several from various organizations. Operational consistency among several systems is also key, so that customers do not have to re-learn different operational procedures.

Vehicle Standards—many automobile standards are already in place for safety, consistent operation, and interoperability of components. With the addition of shared-use on-board electronics, some standards will likely emerge so that automakers can produce vehicles that more easily integrate and operate more consistently among many shared-use vehicle programs. As an example, shared-use vehicles might have a common interface (i.e., connector) for on-board monitoring and control electronics. Shared-use vehicle technology manufacturers could also benefit by adopting some uniform components for the growing shared-use vehicle market segment (e.g., smartcard readers placed in vehicles).

This review details technology issues and operational methodologies that have been emerging in the shared-use vehicle arena. This discussion spans the elements of vehicle management and system operations relative to MOP development. In this discussion, various trade-off issues are described and qualitative benefits are compared among different system designs.

1.1.1. Shared-Use Vehicle Management Background

Prior to describing a variety of reservation systems at various levels of technology application, it is first necessary to address some implementation of shared-use vehicles themselves. As mentioned previously, automobiles are almost always considered to be the "vehicle" in a shared-use system. However, this is not necessarily true—these systems can include other transportation modes such as bicycles and scooters. In fact, shared-use bicycle systems often come to mind when individuals are first introduced to the carsharing concept. The MOP-related technology review being completed evaluates ITS technologies suitable for a wide range mobility options (e.g. autos, NEVs, bicycles, Segway HTs, and scooters).

In the simplest of systems (i.e., "manual" operation), a user can call a reservation center (system management center) and request a vehicle for a trip. An operator then checks previous reservations for the vehicle(s) of interest and if a time slot is available, the reservation is recorded. Over the last several years, there has been significant development and proliferation of automated reservation systems throughout society in general. For example, lodging, traditional car rental, and the airline industries now employ automated reservation systems that can be accessed both from the phone (entering data via a touch-tone pad) and from the Internet. For shared-use vehicle systems, it is a natural fit to have both phone- and/or internet-based automated reservation systems. Generic automated reservation systems can easily be modified for shared-use vehicle systems, little specialization is required for this implementation. Most on-line automated reservation systems show a calendar with dates and times for which there are available vehicles and have a simple intuitive interface.

Reservations provide users with the comfort and security of knowing that a vehicle is available for them at a specific time and place. Reservations are also useful for system management, allowing the system to maximize vehicle usage throughout the day. For multi-nodal shared-use vehicle systems where one-way trips are common, reservations can play an important role in maintaining a proper distribution of vehicles at all stations throughout the day. By knowing the travel demand ahead of time via reservations, it is possible to estimate when a lack of vehicles may occur at any one station and corrective action can take place (Barth et al., 2001). With reservations, three general steps taken are: 1) reservations are submitted (on-line or phone); 2) at the time of the trip, a user approaches the vehicle and obtains access; and 3) the user carries out the trip. At the completion of the trip, trip data are recorded (either manually or via communication between the vehicle and system).

Airline Reservation Systems Background

The airline industry has been the dominant presence of digital networked reservation systems for nearly 50 years. The original systems created by the airline industry preceded the prominence of the Internet and the online travel agencies (e.g., Expedia, Orbitz, Travelocity etc.). Nearly every aspect of online Internet-based reservations has evolved around or is intricately tied to the airline industry reservation system, which is referred to as the Global Distribution System (GDS).

Since the airline-based travel systems preceded the international deployment of the Internet as a distribution channel for travel, this discussion starts with an understanding of the existing airline electronic distribution infrastructure, the Global Distribution System. The airline industry created the first GDS in the 1960s as a way to keep track of flight schedules, availability, and prices. Although accused of being outdated due to their use of legacy computer system technology, the GDSs were actually among the first e-commerce companies in the world facilitating business-to-business (B-2-B) electronic commerce as early as the mid 1970s, when SABRE (owned by American Airline) and Apollo (United) began installing their propriety internal reservations systems in travel agencies. It is these original, legacy GDSs that today provide the backbone to the Internet travel distribution system (Das, 2002).

At its inception, the Global Distribution System (GDS) represented a closed, dedicated connection of terminals displaying travel information about airlines, hotels, car rentals, cruises and other travel products. Used almost exclusively by travel agents, the GDS created a distribution chain that was relatively linear, allowing each chain player to collect a portion of the transaction. Today, however, the GDS has been reduced to just one component of a much larger ecosystem of networked travel information with advances in communication and software. It is this larger structure - the Global Distribution Network or GDN - that is dramatically affecting how business is done in the hospitality and travel industries. This emerging distribution model might be more closely described as a multi-dimensional flow of information and transactions with any intermediary in the channel able to distribute travel information and complete a transaction directly with the customer.

Traditionally, the travel reservations were made utilizing one of two methods: either at the travel agent’s desktop or at the reservation center of individual suppliers (i.e., accessed by consumers via the telephone). The airline or hotel supplier was connected to travel agents through the GDS, which created a straightforward variable cost structure to sell travel products. Although designed for the airlines, the GDS’s widespread distribution (40,000 terminals worldwide in 2002) attracted other hospitality and travel companies to list their inventory (Das, 2002). Since their information is displayed in a similar format to airlines, hotel, car rental, and tour wholesaler products utilize the GDS to manage reservations. The inventory is essentially on consignment to the GDS at a predetermined price, regardless of market fluctuations after the product allotment was made available.

There are currently four major GDS systems:

1. Amadeus
2. Galileo
3. Sabre
4. Worldspan

In addition, there are several smaller or regional GDSs, including SITA's Sahara, Infini (Japan), Axess (Japan), Tapas (Korea), Fantasia (South Pacific), and Abacus (Asia/Pacific) that serve interests or specific regions or countries (Das, 2002). Focusing on the four major GDS's provides sufficient background and understanding of the evolution of reservation systems and how to best interface new technologies.

With the evolution of the Internet and having GDS's already exist, there was the opportunity for greatly improving the airline reservation methodology. Orbitz was originally conceived by the major airlines in the early 1990's when the Internet was in its humble beginnings as a retail medium and airlines still paid hefty commissions to travel agencies. At the time, three major travel agencies (American Express, Carlson Wagonlit, and Rosenbluth) controlled a majority of airline ticket sales. The four computerized reservation systems (Sabre, Galileo, Worldspan and Amadeus) provided the automation for the 80 percent of airline tickets sold through the travel agency channel (Castleberry, 1998).

Microsoft, being heavily involved with the inner workings and displays of most personal computers, was quickly involved in the online travel agency development and deployment. Microsoft as a result created and developed Expedia. The advantage of Orbitz, Expedia, Travelocity (which is part of Sabre), or any other online travel agency, is that they serve as consolidated online travel stores, offering flights and fares from multiple vendors for a one-stop travel planning and purchasing experience. As time passed, Travelocity and Expedia became smaller threats to airline costs as ticket commissions became a smaller component of airline ticket sales. The online travel agency sites currently make money from other commissions (like car rentals, hotels, cruises) or from advertising and special preferred relationship deals with various travel suppliers, and user fees (Castleberry, 1998).

1.2 Communications Background

Critical to many ITS applications is the ability to communicate between different devices and/or users. A high degree of development in the mobile wireless communication arena has occurred in recent years with the proliferation of cellular devices, personal digital assistants (PDAs), and other mobile computing platforms. Much of this development has been associated with the information needs of consumers, such as messaging, sending and receiving emails, mobile computing, and downloading information from the Internet. There has also been a good deal of activity in the communications arena of ITS. Five general types of communications linkages have been defined for ITS, which include:

- Wide Area Broadcast Communications;
- Wide Area Two-Way Wireless Communications (e.g., cellular);
- Dedicated Short Range Communications;
- Vehicle-to-Vehicle communications; and
- Wireline communications [US DOT, 2005].

These communication linkages involve numerous ITS applications for a variety of purposes, such as safety, remote diagnostics, maintenance, and entertainment. In general, ITS applications have different communication requirements in terms of bandwidth, latency, and quality of service (QoS). For example, vehicle-to-vehicle communications in an automated highway system scenario will require local high bandwidth communications, while applications such as remote emergency diagnostics will need a low-bandwidth, highly available connection. It is important to note that the wireless network architecture developed for personal data communication needs (e.g., Internet-capable mobile phones) won't necessarily be able to satisfy all ITS communication requirements. As a result, specific wireless communication architectures and methods are being developed and tailored for various ITS applications (e.g., see (Bana & Varaiya, 2002; Lee et al., 2001; Punnoose et al., 2001; and Munaka, 2001)).

Wireless communications will play a significant role for MOP development within transit-oriented developments, particularly in communicating information between users, the system, and vehicles. Much of the communications needs make use of the Internet, since it is often widely available and a variety of Internet-based communication protocols have already been established. Using the Internet as the backbone for communications, a variety of architectures are applicable for TODs. For example, an architecture for generic local communications between a "system" and vehicles is shown in Figure 2.1. This architecture is useful for vehicle (or any other shared resource) access control, as well as for uploading and downloading vehicle information. This architecture is not well suited for real-time applications unless the resources (vehicles in this case) do not travel far from a local short-range communications unit.

Cellular based communications can be used to send wireless messages between the system and the resources. General Packet Radio Service (GPRS) communications, considered as wireless IP networks, are now widely accepted standards in North America. They primarily provide packet data service for mobile users by automatically utilizing idle cellular phone channels to send packet data traffic. GPRS has been the primary target of ITS applications that require Wide Area Network (WAN) data communications. A mobile end system communicates with the GPRS network via a 19.2 kilobits per second or greater raw duplex wireless link, which is shared by several mobile end systems.

Additional intelligent wireless techniques such as frequency hopping, RS code, roaming, and dynamic channel relocation are used to provide a fairly robust data channel (Lin, 1997). When implementing such a wide-area communication architecture, a monthly subscription fee must be paid. Further, a wide-area cellular system will always have a certain degree of data packet loss and data packet latency, which might affect shared-use vehicle system operations (see (Barth et al., 2002)).

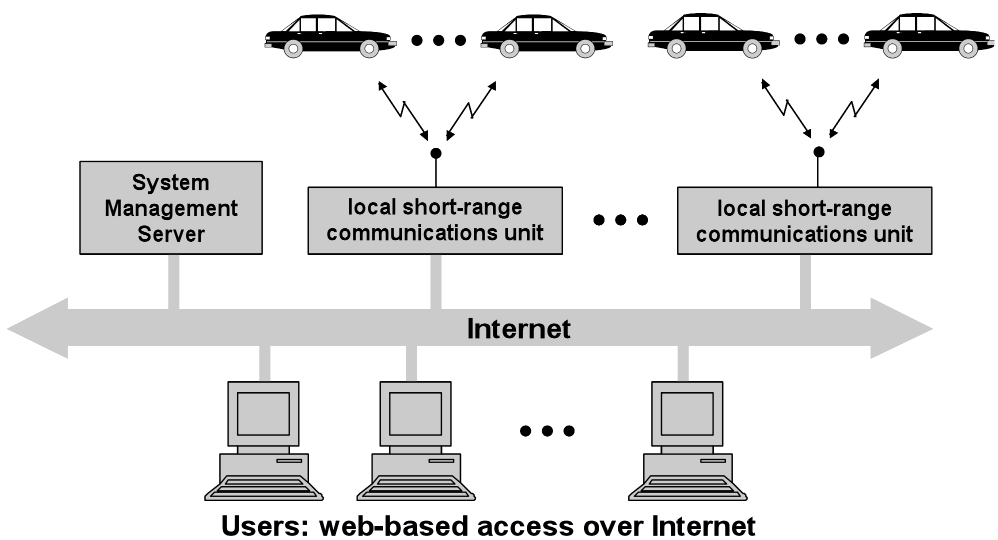


Figure 2.1. Generic local communication architecture.

The MOP development requires Wide Area Network communication utilizing Internet-accepted communication standards and protocols. Various wireless WAN communication methods exist such as, cellular, satellite, and regional wireless (Wi-Max). The technology evaluation relative to WAN integration focuses first on wired WAN and wired LAN connectivity and integrates wireless solutions when necessary. The wired LAN and WAN hardware and software have been proven and tested as the most cost effective and reliable network communication methods. WAN technology integration utilizing wireless data transmission is proposed and evaluated when wired connectivity is not feasible due to hardware infrastructure limitations. Wireless WAN communications vary regionally and performance is often variable depending upon site specific characteristics such as signal strength, usage demand, and RF interference.

1.3 Background of Digital Devices for Fare Payment and Access Control

The two technology areas of fare payment and access control are being evaluated together for the purposes of this review. While each have their own protocols, standards, and development history, the technologies are beginning to merge for the purpose of mobility applications. Tokens and methodologies utilized by patrons of mobility services for gaining access to a vehicle or service are also being utilized to identify the users respective account and levy charges for services provided. For this reason, the devices, protocols, and standards that serve this dual purpose are being evaluated in this review. Examples of these technologies include smart cards, proximity cards, magnetic strip cards, RFID, and Personal Area Network (PAN) based wireless electronic payment.

1.3.1. Vehicle Access Control

Coupled with reservations and/or on-demand check-out procedures, there are several different ways to control vehicle access. There have been several methods developed in different shared-use vehicle system models:

Lockbox: All users can carry a single key that allows access to a lockbox located at a shared-use vehicle system site. In the lockbox, the car-keys of the different vehicles are available. Many systems have taken this a step further by using common smartcards to access the lockboxes (e.g., COCOS) (Britton, 2000).

Common Key: In this scenario, all of the shared-use vehicles are re-keyed so that a single key can be used for all vehicles. All users then have a copy of the same key and can access any of the vehicles (e.g., CarLink II) (Shaheen, 2004).

Smartcard Open Access to All Vehicles: Instead of a common key, on-board electronics (i.e., card reader secured to a door lock mechanism) can be used to read smartcards issued to the users. In this scenario, all vehicles would unlock using any system smartcard. Once in the vehicle, a permanently mounted or tethered key would be used to start the vehicle (or ignition pop-up key featured in Honda's Diracc program in Singapore (hondadiracc.com). This method, along with the common key and lockbox methods, depends on users following an honor system to enforce reservations, since any user can access a vehicle at any time.

Smartcard Exclusive Access for Specific Users: Similar to that above, smartcards are issued to users. Each smartcard has a specific code, and when vehicle access is requested, only the designated smartcard (with the associated PIN code) would release the requested vehicle for use. This vehicle access control requires that the smartcard code be transmitted to the vehicle prior to the time of vehicle access for that user. Once in the car, the user can start the vehicle, again using a permanently mounted or tethered key.

Smartcard Exclusive Access for Specific User with PIN Confirmation: This method is similar to that above where smartcard codes are used to enable specific user access for each trip. However, an additional step is required in that once the user is in the car, he/she has to enter a personal identification number (PIN) on an input device (or message display terminal, typically mounted on the dashboard) to enable the ignition system. This is similar to bank automated teller machines to help prevent fraudulent use of lost or stolen cards.

In all of the smartcard options, key "fobs" (i.e., small devices that can hang from a key chain) can also be used. The largest U.S. carsharing service providers are using such key fobs, supported by the AWID standard. Furthermore, PDAs or other wireless devices could be used for keyless access by performing short-range communication (e.g., infrared or bluetooth) with the vehicle.

All of these vehicle access solutions have tradeoffs in convenience, security, and cost. The lockbox technique provides a small amount of security in that users have to go through an extra step to gain access to the vehicle keys. The common key method is the least secure method, since any lost key could be found and used for an entire fleet of vehicles. The smartcard-open-access method provides a small increase in security since a person who finds a lost card won't necessarily know how to use it. The smartcard-exclusive-access method provides significantly more security but at the cost of requiring the ability to communicate smartcard codes to the vehicle. The smartcard-exclusive-access-with-PIN provides the most security and has the added cost of requiring a PIN input device inside the vehicle. The majority of mobility or transit based systems of any significant size or complexity are transitioning towards RFID, contactless, or smartcard access systems.

1.3.2. User Identification and Fare Payment

Numerous technologies have traditionally been utilized for user identification and fare payment. These technologies include:

- Bar Codes
- Magnetic stripes
- Ibuttons
- Chip Cards
- RF Tags

Bar code systems which are traditionally associated with retail inventory management and register systems have been utilized successfully for product identification. The usage of bar codes within the transportation sector requires the utilization of electro-optical readers that must address issues of readability. The readability of a bar code is dependent upon scanning speed, scanning angle, contrast, and lighting conditions.

Magnetic stripe systems utilize similar principles as the bar code but incorporate magnetic readers versus optical readers. This technology has universal use within the credit/debit card arena and is well integrated within the consumer market. Magnetic stripe systems have been incorporated into transit systems with some success. The magnetic stripe cards can be issued on plastic credit card specification stock or on disposable paper stock. Magnetic stripe systems are impacted by weather, dirt, and degradation of cards.

Ibuttons entered the market with the goal of alleviating some of the optical and magnetic reader issues associated with bar codes and magnetic stripe systems. The Ibutton systems have entered the transportation sector for controlled parking, transit, and meter systems. Ibutton applications are expanding to include read/write capability and fare payment activities. While Ibuttons have overcome some of the traditional issues associated with bar codes and magnetic stripes, the read process still requires physical contact between the Ibutton and reader. Technologies such as the Ibutton and magnetic stripe technologies are discussed generally but not in depth since the majority of ITS transportation-related efforts are transitioning towards contactless technologies.

Smart cards utilize smart chips that are read/write capable and come in contact or contactless configurations. The contactless configurations generally fall under ISO/IEC 14443 international standards and operate at a distance of less than 10 centimeters utilizing the 13.56 MHz frequency. Contact smart cards utilize the ISO/IEC 7816 standard and require electrical contacts between the reader and the card. Smart cards have been utilized successfully for numerous combined access and fare payment applications (smartcardalliance.org, 2007).

RFID tags have widespread use in supply chain applications for tracking inventory. Two general categories exit for RFID technologies: passive and active. Passive RFID tags utilize the reader's broadcast frequency to generate sufficient power within the card to then broadcast identity information within the proximity of a reader. Active RFID tags broadcast a signal through their own power source and transmitter. A reader then receives the broadcast and identifies the identity of the tag. Generally, the passive RFID tags are less expensive and are utilized in high volume inventory applications. The active RFID tags are typically utilized in applications of lower volume and higher transmitting range requirements. RFID tags have been successfully implemented for automated toll collection within the ITS arena (ITS America, 2001).

1.4 Network Reference Model Background

Understanding and knowledge of digital communication network models proves very useful for evaluating and comparing digital protocols, hardware, and software. These two reference models are the ISO OSI 7 layer reference model and the 4 layer TCP/IP reference model. The two models are further described below. While most digital communications network protocols refer to the OSI 7 layer model, Internet communications primarily utilize TCP/IP.

1.4.1. OSI Reference Model Layers

The OSI Reference Model consists of seven conceptual layers, each assigned a numerical value from one to seven. Each progressive layer number represents the system hierarchy and indicates proximity to the actual hardware used to implement a network. The first and lowest layer is the physical layer, which is where signal transmission and hardware are implemented. The seventh and highest layer is the application layer, which deals with high-level applications utilized by end users and the operating system software. The MOP being developed within this program will be used by applications operating in the seventh layer and communicate with hardware implemented at the physical layer. The technology being implemented for interfacing with mobility control devices (e.g. bike lockers, Segway access mechanisms, vehicle telematics) operate down to the lowest layer of signal transmission (physical layer).

This seven layer OSI Reference Model defines how the vast majority of the digital networks currently function. OSI was an effort formed by the International Organization for Standardization in 1982 with the goal of producing a standard reference model for the hardware and software connection of digital equipment (ISO/IEC 7498, 1994). The important concept to realize about the OSI Reference Model is that it does not define a network standard, but rather provides guidelines for the creation of network standards and integration relationships.

Transitioning up from the first layer to the seventh represents moving up the layer stack and therefore, increases the level of abstraction. This means that the higher a layer is in the stack, the more it incorporates logical concepts and applications, and the less it deals with the hardware of a network.

The OSI Reference Model does not formally define any relationship between groups of adjacent layers. The OSI Reference Model is frequently divided into two layer groupings: the lower layers, and the upper layers. Figure 2.2 provides a visual representation of the OSI Reference Model with the separation of application and transport layers.

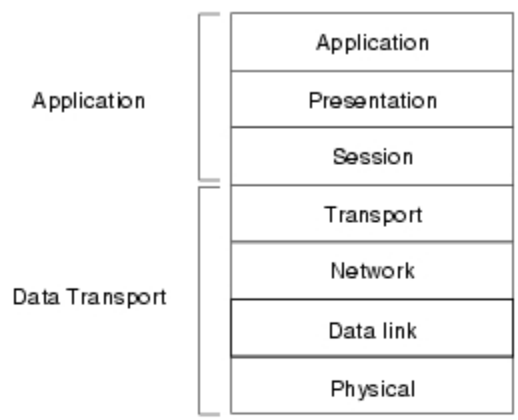


Figure. 2.2. OSI Reference Model layers (Cisco, 2006).

Lower Layers (Layers 1, 2, 3 and 4) — The physical, data link, network and transport layers are primarily concerned with the formatting, encoding and transmission of data over the chosen network. The tasks don't discern by data purpose or application, the tasks are only responsible for transmitting data between devices. The communication tasks are implemented in both hardware and software, with the gradual transition from hardware to software occurring as you proceed up from layer 1 to layer 4. Layer 4 is often considered a transitional layer between the transport of data between devices and how a device is utilizing the data (application).

Upper Layers (Layers, 5, 6 and 7) — The session, presentation, and application layers of the model are the ones that are associated primarily with interacting with the user, and implementing the applications that utilize the network. The protocols that run at higher layers are minimally concerned with the low-level hardware details of how data gets sent from one place to another. The upper layers rely on the lower layers to provide delivery of data and are primarily implemented as software running on a computer or other hardware device.

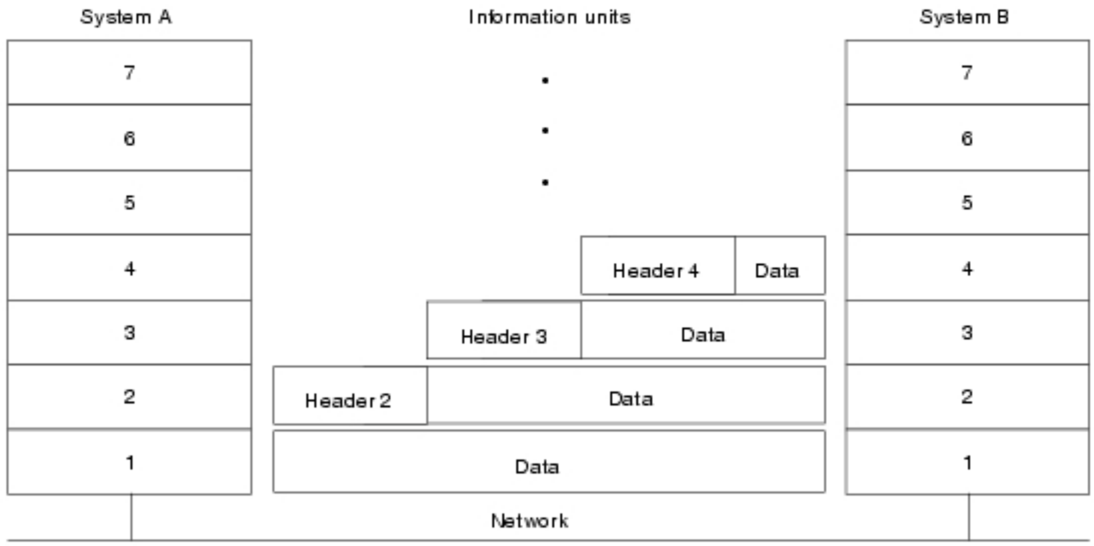


Figure. 2.3. Network data transfer within the OSI Reference Model (Cisco, 2006).

Figure 2.3 shows a representation of digital communication between two networks utilizing the OSI Reference Model. Each layer attaches a header to provide identification and instruction for subsequent operations. Only headers are evaluated as packets transition through the transport process, data begins to be interpreted in the application layers. While the OSI Reference Model is a conceptual framework for digital communications, TCP/IP has evolved to be the most widely utilized digital communications standard.

1.4.2. TCP/IP Suite

TCP/IP is the widely accepted standard utilized to provide network-layer and transport-layer functionality. Its widespread use and nearly universal acceptance has been due to a number of important factors, not the least of, is the fact that it is tied to the Internet as the primary internet communication protocol method. A brief list of TCP/IP qualities includes:

- TCP/IP defines a structured method for identifying and addressing devices on both small and large networks. The addressing system also consists of a centralized administration capability for the Internet, to ensure that each device has a unique address.

- TCP/IP is specifically designed to facilitate the routing of information over a network of varying complexity. TCP/IP routers enable data to be delivered between devices on different networks by moving it incrementally from one network to the next.

- TCP/IP operates primarily at layers three and above, and includes provisions to allow it to function on almost any lower-layer technology, including LANs, wireless LANs and WANs of various sorts. This flexibility means that one can mix and match hardware that implement a variety of different underlying networks and connect them all using TCP/IP.

- One of the most valuable characteristics of TCP/IP is how scalable its protocols have demonstrated to be. Over the decades it has proven its worth as the Internet has grown from a small network with just a few machines to an enormous international inter-network with millions of hosts.

- The TCP/IP standards are open standards freely available to the international public. Furthermore, the process used to evolve and develop TCP/IP standards is also completely open. TCP/IP standards and protocols continue to be modified using the unique, democratic Request for Comments "RFC" process, with all interested parties invited to participate.

TCP/IP standards are being reviewed and updated to facilitate improved communications and technological growth. The current TCP/IP standard in broad use incorporates IP Version 4. The continued migration to the new IP Version 6 (IPV6) protocol is in its early stages. It is likely that TCP/IP will remain a big part of networked systems for the foreseeable future as improvements and enhancements are incorporated. Technology evaluations will consider the relationship to current TCP/IP standards.

1.5 Bodies for Standards Development

Numerous national and international organizations, groups, committees, institutes, consortiums, and commissions exist with the premise of promoting, creating, and implementing standards within the computer, electronics, and transportation industries. The groups listed below have a history of standards development which overlap significantly with the goals of MOP development.

- AASHTO (American Association of State Highway and Transportation Officials)
- ANSI (American National Standards Institute)
- APTA (American Public Transportation Association)
- ASC X12 (Accredited Standards Committee)
- ATIS (Alliance for Telecommunications Industry Solutions)
- DISA (Data Interchange Standards Association)
- ETSI (European Telecommunications Standards Institute)
- FIPS (Federal Information Processing Standard)
- IATA (International Airline and Transportation Association)
- ICAO (International Civil Aviation Organization)

- IEEE (Institute of Electrical and Electronic Engineers)
- ISO/IEC (International Standards Organization/ International Electrotechnical Commission)
- ITE (Institute of Transportation Engineers)
- ITU (International Telecommunications Union)
- NTCIP (National Transportation Communications ITS Protocol)
- SAE (Society of Automotive Engineers)
- ITS (US Department of Transportation Intelligent Transportation Systems)
- W3C (World Wide Web Consortium)

The protocols, standards, and efforts of these groups (and many others) have been evaluated relative to MOP development and integration. Once a standard is widely adopted on a national or international level, standards are approved by one of several key agencies. Relative to MOP, these agencies have the greatest influence: IEEE, ANSI, ISO/IEC, ITS and IATA. Standards currently in place with these key agencies will be briefly reviewed.

1.5.1. International Standards Organization (ISO)/International Electrotechnical Commission (IEC) Standards

ISO/IEC is one of the worldwide standard-setting bodies for technology, including plastic cards. The primary standards for smart cards are ISO/IEC 7816, ISO/IEC 14443, ISO/IEC 15693 and ISO/IEC 7501.

ISO/IEC 7816 is a multi-part international standard broken into fourteen parts. ISO/IEC 7816 Parts 1, 2 and 3 deal only with contact smart cards and define the various aspects of the card and its interfaces, including the card's physical dimensions, the electrical interface and the communications protocols. ISO/IEC 7816 Parts 4, 5, 6, 8, 9, 11, 13 and 15 are relevant to all types of smart cards (contact as well as contactless). They define the card logical structure (files and data elements), various commands used by the application programming interface for basic use, application management, biometric verification, cryptographic services and application naming. ISO/IEC 7816 Part 10 is used by memory cards for applications such as pre-paid telephone cards or vending machines. ISO/IEC 7816 Part 7 defines a secure relational database approach for smart cards based on the SQL interfaces (SCQL).

ISO/IEC 14443 is an international standard that defines the interfaces for a "close proximity" contactless smart card, including the radio frequency (RF) interface, the electrical interface, and the communications and anti-collision protocols. ISO/IEC 14443 compliant cards operate at 13.56 MHz and have an operational range of up to 10 centimeters (3.94 inches). ISO/IEC 14443 is the primary contactless smart card standard being used for transit, financial, and access control applications. It is also used in electronic passports and in the FIPS 201 PIV card.

ISO/IEC 15693 describes standards for "vicinity" cards. Specifically, it establishes standards for the physical characteristics, radio frequency power and signal interface, and anticollision and transmission protocol for vicinity cards that operate to a maximum of 1 meter (approximately 3.3 feet).

ISO/IEC 7501 describes standards for machine-readable travel documents and has made a clear recommendation on smart card topology for ID-1 and ID-2 card formats.

1.5.2. American National Standards Institute (ANSI) Standards

ANSI recommends standards directed to the needs of the U.S. and supervises standards-making activities. It does not write or develop standards itself. Thus, in the U.S., any group that participates in ISO must first participate in ANSI. The International Committee for Information Technology Standards (INCITS) serves as ANSI's Technical Advisory Group (TAG). Working groups within INCITS, such as, B10 (Identification Cards and related devices) and T6 (Radio Frequency Identification Technology) contribute directly to ISO groups.

1.5.3. International Civil Aviation Organization (ICAO)

The International Civil Aviation Organization (ICAO) is responsible for issuing guidance on the standardization and specifications for Machine Readable Travel Documents (MRTD) – i.e., passports, visas, and travel documents. ICAO has published a new specification for electronic passports that uses a contactless smart chip in the passport to securely store information on the passport holder's data page.

1.5.4. International Airline and Transportation Association (IATA)

IATA develops standards for recommendation to the airline and transportation industry. IATA has formed a task force to develop interoperability standards for smart card-based ticketless travel. Its mission is to ensure easy and convenient negotiation of electronic airline tickets.

1.5.5. American Public Transportation Association (APTA)

The American Public Transportation Association (APTA) Uniform Transit Fare Standard (UTFS) specifications are currently under development. A set of documents should be available soon defining the Regional Interoperability Standard (RIS) for electronic transit fare payments. The APTA UTFS goal is to provide a series of documents that allows industry to create an open architecture payment environment and that facilitates the integration of independent transit payment systems.

1.5.6. IEEE 802 Standards

The IEEE 802 family of standards has evolved to define lower layer communication protocols and transmission characteristics for networked communications methods. The

802 family consists of numerous sub groupings for specific communication methods. Each sub grouping is defined for a specific medium (e.g. RF frequency, bandwidth, transmission media) and communication protocols for device compatibility. Devices which are 802-family compliant will possess the capability to exchange data with other devices in the family. The format and data interpretation is handled by additional standards and protocols that function in collaboration with the IEEE 802 standards. The 802 family of standards defines device standards for the Physical and Data Link layers of the OSI Reference Model, as shown in Figure 2.4.

1.5.7. USDOT National Intelligent Transportation Systems (ITS)

The National ITS Architecture was created as a national planning guide for the implementation of ITS strategies in urban, suburban, and rural regions. The architecture is primarily organized by user services as perceived from the viewpoint of a transportation user. The architecture is further segregated into a logical architecture (how data flows) and physical architecture (interrelation of components). The transportation components within the physical architecture are referred to as subsystems. Figure 5.1 shows the National ITS Architecture of Subsystems and Communications as shown in the National ITS Reference Guide (Iteris, 2005). The subsystems are the white boxes while the four general communication methodologies are shown in the pink ovals.

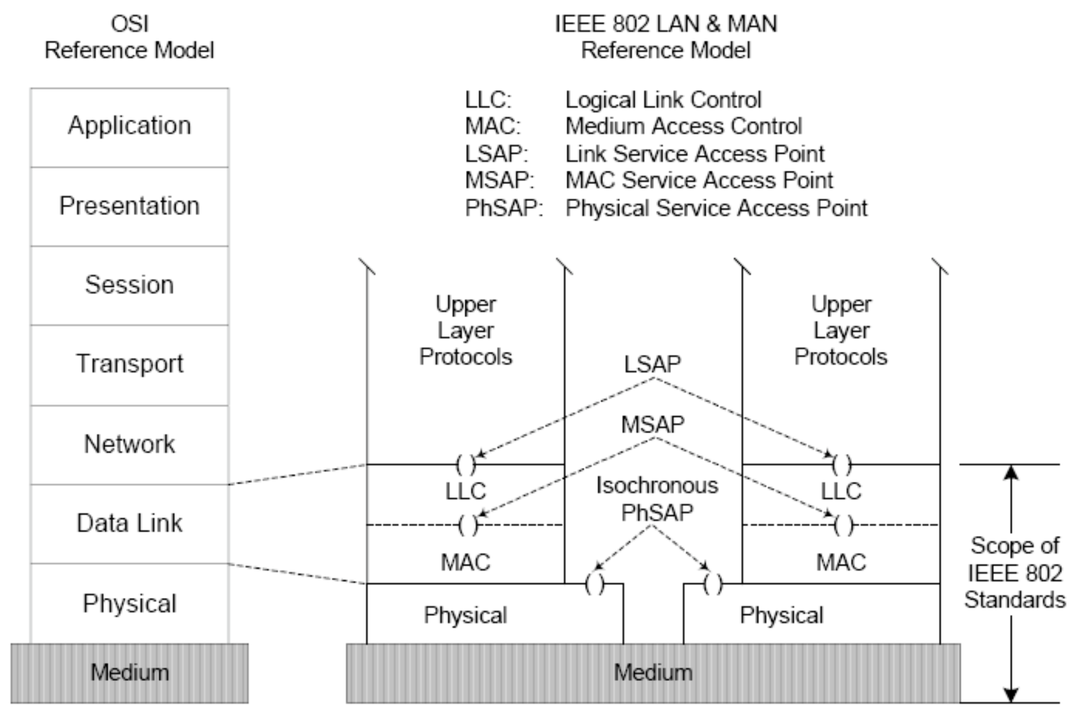


Figure. 2.4. Relationship between OSI Reference Model and IEEE 802 standards (www.ieee.org).

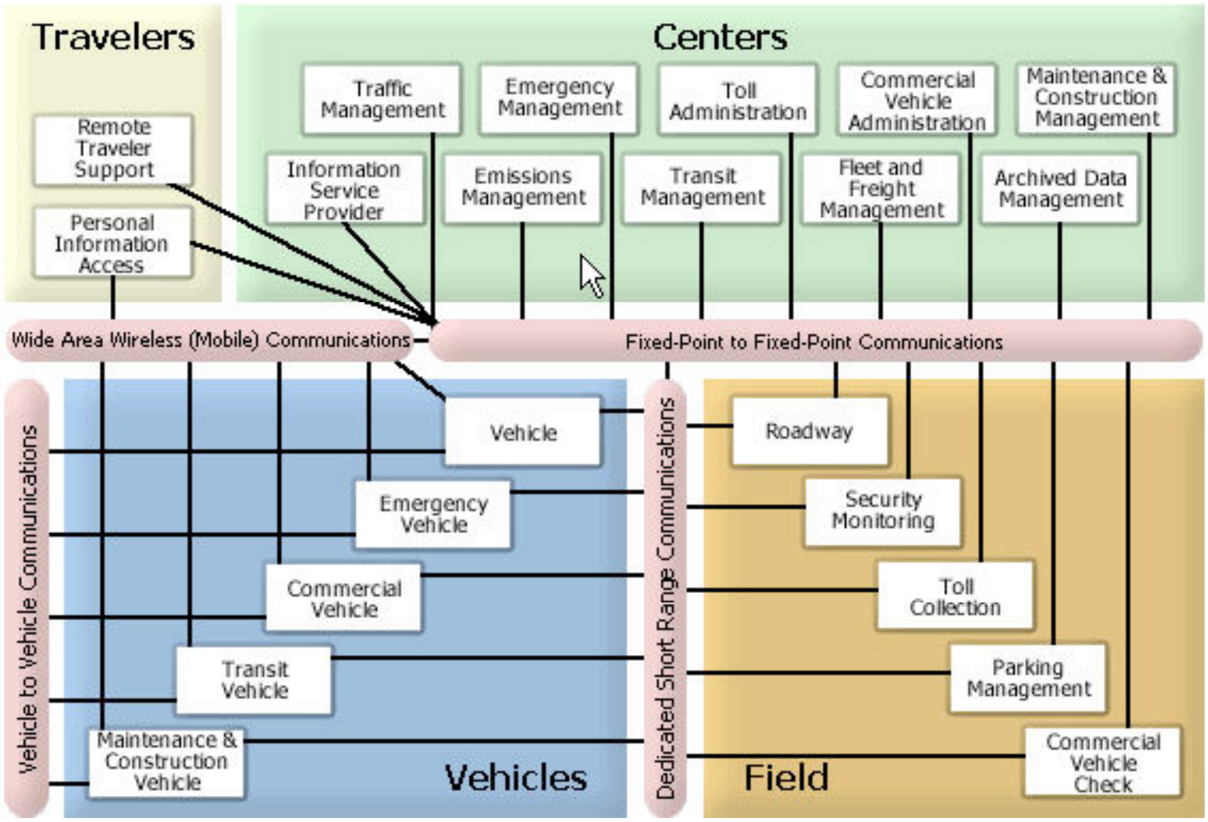


Figure 2.5. National ITS Architecture of Subsystems and Communications (USDOT, 2005).

This research investigation focuses on numerous subsystems shown in Figure 2.5. These subsystems include:

- Transit vehicles;
- Vehicles;
- Remote traveler support;
- Personal information access;
- Transit management;
- Fleet management;
- Information service provider;
- Roadway; and,
- Parking management.

Additionally, all of the four communications methods could potentially be utilized for implementing the full array of subsystems listed above. The National ITS Architecture creates a framework for implementing the various user bundles, subsystems, and ITS components. When considering the daunting task of implementing all the MOP components in an integrated manner, a more detailed implementation-specific architecture is required. While it is feasible for the MOP to comply with the NITS Architecture, much work is required to define the protocol communication specifications.

1.5.8. National Institute of Standards and Technology (NIST)

As a result of Homeland Security Presidential Directive 12 (HSPD-12), issued by President George W. Bush on August 27, 2004, NIST published Federal Information Processing Standard Publication 201 (FIPS 201) and Personal Identity Verification (PIV) of Federal Employees and Contractors, on February 25, 2005. FIPS 201 provides the specifications for a standard Federal smart ID card, called the PIV card, which must be used for both physical and logical access and can be used for other applications as determined by individual agencies. The PIV card is a smart card with both contact and contactless interfaces. Government agencies are currently implementing FIPS 201-compliant systems. FIPS standards are developed by the Computer Security Division within NIST. FIPS standards are designed to protect Federal computer and telecommunications systems. The FIPS standards apply to smart card technology and pertain to digital signature standards, advanced encryption standards, and security requirements for cryptographic modules (NIST, 2007).

1.5.9. Industry Groups Promoting Standards for Travel and Smart Cards

There are numerous industry related groups, associations, forums, alliances, and partnerships that are created for the collaboration on technology and promotion of industry related standards. A number of these alliances significantly affect standards related to development of a MOP or the technologies which would implement a MOP. Some of the more relevant groups are presented below.

PC/SC Workgroup

The PC/SC Workgroup was formed in 1996 and included Schlumberger Electronic Transactions, Bull CP8, Hewlett-Packard, Microsoft, and other leading vendors. This group has developed open specifications for integrating smart cards with personal computers. The specifications are platform-independent and based on existing industry standards. They are designed to enable application developers to create smartcard-based secure network applications for banking, health care, corporate security, and electronic commerce. The specifications include cryptographic functionality and secure storage, programming interfaces for smart card readers and PCs, and a high-level application interface for application development. The specifications are based on the ISO/IEC 7816 standard and support EMV and GSM application standards.

OpenCard

The OpenCard Framework is a set of guidelines announced by IBM, Netscape, NCI, and Sun Microsystems for integrating smart cards with network computers. The guidelines are based on open standards and provide an architecture and a set of application program interfaces (APIs) that enable application developers and service providers to build and deploy smart card solutions on any OpenCard-compliant network computer. Through the use of a smart card, an OpenCard-compliant system will enable access to personalized data and services from any network computer and dynamically download from the Internet all device drivers that are necessary to communicate with the smart card. By providing a high-level interface which can support multiple smart card types, the OpenCard Framework is intended to enable vendor-independent card interoperability. The system incorporates Public Key Cryptography Standard (PKCS) - 11 and is expandable to include other public key mechanisms.

GlobalPlatform

GlobalPlatform (GP) is an international, non-profit association. Its mission is to establish, maintain and drive adoption of standards to enable an open and interoperable infrastructure for smart cards, devices and systems that simplifies and accelerates development, deployment and management of applications across industries. As of January 2002, over 20 million GlobalPlatform smart cards were in circulation across the world, with an additional 200 million GSM cards that use GlobalPlatform technology for Over-The-Air (OTA) application download.

Common Criteria

Common Criteria (CC) applies to security evaluation for IT products and systems. CC's goal is to provide a common or standardized way to evaluate IT products and services, thus producing a certain assurance level for those products and systems. CC was developed by organizations that sponsored previous criteria from the United States, Canada, and Europe. These organizations came together and developed the Common Criteria in 1993. In 1996, Common Criteria v1.0 was produced; in 1998, v2.0 was produced; and in 1999, the most recent version, v2.1, was produced. CC v2.1 complies with ISO/IEC 15448.

2. Communications Hardware

In recent years, there has been a tremendous amount of evolution associated with communications hardware linked with ITS applications. In many intelligent transportation system applications, there have been numerous communication architectures developed for a variety of purposes, such as safety, remote diagnostics, maintenance, traffic management, and advanced vehicle control (or "telematics"). The review in progress includes commercially available hardware options for communications between central computers and remote modal option sites (e.g., cars, parking spaces, and bike lockers). Specific technologies will include wired technologies, such as cable and digital subscriber line (DSL), wireless area network (WAN) technologies, including 1xRTT, general packet radio service (GPRS), short message service (SMS)/Text Messaging, Ardis, Mobitex, ReFlex Paging, compressed digital packet data (CDPD), and local wireless to private local area network (LAN) technologies, such as Bluetooth, 900Mhz/2.4Ghz ISM Band, WiFi, and Point-to-Point directional. The evaluation is comparing and contrasting hardware technology issues relative to hardware cost, security implications, power considerations, reliability, Internet Protocol (IP) address discovery process, and quality of service issues. The final hardware evaluation will clarify hardware configurations and architectures which are compatible with MOP integrated transit implementations.

2.1 Hardware Architecture Requirements for MOP Implementation

The implementation of a MOP requires the dissemination of TOD mobility oriented data transmitted and shared over a network (including the Internet). This basic requirement identifies the boundaries of specific hardware requirements suitable for this type of application.

The architecture requires several hardware components:

- Internet Connectivity – Broadband Internet connectivity is needed to have rapid dissemination of database style information to requesting parties.

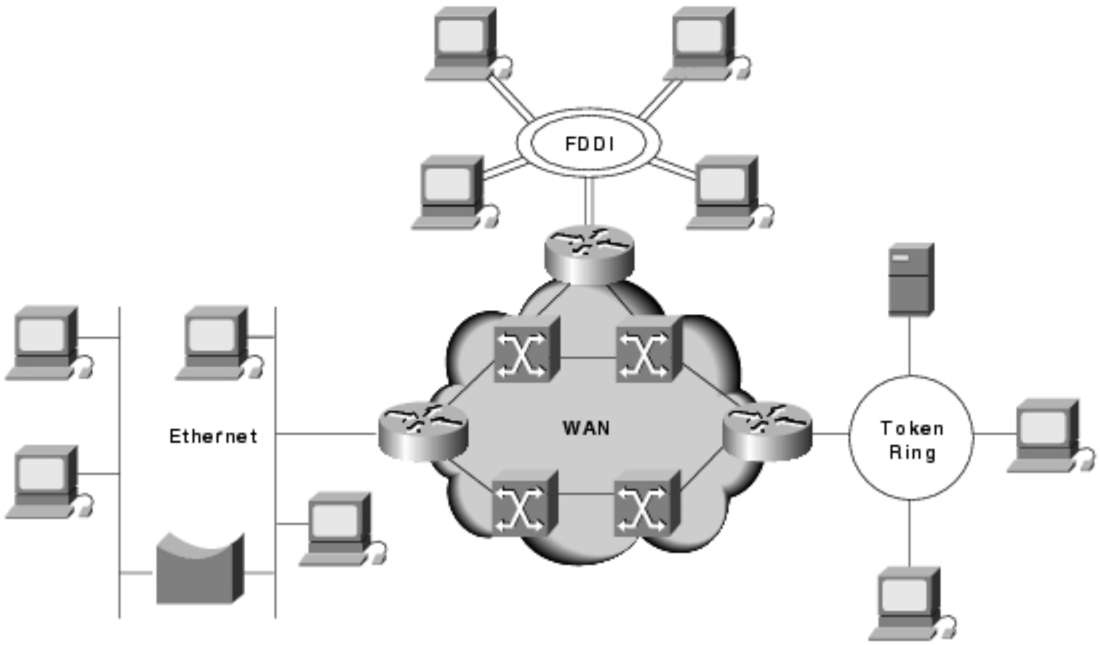
- LAN – A Local Area Network is most suitable for transferring data from electronic devices to the hardware processing the data and running processor based applications. The LAN would potentially consist of several interrelated networks consisting of WLAN (802.11 a/b/g, Wi-Fi), WPAN (802.15.1, 802.15.4), Ethernet, etc.

- Processing Hardware – Hardware capable of running applications, processing data and storing data.

- Networking Hardware – Wiring, routers, hubs, controllers, modems and switches.

- Electronic end devices – electronic lockers, display kiosk terminals, shared use vehicles, smart parking monitoring, etc.

The network architecture utilized within a TOD can vary significantly due to communication requirements, end devices, resources, and regional or geographic constraints. Numerous LAN and WAN architectures have evolved ad been standardized to address networking requirements. Some of the more common and established network configurations with accepted standards are shown in Figure 3.1.



1.1.1

Figure. 3.1. Traditional network configuration incorporating several LAN configurations (Cisco, 2006)

2.1.1. Hi Speed Internet (Broadband)

The MOP configured architecture will undoubtedly include some type of Internet-connected database management processor. This Internet-linked processor may serve as a data repository or perform user-oriented web based applications. Independent of the applications, a reliable high speed Iinternet connection will be desired.

The standard broadband technologies in most areas are T1, DSL, and cable modems. Newer technologies being deployed include: Satellite, VDSL, fiber optic, Wi-Max, EV-DO and others.

Traditional T1s are still the most reliable and solid Internet choice for corporate and commercial applications. It's not the fastest and can be expensive, but it has the highest up time and the least potential points of failure since it connects directly to the phone company. ISDN is the US T1 standard with 24 DS0 channels and total speed of 1,544 Kilobits/second.

Cable modems have matured over the years in many regions. They offer very high speeds with reasonable consistency. It is however still a shared bandwidth system so if another entity utilizes excessive bandwidth, your network performance is compromised.

Satellite Internet employs a satellite in geostationary orbit to relay data from the satellite company to each customer. Satellite Internet is usually among the most expensive ways of gaining broadband Internet access, but in rural areas, it is often the only viable option. Satellite Internet also has a high latency problem caused by the signal having to travel out into space to the satellite and back to Earth again. The signal delay can be as much as 500 milliseconds to 900 milliseconds, which makes this service unsuitable for applications requiring real-time user input.

Power-line Internet is a new service still in its infancy that may eventually permit broadband Internet data to travel down standard high-voltage power lines. However, the system has a number of complex issues, the primary one being that power lines are inherently a very noisy environment.

The applications and architecture developed for the MOP internet communication will determine the required speed for the broadband connection. The recommended connection would consist of a dedicated link to the service provider. These implementations include: DSL variants, fiber optic, T1, and cable modems. Other options should be evaluated once these are determined to not be suitable.

2.1.2. LAN Hardware

There are several different types of wired hardware implementations such as Ethernet, Token Ring, FDDI, Token Bus, etc. Ethernet is the most widely used hardware scheme with an abundant supply of hardware providers. Ethernet has been broadly adopted with proven reliability and it is relatively inexpensive. Ethernet is a 10-Mbps baseband LAN specification developed by Xerox, Intel, and Digital Equipment. In order to build an Ethernet hub you need the following: an Ethernet Network Interface Card (NIC) or equivalent for each networked computer/processor, an Ethernet compatible hub with at least the same number of ports as there will be computers in the LAN, and Ethernet cables (or 10/100/1000BaseT cables) to connect each computer's NIC to the Ethernet hub. Most Ethernet networks use 10/100BaseT cables with RJ45 jacks at each end. To allow the processors in the LAN to access the Internet via a local Internet Service Provider (ISP) an Ethernet modem is required which translates the ISP's carrier signal into a LAN compatible signal. A single processor (computer) with a ISP modem and a router would be the minimum hardwired LAN requirement. The remainder of the LAN architecture could consist of Wireless LAN (WLAN) or Wireless Personal Area Network (WPAN).

2.1.3. WLAN and WPAN

The implementation of a Wireless LAN or PAN may be desired to resolve cabling issues which arise from a traditional wired LAN configuration. Wireless networks have reduced performance and reliability compared to a wired network but offset this reduced performance with minimal wiring and non-tethered operation. For many transportation related applications the wireless communication is a design requirement. Installation constraints may also dictate a wireless network option versus a wired implementation. Several options exist for integrating wireless network communications within a LAN architecture.

The predominate industry accepted wireless standard is Wi-Fi or 802.11 b/g/n. This network technology is often referred to as Wireless Ethernet due to its similarity to a Ethernet wired LAN configuration. WLAN configurations that utilize 802.11 protocols require a Wireless Ethernet RF transceiver which when coupled with a processor consumes sufficient electricity to require at least a periodic power connection. For installations able to accommodate a wired power source, the 802.11 hardware provides reliability and sufficient bandwidth at reasonable costs.

Applications which require wireless networking and lower power consumption fall into the category of Wireless Personal Area Networks (WPAN). Bluetooth and Zigbee networks fit within the 802.15.1 and 802.15.4 specifications, respectively. Bluetooth WPANs have been integrated within personal computing devices for several years and have prominence for higher bandwidth wireless applications consisting of audio or file transfer (Shinde, 2005; Ferro, 2005). Zigbee WPANs are being deployed for applications requiring minimum power and lower bandwidth (industrial processs monitoring, building security, gaming controllers etc.) (Baker, 2005).

Characteristic	ZigBee	Bluetooth
Range		
As designed	10-100 metres	10 metres
Special kit or outdoors	up to 400 metres	100+ metres dep. on radio
Data rate	20-250 Kbps	1 Mbps
Network Latency (typical)		
New slave enumeration	30ms	20s
Sleeping slave changing to active	15ms	3s
Active slave channel access	15ms	2ms
Power profile	Years Optimizes slave power requirements	Days Maximises adhoc functionality
Security	128 bit AES and application layer user definable	64 bit, 128 bit
Operating Frequency	868 Mhz, 902-928 MHz, 2.4 GHz ISM	2.4 GHz ISM
Complexity	Simple	Complex
Network Topology	Adhoc, star, mesh hybrid	Adhoc piconets
Number of devices per network	2 to 65,000	8
Scalability/Extendability	Very High/Yes	Low/No
Flexibility	Very High	Medium, profile dependent
Resilience and reliability	Very High	Medium

Figure. 3.2. ZigBee and Bluetooth comparison (Baker, 2005).

The implementation of a WPAN utilizing Zigbee or Bluetooth requires an Ethernet gateway to integrate the WPAN within the larger Ethernet based LAN (Cirronet, 2006). The LAN then utilizes a router and modem to connect with the WAN (Internet). Bluetooth technology has been adopted for several years for PAN network style applications and possesses a broader market penetration. Zigbee is still evolving as a low power networking device and has yet to be proven for mobility applications such as vehicle telematics and remote access mobility devices. Zigbee hardware devices have found initial market penetration within the industrial monitoring and security industry. These initial ZigBee successes have utilized application specific design and require application specific network protocols and architectures. Integration of Bluetooth and Zigbee devices within a MOP integrated program shows promise, but careful testing should take place relative to network integration and communication architectures prior to committing to a single configuration.

	Bluetooth	Wi-Fi
Frequency band	2.4 GHz	2.4 GHz, 5 GHz
Coexistence mechanism	Adaptive frequency hopping	Dynamic frequency selection, Adaptive power control
Multiplexing	FHSS	DSSS, CCK, OFDM
Future multiplexing	UWB	MIMO
Noise adaptation	Link layer	Physical layer
Typical output power	1–10 mW (1–10 dBm)	30–100 mW (15–20 dBm)
Nominal range	10 m	100 m
Max one-way data rate	732 kb/s	31.4 Mb/s
Basic cell	Piconet	BSS
Extension of the basic cell	Scatternet	ESS
Topologies	Various analogies: see Subsection Network Topologies	
Maximum number of devices in the basic cell	8 active devices; 255 in park mode	Unlimited in ad hoc networks (IBSS); up to 2007 devices in infrastructured networks.
Maximum signal rate	1 Mb/s	54 Mb/s
Channel access method	Centralized: polling	Distributed: CSMA/CA
Channel efficiency	Constant	Decreasing with offered traffic
Spatial capacity	From 0.1 to 400 kb/s · m^2	About 15 kb/s · m^2
Data protection	16-bit CRC (ACL links only)	32-bit CRC
Procedures used for the network setup	Inquiry, Page	Ad hoc networks: Scan, Authentication Infrastructured: Scan, Authentication, Association
Average speed in network setup without external interferences	5 s + $n \cdot 1.28$ s, where n is the number of slaves in the piconet, ranging from 1 to 7	$n \cdot c \cdot 1.35$ ms for an unsaturated network, c probed channels ($1 \le c \le 13$), n stations (excluding the AP), active scan, infrastructured topology
Authentication	Shared secret, pairing	Shared secret, challenge-response
Encryption	E0 stream cipher	RC4 stream cipher, RES
QoS mechanism	Link types	Coordination functions
Typical current absorbed	1–35 mA	100–350 mA
Power save modes	Sniff, hold, park; standby	Doze

Figure. 3.3. Wi-Fi and Bluetooth comparison (Ferro, 2005).

Several studies have noted some RF interference with other devices operating on the same frequency as ZigBee and Bluetooth implementations (Shuaib, 2006; Ferro, 2005). The potential for RF interference should be carefully evaluated for proposed implementations. Additionally, ZigBee modules possess various levels of networking communication protocols (Husemann, 2004; Sakane, 2005). Additional programming may be required to successfully implement Zigbee based mesh networks and similar self healing architectures. This characteristic should be carefully considered if integrating a wireless PAN within the TOD.

Broadband market penetration can be generalized and summarized relative to type of service. Satellite broadband services have minimal market penetration, and powerline carrier services are scarce as well. Pure IP and Ethernet services over fiber are growing in acceptance, but they are not well established, and ISDN has almost disappeared in the United States. Other services, such as 3G mobile and metro Ethernet over active fiber have some presence in the market but vary by region and are limited in their penetration thus far. In this context, broadband wireless is competing fairly well with developing technologies. Still, it has only small market penetration relative to the more established technologies, and these are T1/E1 (including fractional and multiple T1/E1), frame relay, DSL, and cable data. Among the incumbent technologies, cable data and DSL are the leading technologies for residential services, and business class DSL, T1/E1, and frame relay are the dominant service offerings for small and medium sized businesses.

2.2 Dedicated Short Range Communications

Dedicated Short Range Communications (DSRC), within the ITS arena, allows for high-speed communications between vehicles and the roadside, or between vehicles. The unobstructed range of DSRC is up to 1,000 meters. Potential DSRC applications for public safety and traffic management include:

- Intersection collision avoidance;
- Approaching emergency vehicle warning;
- Vehicle safety inspection;
- Transit or emergency vehicle signal priority;
- Electronic parking payments;
- Commercial vehicle clearance and safety inspections;
- In-vehicle signing;
- Rollover warning;
- Probe data collection; and,
- Highway-rail intersection warning (its.dot.gov, 2003).

The IEEE 802.11p specification is being identified for vehicular communications with the future potential to be complimentary with MOP integration. The 802.11p specification has yet to be implemented for MOP related applications. It is recommended that the development of DSRC applications be monitored for evaluation as a complimentary MOP communications architecture. DSRC is not addressed further in this document due to the continued development of the specification and necessity for further evaluation. DSRC and 802.11p should not be discounted from being a potential communications architecture in future MOP related applications.

3. Communication Protocols and Standards

The extensive proliferation of Internet based informational user services within the transportation industry has created the need for a MOP, linking information about a broad range of mobility options to trip planning systems and travel information aggregators. While the MOP protocol defines the architecture of data transmitted between cooperating parties, it doesn't define internal system communication methods, transport protocols, and standards. Since the MOP must be integrated with these established and emerging technologies; it is beneficial to review the most relevant.

Architectures associated with wired and wireless digital network technologies have been explored and evaluated. The protocols encompass the following communication architectures: cable and digital subscriber line (DSL), wireless area network (WAN) technologies, including 1xRTT, general packet radio service (GPRS), short message service (SMS)/Text Messaging, Ardis, Mobitex, ReFlex Paging, compressed digital packet data (CDPD), and local wireless to private local area network (LAN) technologies, such as Bluetooth, 900Mhz/2.4Ghz ISM Band, WiFi, and Point-to-Point directional.

New advanced transportation information systems (ATIS) and web-based services are now being developed beyond specific modes (e.g., 511 services). The literature search and technology review includes efforts to help enhance the technology integration design. The review also includes a survey of relevant Intelligent Transportation Systems (ITS-NTCIP) Standards, case studies of web services based on standards such as eXtensible markup language (XML) and simple object access protocol (SOAP), and the XML based communications.

3.1 IEEE Protocols and Standards

The IEEE 802 family of standards is maintained by the IEEE 802 LAN/MAN Standards Committee (LMSC). The most widely used standards are for the Ethernet family, Token Ring, Wireless LAN, Bridging and Virtual Bridged LANs. An individual Working Group provides the focus for each area. Development of a MOP for transportation mobility will inevitably rely on several IEEE network standards for the transport of data. The IEEE standards listed below define physical and link layer protocols of Personal Area Network (PAN) communications encompassing a few feet up to regional systems of many miles (WiMAX, WRAN). The 802 family and working groups are listed below:

- IEEE 802.1 Higher layer LAN protocols
- IEEE 802.2 Logical link control
- IEEE 802.3 Ethernet
- IEEE 802.5 Token Ring

- IEEE 802.11 Wireless LAN (Wi-Fi)
- IEEE 802.12 demand priority
- IEEE 802.13 Cat.6 - 10Gb LAN
- IEEE 802.15 Wireless PAN
- IEEE 802.15.1 (Bluetooth)
- IEEE 802.15.4 (ZigBee)
- IEEE 802.16 Broadband Wireless Access (WiMAX)
- IEEE 802.16e (Mobile) Broadband Wireless Access
- IEEE 802.17 Resilient packet ring
- IEEE 802.18 Radio Regulatory TAG
- IEEE 802.19 Coexistence TAG
- IEEE 802.20 Mobile Broadband Wireless Access
- IEEE 802.21 Media Independent Handoff
- IEEE 802.22 Wireless Regional Area Network

3.1.1. IEEE 802.3

Ethernet (IEEE 802.3) is used to link computers in both small residential and large commercial situations and is the most widely used network hardware standard today. It often delivers internet access from other longer range hardware standards to multiple computers within a home or business. Ethernet equipment is relatively small, affordable, and can carry data at higher speeds of 100mbps to 1000mbps. Ethernet is rarely used outside the local area networks found inside of business or homes due to its range limitations of a few thousand feet. Therefore, other network infrastructure is required to link computers over great distances (using WAN protocols). Ethernet most commonly forms a LAN and is linked to other LANs via network infrastructure standards with long distance capabilities. Ethernet has been and is likely to remain for years the most used standard for the transmission of digital information over short distances.

3.1.2. IEEE 802.11

The first wireless networking standard to be defined in the 802 wireless family was 802.11 providing specifications to address both the Physical (PHY) and Media Access Control (MAC) layers. It was approved by the IEEE in 1997, and defines three possible physical layers. The 802.11 standard is commonly referred to as Wi-Fi and performs nearly the same role as Ethernet does in consumer settings, but without the wires. Wi-Fi allows a node to lie anywhere within a 100 to 1000 foot range of a Wi-Fi enabled router and have a constant, secure connection to the Local Area Network. Wi-Fi originated with speeds of 11mbps in the form of IEEE 802.11b, but has evolved to achieve speeds between 54mbps and 108mbps (802.11g and 802.11n, respectively).

In 2005, an even newer standard began to emerge known as 802.11n. While not officially ratified to date, so called "Pre-N" devices have begun to be sold in the consumer marketplace based upon the 802.11n standard that is still in the ratification process at the IEEE. The 802.11n specification calls for transmission speeds of 108 to 540mbps while still maintaining full support for the 802.11b/g standards speeds between 1 and 54mbps. While in the 802.11g standard the longer range, lower speed backward compatible 802.11b standard was utilized to increase the range and connection stability nodes received when further from the 'g' access point, 802.11n uses previous standards almost exclusively for compatibility with older equipment. This is due to the fact that 802.11n devices are able to communicate at 54 to 108mbps speeds at ranges greater than those offered by 802.11b when operating at 1 to 5mbps. 802.11n is not expected to begin to receive widespread adoption until late 2006 or 2007, both because it has not yet received IEEE certification and it has the current standard’s enormous market saturation to attempt to replace (IEEE, 2006).

3.1.3. IEEE 802.15

The IEEE 802.15 Working Group develops standards for low-complexity and low-power consumption wireless connectivity. In March 1998, the Wireless Personal Area Network (WPAN) study group was formed. In May 1998, the Bluetooth Special Interest Group (SIG) was formed, and in May 1999 the IEEE WPAN Study Group became IEEE 802.15, the WPAN Working Group (IEEE, 2006).

As of late 2006, there are currently four IEEE 802.15 standards projects in development:

802.15.1-2002 - 1Mb/s WPAN/Bluetooth v1.x derivative work

P802.15.2- Recommended Practice for Coexistence in Unlicensed Bands

P802.15.3 - 20+ Mb/s High Rate WPAN for Multimedia and Digital Imaging

P802.15.3a – Wireless USB, 110+ Mb/s Higher Rate Alternative PHY for 802.15.3

P802.15.4 – Zigbee, 200 kb/s max for interactive toys, sensor and automation needs

Bluetooth, IEEE 802.15.1, is a short range wireless network standard originally developed by Ericsson Corporation. Bluetooth supports three power/range levels: 1mW/10cm, 2.5mW/10m, and 100mW/100m. Bluetooths current maximum transmission rate is 2.1mbps. While this seems very low compared to much older Wi-Fi standards such as 802.11b, Bluetooth is designed to fit a special section of the market, rather than to be a widespread, high-performance technology. Bluetooth is almost always used in a paired or "ad-hoc" type network. In an ad-hoc network, no router exists, but the nodes are simply responsible for negotiating communication among themselves automatically.

Common Bluetooth devices and applications include mobile phone headsets, PC-to-organizer/PDA synchronization, and other situations in which small devices need low power, short range communication capability. Bluetooth is a staple feature on most of today's newest and smallest portable information and communication devices.

ZigBee (802.15.4) fills yet another niche. Unlike Bluetooth or wireless USB devices, ZigBee devices have the ability to form a mesh network between nodes. Meshing is a type of multi-trunked tree structure from one device to another. This technique allows the short range of an individual node to be expanded and multiplied, covering a much larger area.

There are three categories of ZigBee devices:

ZigBee Network Coordinator. Smart node that automatically initiates the formation of the network.

ZigBee Router. Another smart node that links groups together and provides multi-hoping for messages. It associates with other routers and end-devices.

ZigBee End Devices. Where the rubber hits the road—sensors, actuators, monitors, switches, dimmers and other controllers.

3.1.4. IEEE 802.16

IEEE 802.16 (Wi-Max) specifications support the development of fixed broadband wireless access systems to enable rapid worldwide deployment of innovative, cost-effective and interoperable multi-vendor broadband wireless access products. Mobile WiMAX is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. The Mobile WiMAX Air Interface adopts Orthogonal Frequency Division Multiple Access (OFDMA) for improved multi-path performance in non-line-of-sight environments. Scalable OFDMA (SOFDMA) is introduced in the IEEE 802.16e Amendment to support scalable channel bandwidths from 1.25 to 20 MHz. The Mobile Technical Group (MTG) in the WiMAX Forum is developing the Mobile WiMAX system profiles that will define the mandatory and optional features of the IEEE standard that are necessary to build a Mobile WiMAX compliant air interface that can be certified by the WiMAX Forum.

3.2 Wide Area Network Communication Protocols

The more established wired digital communication methods include: T1/E1 (including fractional and multiple T1/E1), frame relay, DSL, and cable data. Cable data and DSL are the leading technologies for residential services, and business-class DSL, T1/E1, and frame relay are the dominant service offerings for small and medium sized businesses. The largest enterprises that require large data transfers tend to prefer higher-speed optical services (fiber-optics) using both packet and circuit protocols.

3.2.1. DSL Wired Protocols

Digital Subscriber Line (DSL) technology is a modem technology that uses existing twisted-pair telephone lines to transport high-bandwidth data, such as multimedia and video, to service subscribers. The term xDSL covers a number of similar yet competing forms of DSL, including ADSL, SDSL, HDSL, RADSL, and VDSL. xDSL is drawing significant attention from implementers and service providers because it promises to deliver high-bandwidth data rates to dispersed locations with relatively small changes to the existing telephone company infrastructure. xDSL services are dedicated, point-to-point, public network access over twisted-pair copper wire on the local loop ("last mile") between a network service provider (NSP) central office and the customer site, or on local loops created either intra-building or intra-campus. Currently the primary focus in xDSL is the development and deployment of ADSL and VDSL technologies and architectures.

The American National Standards Institute (ANSI) Working Group T1E1.4 has approved an ADSL standard at rates up to 6.1 Mbps (ANSI Standard T1.413). The European Technical Standards Institute (ETSI) contributed an annex to T1.413 to reflect European requirements. T1.413 currently embodies a single terminal interface at the premises end.

VDSL achieves data rates nearly 10 times greater than those of ADSL. ADSL employs advanced transmission techniques and forward error correction to realize data rates from 1.5 to 9 Mbps over twisted pair, ranging to 18,000 feet; VDSL employs the same advanced transmission techniques and forward error correction to realize data rates from 13 to 55 Mbps over twisted pair, ranging to 4,500 feet.

At present several organizations/forums have begun work on VDSL:

- T1E1.4 - The U.S. ANSI standards group T1E1.4 has just begun a project for VDSL, making a first attack on system requirements that will evolve into a system and protocol definition.

- ETSI - The ETSI has a VDSL standards project, under the title High-Speed Metallic Access Systems. ETSI works very closely with T1E1.4 and the ADSL Forum, with significant overlapping attendees.

- DAVIC - DAVIC has taken the earliest position on VDSL. Its first specification due to be finalized will define a line code for downstream data, another for upstream data, and a MAC for upstream multiplexing based on TDMA over shared wiring.

- The ATM Forum - The ATM Forum has defined a 51.84 Mbps interface for private network UNIs and a corresponding transmission technology.

- NIPP-NAI develops and maintains standards and technical reports for systems and associated interfaces, for high-speed bi-directional digital transport via metallic facilities (e.g., xDSL) and for access to telecommunications networks through optical and electrical, analog and digital, interfaces. The work of this group focuses on physical layer functionality. NIPP-NAI makes recommendations to NIPP on related matters before US and international standards organizations.

3.2.2. T1, E1, Frame Relay, and Cable Wired Protocols

T1 is usually delivered over copper pairs and is characterized by high reliability and availability, reasonable throughputs, 1.5 megabits per second (Mbps), and inherent quality of service. Its limitations are equally significant. T1s cannot burst to higher speeds to meet momentary needs for higher throughputs, and they are difficult to aggregate if the user wants consistently higher throughput speed. Because it is circuit based and reserves bandwidth for each session, T1 offers extremely consistent performance regardless of network loading. Maximum throughput speeds are maintained at all times, and latency, jitter, and error rates are well controlled.

ANSI T1.403 defines the electrical specification for 'T1' telecommunication lines used in North America (and other territories operating networks using T1 lines) for services including primary rate ISDN. The European equivalent for T1 is El (CEPT-E1) and is defined by G.703 electrical specification.

Frame relay is a packet-based protocol developed during the early 1990s for use over fiber-optic networks. Frame relay permits reservation of bandwidth and enables tiered service offerings, but it is not capable of supporting quality-of-service (QoS) guarantees for multimedia, as does ATM, or some of the ancillary protocols associated with IP. Also, frame relay does not permit momentary bursting to higher throughput rates or self-provisioning. Frame relay is rarely used to deliver multimedia and other applications demanding stringent traffic shaping, and it is never used to deliver residential service. Usually, frame relay is employed to connect multiple remote locations in an enterprise to its headquarters, and connections over thousands of miles are entirely feasible.

The final major competitive access technology existing today is hybrid fiber coax, the physical layer utilized by the multichannel systems operators (MSOs) or cable television companies. Hybrid fiber coax consists of a metro core of optical fiber that frequently employs SONET equipment along with last mile runs of coaxial television cable. Each run of cable serves a considerable number of customers, as few as 50 and as many as several thousand. The coaxial cable itself has potential bandwidth of 3 gigahertz, of which less than a gigahertz is used for television programming. Most cable operators allocate less than 20MHz of bandwidth to data.

3.3 Regional Wireless Networks

Once complete, the MOP is intended to provide seamless integration of numerous mobility services operating across accessible communication platforms. The digital communication networks supporting the mobility system will likely consist of an integrated combination of wired and wireless networks on both a local and regional scale. Wide-area wireless communications provides a communications link via a wireless device between a user and an infrastructure-based system. The wireless Wide Area Network (WAN) can be created site-specific on a licensed or unlicensed RF. Alternatively, wireless WAN service can be purchased from a cellular provider. Due to the cost of a typical installation, a private wireless WAN is typically isolated to a few communication nodes (< 4) with high data transfer and/or security requirements (wirelesswans.com, 2005). Applications which require many wireless communication nodes separated by significant distance are typically configured on a pre-existing wireless WAN or cellular service. Each communications device then incurs a fee for data transfer.

3.3.1. Cellular Networks and Protocols

The more common cellular protocols currently in use or in deployment are:

- CDMA2000;
- UMTS; and,
- GPRS.

Currently UMTS (WCDMA) is being developed as the primary protocol for G3 devices (newest generation wireless devices), while GPRS and CDMA are currently deployed for G2.5 devices. All three of these protocols have the ability to deliver data wirelessly to an Internet address (IP address) through a service provider.

The 3G Partnership Project (3GPP) and 3G Partnership Project 2 (3GPP2) have been defining standards for enhancements to current 3G systems. Extensions to both UMTS (WCDMA) and CDMA2000 have been defined with the objective of adding network capacity and features to enable operators to offer new data-oriented services over their existing networks. These extensions are: Evolution Data-Optimized1 (1xEVDO), also known as High Rate Packet Data (HRPD) is a data optimized evolution of CDMA2000 developed by the 3GPP2. In a 1.25 MHz channel, 1xEVDO offers, over the air peak data rates of 2.4 Mbps (Rev 0) and 3.1 Mbps (Rev A) in the downlink (DL) and 153.6 kbps (Rev 0) and 1.8 Mbps (Rev A) in the uplink (UL). 1xEVDO-Rev 0 has had initial success in South Korea and is now being widely deployed. High-Speed Downlink Packet Access (HSDPA). HSDPA as defined by 3GPP provides downlink enhancements to WCDMA R’99. This enhancement offers over the air downlink peak data rate of up to 14 Mbps in a 5 MHz channel, and with a further release known as, High-Speed Uplink Packet Access (HSUPA), provides capacity enhancements to the uplink as well.

Evaluation by Storsul has concluded the technologies will become available in a phased fashion. 1xEVDO Rev 0 was initially launched in Korea and Japan in 2003 followed by

Operator	2004 Customers (thousands)	2006 Customers (thousands)	2005 Growth	Technology
Cingular	49,109	54,000	9.96%	GSM, GPRS, EDGE, UMTS, TDMA
Verizon	43,816	51,300	17.08%	CDMA, 1xRTT, EV-DO12
Sprint	21,507	47,600	26.08%	CDMA, 1xRTT, EV-DO
Nextel	16,247			iDEN
T-Mobile	17,314	21,690	25.27%	GSM, GPRS, EDGE

Figure. 4.1. Evaluation results of US cellular market and technologies (Storsul, 2006).

extensive deployments in the in 2004 and 2005. The 1xEVDO-Rev A standard was approved in March 2004 and the commercial launch of services based on this standard took place in 2005 with more extensive deployments expected in 2006. The first commercial HSDPA deployment was announced in December 2005 and operators in Europe and Japan have announced plans for HSDPA deployments in 2006. Mobile WiMAX is expected to begin rolling out in late 2006 and early 2007 (Storsul, 2006). Figure 4.1 shows US market share, growth, and technology implementation.

3.3.2. Paging and Short Message Services

The evolution of wireless services has focused on increasing bandwidth and associated data transfer speeds of large data files. Several short message data transfer services still co-exist with the ever increasing bandwidth development. Some of these services developed prior to the dominance of the cellular phone voice/data services while others have evolved in parallel. These lower bandwidth services include:

- Short Message Service (SMS) commonly referred to as text messaging;

- Two Way Paging – ReFlex, Ardis, Mobitex

These services have some select markets associated with paging, resource tracking, and emergency services. While these communication technologies are not central to development of a MOP, they may provide communication methods when more prevalent methods are not available. The general protocols and implementations will be discussed with some of these services.

Short Message Service

Short Message Service (SMS/Text Messaging) is a technology that enables the sending and receiving of messages between cellular devices. SMS first appeared in Europe in 1992 and was included in the GSM (Global System for Mobile Communications) standards early on. It was later ported to wireless technologies like CDMA and TDMA. The GSM and SMS standards were originally developed by European Telecommunications Standards Institute (ETSI). Now the 3GPP (Third Generation Partnership Project) is responsible for the development and maintenance of the GSM and SMS standards.

As suggested by the name “Short Message Service”, the quantity of data that can be held by an SMS message is very limited. One SMS message can contain at most 140 bytes (1120 bits) of data, so one SMS message can contain up to 160 characters if 7-bit character encoding is used. (7-bit character encoding is suitable for encoding Latin characters like English alphabets.)

The architecture of cellular based SMS messaging and a high bandwidth Internet-connected LAN fulfill most the messaging network requirements for a MOP integrated architecture. The protocols and methods for integrating a SMS and LAN based system are discussed in greater detail (Zhang, 2004). SMS messaging and UDP protocols over CDPD or GPRS has proven effective previously for vehicle telematic applications.

Two-Way Paging

The paging network which began with uni-directional (downlink) communications has evolved to include bi-directional short message communications. While the majority of personal communications users have migrated to cellular phones consisting of voice and data communications, a few niche markets still utilize the two way paging system. These markets include resource tracking in which identification and location information is relayed to a centralized system. Two of the more prominent two way paging systems are Mobitex and Ardis.

Mobitex wireless data technology provides a cost-effective, reliable and responsive communications medium. Because data is sent in packets, users are charged for the amount of bytes they actually send and not for the time a connection is open. The system operates on the 400, 800 and 900 MHz frequency bands. The network uses cellular radio technology similar to that used in mobile telephone networks. The Mobitex System (detailed on www.mobitex.com) also supports a number of standardized protocols such as the X.25 protocol and the MDOT protocol.

ARDIS network is a nation-wide packet-switched wireless wide area network that offers shared public network services to many users across USA and several other countries. The ARDIS network is a terrestrial, trunked packet data radio network for data applications only; currently no voice. ARDIS operates in the 806 MHz to 821 MHz range for uplinks and in the 851 MHz to 866 MHz range for downlinks. ARDIS has subsidiaries or affiliated networks in the UK, Canada, Germany, Australia, Malaysia, Singapore, and Thailand. Currently supports 4,800 bps in most areas; 19,200 bps is available in 33 areas in the U.S. and some parts of Canada. The ARDIS supported protocols include: X.25, asynchronous, Bisynchronous natively: TCP/IP and IBM's SNA (LU 2 and LU 6.2) is supported through third-party gateways (mobileinfo.com, 2007).

3.4 NTCIP Protocols, Standards, and Developments

The National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) is a family of standards that provides both the protocols and the data objects necessary to allow electronic traffic control equipment from different manufacturers to operate with each other within a system. The NTCIP is the first set of standards for the transportation industry that allows transportation systems to be built using a "mix and match" approach with equipment from different manufacturers. Therefore, NTCIP standards reduce the need for reliance on specific equipment vendors and customized one-of-a-kind software. To assure both manufacturer and user community support, NTCIP is a joint product of the National Electronics Manufacturers Association (NEMA), the American Association of State Highway and Transportation Officials (AASHTO), and the Institute of Transportation Engineers (ITE) (www.ntcip.org).

An application profile specifies a set of protocols and standards that define communications and interfaces at the highest levels. Within the context of the OSI Basic Reference Model, NTCIP application profiles are applicable to the three highest layers: the application, presentation and session layers. This standard also defines requirements applicable to the transport layer (layer four), and altogether defines message form, message usage and transport sufficient for center-to-center exchange of data encoded in the eXtensible Markup Language (XML). The most relevant NTCIP standards with respect to MOP development are discussed below.

3.4.1. NTCIP 2306 Center-to-Center Communications

The NTCIP 2306 specification is entitled "Application Profile for XML Message Encoding and Transport in ITS Center-to-Center Communications."

The NTCIP-C2C XML provides a way to specify WSDL, or Web Services Definition Language, for the following combinations of message encoding and transport:

- SOAP over HTTP: Using SOAP encoded messages over the hypertext transfer protocol (HTTP), centers will be able to describe and deploy center interfaces that support the request-response and subscription-publication message patterns.

- XML over HTTP: Using XML encoded messages over the HTTP, centers will be able to describe and deploy interfaces that support the request-response (via HTTP POST) and request-only message patterns (HTTP GET). HTTP POST is suitable for the exchange of messages (request-response), while the HTTP GET is suitable for the request of an XML document by name.
- XML over FTP: Using the file transfer protocol (FTP), centers will be able to describe interfaces that support XML document requests by name.

This 2306 standard should be used by transportation and traffic engineers involved with the design, specification, selection, procurement and installation, operation, and maintenance of central computer systems that will interface with other central systems. Specifically, it defines mechanisms for using the Simple Object Access Protocol (SOAP) and the Web Services Description Language (WSDL) to support customer-initiated requests for information from a central system. Compliant systems will implement these requirements to ensure compatibility with compliant applications. The standard is intended to be utilized in conjunction with the Traffic Management Data Dictionary (TMDD) and Message Sets standard, which defines the vocabulary of information that can be exchanged using this standard.

3.4.2. NTCIP 2304 Application Profile for DATEX-ASN (AP-DATEX)

NTCIP 2304 - Application Profile for DATEX-ASN (AP-DATEX), is one of the center-to-center protocols defined by the NTCIP. This standard specifies how DATEX-ASN is to be used within the United States. DATEX-ASN is also an international standard (ISO 14827 Parts 1 and 2) developed by the NTCIP Center-to-Center Working Group in cooperation with the International Organization for Standardization (ISO). The DATEX-ASN ensures all implementations of DATEX-ASN within the United States use the same base options and are therefore interoperable. If different traffic or transit management centers were to select different options, it could lead to a failure to interoperate, even though both use DATEX-ASN.

3.4.3. NTCIP 1104 Center-to-Center Naming Convention Specification

This standard is applicable to communications between two (or more) management systems within the Intelligent Transportation Systems (ITS) environment. This base standard lists the requirements for establishing names for management systems and for the objects managed by those systems. The term object is used loosely to include not only physical equipment such as ramp meter controllers and portable message signs, but also other data categories about which centers might desire to exchange information, such as incidents, as well as other data classes within the center.

3.4.4. Traffic Management Data Dictionary and Message Sets for External Traffic Management Center Communications (TMDD MS/ETMCC)

The Institute of Transportation Engineers (ITE), working cooperatively with the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO), is leading a national effort to develop a standardized Traffic Management Data Dictionary (TMDD). A companion effort in this cooperative program is developing Message Sets for External Traffic Management Center Communications (MS/ETMCC) which occur between (TMC's) and other external Intelligent Transportation Systems (ITS) centers. While the development of the TMDD MS/ETMCC is not specifically an NTCIP effort, it is being presented within the context of the NTCIP standards.

The data dictionaries are an essential component in the design and operation of modern computer based systems. They provide the basic information definitions (generally described as data elements) upon which communications between systems depend. Specifically, a data dictionary provides the information definition (semantics) and specific format (syntax) for individual Data Elements (DEs) and is the basis of the database of a modern traffic management system (TMS). Thus, an agreed upon data dictionary with unambiguous definitions is one of the essential standards required to exchange messages between individual traffic management systems as well as between a TMS and other ITS users and/or suppliers of traffic related information.
Data Dictionaries then work in conjunction with at least two other sets of standards to provide effective data communications interchange between users. These other standards sets include message sets established to handle individual information exchanges on specific topics. In a loose sense, message sets are the sentences where DE's are the individual words. The additional required set of standards provides for the actual communications protocols of which an example is Datex-ASN. These standards describe how the messages are encoded for transmission and then transmitted and received by the other party.

The two volumes together make up the Traffic Management Data Dictionary and Message Sets for External Traffic Management Center Communications (TMDD MS/ETMCC). Volume I identifies and describes the needs and requirements for a traffic management center (TMC) to provide services to external centers (EC) via a communications interface. This subject area is frequently called external traffic management center communications (ETMCC). The purpose of Volume II: TMDD MS/ETMCC Design Content includes the data concept definitions (dialogs, messages, data frames, data elements, and object classes) for the TMDD MS/ETMCC (tmdd.org, 2007).

3.5 National ITS Architecture

Promoted and maintained by the USDOT, the National ITS Architecture provides a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc.). The architecture defines:

- The functions (e.g., gather traffic information or request a route) that are required for ITS;
- The physical entities or subsystems where these functions reside (e.g., the field or the vehicle); and,
- The information flows and data flows that connect these functions and physical subsystems together into an integrated system.

The Logical Architecture is based on a Computer Aided Systems Engineering (CASE) model. It models the requirements of the flow of data and control through various functions included in Intelligent Transportation Systems (ITS). Structured Data Flow Diagrams and Specifications, the components of the "Structured Analysis" approach used to define the Logical Architecture, are presented have been evaluated relative to MOP development. The Logical Architecture includes the input (source) terminators and output (sink) terminators of ITS, but not the information embedded in these terminators, and defines the information flow into, within, and out of the systems. It is the formal representation of the ITS operational concepts that are described in the Theory of Operations Document.

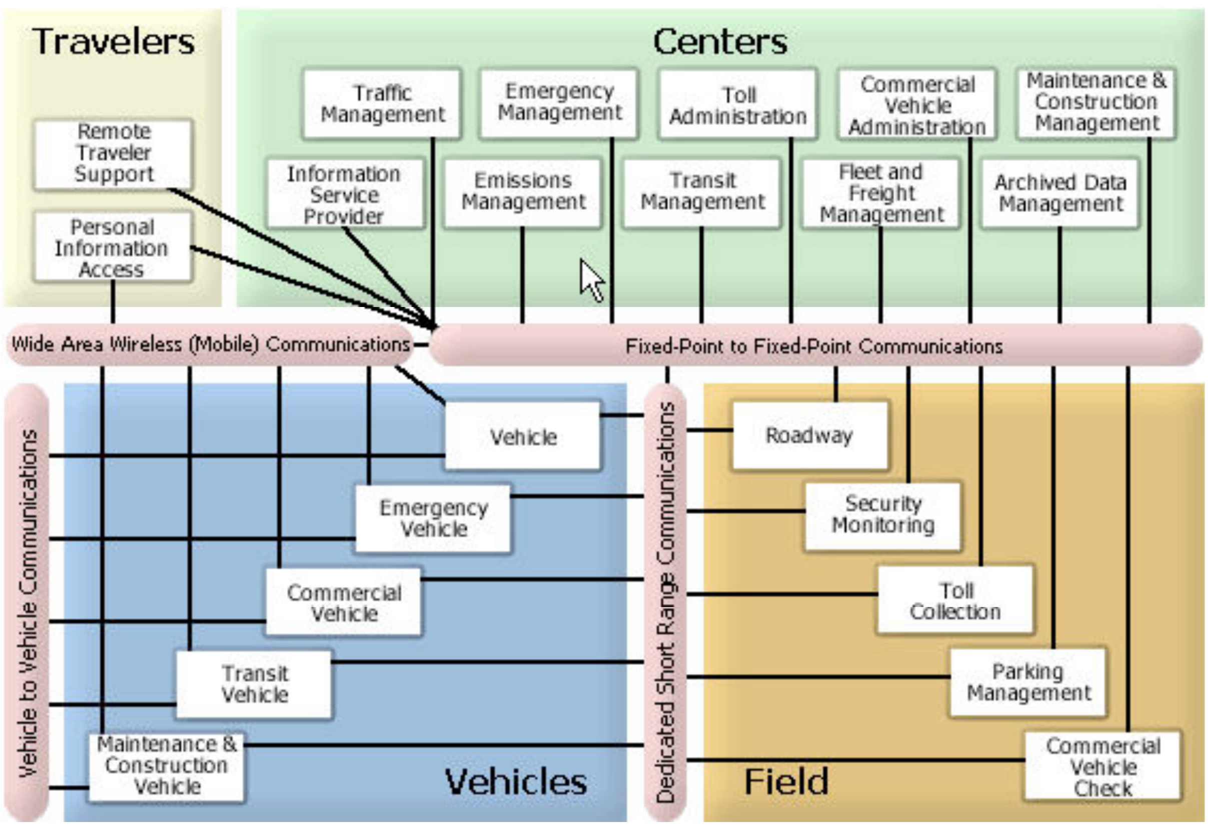


Figure. 4.2. National ITS Architecture, Version 6.0 (iteris.com, 2007).

The Logical Architecture is first illustrated as a single function in a high level "System Context Diagram". This diagram shows the inputs (sources) and outputs (sinks), between ITS and external terminators. The Context Diagram is then decomposed into the highest level Data Flow Diagram (DFD) that shows the highest level processes within the ITS

Architecture. These processes are then further decomposed into lower and lower level DFDs.

At the lowest level of this decomposition, Process Specifications (P-Specs) are written to define the functions necessary to satisfy the USRs and how the output data flows are constructed from its input data flows. P-Specs are used to represent the sources and sinks of data flows within ITS.

The Logical Architecture is also mapped into a Physical Architecture which assigns the logical processes to physical subsystems. This mapping is documented in the Physical Architecture Document. Several physical subsystems have been defined which have significant overlap with development a MOP that would have the eventual goal of integrating with the National ITS Architecture. These subsystems are presented below.

3.5.1. National ITS Remote Traveler Support Subsystem

This subsystem provides access to traveler information at transit stations, transit stops, other fixed sites along travel routes (e.g., rest stops, merchant locations), and major trip generation locations such as special event centers, hotels, office complexes, amusement parks, and theaters. Traveler information access points include kiosks and informational displays supporting varied levels of interaction and information access. At transit stops, simple displays providing schedule information and imminent arrival signals can be provided. This basic information may be extended to include multi-modal information including traffic conditions and transit schedules along with yellow pages information to support mode and route selection at major trip generation sites. Personalized route planning and route guidance information can also be provided based on criteria supplied by the traveler. The subsystem (Figures 4.3 and 4.4) also supports electronic payment of transit fares (iteris.com, 2007).

3.5.2. National ITS Transit Vehicle Subsystem

This subsystem resides in a transit vehicle and provides the sensory, processing, storage, and communications functions necessary to support safe and efficient movement of passengers. The types of transit vehicles containing this subsystem include buses, paratransit vehicles, light rail vehicles, other vehicles designed to carry passengers, and supervisory vehicles. The subsystem collects accurate ridership levels and supports electronic fare collection. The subsystem supports a traffic signal prioritization function that communicates with the roadside subsystem to improve on-schedule performance. Automated vehicle location functions enhance the information available to the Transit Management Subsystem enabling more efficient operations. On-board sensors support transit vehicle maintenance. The subsystem supports vehicle operator authentication prior to operation of the vehicle and remote vehicle disabling. The subsystem also furnishes travelers with real-time travel information, continuously updated schedules, transfer options, routes, and fares (iteris.com, 2007).

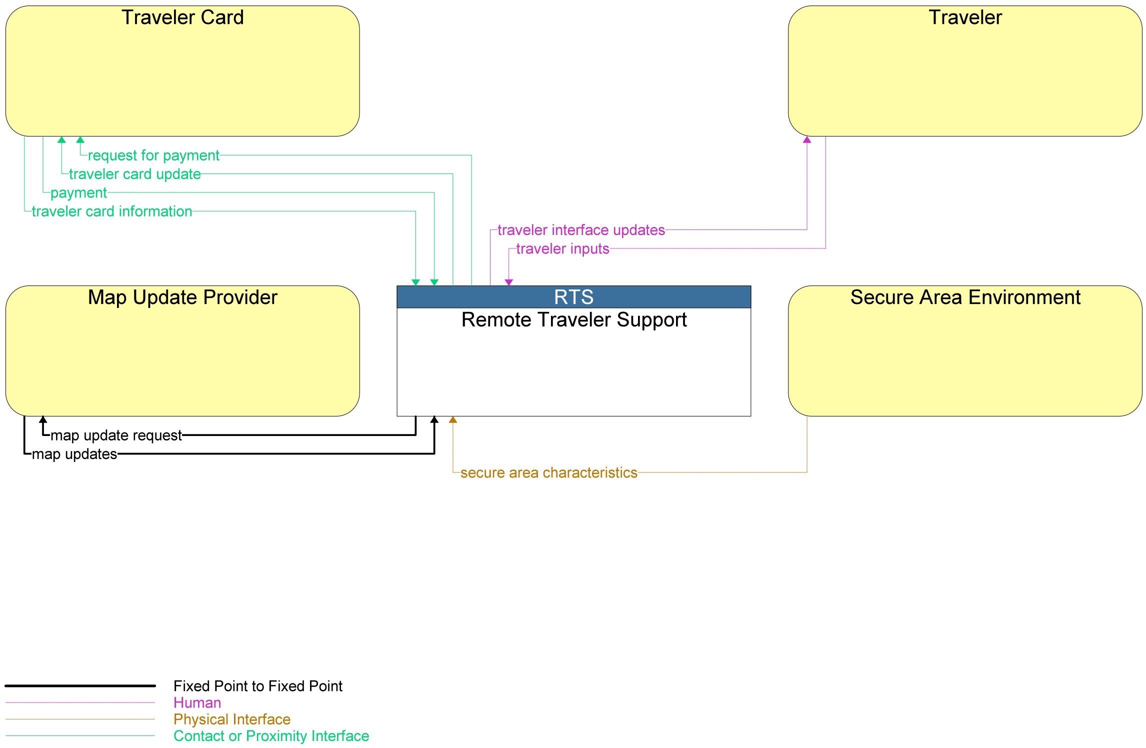


Figure. 4.3. National ITS Architecture for Remote Traveler Support (iteris.com, 2007).

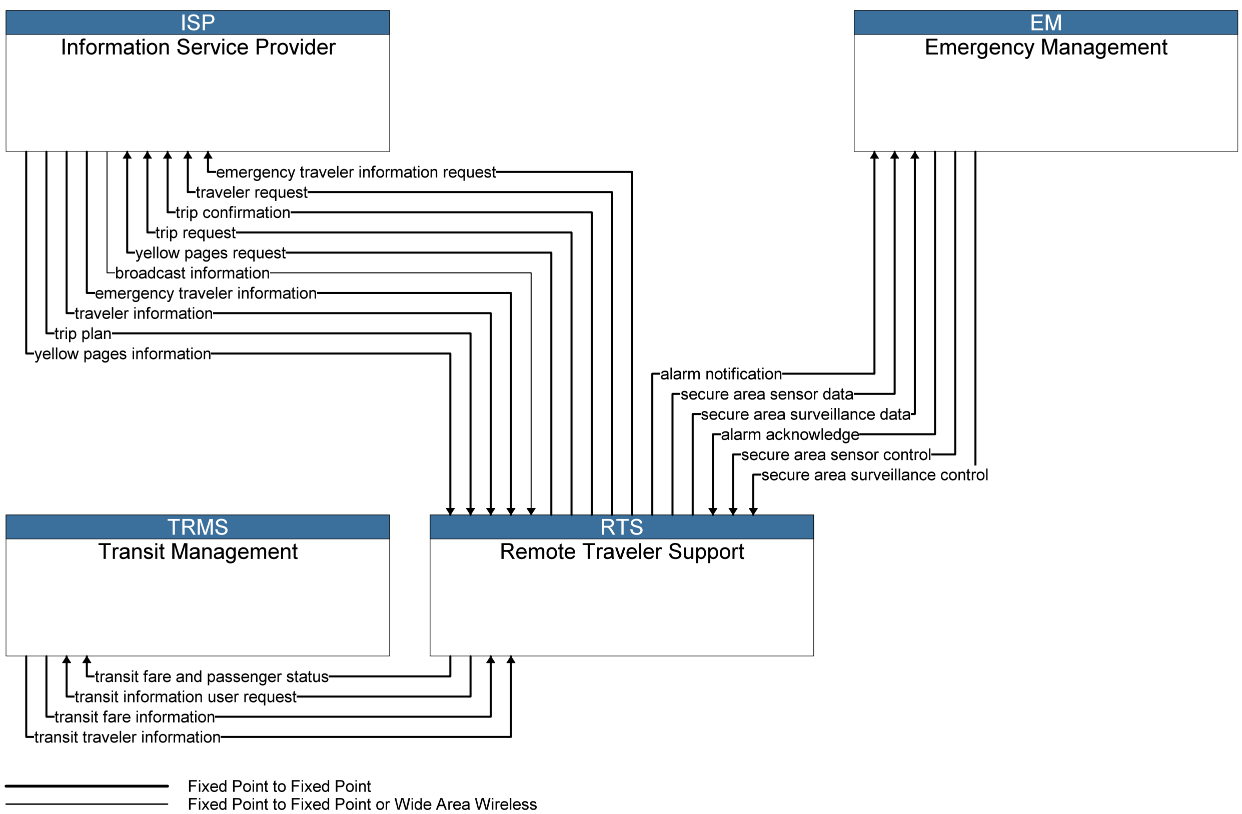


Figure. 4.4. National ITS Architecture for Remote Traveler Support (iteris.com, 2007).

3.5.3. National ITS Transit Management Subsystem

The Transit Management Subsystem manages transit vehicle fleets and coordinates with other modes and transportation services. It provides operations, maintenance, customer information, planning and management functions for the transit property. It spans distinct central dispatch and garage management systems and supports the spectrum of fixed route, flexible route, paratransit services, transit rail, and bus rapid transit (BRT) service. The subsystem's interfaces allow for communication between transit departments and with other operating entities such as emergency response services and traffic management systems. It provides current transit operations data to other center subsystems. The Transit Management Subsystem collects and stores accurate ridership levels and implements fare structures for use in electronic fare collection. It collects operational and maintenance data from transit vehicles, manages vehicle service histories, and assigns vehicle operators and personnel to vehicles and routes. The Transit Management Subsystem also provides the capability for automated planning and scheduling of public transit operations. The subsystem furnishes travelers with real-time travel information, continuously updated schedules, schedule adherence information, transfer options, and transit routes and fares (iteris.com, 2007).

3.5.4. National ITS Information Service Provider Subsystem

This subsystem (Figure 4.5) collects, processes, stores, and disseminates transportation information to system operators and the traveling public. One role of the ISP subsystem is focused on delivery of traveler information to subscribers and the public at large. Information provided includes basic advisories, traffic and road conditions, transit schedule information, yellow pages information, ride-matching information, and parking information. The subsystem also provides the capability to provide specific directions to travelers by receiving origin and destination requests from travelers, generating route plans, and returning the calculated plans to the users. In addition to general route planning for travelers, the ISP also supports specialized route planning for vehicle fleets. In this third role, the ISP function may be dedicated to, or even embedded within, the dispatch system. Reservation services are also provided in advanced implementations. The information is provided to the traveler through the Personal Information Access Subsystem, Remote Traveler Support Subsystem, and the Vehicle Subsystem through available communications links. Both basic one-way (broadcast) and personalized two-way information provision are supported. The ISP is most commonly implemented as an Internet web site, but it represents any traveler information distribution service including systems that broadcast digital transportation data (e.g., satellite radio networks) and systems that support distribution through dedicated short range communications networks (iteris.com, 2007).

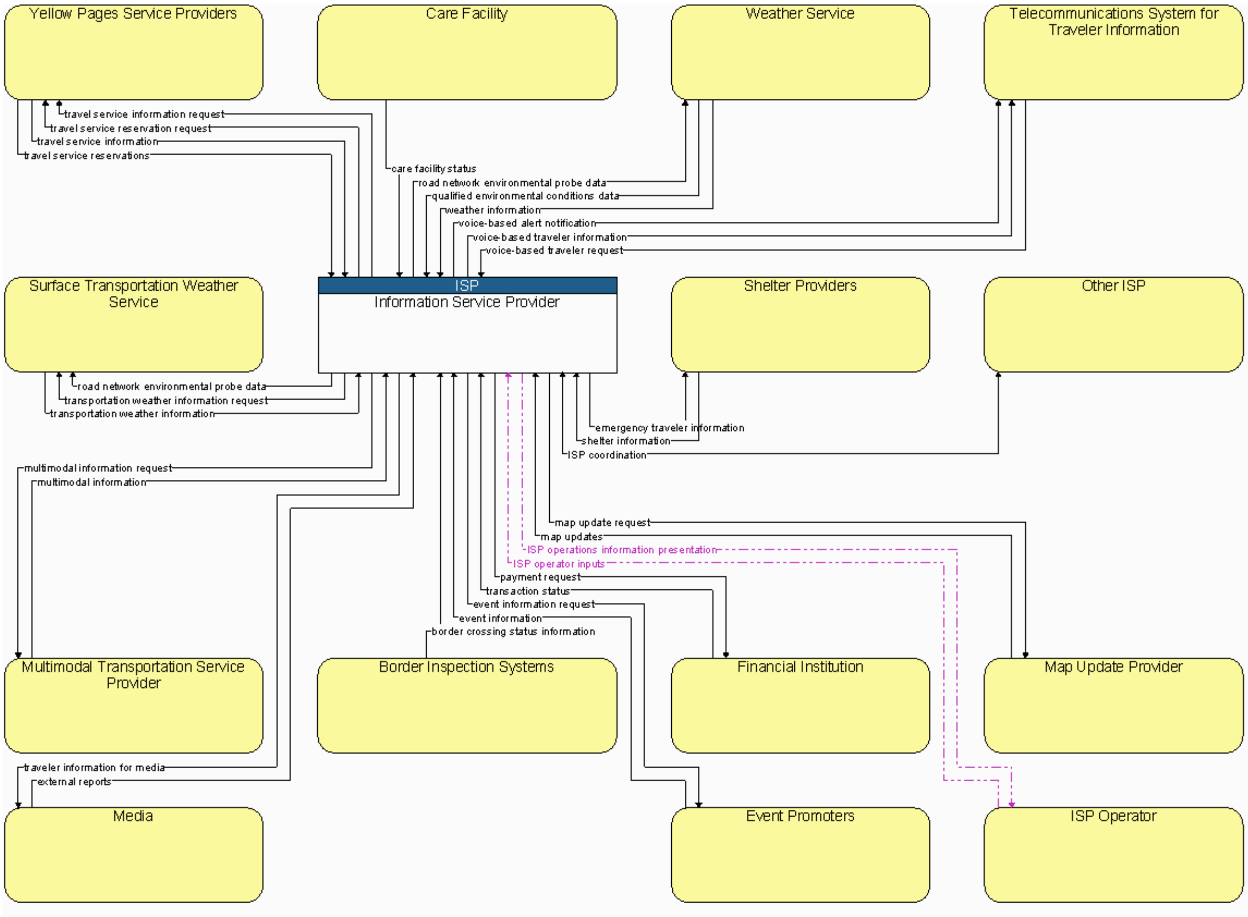


Figure. 4.5. National ITS Architecture for Information Service Provider (iteris.com, 2007).

3.6 SAE Standards

The Society of Automotive Engineers (SAE) oversees the development of standards that are used worldwide as a benchmark for design, procurement, and technical guidance. The SAE standards form a critical link between engineers, manufacturers, suppliers, and the international marketplace. The Advanced Traveler Information Systems (ATIS) Bandwidth Limited family of standards, created by the SAE standards development organization, applies to reduced bandwidth interfaces (such as wide-area-wireless interfaces). This standards group addresses primarily the interfaces between the Information Service Provider and the PIAS (personal), RTS (public), and Vehicle subsystems and is therefore mapped to the relevant architecture flows in the National ITS Architecture. This group provides the vocabulary (called data elements and messages) necessary to exchange information between these ITS systems. Figure 4.5 provides a graphical representation of the SAE ATIS XML related standards. This ATIS Group includes the following Standards Activities:

- SAE J2630 Converting ATIS Message Standards from ASN.1 to XML
- SAE J2540-1 RDS (Radio Data System) Phrase List

- SAE J2540-2 ITIS (International Traveler Information Systems) Phrase Lists
- SAE J2540-3 National Names Phrase List
- SAE J2540 Messages for Handling Strings and Look-Up Tables in ATIS Standards
- SAE J2529 Rules for Standardizing Street Names and Route IDs
- SAE J2369 Standard for ATIS Message Sets Delivered Over Bandwidth Restricted Media
- SAE J2354 Message Set for Advanced Traveler Information System (ATIS)
- SAE J2266 Location Referencing Message Specification (LRMS)

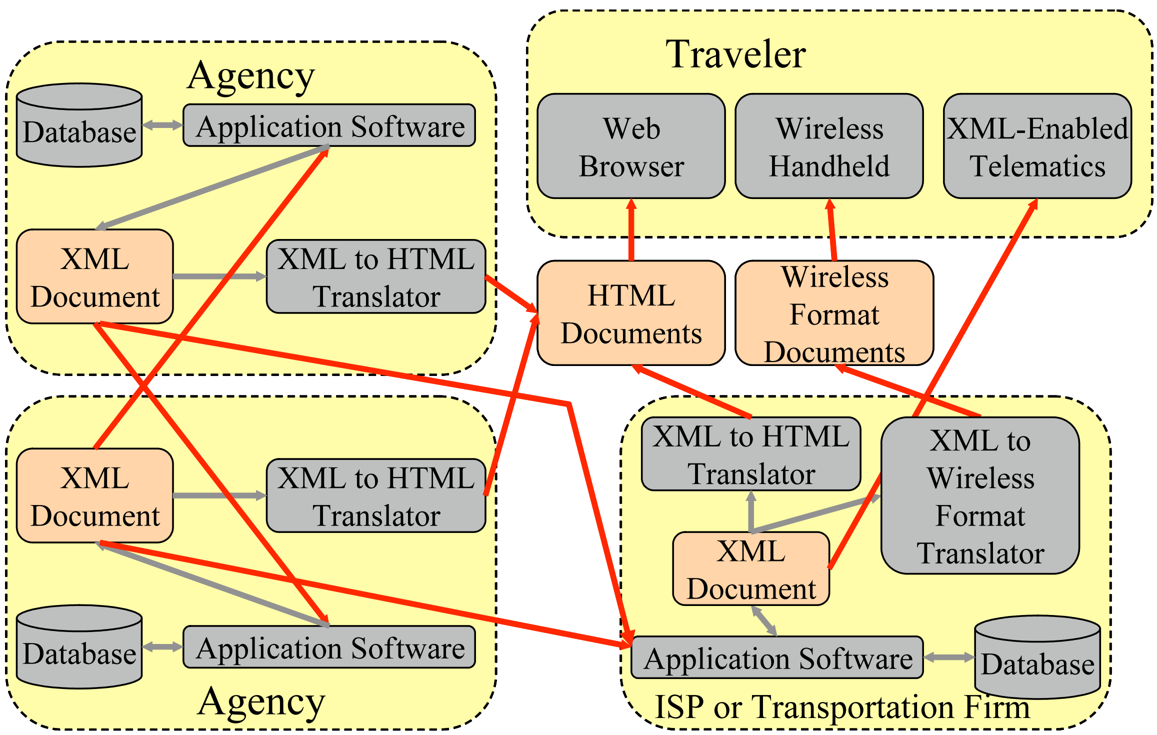


Figure. 4.6. XML and the SAE Traveler Information Standards (McGurrin, 2006).

3.6.1. SAE J2630 - Converting ATIS Message Standards from ASN.1 to XML

The SAE J2630 - Converting ATIS Message Standards from ASN.1 to XML standard was developed specifically to support conversion of the ASN.1 used in the SAE J2354 message set into a stand-alone XML schema for traveler information. To ensure that the translations could be used successfully for other ITS Standards, the IEEE 1512 standards family, Standards for Traffic Management Center-to-Center Communications, and Transit Communications Interface Protocols (TCIP) message sets were also considered during development of SAE J2630. Note that this standard was developed specifically to support conversion of the ASN.1 that was developed for ITS Standards. It does not support conversion of the entire ASN.1 language. This standard is distinct from other standards that have been developed that define XML Encoding Rules (XER) for ASN.1 and rules for mapping XML schemas into ASN.1 (DOT ITS, 2007).

3.6.2. SAE J2369 - Standard for ATIS Message Sets Delivered Over Reduced Bandwidth Media

This standard defines the message set for the transmission of Advanced Traveler Information System (ATIS) messages over reduced bandwidth media such as high speed FM Subcarriers and other wireless devices. It provides a standardized message set and methodology for delivery of compressed ATIS messages of incident information and segment travel times, speeds and congestion values (both current and predicted).
As a media independent format, this standard is suitable for use over most packet format wireless methods as well as use over Internet wire line connections where large bitmaps are prohibitive to deliver. SAE J2369 does not address methods of access denial or encryption, allowing the data provider to employ whatever methods desired. It does provide methods for combining both pubic and private data to allow a blend of "free" and "paid" content. It provides a number of compatible “evolutionary” messages for deployment areas where flow modeling and predictive information does not yet exist (DOT ITS, 2007).

3.6.3. SAE J2354 - Message Set for Advanced Traveler Information System (ATIS)

Clearly defined message sets are essential components in the design and operation of modern, computer-based ITS systems. Specifically, a message set provides a series, or set, of individual messages, established in a strict format, for exchanging information on a given topic. An agreed-upon message set with unambiguous definitions is one of the essential standards required to exchange messages between ITS systems.

Message sets work in conjunction with at least two other sets of standards to provide an effective data exchange. The first required set of standards include data dictionaries that provide the definition and syntax of individual data elements (DEs) that make up the specific message content of a message. In a simple analogy, message sets are the sentences where DEs are the individual words. The second set of standards needed for data exchange provides the actual communications protocols, and describes how messages are encoded for transmission, transmitted and then decoded by the receiver.

This standard, provides the messages and data elements that are exchanged among traveler information providers (data providers) and travelers (data consumers). The most recent revisions to the standard, includes the integrated use of the International Traveler Information System (ITIS) phrase lists for communicating event information, addition of

XML-based versions of each entry, and reuse of data elements from other functional area data dictionaries (e.g., Traffic Management Data Dictionary).

This standard, SAE J2354, Message Set for Advanced Traveler Information System (ATIS), provides two basic types of ATIS, based on whether or not the traveler (data consumer) interacts with the traveler information provider (data provider). One-way communication of traveler information includes predefined information broadcast to travelers, such as radio and TV broadcasts and some web pages. Two-way, transactional traveler information includes all means whereby the traveler makes specific, personalized requests and receives customized information (DOT ITS, 2007).

The messages defined in this standard are divided into seven major groupings of ATIS applications; message sequencing for each type of message (dialogs) is also included:

- Traveler Information - traffic, incidents, events, weather, environmental conditions, public transit schedules
- Trip Guidance - route plan to a specific destination, including the mode of transportation, points of interest, etc.
- Directory Services - electronic “Yellow Pages”, possibly location-based
- Parking - parking lot and space availability
- Settings - traveler’s personal preferences for format and content of traveler information
- Mayday - emergency information, including requests for assistance and vehicle information
- Reduced Bandwidth - streamlined version of certain data elements to accommodate bandwidth restricted media

3.7 Standard Implementations

Integrated Corridor Management on I-580

The U.S. Department of Transportation began the Integrated Corridor Management (ICM) Initiative to improve safety and mobility, and to advance the development and deployment of ICM systems throughout the United States. The goal of the initiative is to develop and provide the organizational guidance, operational capabilities, and ITS technical methods needed for effective integrated corridor management. The U.S. DOT will conduct demonstration projects in selected metropolitan corridor networks, using proven and emerging ITS technologies, to increase the effective use of the total corridor capacity. MTC, Caltrans and Alameda County CMA submitted the I-880 Corridor as a demonstration site. The corridor extends from the Bay Bridge to Santa Clara County. The

I-880 Corridor has been selected by US DOT as one of the eight sites in the nation for the Stage One consideration.

The I-580 Smart Corridor Project incorporates key ITS standards including NTCIP field devices-to-center protocol and NTCIP center-to- center protocol. The design also included ATSC digital television standards deployment, allowing centers to share closed-circuit television video. Additionally incorporated into the design is the Tri-Valley traveler information Internet web site which provides information to travelers on priority corridor congestion, video images of corridor congestion, and access to public transit information.

The APTS includes automatic vehicle location (AVL) and computer-aided dispatching (CAD). A wireless communications infrastructure provides real-time digital communications with ITS devices within transit vehicles. Separate voice communications channels are provided between the APTS dispatchers and the transit vehicle drivers. Interestingly, the architecture of the vehicular ITS subsystem includes a fully open architecture and the ability to add intelligent devices in the vehicle. An ergonomically designed interface with the driver provides the driver with key information without impacting safety. The single interface with the driver supports security, schedule management, electronic fare collection, and information related to vehicular performance.

East Bay SMART Corridors Program

The East Bay SMART Corridors program consists of three major arterial corridors in the east bay portion of the San Francisco Bay Area - San Pablo Avenue, Telegraph Avenue, and the Hesperian/International/E. 14th Boulevard corridors. The intention of the program is to plan and implement a multi-modal advanced transportation management system along the San Pablo Avenue (I-80) corridor, the I-880 corridor, and the INTEL (International/Telegraph) corridor. The SMART Corridors program has evolved into a multi-year, multi-phase program, implementing several major infrastructure improvements in the corridors, and has contributed to forming and strengthening interagency coordination and cooperation. The goals of the East Bay SMART Corridors program are to allow the participating agencies to better manage congestion and incidents along regional routes, improve transportation mobility, efficiency and safety, and to provide timely, multi-modal transportation information to agency transportation managers and to the public.

4. Access Control and Fare Payment Technologies

Transportation related fare payment implementations have generally evolved independently with different, usually incompatible, and frequently proprietary technologies. A review of technologies currently deployed, piloted, or under development provides information relative to the design of the proposed MOP and highlights where there are impediments to and opportunities for integration between modes. The review considered the following characteristics:

- the relationship between the fare payment instrument and billing system;
- degree of networked administration features;
- who issues the instrument;
- links with other access or payment systems;
- whether the instrument is proprietary or open standards-based;
- whether end users are registered;
- whether the instrument is read-only, read-write, recycled, or disposed with each use;
- whether the instrument doubles as an ID device;
- cost to end user; and
- relative wholesale unit cost.

From the transportation user's perspective, it is beneficial for shared-use vehicle system operators to provide a high degree of interoperability and consistency among various ITS vehicle systems, as well as with transit. A key example in this case would be a single access mechanism (e.g., smartcard and/or key fob) that could be used among many shared-use vehicle systems and other mobility services such as transit and parking management. Billing could also be made uniform across many programs, so that one monthly bill is received rather than several from various organizations. Operational consistency among several systems is also key, so that customers do not have to re-learn different operational procedures.

This evaluation is relative to the instrument's ease of use, operability, and integration of the instrument and system. Examples of the instruments being evaluated include international and domestic subway/train/bus transit cards, and various parking cards. The review also encompasses the growing use of cell phones as a micropayment instruments. With the continued evolution towards cashless systems, the integration of financial transactions will focus on digital financial transaction integration with MOP development.

Electronic access control systems have become a substitute for traditional key lock methods. These systems encompass passive and active RFID technologies, smart cards, keyfobs, and electronic keys (e.g. ibutton). The utilization of these technologies as access tokens is common for repeat users of a designated transportation system. The technology review encompasses the technologies suitable for transit systems and associated implementation methods. The access control token is anticipated to serve as the fare payment user device.

4.1 Proximity, Transit, and Smart Card Based Access and Payment

There are four primary card technologies utilized successfully in transportation applications for controlling physical access and/or payment:

- 125 kHz, Proximity cards – industry security cards typically utilizing Weigand format;
- ISO/IEC 15457 Identification cards – thin flexible cards utilizing magnetic recording ;
- ISO/IEC 14443 identification cards – contactless integrated circuit cards (proximity cards), and
- ISO/IEC 15693 – Part 2: Identification cards – contactless integrated circuit cards (vicinity cards).

4.1.1. 125 kHz Proximity Cards

125 kHz read-only technology is used by the majority of today's RFID access control systems and is based on widely accepted industry standards rather than international standards. The industry standards are commonly referred to as Weigand format and allows for a secure, uniquely coded number to be transmitted and processed by a back-end system. The back-end system then determines the rights and privileges associated with that card. The hardware and software utilizing the Weigand format are proprietary depending upon the manufacturer.

4.1.2. ISO/IEC 15457

Thin flexible cards are used to automate the controls for access to goods or services, such as mass transit, highway toll systems, car parks, vouchers and stored value. For these applications, data can be written and/or read by machines using various recording techniques: magnetic stripe, optical character recognition, bar code, etc. ISO/IEC 15457-2:2007 specifies the magnetic stripe and encoding characteristics of thin flexible cards at two points in the card's life cycle:

- at the point of loading into the card-issuing equipment;
- at the point of issue to the public.

4.1.3. ISO/IEC 14443

Contactless smart card technology is based on ISO/IEC 14443 (and ISO/IEC 15693) standards. Cards that comply with these standards are intelligent, read/write devices capable of storing different kinds of data and operating at different ranges. Standards based contactless smart cards can authenticate a person's identity, determine the appropriate level of access, and admit the cardholder to a facility, all from data stored on the card. These cards can include additional authentication factors (such as biometric templates or personal identification numbers) and other card technologies, including a contact smart card chip, to satisfy the requirements of legacy applications or applications for which a different technology is more appropriate. Cards complying with these standards are developed commercially and have an established market presence. Multiple vendors are capable of supplying the standards based components necessary to implement a contactless physical access system, providing buyers with interoperable equipment and technology at a competitive cost.

4.1.4. ISO/IEC 15693

ISO/IEC 15693 forms part of a series of International Standards that specify a contactless smart card. The card can be carried by members of the public in a purse or wallet and when presented nearby a terminal device give access to places, goods or services. In addition, the card can be attached to objects like bags and valuable items which can then be tracked while in the vicinity of a reading device. ISO/IEC 15693-2:2006 defines the power and communications interface between the vicinity card and the reading device. Other parts of ISO/IEC 15693 define the physical dimensions of the card and the commands interpreted by the card and reader.

Power is coupled to the vicinity card by an AC field produced in the reader, also known as a coupler; the powering field has a frequency of 13.56 MHz and is one of the industrial, scientific and medical frequencies available for worldwide use. When sufficient power is received by the card, it is able to respond to commands sent from the coupler. Vicinity cards, which have no power source, can be energized at ranges of up to 1 m from a coupler that can only transmit power within the limits permitted by international radio frequency (RF) regulations.

4.2 RFID, Credit Card Access and Payment

Though the three RFID contactless payment platforms (ExpressPay, PayPass and Visa Contactless) employ discrete encryption methods, they all use the same air-interface protocol described by the ISO 14443 standard. Consequently, all three can be read by a single RFID interrogator built into POS systems.

Contactless smart card technology and applications conform to the ISO/IEC 14443 and ISO/IEC 7816 international standards. A contactless smart card includes an embedded smart card secure microcontroller or equivalent intelligence, internal memory, a small antenna, and communicates with a reader through a contactless radio frequency (RF) interface. Contactless smart card technology is used in applications that need to protect personal information and/or deliver fast, secure transactions, such as transit fare payment cards, government and corporate identification cards, documents such as electronic passports and visas, and financial payment cards. Example applications using contactless smart card technology include:

- The U.S. FIPS 201 Personal Identity Verification (PIV) card being issued by all Federal agencies for employees and contractors;

- The Transportation Worker Identification Credential (TWIC) being issued by the Transportation Security Administration;

- The First Responder Authentication Card (FRAC) being issued in Department of Homeland Security pilots;

- The new U.S. ePassport being issued by the Department of State; and,

- Contactless payment cards and devices being issued by American Express, MasterCard and Visa.

Several large chains in the U.S. have deployed many thousands of RFID readers for credit cards: CVS Pharmacies (all 5,300 locations), McDonald's (12,000 of 13,700 locations), the Regal Entertainment Group of movie theaters, and several other large vendors (Heydt-Benjamin, 2007). A vendor typically deploys an RFID-enabled credit card reader at each cash register. Each reader is continually polling for cards by broadcasting a radio carrier, and can speak with the major brands of RFID-enabled credit cards. A small number of manufacturers produce readers capable of speaking several proprietary protocols. An evaluation of approximately 20 RFID-enabled cards issued in the last year revealed four semantically different protocols between the card and reader (Heydt-Benjamin, 2007). Recent reports estimate the deployment of 20 to 55 million RFID-enabled credit cards in comparison to 398 million conventional credit cards (Heydt-Benjamin, 2007). In addition to traditional payment contexts, RFID-enabled credit cards are becoming accepted in other contexts such as public transportation. The New York City subway recently started a trial of 30 stations accepting an estimated 100,000 RFID-enabled credit cards. A participant in this trial uses her credit card as a transit ticket as well as a credit card in place of the traditional magstripe-based dedicated subway tickets.

The following standards and reference material are relative to contactless card payment.

ISO/IEC 7813:1995 Identification cards – Financial transaction cards.

ISO/IEC 14443-1:2000 Identification cards – Contactless integrated circuit(s) cards – Proximity cards – Part 1: Physical characteristics.
– Part 2: Radio frequency power and signal interface.
– Part 3: Initialization and anti-collision.
– Part 4: Transmission protocol.

ISO/IEC 7816-4:1995 Information technology – Identification cards – Integrated circuit(s) cards with contacts - Part 4: Interindustry commands for interchange.

ISO/IEC 13239 Information technology – Telecommunications and information exchange between systems – High-level data link control (HDLC) procedures.

ISO/IEC FDIS 10373-6:2001 Identification cards – Test Methods – Part 6: Proximity Cards.

4.2.1. Industry Efforts of EMVCo and PCICo

PCICo is a collaborative effort of five credit card associations (American Express, Discover Financial Services, JCB, MasterCard Worldwide, and Visa International). PCI refers to the Payment Card Industry standards which include several initiatives such as data security, PIN security, etc. PCI's primary motivation is the development of the PCI Data Security Standards (DSS), which address the security of cardholder data that is stored, processed, or transmitted. On the 15th of December 2004, Visa, MasterCard, American Express and Discover aligned their individual policies and created Payment Card Industry Data Security Standard.

The PCI Security Standards Council is an independent body formed to develop, enhance, disseminate and assist with implementation of security standards for payment account security. The PCI Security Standards Council will maintain and evolve the PCI Data Security Standard, while working to promote its broad industry adoption, and while providing the tools needed for compliance with the standard. These tools include critical documents such as audit guidelines, scanning vendor requirements, and, in a few months, a self assessment questionnaire. These functions are as important as the promulgation of the standard itself.

Chip/PIN is a method of payment that further verifies the credit card is valid and held by the proper owner. Instead of signing a paper receipt to verify a card payment, the user enters a four-digit Personal Identification Number (PIN), just like you do at a cash machine. The "I Love PIN" logo was launched as a way of informing customers that the UK is moving to Chip-PIN. This means the user needs to remember their PIN number when making transactions. By accepting Chip-PIN transactions, the merchant is not responsible for fraudulent transactions as they would be under normal "swipe" transactions.

Whereas PCICo focuses on the security of the data that is stored, processed, or transmitted by merchants, service providers, or data storage entities EMVCo focuses on the chip standards.

EMV is the EuroCard, MasterCard, Visa chip card protocol standard. EMVCo LLC was formed February 1999 by Europay International, MasterCard International and Visa International to manage, maintain and enhance the EMV Integrated Circuit Card Specifications for Payment Systems. With the acquisition of Europay by MasterCard in 2002 and JCB International joining the organization in 2005, EMVCo is currently operated by JCB International, MasterCard International, and Visa International.

The EMV Specifications are built upon the existing ISO 7816 series of standards for Integrated Circuit Cards with Contacts. EMVCo's primary role is to manage, maintain and enhance the EMV Integrated Circuit Card Specifications to ensure interoperability and acceptance of payment system integrated circuit cards on a worldwide basis. EMVCo is a standards body that defines the physical and electronic requirements for chip cards. It is concerned only with the cards and not the cardholder data that is retained with merchants, service providers, or data storage entities.

4.2.2. RFID Access Control and Implementation

Radio frequency identification (RFID) tags are used in a wide range of applications such as: identifying animals, tracking goods through the supply chain, tracking assets such as gas bottles and beer kegs, and controlling access into buildings. RFID tags include a chip that typically stores a static number (an ID) and an antenna that enables the chip to transmit the stored number to a reader. Some RFID tags contain read/write memory to store dynamic data. When the tag comes within range of the appropriate RF reader, the tag is powered by the reader's RF field and transmits its ID to the reader.

RFID tags are simple, low-cost and commonly disposable, although this is not always the case. There is little to no security on the RFID tag or during communication with the reader. Any reader using the appropriate RF frequency (low frequency: 125/134 KHz; high frequency: 13.56 MHz; and ultra-high frequency: 900MHz) and protocol can get the RFID tag to communicate its contents. (Note that this is not true of car keys which contain a secure RFID tag.) Passive RFID tags (i.e., those not containing a battery) can be read from distances of several inches (centimeters) to many yards (meters), depending on the frequency and strength of the RF field used with the particular tag. RFID tags have common characteristics, including:

- Low cost designs and high volume manufacturing to minimize investment required in implementation.
- Minimal security in many applications, with tags able to be read by any compatible reader. Some applications like car keys do have security features, most notably provisions to authenticate the RFID tag before enabling the ignition to start the car.
- Minimal data storage comparable to bar code, usually a fixed format written once when the tag is manufactured, although read/write tags do exist.
- Read range optimized to increase speed and utility.

4.3 Cellular Based Access and Payment

Payment with cellular devices are predominately completed with Near Field Communication (NFC), which is one of the newest wireless networking technologies for short-range wireless connectivity. NFC is promoted as providing intuitive, simple, and safe communication when two NFC-compatible devices are brought within four centimeters of one another. NFC operates at 13.56 MHz and transfers data at up to 424 Kbits/second. Trials of this technology have successfully illustrated how people carrying mobile phones or smart cards with built-in NFC can make purchases, get directions, exchange information, and buy transportation simply by bringing them close to NFC-enabled devices embedded in information kiosks, retail registers, advertising signs, vending machines, and thousands of other devices, systems and signage.

ISO/IEC 18092:2004 defines communication modes for Near Field Communication Interface and Protocol (NFCIP-1) using inductive coupled devices operating at the center frequency of 13.56 MHz for interconnection of computer peripherals. It also defines both the active and the passive communication modes of NFCIP-1 to realize a communication network using NFC devices for networked products and also for consumer equipment. The 18092 standard specifies, in particular, modulation schemes, codings, transfer speeds and frame format of the RF interface, as well as initialization schemes and conditions required for data collision control during initialization. Furthermore, the standard defines a transport protocol including protocol activation and data exchange methods.

4.3.1. NFC Implementations

The greater Frankfurt area transport organization Rhein-Main-Verkehrsverbund (RMV) in Hanau, Germany, rolled out a commercial service utilizing NFC-equipped Nokia cellular phones to pay for bus tickets. The NFC-phones are compatible with the contactless smart card infrastructure already installed in the city. Users board busses and trams and hold their phones towards the card reader in the bus, (see Figure 5.1) to pay for tickets. The phone's display confirms the possession of a valid ticket. Both riders and RMV gain from the new system. Riders receive the lowest possible fares and gain access to a cost-saving loyalty program at retail outlets, restaurants and attractions. RMV takes advantage of across-the-board reductions in the costs of ticketing machines, paper use, service, maintenance, and repair (smart card alliance, 2006).

The City of Caen, a popular tourist destination in France, is conducting a large scale trial of NFC technology. Two hundred citizens use their NFC-enabled cellular phones to pay for parking at a local car park, obtain information from signs throughout the town, and buy groceries at the local market, each by bringing a mobile phone close to an NFC-enabled POS terminal. Throughout town, they can place NFC-enabled phones near NFC-enabled posters, signs, or billboards to automatically load schedules and movie trailers, and to purchase and retain paperless tickets (NFC Forum.org, 2007).

Figure 5.1. Use of NFC capable phone for transit and POS transactions (NFC Forum.org, 2007).

In the U.S., MasterCard is recruiting customers of 7-Eleven's Speak Out mobile phone service for a trial that lets them download a contactless payment application that allows their phone to function as PayPass enabled MasterCard credit card. As participants join the trial, they receive a Nokia 3220 mobile phone, along with instructions on how to configure the phone for contactless payments. Once the phone is set up, the participant can use it to make purchases at any of the 32,000 merchant locations worldwide that accept MasterCard's PayPass RFID-enabled payments (Heydt-Benjamin, 2007).

Tokyo's JR East, in collaboration with NTT DoCoMo, issued the Suica transit application on NFC-enabled mobile phones. The application supports the identical functionality of the Suica smart card on the phone and provides additional user convenience features via the interactive display provided by the handset. This approach has enabled NTT DoCoMo to become part of the fulfillment channel for transit products as they can be delivered to the phone over the wireless network (Smart Card Alliance, 2006).

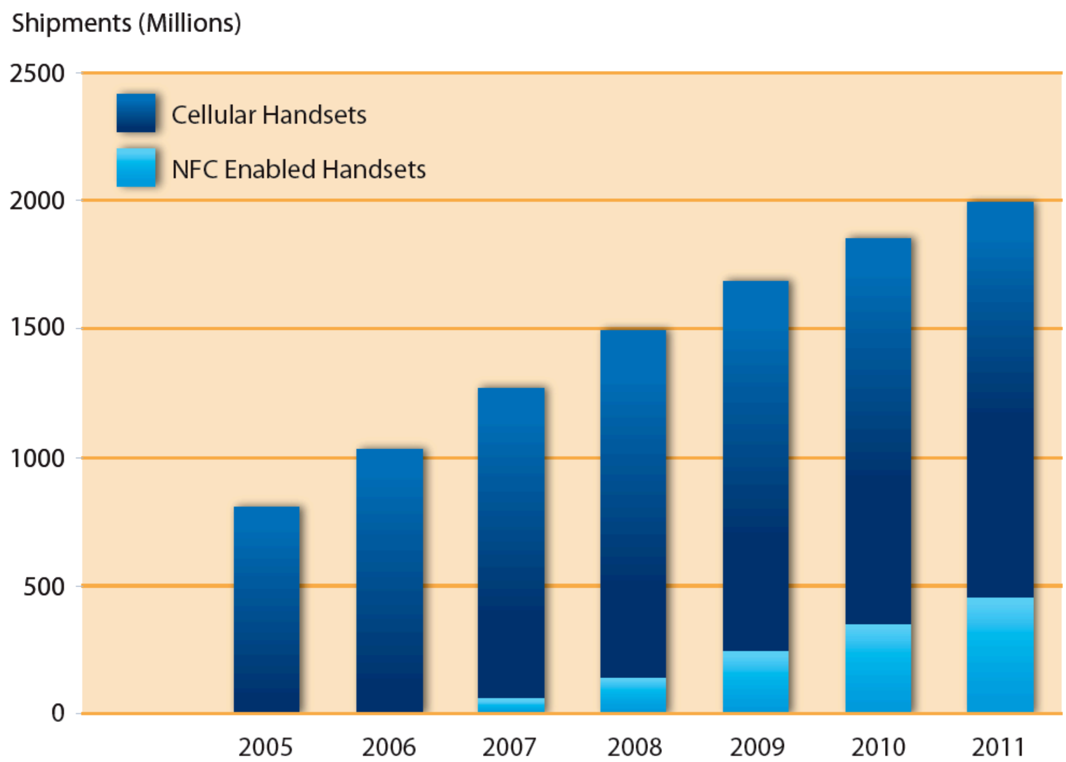


Figure 5.2. Predicted market penetration of NFC enabled phones (NFC Forum.org, 2007).

4.4 RF, Proximity, and Smart Card Transit Applications

Contactless transit fare payment systems are currently operating or being installed in such cities as Washington, DC, Chicago, Boston, Atlanta, San Francisco and Los Angeles. Contactless smart cards have the ability to securely manage, store and provide access to data on the card, perform on-card functions (e.g., encryption and mutual authentication) and interact intelligently with a contactless smart card reader. Contactless smart card technology is available in a variety of forms – in plastic cards, watches, key fobs, documents and other handheld devices (e.g., built into mobile phones). Figure 5.3 provides relative technology implementation levels for various RF technologies. Figure 5.4 reviews some of the transit implementations and the characteristics of each.

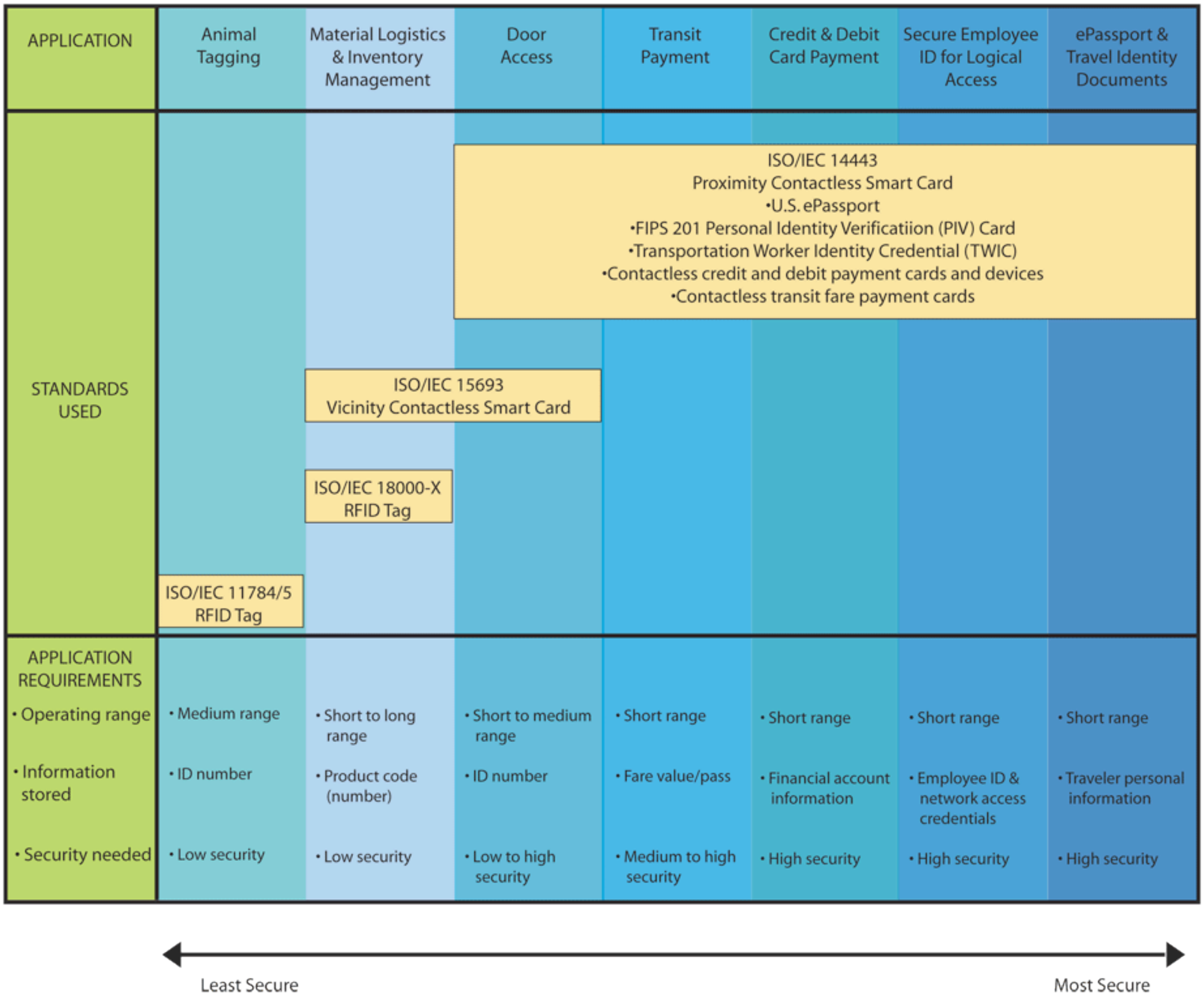


Figure 5.3. smart cards protocols, characteristics, and applications (Smart Card Alliance, 2007a).

Back office operations of their distribution, customer service, and revenue accounting procedures are shown to have varying management procedures depending upon system configuration. Figure 5.4 shows that MTC, WMATA, and CTA have chosen to process its smart card transactions internally instead of outsourcing smart card distribution, customer service, and reconciliation of revenue receipts. CTA also offers an interesting feature in its Chicago Card Plus program, where customers can elect automatic reloading features that guard against being left with a valueless card. Some cards also include a "guaranteed last ride" function that provides one last ride as long as there is any value left on the card, with the resulting negative balance resolved when value is added to the card.

Permanent Citizens Advisory Committee
Table 1
Comparison of Smart Card Programs

Agency	Port Authority of New York and New Jersey (PANYNJ)	Metropolitan Transportation Authority (MTA)	Chicago Transit Authority (CTA)		Metropolitan Transportation Commission [San Francisco Bay Area] (MTC)	Washington Metropolitan Area Transportation Authority (WMATA)
Card Name	**SmartLink**	**None**	**Chicago Card**	**Chicago Card Plus**	**TransLink**	**SmarTrip**
Smart Card Start Date	2001-2005 (Pilot)	None	2002	2004	2002	1999
# of Transit Agencies To Be Linked with Smart Card	2	N/A	3	3	26	16
Transportation Modes in Phase 1 Pilot Tests	Monorail (AirTrain Newark), NJT Commuter Rail	N/A	Subway, Bus	N/A	Subway, Bus, Ferry, Commuter Rail	Subway
Can Parking Fees Be Paid with Smart Card?	No	N/A	No	No	Yes	Yes
Automatic reload: customer's credit card charged a predetermined amount when card account balance falls below specified value.	Yes	N/A	No	Yes	No	No
Guaranteed Last Ride Feature: Allows customers one last ride with any value remaining on the card.	No	N/A	Yes	Yes	No	No
Are Smart Card Distribution, Customer Service, and Reconciliation of Revenues Outsourced?	No	N/A	No	No	Yes	Yes
Can the Card Be Purchased Online?	No	N/A	Yes	Yes	Yes	Yes
Can the Card's Value Be Reloaded at Retail Outlets?	No	N/A	No	No	Yes	Yes*
Current Smart Card Uses	Monorail (AirTrain Newark), NJT Commuter Rail	N/A	Subway, Bus	Subway, Bus	Bus, Commuter Rail, Light Rail, Ferries	Parking, Subway, Bus
Next Steps	Implement on PATH service. Outsource smart card revenue allocation functions. Formalize operating rules and procedures for revenue sharing. Investigate partnerships and business opportunities to recover smart card costs.	N/A	Focus on building greater interest in the Transit Benefit program and increasing the distribution of the Chicago Card and Chicago Card Plus with the current functionality rather than adding other features to the cards at this time.		Enable customers to travel on any system without purchasing a particular type of pass. Make smart cards available at hotels by connecting it to guests' room keys.	Offer limited-use disposable smart cards to serve the infrequent user. Transfer the transit card application, payment, and customer service activities to a WMATA contractor or financial institution who can issue a card for use in the Metro system.
Available to Visitors for Purchase for Short-Term or	N/A	N/A	No	No	No	Yes

* Available at WMATA's Retail Stores Located Within the System

Figure 5.4. Integration of smart cards for transit applications (Brower, 2004).

Additional evaluation of regional transit system cards shows that in addition to the ability to purchase the TransLink card online, MTC plans to offer customers the option of reloading value on their smart cards at participating retail outlets (Figure 5.4). WMATA's SmarTrip card is available for purchase online as well as in WMATA's retail stores located within the system, which makes the card available to visitors for short-term or infrequent use. CTA's Chicago Card and Chicago Card Plus are not available for purchase at retail outlets. MTC is exploring the possibility of making smart cards available at hotels for visitors to use for local and regional transportation (Brower, 2004). Transit based applications and associated technology is shown in Figure 5.5.

Examining Fare Collection Approaches and Technologies	
System Approaches	**Examples of Cities with This Technology**
Fare Media	
Printed Tickets and Passes	*Most Transit Operators*
Tokens	*San Jose*
Magnetic Fare Cards	
Read Only	*Seattle*
Read/Write	*Las Vegas, Minneapolis, Houston*
Smart Card	
Plastic Long/Life Reusable	*Chicago, Wash DC, Atlanta, LA*
Paper Disposable	*Atlanta*
Fare Collection Methods	
On-Board	
Manual Supervision with Farebox	*Most Transit Operators*
Off-Board	
Manual with Turnstiles	*Philadelphia, Cleveland*
Automated with Fare Gates	*BART, Wash DC, New York*
Proof-of-Payment	*Portland, LA, Baltimore, Las Vegas*
Equipment Technology	
On-Board	
Registering Farebox	*Seattle, Dallas*
Validating Farebox	*Montebello, Orange County, Wash DC*
Printed Ticket Issuer	
Magnetic Card Swipe Reader	*Seattle*
Mag Card Read/Encode/Issue Unit	*Cleveland, Minneapolis, Houston*
Smart Card Read/Encode Unit	*Wash DC, Chicago*
Smart Card Read/Encode/Issue Unit	*Atlanta*
Off-Board	
Printed Ticket Vending Machine	*Portland, LA, LIRR, NJT*
Mag Card Ticket Vending Machines	*Las Vegas, BART, Wash DC*
Printed Ticket Validator (Print)	*Portland, Caltrain*
Smart Card Validator (Read/Encode)	*Caltrain (Translink)*
Credit/Debit Card Sales at TVMs	*Wash DC, Chicago*
Web-Site Sales and Directed Autoload	*Wash DC, Chicago*

Figure 5.5. Evaluation of card technology for transit applications (APTA III, 2007).

According to a cubic.com press release, Cubic Transportation Systems Ltd, developers of the Oyster smart card transport ticketing system for London won a 2006 RFID (Radio Frequency ID) Breakthrough Award. This is the fifth award for Oyster, a system utilized by millions of people every day to travel on London's Undrground and buses. Additionally, attendees of the American Public Transportation Association (APTA) Fare Collection Workshop hosted a demonstration of the agency's Transit Access Pass (TAP), using a new ANSI (American National Standards Institute) "Limited Use" version of a smart fare card, a first for a West Coast transit agency.

The Oyster card, based on Philips' NFC-compatible MIFARE technology, has rapidly gained high acceptance. It accounted for 25 percent of London's Underground weekday journeys within a year of its rollout in 2004 and climbed to nearly 50 percent a year later. In 2006, five million cards were in circulation and 3.9 million fares were paid daily using the Oyster card. Promoters say that the card's ease of use, coupled with the fact that an Oyster card-paid fare is priced lower than the cash fare, fueled its acceptance. (Smart Card Alliance, 2006).

On July 11, 2006, in partnership with MasterCard and Citibank, MTA New York City Transit (NYCT) officially launched a trial of standard, contactless bank-issued smart card devices to pay transit fares directly at the point of entry without the need to purchase fare media. The trial was implemented at 30 subway stations principally along NYCT's heavily traveled Lexington Avenue line. At each staffed point of entry in these stations, one fare gate has been equipped with a standard ISO/IEC 14443 and MasterCard PayPass certified smart card reader. These fare gates also continue to accept NYCT's current fare media, the MetroCard (Smart Card Alliance, 2006).

The Utah Transit Authority (UTA) has undertaken a pilot of contactless media fare collection in 2006. Readers for contactless payment were installed on 41 UTA Ski Service buses and used to track acceptance and use of ski resort season passes, employee IDs, and cards issued by the Salt Lake Visitor's Bureau as bus passes. The pilot will included the use of the readers as POS devices for micropayment transactions using contactless financial payment devices issued by the major financial payment brands (American Express, Mastercard and Visa). The pilot was conducted during the 2006-2007 ski season, from November or December 2006 to April 2007 (Smart Card Alliance, 2006).

4.4.1. APTA Universal Transit Fare System Standard

Development of Universal Transit Fare System (UTFS) Standard and its parts have been guided by the APTA UTFS Task Force. It is the mission of the Task Force to develop a series of documents that provides industry guidance for the creation of an open architecture payment standard. The UTFS standard promotes greater access and convenience to the public transportation network and enables integration of independent payment systems. To accomplish this mission, the task force membership established a broad representation of the transit industry specifically including transit system operators, the Federal Transit Administration (FTA), manufacturers, engineering and consulting

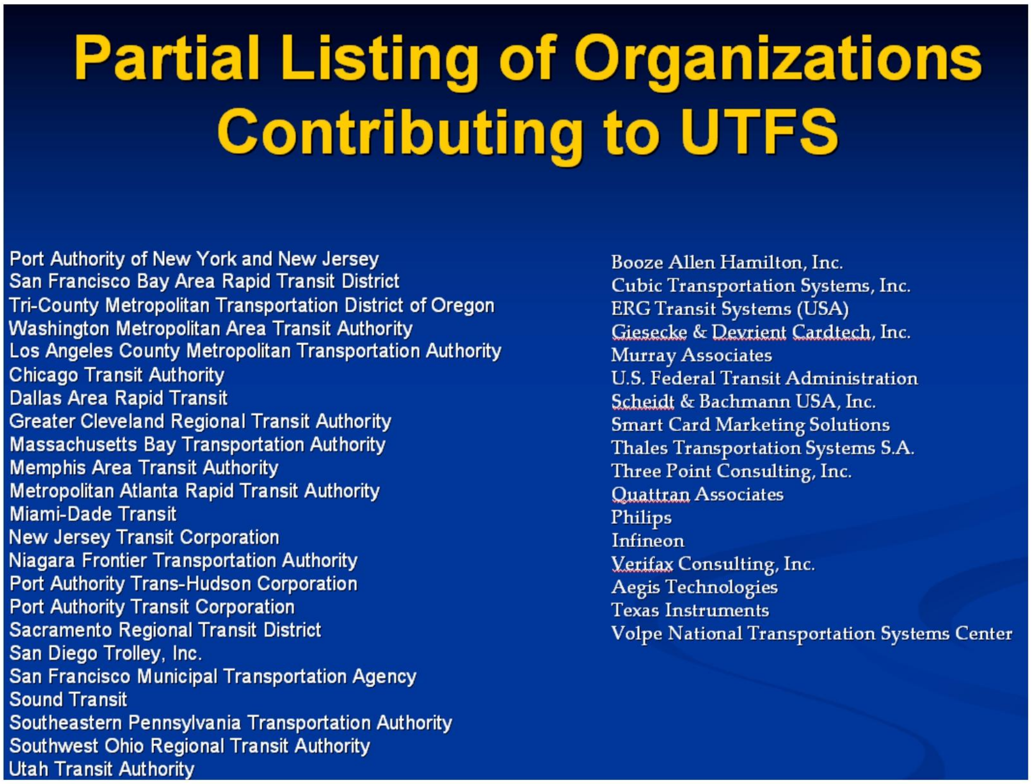


Figure. 5.6. Organizations participating in UTFS standards development (Schroeder, 2007)

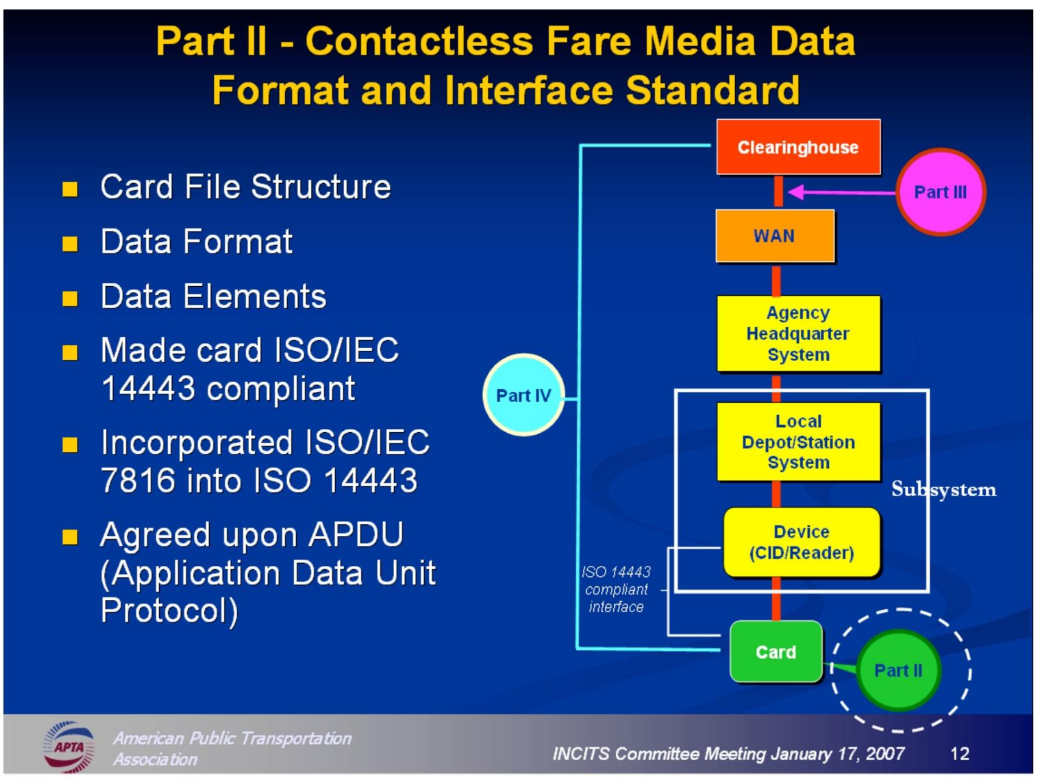


Figure. 5.7. UTFS standards development architecture (Schroeder, 2007)

firms, transit labor organizations and others with an interest in the revenue management aspects of the transit industry, as shown in Figure 5.6.

This Standard is Part I of a suite of standards that together form the Contactless Fare Media System Standard (Standard). This and other parts of the Standard include the following:

- Part I - Introduction and Overview
- Part II - Contactless Fare Media Data Format and Interface Standard
- Part III - Regional Central System Interface Standard
- Part IV - Security Planning and Implementation Guidelines and Best Practices
- Part V - Compliance Certification and Testing Standard

The parts of the Standard noted above are designed to be implemented together as part of a foundation for end-to-end integration of fare collection information processing to best provide interoperable systems within a region. Figure 5.7 provides the architecture of the Standard and its various components and concepts. By applying the Standard to the design of a new fare collection system or upgrade of an existing system combined with adherence to a set of regional implementation, security and operating rules, interoperability with other compliant systems may be achieved. Figure 5.8 displays the regional central system specification (Part III) and the relationship with transit fare cards.

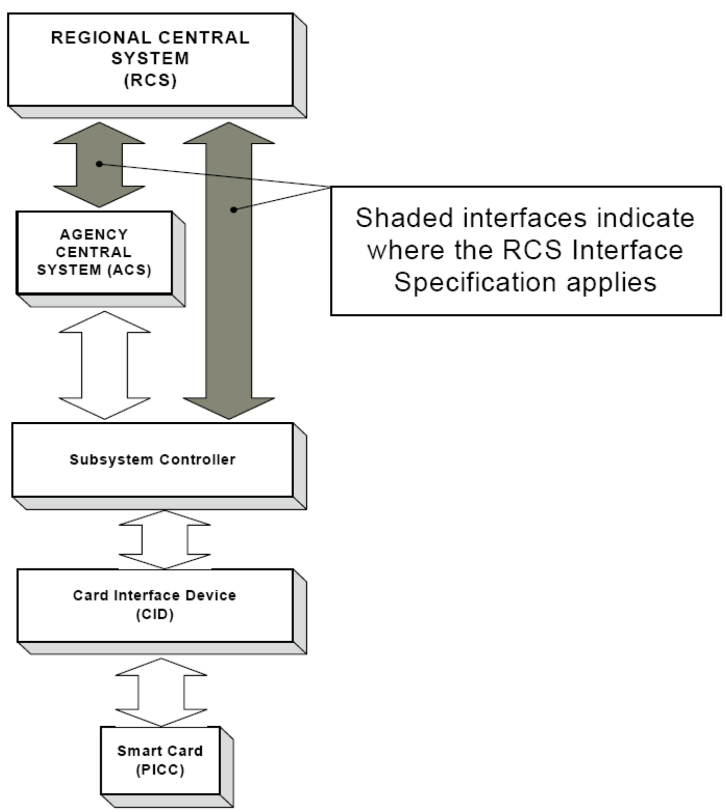


Figure. 5.8. Regional Central System Specification flow diagram (APTA III, 2006).

5. Trip Planners and Reservation Systems

In recent years there has been a proliferation of trip planners and transportation-related automated reservation systems that are available to users on the Internet. Traditionally, the systems have been designed around airplane travel, however lodging and car rental online reservation systems are now common. A thorough review of existing Internet based trip planning and reservation systems has been conducted, with the eventual goal of integration with the Mobility Options Communication Protocol.

A review of the reservation systems utilized by major carsharing organizations (e.g., Zipcar, Flexcar, City CarShare, Communauto) quickly revealed systems of proprietary nature that appear to function independently without sharing of customer data or trip information. While some open standards and technology development may be taking place among carsharing operators, it is not being openly discussed in the transportation arena. Conversely, the protocols in the transit, airline, rental car, and fare payment industries are rapidly evolving to promote mobility linkages, data sharing, and continuing standardization of architectures and protocols. The assessment of trip planners and reservation systems will focus on the industries making the most significant advancements relative to Internet-based systems and interoperability.

5.1 Airline and Travel Reservations

As discussed previously, the airline industry reservation system consists of four Global Distribution Systems. GDSs and Central Reservation Systems (CRSs) host static information and provide access to availability of inventory, and rates of various service providers. This data can be queried and accessed by the travel agents worldwide that subscribe to the GDS. CRSs/GDSs have the same relationship to travel data that credit bureaus have to financial data: they centralize and store vast amounts of information about the traveler, but they get the information through intermediaries, the GDSs remain in the background, and have minimal direct contact with the people for whom they retain information.

Passenger Name Records (PNRs) are airline records, but few airlines host their own databases. Most airlines store their PNRs in a virtual partition in the database of a Computerized Reservation System (CRS). Federal regulations utilize the “CRSs” terminology, but they are commonly referred to as Global Distribution Systems (GDSs). The four major CRSs/GDSs worldwide and their respective PNR access web site are listed below. The PNR website will return the itinerary information when provided with the traveler’s confirmation/reservation number.

Sabre:
VirtuallyThere.com
Galileo / Apollo:
ViewTrip.com

Amadeus
CheckMyTrip.com
Worldspan
MyTripAndMore.com

Of the major airlines in the USA, American, Alaska, and ATA are hosted in Sabre; Delta and Northwest are hosted in Worldspan; and United is transitioning from Galileo (Apollo) to Amadeus for compatibility with Lufthansa and other Star Alliance members hosted in Amadeus.

A few airlines, including jetBlue and Southwest in the USA, have built their own hosting systems, with limited connections to the CRSs so that travel agencies can make reservations through their CRSs. Continental, US Airways, and some other airlines in the USA and abroad (notably including Virgin Atlantic) use the SHARES system. SHARES doesn't have travel agency subscribers, only airline users, and isn't considered a CRS or regulated as one.
All of the big four CRSs, and the SHARES hosting system, were built on IBM's Transaction Processing Facility (TFP) platform. Ongoing efforts to migrate them off TFP and mainframe platforms have proven extremely difficult, slow, and expensive. Figure 6.1 shows the major airlines and respective GDSs.

CRSs/GDSs don't just store data: they also are the center of travel networking. CRSs/GDSs connect airlines to each other, to travel agencies, and to car rental companies, hotels, cruise lines, tour operators, and other providers of travel services. Whenever an individual makes a reservation, a PNR is created. PNRs cannot be deleted: once created, they are archived and retained in the CRS/GDS, and can still be viewed, even if the individual never bought a ticket and cancelled the reservations.

When a travel agent makes a reservation, they enter data on a CRS/GDS terminal, and create a PNR in that CRS/GDS. If the airline is hosted in a different CRS/GDS, information about the flight(s) on that airline is sent to the airline's host system, and a PNR is created in the airline's partition in that system as well. What information is sent between airlines, and how, is specified in the Airline Interline Message Procedures (AIRIMP) manual, although many airlines and CRSs/GDSs have their own direct connections and exceptions to the AIRIMP standards.

Name	Founded in	Started by / Owned by	Approx No. TA Locations Year '02	Region
Amadeus	1987	Air France, Iberia, Lufthansa, and SAS	57,000#	Mainly Europe, Mid East, North Africa & Asia Pacific
Galileo	1993*	Founded by a consortiums of 11 major North American and European airlines led by United Airlines. Currently owned by Cendant Corporation	47,000	Global presence very strong in the US and Western Europe
Sabre	1976	American Airlines. Currently a separate entity owned by AMR corporation	60,000	Global presence very strong in the US and Asia Pacific
Worldspan	1990	Founded by Delta, TWA, and North West Airlines. Currently being sold to Transaction Processing Corporation.	20,000	Mainly in the US and Europe
* Apollo which started operations in late 1970's by United was merged into Galileo in 1993				
# Source: (Samipatra Das, October 2003)				
! ! Sources (Amadeus Web Site, 2003; Galileo Web Site, 2003; Sabre Web Site, 2003; Worldspan Web Site, 2003)				

Figure. 6.1. Global Distribution Systems membership, participants and location (Amdekar, 2006).

5.1.1. Online Travel Agencies

In 1999, five major airlines (United, American, Delta, Northwest, and Continental) began efforts to work towards the creation of a new online travel agency. Dubbed "Orbitz," the new Web site was launched in June 2001, and since then has grown into a technology leader in its quest to update the legacy systems of airline reservations (Granados, 2003). The airlines claimed that Orbitz would dramatically decrease the high costs of making reservations. For that purpose, Orbitz was designed and powered by ITA Software (www.itasoftware.com), a pricing and airfare shopping technology developer launched by researchers from the Artificial Intelligence Laboratory at MIT. ITA is also a software vendor for Continental.com, AmericaWest.com and Air Canada's Fly Tango. This software is attractive because it obtains fares directly from the Airline Tariff Publishing Company (www.atpco.net), which collects and distributes fares from airlines worldwide, and schedules from OAG (www.oag.com). By using ITA's Global Airfare Pricing and Airfare Shopping System, Orbitz is able to avoid reliance on legacy system infrastructures and high CRS and GDS fees (Granados, 2003). Figure 6.2 illustrates the technological structure of fare distribution in the airline industry with respect to Orbitz.

If, for example, a person completes a reservation on United Airlines (which outsources the hosting of its reservations database to the Galileo CRS/GDS) through the Internet travel agency Travelocity.com (which is a division of Sabre, and uses the Sabre CRS/GDS), Travelocity.com creates a PNR in Sabre. Sabre sends a message derived from portions of the Sabre PNR data to Galileo, using the AIRIMP (or another bilaterally-agreed format). Galileo in turn uses the data in the AIRIMP message to create a PNR in United's Galileo partition.

If, for example, a person completes a reservation on United Airlines (which outsources the hosting of its reservations database to the Galileo CRS/GDS) through the Internet travel agency Travelocity.com (which is a division of Sabre, and uses the Sabre CRS/GDS), Travelocity.com creates a PNR in Sabre. Sabre sends a message derived from portions of the Sabre PNR data to Galileo, using the AIRIMP (or another bilaterally-agreed format). Galileo in turn uses the data in the AIRIMP message to create a PNR in United's Galileo partition.

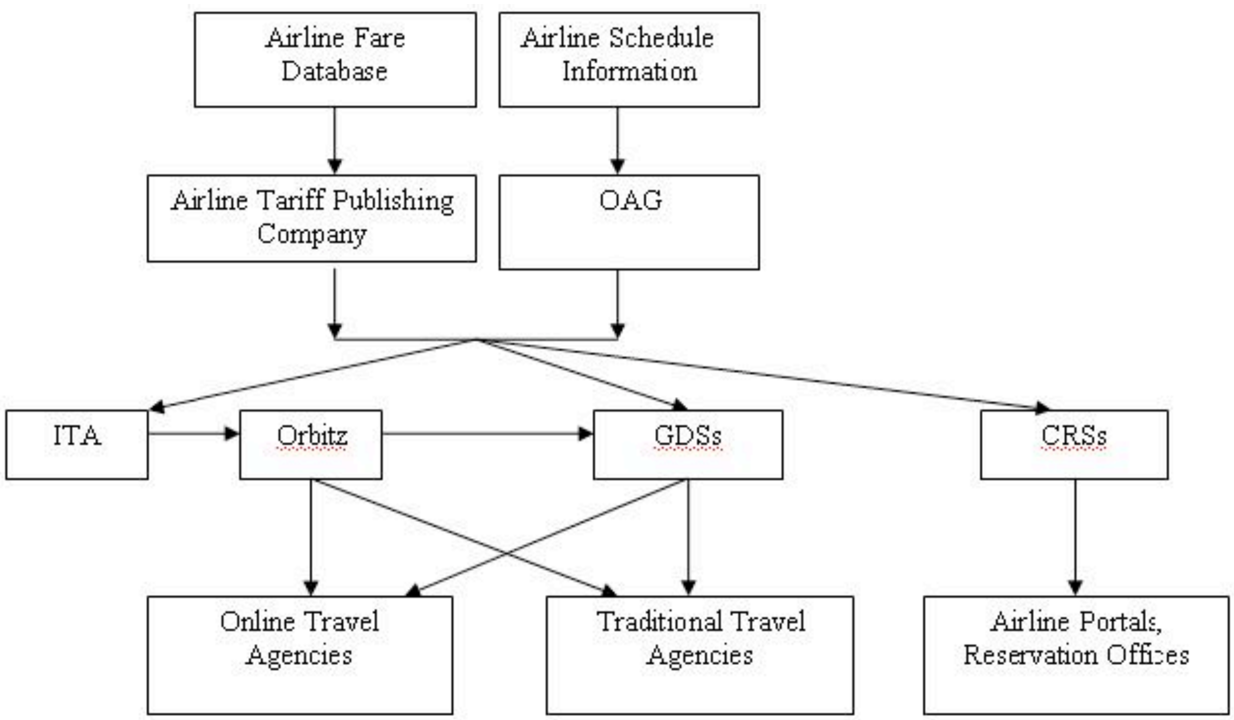


Figure 6.2. Online Travel Agency data architecture (Amdekar, 2006)

If a set of reservations includes flights on multiple airlines, each airline is sent the information pertaining to its flights. If information is added later by one of those airlines, it may or may not be transmitted back to the CRS/GDS in which the original reservation was made, and almost never will be sent to other airlines participating in the itinerary that are hosted in different CRSs/GDSs. There can be many different PNRs, in different

CRSs/GDSs, for the same set of reservations, none of them containing all the data included in all of the others.

If hotel, car rental, cruise, tour, sightseeing, event, theme park, or theater ticket bookings are made through the same travel agency, Web site, or airline, they are added to the same PNR. So a PNR isn't necessarily, or usually, created all at once: information from many different sources is gradually added to it through different channels over time.

Several options exist relative to MOP development, which range from an independently created reservation/planning service to a membership with one of the primary GDSs. The details of how to design the MOP reservation structure will depend upon the option selected. A few details regarding online travel agency style integration is detailed below.

5.2 Open Travel Alliance

The OpenTravel Alliance, which began in May 1999, is a consortium of suppliers in all sectors of the travel industry, including air, car rental, hotel, travel agencies, and tour operators, as well as related companies that provide distribution and technology support to the industry. The OpenTravel has over 125 members representing all sectors of the travel industry. The Alliance is comprised of numerous working groups – air, car, hotel, and non-supplier (travel integration) – together with an interoperability committee to coordinate their efforts. The OpenTravel defines open messages in eXtensible Markup Language (XML) that make it possible to exchange business data seamlessly among different systems, companies, and industries over the Internet. OpenTravel specifications are open documents and will remain freely available to all industry participants. OpenTravel specifications provide a framework for companies in the travel industry to create new relationships with customers as well as to create new partnerships with fellow companies in the business.

The OpenTravel Alliance (OTA) 2002B Specification is comprised of two documents:

- a text-based PDF document that describes the XML-based message sets; and,
- a ZIP archive that contains the actual XML message sets, stored in 134 XML Schema .XSD files).

There have been several working groups created within the OTA to represent different components of the travel industry. These include:

1. Air Working Group;
2. Car Working Group;
3. Hotel Working Group;
4. Package Tours/Holiday Bookings;
5. Golf Tee Times;
6. Insurance;

7. Travel Itinerary Messages;
8. Rail Messages; and,
9. Loyalty Messages.

The sections with greater relevance to MOP development are presented below.

Section 2: Car Working Group. The 2002B release makes extensive use of shared components to make the messages interoperable with other OTA working groups. Examples of such cross-industry components include Customer Information, Payment information and Flight Arrival Details. This commonality and interoperability work makes the OTA specification much more modular and reduces barriers to entry.

Section 7: Travel Itinerary Messages. The Travel Itinerary message (or Passenger Name Record) is widely used to integrate, manage and service travel content. The following is a list of travel content information traditionally contained within the Travel Itinerary (includes but not limited):

(a) Personal Traveler Related Information -- Name, Address, Phone, etc.;
(b) Booked Travel Segments -- Air, Car, Hotel, Tour/Cruise, etc.;
(c) Ticketing, Pricing & Form of Payment Information;
(d) Special Service Request and Remark Details;
(e) Travel Itinerary or PNR Synchronization;
(f) Complete Travel Itinerary Book Request;
(g) Travel Itinerary Update/Modify; and,
(h) Travel Itinerary Cancel/Ignore.

Section 8: Rail Messages. The *rail availability* request provides the ability to request rail services between two station pairs on a specific date, for a specific number of passengers of a particular passenger type. The *book request* message requests a train reservation on a specific rail service provider for travel between two or more stations on specific dates for a specific number and type of passengers in specific classes of service.

While development of a MOP is not required to interface with the GDSs, online travel agencies, or Open Travel Alliance definitions, compatibility and interoperability with these agencies should be considered.

6. Conclusions and Recommendations

The MOP is envisioned to perform as an open source protocol for linking information detailing a broad range of mobility options to trip planning systems and travel information aggregators across the Internet. The successful implementation of a MOP integrates mobility services and provides a framework to disseminate mobility related information. This technology review has provided an overview of relevant communication, access and payment technologies, applicable standards, and architectures of travel associated reservation systems. Significant conclusions and recommendations are presented for the most relevant technologies, specifications, and implementations.

Communication hardware integration associated with MOP development will consist of a variety of wired and wireless devices. Wired devices have proven reliability, quality of service, and are cost effective when available. Availability, geographic constraints, physical infrastructure constraints, implementation preferences, and mobility requirements may restrict the usage of wired communications. In these instances, wireless communication hardware can be utilized to overcome these barriers.

The most likely implementation of wireless communications for MOP integration is associated with on-board electronics. Communication devices placed on vehicles will require a wireless link. Wireless WAN, wireless PAN, and wireless LAN technologies have been evaluated for these applications. Wireless WAN evaluation has demonstrated that cellular based short message service has been demonstrated to be the most effective on the SMS or GPRS networks. Some regions have pager-based two way messaging coverage that provide a cost effective alternative to cellular based messaging. Wireless LAN technologies are predominately 802.11b/g/n based (Wi-Fi) and have been demonstrated as the most cost effective and reliable solutions when sufficient electrical power and processor capabilities are provided. Wireless PAN developments appear have the most significant contribution towards a MOP.

Wireless PANs have lower power and processing requirements and can be integrated in a mobile platform. These devices can independently establish a communications link and transmit pertinent data. Bluetooth has proven to be a viable PAN technology when there are higher bandwidth requirements, while Zigbee devices are showing promise for lower bandwidth communications. Zigbee has very low power requirements and is therefore suitable for battery powered platforms. End user devices, lacking a power source, can be linked with a MOP based system utilizing devices integrated with Zigbee communications. The drawback of PAN devices is the lack of inherent TCP/IP protocol communications. An intermediary device and communications method needs to be implemented and tested for MOP compliant implementation. The current communication protocols for PAN devices also lack the security available for TCP/IP compliant networks. Resolution of these PAN limitations will allow for significant advancements for MOP integrated hardware.

Significant protocols and standards development has occurred in recent years regarding interoperability of transportation related communications. Exchange of transportation related information between associated agencies has become a priority for numerous institutes, working groups, associations, and government bodies. The medium of choice for the data exchange is inarguably the Internet utilizing primarily TCP/IP protocols. The following standard bodies have the greatest involvement in transportation related communication standards development:

NTCIP:

- NTCIP 2306: Application Profile for XML Message Encoding and Transport in ITS Center-to-Center Communications.
- NTCIP 2304: Application Profile for DATEX-ASN
- NTCIP 1104 Center-to-Center Naming Convention Specification

ITE:

- TMDD MS/ETMCC: Traffic Management Data Dictionary and Message Sets for External Traffic Management Center Communications.

SAE:

- SAE J2630: Converting ATIS Message Standards from ASN.1 to XML
- SAE J2369: Standard for ATIS Message Sets Delivered Over Reduced Bandwidth Media
- SAE J2354: Message Set for Advanced Traveler Information System

USDOT National ITS Architecture

- Remote Traveler Support Subsystem
- Information Service Provider Subsystem
- Transit Vehicle Subsystem

The efforts and developments of these standards should be closely monitored when designing and implementing a Mobility Options Protocol within a Transit Oriented Development.

Electronic fare payment and access control is beginning to have significant penetration within the transportation arena. Transit operators are realizing significant benefits to having a single token serve as the user's device for fare payment and granting access to the service. Additional benefits arise when the token is contactless and/or is integrated with another device (e.g. phone, PDA, contactless credit card etc.). While these systems to date have predominately utilized proprietary technologies developed by third parties, systems are evolving to include contactless payment technology standards. These standards are implemented primarily on contactless credit cards and a select number of cellular phones. The standards of international acceptance by industry related groups and international standards bodies are listed below:

ISO/IEC:

- ISO/IEC 14443: Contactless integrated circuit cards – proximity cards;

- ISO/IEC 7816: Identification cards – integrated circuit cards with contacts;
- ISO/IEC 18092: Near Field Communication Interface and Protocol (NFCIP-1)

APTA:

- UTFSS: Universal Transit Fare System Standard

Several options exist relative to MOP integration with reservation systems and trip planners, which range from an independently created reservation/planning service to a membership with one of the primary Global Distribution Systems. When a travel agent makes a reservation, they enter data on a CRS/GDS terminal, and create a Passenger Nam Record in that CRS/GDS. If the airline is hosted in a different CRS/GDS, information about the flight(s) on that airline is sent to the airline's host system, and a PNR is created in the airline's partition in that system as well. What information is sent between airlines, and how, is specified in the Airline Interline Message Procedures (AIRIMP) manual, although many airlines and CRSs/GDSs have their own direct connections and exceptions to the AIRIMP standards. Since the travel industry and GDSs now incorporate rental cars and non-air modes of travel, utilizing the GDSs architecture for MOP related reservations may prove useful.

Alternatives to the GDS exist and the most prominent is the OpenTravel Alliance represented by a consortium of suppliers in all sectors of the travel industry, including air, car rental, hotel, travel agencies, and tour operators, as well as related companies that provide distribution and technology support to the industry. The OpenTravel specifications define open messages in eXtensible Markup Language (XML) that make it possible to exchange business data seamlessly among different systems, companies, and industries over the Internet. OpenTravel specifications are open documents and will remain freely available to all industry participants. OpenTravel specifications provide a framework for companies in the travel industry to create new relationships with customers as well as to create new partnerships with fellow companies in the business.

The OpenTravel Alliance (OTA) 2002B specification is comprised of two documents:

- a text-based PDF document that describes the XML-based message sets; and,
- a ZIP archive that contains the actual XML message sets, stored in 134 XML Schema .XSD files).

While the travel industry electronic databases are dominated by the extensively evolved airline GDSs based system, some development is taking place for interoperability outside of the GDSs. The MOP integrated approach should include a systematic evaluation of: database management requirements, collaborating agency data exchange, regional integration, security, interoperability with user platforms, and regulatory compliance.

A significant amount of complexity is involved when attempting to create a Mobility Options Protocol that incorporates the most recent advancements in communications, fare payment, access control and electronic reservation systems. A successful communications protocol must define a sufficient amount of parameters to allow interoperability, but remain flexible for evolving technologies. The goal of this technology and literature review has been to provide sufficient information to create a MOP that improves current mobility operations and advances future transportation oriented developments.

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8. Article Summary

STDS – Industry standards for transportation, access control, and fare payment
COMP – Communication protocols relative to wireless and wired devices
COMH – Wireless and wired communication hardware
PYMT – Electronic fare payment references
RESV – Electronic/automated reservation services

Low – Used primarily for author and technical reference
Med – Used for author reference and may have direct application to the program
High – Used for author reference and likely has direct application to the program

Abernethy 2002	STDS, RESV	• System architecture description for transportation center interoperability • Early development of center to center communications	High
Adams, 2005	COMP/COMH	• Introduction to 802.15.4 protocols, hardware, and architecture • Specifications and Characteristics are provided	Med
APTA I, 2007	PYMT	• The specification for components of the data architecture to be used on a Proximity Integrated Circuit Card (PICC). • The messages between the Regional Central System (RCS) and the Agency Central Computer or sub-system controller. • Standard applies to contactless fare collection systems where two or more transit agencies share a common PICC.	High
APTA II, 2006	PYMT	• Standard is to provide a consistent and uniform method for storing, retrieving and updating data from contactless fare media used in transit applications. • Application standard for the design of a new fare collection system or upgrade of an existing system. • Standard defines a set of regional implementation, security and operating rules for interoperability with other compliant systems.	High
APTA III, 2007	PYMT	• Defines standards for the structure and components of the messages that are sent between the Regional Central System (RCS) and other components of a contactless fare media system. • Messages definitions are used to send data to the RCS resulting from a transaction or action performed by a Proximity Integrated Circuit Card (PICC) or Card Interface Device (CID), and for the RCS to send data and control messages relating to a CID or PICC to system components, such as an Agency Central System (ACS) or Sub-system Controller.	High
APTA IV, 2006	PYMT	• Comprehensive approach that recognizes and addresses all aspects of the AFC system from a security perspective. • Security planning to recognize the strengths and weaknesses of the design and ensure that the weakest	Med

		points do not compromise the protection of assets within the system.	
Aust, 2002	COMP	• Details system architecture issues between WLAN and WAN • Provides communication protocol issues for transferring communication between a GPRS WAN and 802.11	Low
Bana, 2001	COMP, COMH	• SDMA characteristics are discussed for ad-hoc vehicle communications • Advantages and disadvantages are discussed • Positioning characteristics of SDMA are detailed	Med
Baker, 2005	COMP/COMH	• Technology comparison between Bluetooth and ZigBee • Applications evaluation for Zigbee and Bluetooth • Light discussion of protocols	Med
Barth, 2000	COMP/COMH	• Presentation and evaluation of ITS technologies associated with shared use vehicle systems relative to multi-station architecture • Key ITS component functionality is described and presented • Communication methods are discussed in detail • Operational procedures are discussed in detail	Low
Barth, 2000	COMP, COMH	• Discussion of shared vehicle system architecture with multiple stations • Communications between vehicles, users, kiosks, and computers systems is presented	Med
Barth, 2001	COMH, COMP	• Discussion of shared vehicle system architecture with multiple stations • Communications between vehicles, users, kiosks, and computers systems is presented	Med
Barth, 2002	COMP/COMH	• Communication requirements for shared vehicle system are presented • Cellular and DSRC communications are discussed in detail • The hybrid communication architecture for shared use vehicle system is discussed at length. • Advantages of hybrid system are presented	Low
Barth, 2002b	STDS	• Preferred nomenclature is presented for shared vehicle systems • System architectures are discussed and presented • Industry related obstacles and barriers are discussed	Med
Blythe, 1999	PMT/ACS	• Discussion of RFID technology for transportation tolls and vehicle access • Overview of European systems • Technology and architecture considerations are provided	Low
Brower, 2004	PYMT	• Review of smart card technologies and implementations • Evaluation of smart card technology with respect to New York's transit requirements	Med
Burden, 2006	PYMT	• Evaluation of NFC for transit applications • Review of NFC implementations in transit scenarios • Evaluation of NFC relative to alternatives	Med
Castleberry, 1998	COMP	• Discussion of airlines GDS's and relationship to the travel industry. • Details the PNR and how data is stored and transmitted within the GDS's	Med
Chin, 2003	COMP	• Protocol alternates for Ultra-wideband applications	Low

		• Alternate communication protocols are presented relative to PHY layer, bandwidth, range, and transmission power	
Cisco, 2005	COMP	• Discusses the Background and history of Internet Protocol • Presents the format and structure for IP messaging • Presents standard accepted methods of IP messaging	Low
Cisco, 2006	COMP	• Provides a good general background of network configurations, protocols, hardware configuration, and communication methods • Suitable reference for basic network topologies	Med
Cubic.com	PYMT, RESV	• Major provider of ITS transit based reservation, access, payment systems	High
Das, 2002	COMP, STDS	• Discussion of airlines GDS's and relationship to the travel industry. • Details how reservations are made and the system architecture for electronic reservations	Med
EMV, 2006	PYMT	• Manual that describes the minimum functionality required of Proximity Integrated Circuit Cards (PICCs) and Proximity Coupling Devices (PCDs) • Describes the related ISO standards for PICCs and PCDs • Information presented relative to the PayPass protocols	Med
Ferro, 2005	COMP/COMH	• Comparison of 802.11 and Bluetooth technologies and protocols • System architectures and characteristics are described • Power and communication specifications are provided	High
FHWA, 2005	STDS	• Discusses the general ITS technologies associated with User Services • Defines User Bundles and the associated User Services • Serves as a guide for the beginning planning stages of ITS implementations for national cohesion among ITS systems	Med
globalstarusa.com	COMH, COMP	• Presentation of LEO satellite services • Discussion of hardware options and services	Low
Helal, 2000	COMP	• Describes utilizing Mobile-IP protocols on a wireless LAN architecture • Provides some detail on 802.11 integration with WAN • Discusses WAN/LAN integration, protocol, and architecture issues	Low
Hong-qiang, 2006	COMP	• Presentation and explanation of cryptographic Hash functions • Implementation and structure of SHA-512 Hash function	Low
Husemann, 2004	COMP/COMH	• Architecture of a personal mobile hub is presented • Protocols associated with a wireless PAN to WAN interface are presented • Hardware associated with wireless WAN to wireless PAN is detailed	Med
iataonline.com	STDS, RESV	• ATA/IATA reservation interline message procedures for passenger (AIRIMP) standards • Standard communication protocols for online airline reservations	High
IEEE.org, 2006	COMP	• IEEE organization developing Electrical Engineering protocols and standards • Professional organization for the electronic and electrical	High

		engineering	
ISO/IEC 7498	STDS	• Model for digital communications network • 7-layer reference model • General architecture model for digital communications	Med
ITSA, 2001	STDS/PYMT	• Details the role of Electronic Payment Services with the ITS Architecture • Provided 7 case studies of EPS deployments. • Evaluates future EPS technologies for the transportation sector.	Med
Jabs, 2001	COMP	• Evaluation of 802.11 power consumption relative to protocols • Protocol development for low power installation	Med
Kim, 2005	PMT/COMP	• Protocol definitions and methodology for wireless cash transactions • Review of specific BCY protocol methods • Evaluation of protocol strengths and weaknesses	Low
Koulamas, 2004	COMP	• Interfacing ad-hoc wireless networks with IPv4 and IPv6 • Internet protocol issues are addressed relative to multihop wireless networks	High
Koyama, 2005	COMP/RES	• Web services proxy (WS-Proxy) for XML communications • Intermediary architecture for managing XML communications • Architecture is presented	Med
Lee, 2001	COMP	• Token ring architecture for ITS communications was determined to be robust and perform well under heavy load • Characteristics of networking protocols and ITS networking requirements	Med
Lin, 1997	COMP, COMH	• Digital cellular data network is discussed with associated protocols • Details associated with CDPD are surveyed	Low
Meng, 2004	PMT/COMP	• Details the analysis method for determining e-payment transaction accountability • Evaluation methodology for protocols e-payment requirements	Low
Munaka, 2001	COMP	• DSRC based ITS vehicle communication architecture is discussed between vehicles and base stations • Network efficiency is discussed and solutions presented for addressing multicast issues	Med
Negri, 2004	COMP	• Characterization of Bluetooth power consumption • Protocol methods to reduce power consumption of wireless modules	Med
NFC-Forum.org	PYMT	• Summary of NFC technology and implementations • Presentation of NFC in transit applications • Deployment plans for NFC technology	Med
orbcomm.com	COMH, COMP	• Presentation of LEO satellite services • Discussion of hardware options and services	Low
Ondrej, 2006	COMP/COMH	• Detailed description of ZigBee networks • Strengths and weaknesses of ZigBee performance • Overview of ZigBee communication Architecture	High
Ondrus, 2007	PYMT	• Evaluation of the Swiss industry for NFC implementation • Comparison of NFC to established payment technologies	Med
opentravel.org	RESV, STDS	• International organization for developing standards for internet based travel data exchange	High

		• XML message formats and content for the travel industry	
PCI SSC, 2007	PYMT	• Industry security standards for card payment • Description of transaction security requirements and recommendations • Network and hardware requirements are discussed relative to security issues	Med
protocols.com	COMP	• Details pertinent past, present, and near term future wireline and wireless communication protocols • Provide application specifics and general protocol format	Med
Punnoose, 2001	COMP	• Future vehicle based communications are discussed ranging from CAN Bus, Bluetooth, DSRC, Cellular etc. • Protocols necessary to address the intercommunication of vehicle based networks is discussed	
Rao, 2000	COMP	• Discussion of various WLAN technologies and protocols • Comparison of US, Europe, Asia WLAN protocols and technologies • Compatibility issues are addressed relative to WLAN protocols	Low
Rao, 2005	COMP	• 802.11g performance characteristics and graphs are presented • Discussion of data loss relative to architecture and protocols	Low
Sakane, 2005	COMP	• Protocol integration methods between 802.15.4 and IPv6 are presented • Details are provided for protocol structure and system architecture	High
satwest.com	COMH, COMP	• Presentation of LEO satellite services • Discussion of hardware options and services	Low
Scinteie,2004	STDS/TRP	• Discusses technologies associated with Traveler Information services • Provides implementation considerations of Traveler Information technologies •	Med
Schroeder, 2007	PYMT	• Presentation of APTA National Standards fare payment effort • Summary of smart card developments and standards • Presentation of steps for evolving fare payment national standard	High
Shaheen, 2006	STDS, RESV	• Discussion of carsharing status for US and Canada • Details of users, vehicles, locations, technologies, operations are presented • General trends and forecasts can be interpreted	Med
Shaheen, 2000	COMP/COMH	• Operational characteristics of the CarLink system are presented • User patterns are detailed • Links to transit are presented and discussed at length • Technology issues are addressed	Low
Shaheen, 2002	COMP/COMH	• Evaluation of primarily North American Carsharing Systems • Evaluation of system type, number of vehicles, technology implentations • Analysis of carsharing growth	Low
Shinde, 2005	COMP	• Evaluation of PAN protocols	High

		• Presentation of MAC and PHY layer specifications • Details of QoS, range, power, and bandwidth	
Shuaib, 2006	COMP/COMH	• Evaluation of ZigBee, Bluetooth, and 802.11 wireless performance simultaneously • Bluetooth had significantly more effect on Wi-Fi throughput than ZigBee's effects on Wi-Fi • Data throughput effects ranged from neglible to 20 percent decreases	Med
Smart Card Alliance, 2006	PYMT	• Description of smart card characteristics, standards, and implementations for transportation. • Description of smart card transportation pilot prgrams	High
Smart Card Alliance, 2007	PYMT	• Description of RFID and smart card technologies • Application description for RFID and smart cards • Protocols and standards for RFID and smart cards	Med
Storsul, 2006	COMP/COMH	• Evaluation of US Cellular technology deployment • Market Share of US Cellular devices • Presentation of data services for US cellular	Med
Tan, 2002	PMT/COMP	• Details methodology for processing anonymous electronic payment • Provides a brief background of electronic payment methodoligies • Details protocols and implementation strategy for specific scheme	Med
USDOT 2005	STDS	• Interactive web site for exploring the National ITS Architecture • Defines the ITS Architecture components and layers • Provides general architecture for ITS implementations • Intended to serve as a planning and implementation guide for domestic transportation agencies	Low
Wang, 2005	COMP	• Comparison of 802.11e and 802.15.3 protocols, performance, and power issues	Med
WiMAX Forum, 2006	COMP	• comparison of Mobile WiMAX performance characteristics with contemporary and evolving 3G technologies. • Discussion and performance comparison provides and the role that Mobile WiMAX can play in the evolution of broadband mobile networks.	Med
wirelesswans.com	COMP/COMH	• Describes wireless wan technology components from a technology provider perspective • Provides general pricing for wireless wan systems	Med
www.iso.org	STDS	• Official International Standards Organization website • Provides technical standards for transportation, information technology, communication, and electronics	High
www.ite.org/tmdd	STDS, RESV	• Traffic management data dictionary • Message sets for external traffic management center communications	High
Xiao, 2004	COMP/COMH	• Distance related errors with 802.15.4 devices	Med
Zimmerman, 2001	COMP/STDS	• Discusses the specific roles of information and communications in the transportation sector • 7 case studies of specific information and communication ITS implementations • Primary focuses on ITS related I/C implementations	Low

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