

Intellimotion

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California PATH—Partners for Advanced Transit and Highways—is a collaboration between the California Department of Transportation (Caltrans), the University of California, other public and private academic institutions, and private industry.

PATH's mission: applying advanced technology to increase highway capacity and safety, and to reduce traffic congestion, air pollution and energy consumption.

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Implementing Vehicle Infrastructure Integration (VII): Real World Challenges

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California PATH



In recent years, much attention in the field of ITS has been devoted to conceptualizing and starting development of Vehicle-Infrastructure Integration (VII), which would provide new vehicles with the capability to communicate data with each other and with roadside transceivers located throughout the roadway network. The bulk of the Federal VII activities have been focused on defining an overall architecture and the wireless vehicle-infrastructure communication link, while exploring the institutional challenges to deployment. This article brings a somewhat different perspective to VII by focusing on the real-world challenges that have been encountered and overcome in implementing the first VII testbed environment in California. It is important to understand these practical aspects of installing, operating and maintaining the VII communications infrastructure when developing plans and cost estimates for large-scale national VII deployment. Lessons learned from the initial VII California testbed development and operations are provided in the hope that they can contribute to decisions about VII design and development.

Motivation and Introduction: Understanding, Testing And Deploying Vehicle-Infrastructure Integration

Since the initial thinking about Intelligent Transportation Systems (ITS), the vision of the

Intelligent Vehicle-Highway System has been founded on the notion that vehicles and the roadway infrastructure would function as a well-integrated road transportation system. The National ITS Architecture institutionalized this in a broad sense, showing how data could be exchanged among vehicles, local roadway infrastructure, information centers and travelers. More recently, the VII initiative has been defining a specific approach to providing localized communication between vehicles and the roadside with the high bandwidth, low latency, and high reliability needed to support safety applications.

The prospect of vehicles and the roadway infrastructure *connected* via wireless communications offers both opportunities and risks since a large-scale information system such as this has never before been attempted by the surface transportation community.

Vehicle-Infrastructure Integration (VII)

The VII system in the United States would be enabled by roadside wireless hotspots generated by Dedicated Short Range Communication (DSRC) transceivers operating within 75 MHz of free, FCC-licensed spectrum near 5.9 GHz. These transceivers will be incorporated in Road-Side Equipment (RSE), which will be connected by backhaul communications into a network architecture that addresses secu-

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urity, privacy and other design considerations. Applications, standards and architecture are under active development in order to create a roadside-based network delivering low-latency, highly reliable data communications to support safety and mobility services to users. The coverage would be extensive: the proposed VII system has the potential to cover all urban roads within 2-minute travel times and 70% of signalized intersections in 454 urban areas, while up to 15 new million vehicles per year would be DSRC- and therefore VII-equipped.

To assess the feasibility and desirability of VII, many technical, economic and institutional questions need to be answered. Considering the magnitude of the commitments that will be needed by a wide range of public and private sector organizations in order for VII to be deployed, these questions must be answered very convincingly before deployment can proceed.

VII California

Lessons for deployment might be learned from regional efforts, notably in Florida, Michigan and California and most certainly in the forthcoming US DOT VII Proof of Concept experiments. The effort in California, called VII California, provides the basis for this article. The VII California testbed was established to understand VII and how it can:

- Better manage the safety and productivity of the surface transportation system;
- Combine the resources, expertise, and innovations of the public sector, the auto industry, aftermarket suppliers, and other private sector participants for the benefit of the traveling public.
- Build upon California's considerable existing ITS infrastructure investments; and
- Create opportunities for innovation in the transportation system, exploring commercial uses of the system to fund its deployment and operation.

In order to accomplish these objectives, the VII California testbed is under development. As illustrated in Figure 1, it extends along approximately 60 miles of roadway (the El Camino Real SR-82 arterial and US-101 and I-280 freeways) on the San Francisco Peninsula starting just south of San Francisco International Airport and extending to Silicon Valley.

VII California Testbed Design

Elemental Building Block within Network: Roadside Equipment

The hardware experience accrued in developing the VII California testbed focuses on the RSE and its connection to the existing Caltrans roadside equipment and their function. The RSE is the basic infrastructure building block for VII. Each RSE serves as an in-the-field gateway between locally transmitted vehicle data and the roadside communications infrastructure. At top level, an RSE is a computer with a radio transceiver and an antenna. The computer must have sufficient processing and storage capability to run a gateway application between its two network interfaces, DSRC and backhaul (to the Traffic Management Center and other servers), and to run additional local safety processor software, with data filtering, buffering, aggregation, and formatting, as needed, and illustrated in Figure 2.

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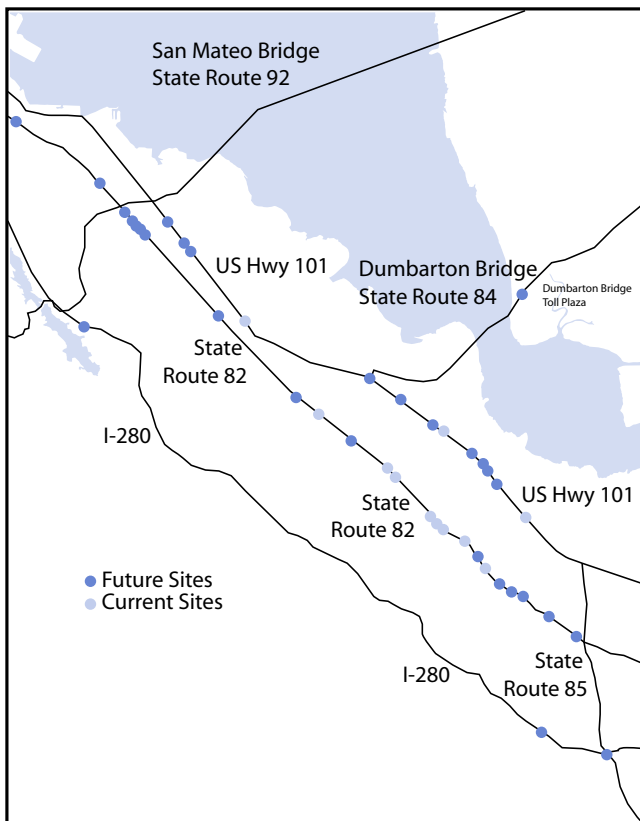


Figure 1 A map of the VII California testbed.

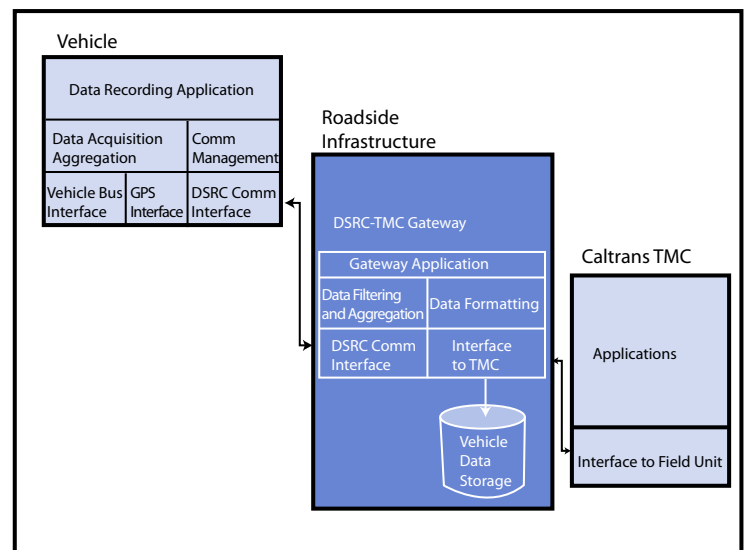
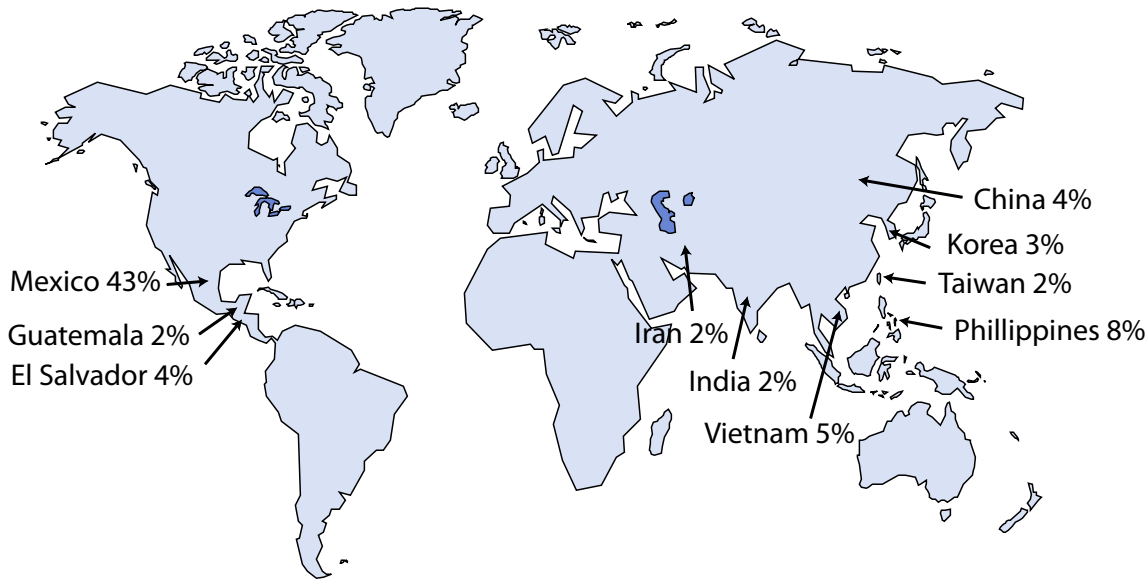


Figure 2 Roadside and Backhaul Communications Architecture, Allowing Data to Move Among the Vehicle, the Roadside Infrastructure and the VII California Network.

Travel Behavior of Immigrant Groups in California

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California's Top Ten Immigrant Groups



California is in the midst of a demographic transformation. According to the 2000 U.S. Census, nearly 30 percent of the California population is now foreign-born, and the state has no single ethnic or racial majority. Demographic forecasts suggest that these patterns will continue: California will continue to attract immigrants from throughout the world and will become increasingly diverse, racially and ethnically. This demographic transformation raises an important question for transportation planners in the state: How can we ensure that transportation systems and services adequately meet the needs of an increasingly diverse population? To answer this question, planners need a firm understanding of the travel behavior of immigrant groups and other selected demographic groups taking into consideration cross-cutting demographic characteristics.

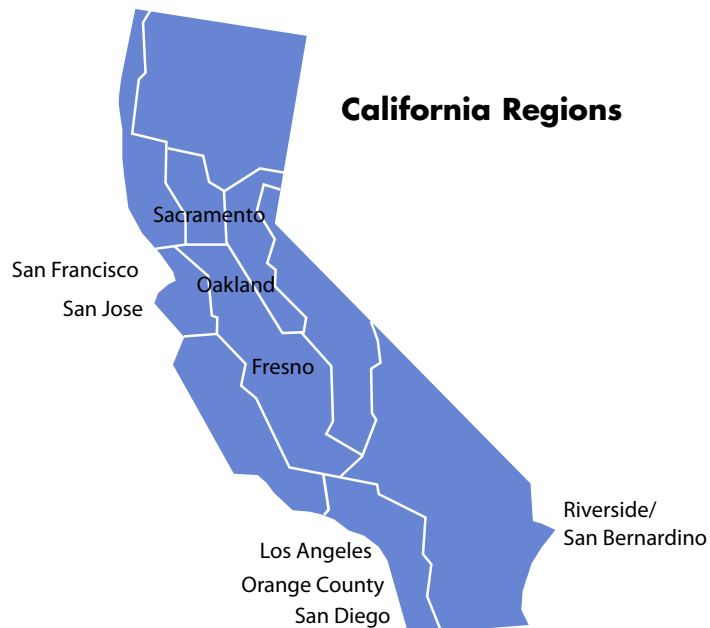
In this project, we explore the needs, constraints, attitudes, and preferences that influence travel choices and the outcomes of those travel choices for immigrants in California. Our research has three components: (1) an investigation of the commute travel of California immigrants using data

from the 1980, 1990, and 2000 Censuses; (2) an exploration of the transportation experiences and needs of Mexican immigrants using focus groups in six California regions; and (3) an inquiry to transportation needs and recommendations of Mexican immigrants, collected from interviews with community-based organizations in nine California regions. Study results are communicated in a CD-ROM that includes summaries of key findings, maps and data, and complete research reports (available at:

http://www.innovativemobility.org/diverse/Diverse_Populations.shtml).

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California Regions



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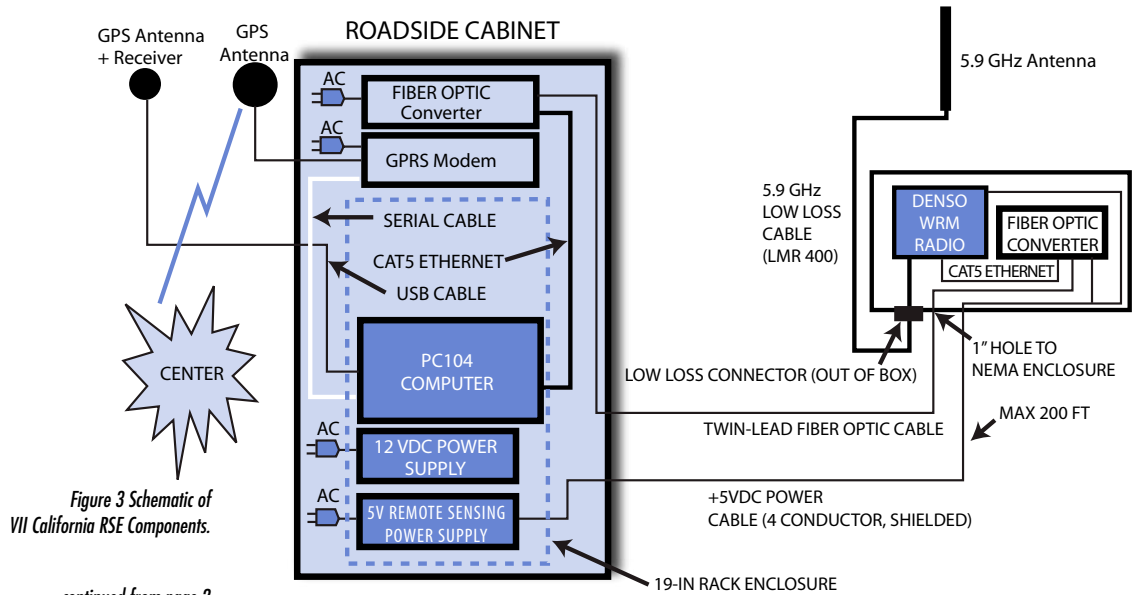


Figure 3 Schematic of VII California RSE Components.

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A schematic of the VII California connected RSE, residing within a traffic controller cabinet, is shown in Figure 3.

The hardware is split into two main clusters. One resides in the roadside cabinet and the second in a separate weatherproof enclosure. This design minimizes the length of the 5.9 GHz antenna cable to maximize signal strength. Some installations require a separation of up to 200 feet between the existing roadside cabinet and the location where the 5.9 GHz antenna needs to be in order to provide coverage of the approaching roadways. Figure 4 illustrates a typical RSE installation.

Network: Transport Layer

A major goal of the VII California testbed is to support an initial set of applications, including probe vehicles, public

information providers, and bidirectional non-public services (such as navigation and tolling). The testbed has been used as a development laboratory, with experiments and small-scale demonstrations of these applications conducted with public and vehicle manufacturer partners, starting with the 2005 ITS World Congress and continuing through the TRB ITS, Vehicle-Highway Automation and Traffic Signal Systems committee meetings in 2007. Use of this testbed has exposed a number of issues for future VII implementations and has motivated development of a message transport layer built on top of IP networking, a set of VII application servers, in-vehicle libraries, and administration tools. Certain aspects of a complete VII architecture are not fully addressed by this prototype software, including security, scalability, and conformance to emerging national VII standards.

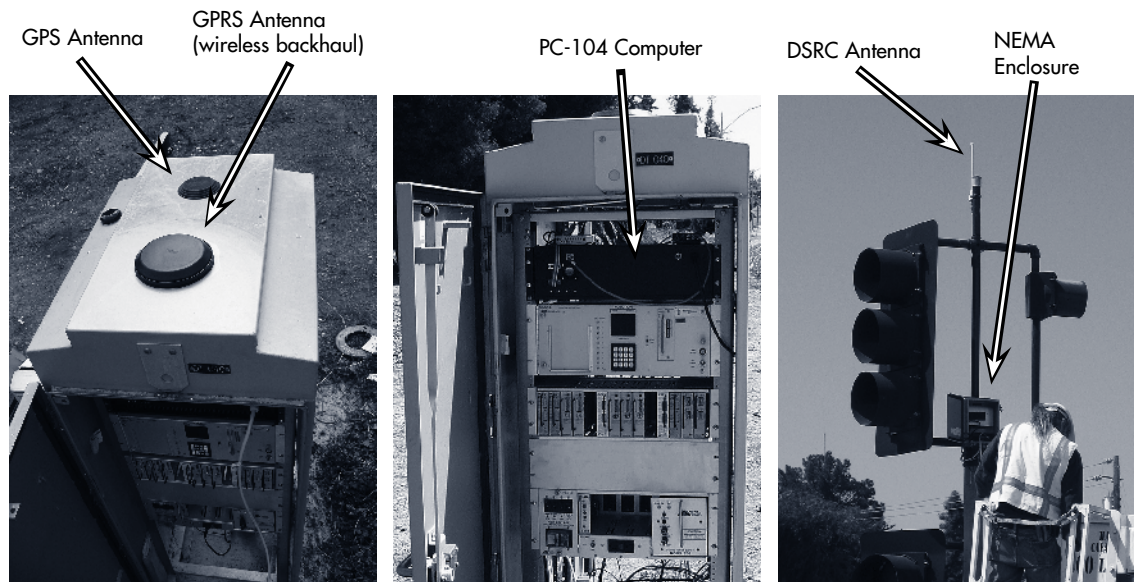


Figure 4 Left and Center: VII California RSE Mounted in Type 332 cabinet on Caltrans Right of Way; Right: DSRC Radio in NEMA Enclosure and Antenna Mounted on Ramp Meter Signal Pole at Freeway on-ramp.

Testbed – Installation, Operations, and Maintenance Issues

RSE Installation

Hardware Issues

The installation process consisted of surveying potential sites, pre-installation infrastructure work if needed, physical installation, and on-the-spot testing and troubleshooting upon completion of the installation.

Multiple survey trips were taken by engineers and researchers and the infrastructure owner and operator (Caltrans) to identify potential sites for RSE installations. This included examining:

- Line of sight issues and potential placements for DSRC antennae
- Placement of RSE
- Space availability in controller cabinet
- Investigation of backhaul
- Use of bucket trucks

In some cases, it was necessary to perform pre-installation infrastructure work on the chosen site. This work could include a variety of improvements to the existing infrastructure to prepare for the actual installation, such as erection of a pole, installation of pull boxes and conduits, or running cables through the existing conduits to make sure there is enough space within them.

At the conclusion of the physical installation, a complete test had to be performed to make sure the system was up and running. This was usually done via a laptop computer with DSRC radio that simulates an OBE by sending and receiving data from the RSE.

Installation Cost

Table 1 provides actual costs for a typical RSE installation using current-generation equipment along Caltrans right of way. The use of MCNU RSUs (the latest generation of DSRC radios) has been approved for installations that will be used during the Proof of Concept (POC) phase of the National VII program, but the purchase cost of the MCNU is not included in Table 1. The costs in Table 1 are associated with installations where the controller is the widely-used Type 170.

This shows a parts cost of ~\$4,600 per RSE installation, exclusive of the cost of the DSRC radio itself, plus an additional ~\$12,000 to ~\$13,500 in labor costs for these early installations. Each installation takes about a week of preparations and one full day to physically install and test an RSE by a crew of three to four maintenance workers and two engineering staff. In the long term, when RSE installations are done in large volume, the parts costs are unlikely to decline significantly since these are already relatively common parts rather than custom-built equipment (except, of course, for the DSRC radio). The labor costs could be expected to decline significantly, except for the unavoidable installation and testing labor.

Hardware Maintenance

After two years since the installation of the first RSE, the research team has gained valuable insights about maintaining RSEs in the real world. Lessons learned are described below.

Reliable and current information is essential to maintenance. To assist in rapidly acquiring and assimilating information about our testbed, we developed a set of software *continued on next page*

Table 1 Costs (\$) associated with VII California RSE installation

Item	Parts (\$)	Labor (person-hours)	Labor (cost/hour)	Labor cost (\$)
DSRC/WAVE Antenna	100			
DSRC/WAVE Antenna Mounts	50	12	50	600
DSRC/WAVE cable (~20 ft)	60			
Base Plate for MCNU and NEMA Box	200	28	50	1,400
GPS (unit plus antenna)	500			
GPS Mounts	75	12	50	600
Fiber Cable (up to 200 ft)	200			
Fiber Converter (4 per site if backhaul is wireless)	1,000			
Fiber Connectors (8 per site if backhaul is wireless)	120			
Power Supply and its Base and Circuit Breaker Switch	130			
Uninterrupted Power Supply	150			
Signal Sensing Circuit or Sniffer including processing and data transfer modules	2,000	80	50	4000
Software Configuration and Testing to match phase timing of each site		80	50	4000
Site Survey		2-4	80	160-320
Installation (maintenance staff)		25-50	30	750-1,500
Installation (engineering staff)		12-20	50	600-1,000
Total	4,585	251-268		12,110-13,420

Table 2 Backhaul Transmission Alternatives

	Bandwidth, kbps		Costs	
	Up	Down	Installation	Monthly Fee
Wireless				
EDGE/Aircard 860 or Raven	130	70-135	\$160 or \$475	\$50.99
HSDPA/Aircard 860 or Inmotion	80	400-700	\$160 or \$2,000	\$50.99
EVDO/Raven	80	400-700	\$1,065	\$61.00
HSDPA/Digi	90	1000	\$565	\$50.99
Landline				
DSL	128	384	\$221	\$40.00
DS1	1540	1540	\$1,842	\$232.20 + \$5 per mile from host
DS1 with DS3 backhaul	1540	1540	\$1,025	\$143.60 + \$5 per mile from DS3
DS3	43120	43120	\$1,390	\$2025 +\$35 per mile from host
ATM 3MG facility	3080	3080	\$900	\$945.00
T1	1540	1540	\$0	\$459.00

continued from page 5

components that run constantly on the RSE hosts and on a designated server. The RSE host components measure the status of the RSE and send reports to the server, which can help diagnose (and even predict) failures. The information includes:

- Temperature, fan speed, and voltage in the RSE hosts.
- Backhaul and DSRC network data rates – actual traffic and maximum capacity.
- Packet loss on network segments.
- Host computer status, such as CPU and disk usage.
- Status of devices connected to the host computer.
- VII application status and performance (number of messages, message queue lengths).
- Configuration settings of various components.

The specific maintenance issues that we have encountered so far include failure of fiber converters due to thermal issues, animal damage, local maintenance crew’s unfamiliarity with the RSEs and failures of the cellular modems.

Institutional Considerations

The cooperation of the owner agency, in our case Caltrans District 4 Maintenance, is essential to get any failed RSE back up and running in a reasonable time. The access to the right of way, controller cabinet and infrastructure is only possible if the owner agency’s representatives are present. Thus no repairs or regular maintenance can take place without their direct support.

Implications for the Future

Hardware

From what we have learned thus far, the design of the RSE must be compliant with all national and local standard specifications and requirements. It should take into account

the ease of installation and later on the ease of access to components for repairs and routine maintenance. If the owner/operator of the RSEs finds it troublesome to keep up with its repair and maintenance, and if the data obtained from the RSEs are not reliable and data flow is not continuous, then RSEs become a burden and lose their utility.

It is best that the system be designed in such a way that repairs and regular updates for software in particular can be done remotely or from a local wireless connection between a laptop computer and the RSE site in a way that also maintains security.

Backhaul Options

Since the installation of our first RSE, we have tried a variety of backhaul options, some using landlines like T1 and some using wireless. The availability and dependability of each backhaul option is a local issue. The fixed and monthly cost of service is a function of the bandwidth and the competition among the service providers. Another local issue is the pre and post installation level of service that one might get from the service provider. Table 2 shows telecommunication transmission costs and bandwidth for the backhaul alternatives considered by VII California.

Institutional Issues

Like any other new addition to existing systems, the inclusion and acceptance of RSEs as a standard traffic engineering device presents a series of challenges. The main challenge is to get the local agencies to buy into its usefulness in meeting their needs. Each infrastructure owner, whether it is state DOT, county or city can each possibly have different specifications and standards, presenting a challenge for future installations. A robust design that can satisfy the specifications and meet the standards of these diverse owners can be the answer.

Summary of Key Lessons Learned

The experience of implementing the first RSEs in the Bay Area has provided some important lessons that should be kept in mind when planning for the national VII deployment and estimating its costs:

- The large majority (almost 90%) of the candidate locations for VII testbed RSE installation were not already equipped with landline backhaul connectivity. Nationwide VII implementation is therefore likely to require significant investments in backhaul communications.
- The selection of backhaul technology for the RSE installations had to be made on a site-by-site basis, meaning a wide variety of backhaul technologies must be available.
- Over time, multiple versions of RSEs are likely to enter the market. It is imperative that they all work together transparently for the equipped vehicles.

Future Directions

The VII California testbed is expanding, with a network of DSRC roadside units (12 at this writing, with plans for up to 40), applications with on-board equipment (on light duty and transit vehicles), and a backhaul network (with heterogeneous backhaul links including T1 landline, 3G modem and soon coming online, WiMAX). Strategic outreach efforts are underway to bring onboard a variety of public and private entities that can benefit from and provide benefits to this project. Development and operation of this testbed has provided a wealth of technical and institutional knowledge in several domains: hardware and software on one hand, and installation, maintenance and operations on the other. Issues that have been encountered and resolved include: agency cooperation by different divisions that were not involved with the initial decision to conceive this project; and installation, maintenance and operation under practical operational constraints (standards of practice and codes, use of legacy systems on the roadside and to transport data via heterogeneous means to 'back office' operations). Significant network and architecture issues remain. The VII California implementation is admittedly experimental and designed to expedite applications development and experiments, but the questions asked and solutions implemented with regard to architecture and distribution of intelligence to the roadside are important to consider as part of the larger VII picture.

These lessons learned will be brought to more mature practice as the VII California testbed transitions from an experiment of VII applied to state and regional needs toward informing national-level decisions. This transition is institutional, as plans and equipment development are underway to develop portions of VII California into a "California test environment" to support the US DOT VII Proof of Concept (POC) experiments and to develop important applications such as bridge tolling. It also includes conducting tests at a test track at PATH's facilities at the Richmond Field Station, urban canyons in the City of San Francisco, and in some of the Bay Area's hilly terrain. These new additions will transform the VII California testbed to open it up to multiple applications over multi-band radios and making this effort more than just the POC. Through this transition, testbed plans will evolve into design standards, and we expect to see cross-fertilization between what has been practical and already implemented in the field and the approach being conceived by the US DOT VII program. Throughout this experience, the lessons learned by the VII California program about implementing an operational testbed should be carefully considered in VII and in any widespread deployment of networked technology in transportation. ❁

Note: This article was written based on a paper and presentation at the 87th annual meeting of Transportation Research Board, January 2008.

Site Readied for Automated Bus Rapid Transit (ABRT) Project





PATH on Paper

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Key Findings on Immigrant Travel

Travel and Commute Mode Trends

Most immigrants in California, like most non-immigrants, travel by car. However, a disproportionate share of immigrants, particularly those new to the U.S. – rely on public transit. This trend, coupled with high rates of immigration, has fueled a 19 percent increase in the number of transit commuters in the state since 1980. Without immigrants, the number of transit commuters in California would be at least half of what it is today.

However, the increase in transit commuters has not kept pace with the growth in the California population. Similarly, the increase in immigrant transit commuters, while significant, has not kept pace with the growth in the foreign-born population. Consequently, immigrants are less reliant on public transit than they were in previous decades – 11 percent in 1980 compared to 8 percent in 2000. The decline in transit use among immigrants can be explained by two trends: (1) the rapid assimilation to auto use with years in the U.S. and (2) the decline in transit use among recent immigrants to California.

Despite these trends, transit commuters are disproportionately immigrants. Forty-seven percent of all transit commuters in the state are foreign born.

Autos

The car is the most important means of transportation for immigrants; nearly two-thirds of all immigrants use single occupancy vehicles as their primary commute mode. Car usage varies by country of origin. Some immigrant groups—immigrants from Iran (94%), Korea (94%), Vietnam (93%), and Taiwan (93%)—travel by car in rates higher than U.S.-born commuters (91%). Other immigrant groups—particularly immigrants from Latin America—are less reliant on cars. For example, only 75 percent of Guatemalans and 83 percent of Mexican immigrants rely on cars.

Overall, newly arrived immigrants are more highly transit dependent than U.S.-born commuters. However, they assimilate to autos quickly once in the U.S., and much of this assimilation occurs after the first five years in the U.S. The rate at which immigrants assimilate to auto use varies by race and ethnicity. Hispanic immigrants most quickly assimilate to auto use; however, their rates of transit use are so much higher than for other racial and ethnic groups that they remain more likely to use transit than U.S.-born white commuters even after 20 years in the U.S. In contrast, after five years in the U.S., Asian immigrants are about as likely to commute by transit as U.S.-born white commuters.

Findings from exploratory research on Mexican-immigrant travel help to elucidate the trend in auto assimilation. For this group, the car is an important and necessary mode of transportation – auto access means more freedom, more job opportunities, and a better quality of life; for some it is a symbol of greater social status. Cars are also essential for commutes to work in industries that involve variable work sites (e.g., construction), the need to carry equipment (e.g., landscaping), and early or late shifts (e.g., service work). Having children also adds to the need for a car.

Auto access is not a simple yes/no situation. Those living in households without a car often get rides from others or borrow cars, and few are truly transit dependent. Conversely, living with someone who has a car does not guarantee access to that car. Mexican immigrants who know how to drive sometimes borrow cars, but they often feel uncomfortable asking and worry about getting into accidents, having the car confiscated if pulled over, or having a breakdown.

Mexican immigrants with limited car access find it difficult to get to healthcare facilities, out-of-town destinations, recreational places, and any destinations at off-peak times; they spend more time commuting, and their employment and educational opportunities are more limited. Limited

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	Number of Commuters	Commute Method				
		Commuters %	SOV %	Carpool %	Transit%	Walk %
Mexico	1,736,334	41.2	54.1	29.1	9.3	4.2
Philippines	373,315	8.9	69.5	19.7	7.3	2.2
Vietnam	221,371	5.3	75.7	17.8	3.7	1.8
El Salvador	178,744	4.2	57.0	21.6	16.2	3.2
China	151,371	3.6	63.8	16.2	13.3	4.8
Korea	133,481	3.2	74.8	18.8	3.1	2.4
Guatemala	99,758	2.4	53.5	21.0	19.2	4.2
India	113,824	2.7	74.8	15.3	5.7	2.7
Iran	82,131	2.0	83.3	10.8	3.3	1.9
Taiwan	81,372	1.9	79.5	13.7	3.8	2.1

car access may affect women and children, in particular, who have to find alternative modes of travel when their husbands take the car to work.

Barriers to auto access include the costs of buying and maintaining a car, inability to get a driver's license, risk of vehicle confiscation, inability to get insurance, and having no way to learn how to drive.

Public Transit

Transit plays a critical transitional service for immigrants, especially their first five years of living in the U.S. Moreover, although recent immigrants rapidly transition to auto commuting, many—particularly Hispanic immigrants—remain reliant on transit many years after immigrating to the U.S. Consequently immigrants transit-commute at rates twice that of U.S.-born commuters – 8 percent compared to 4 percent. Transit usage varies by country of origin.

Given these figures, it is not surprising that a disproportionate percentage (47%) of transit commuters are immigrants. And in some metropolitan areas this figure is much higher. For example, in Orange and Los Angeles, immigrants comprise two-thirds of all transit commuters.

The focus group and interview findings on Mexican immigrant travel suggest that transit plays an important role for meeting transportation needs for daily activities in addition to commuting to work. They appreciate many qualities of transit, including the low cost compared to driving and comfort in comparison to walking.

The research with regards to Mexican immigrant travel also indicates that the disadvantages to transit include the transit fare costs of traveling with children, difficulty traveling with packages, lack of safe and comfortable shelters, lack of safety on buses, long waits, and limited schedules and routes. Unreliability and limited service hours are of particular concern for immigrants using transit to get to work. Women in particular are concerned with safety at stations, treatment by bus drivers and passengers, and inability to communicate in English.

Commute by Metropolitan Area				
	Single Occupant	Carpool	Transit	Other
San Francisco	53%	17%	23%	8%
Fresno	61%	31%	2%	6%
Oakland	63%	20%	11%	6%
Los Angeles	63%	20%	11%	6%
Riverside/SB	66%	27%	2%	5%
Orange	67%	22%	6%	5%
San Diego	69%	21%	6%	5%
Sacramento	73%	20%	3%	5%
San Jose	75%	16%	5%	4%
California	65%	22%	8%	6%

Commute by Carpool

	US Born	Foreign Born
White	10.6%	11.0%
Black	15.3%	13.7%
Asian	12.3%	17.1%
Hispanic	17%	26%
Other	14.8%	15%

Carpooling

Carpooling is an important commute mode for immigrants in California – nearly twice as many immigrants (22%) as U.S.-born persons (12%) rely on carpooling as their primary commute mode. Carpooling also varies by country of origin. Among the top ten immigrant groups in California, Mexican immigrants use carpooling the most (29%) and Iranian immigrants rely on it the least (11%).

The rates of carpooling among immigrants decline with years in the U.S.; but after 20+ years in the U.S., Hispanic and Asian immigrants carpool at rates higher than for U.S.-born whites. Carpooling rates among Mexican immigrants vary across metropolitan areas and are highest—at least in the first 5 years—in Fresno and Orange Counties—both metropolitan areas with limited public transit networks.

Findings from exploratory research on Mexican-immigrant use of carpools reveal that carpooling is often preferable to taking public transit for commuting to work for reasons of reliability and speed, as well as comfort. In addition to work, carpools are organized for traveling to large supermarkets, flea markets, churches, and other destinations. However, depending on others for rides may be problematic with respect to discomfort in asking for a ride, a sense of indebtedness to others, unreliability of the driver, and the risk of a breakdown or being pulled over while on a trip made on the passenger's behalf.

Walking/Biking

While few immigrants report walking as their primary commute mode – 3.5% of immigrants versus 2.8% of U.S.-born persons – walking is still an important alternative means of travel, particularly for non-work travel.

The focus group and interview findings indicate that walking is an important mode for Mexican immigrants, especially those with limited access to cars, and is used to get children to school, go to the park, and do limited shopping. For this group, walking is seen both as a way to save money and a way to get exercise, but it only works when destinations are close. A lack of safe sidewalks, speeding in residential areas, and a lack of safe signal crossings are deterrents.

Some Mexican immigrants rely on biking to save costs or when transit service is not available, but barriers to bike travel include lack of bike lanes, difficult road conditions, and hot weather.

Land Use

Many immigrants enter the U.S. through central-city neighborhoods that serve as ports of entry for new immigrants. We calculated the distribution of the U.S.- and foreign-born populations by density quintiles across Public Use Microdata Areas (PUMAs), geographic units developed by the U.S. Census. See <http://www.census.gov/geo/www/tiger/glossry2.pdf> page A19 for a description of PUMAs

We find that only 13 percent of the U.S.-born population lives in the densest neighborhoods compared to almost 30 percent of immigrants. These dense urban areas also tend to be neighborhoods with extensive transit networks and service. However, with time in the U.S., immigrants are more likely to live outside of the central city in neighborhoods where transit service is more limited.

Immigrants are more likely to choose alternative modes of travel than U.S.-born commuters regardless of metropolitan area. But the rates at which they rely on alternative modes of travel—and substitute one mode for another—vary by metropolitan structure. There tends to be less variation in transit commuting between immigrants and U.S.-born commuters in dense metropolitan areas, where transit use can more easily substitute for driving than in more spatially dispersed areas where using transit is far less convenient. In Los Angeles, even Mexican immigrants with cars made regular use of transit; in San Jose and Fresno they did not.

For Mexican immigrants, land use plays an important role by determining the distances from home to destinations, including work and others, as well as the quality of travel by alternative modes. Long distances are often cited as a reason for needing a car or getting a ride. For nearby destinations, the quality of the built environment influences the safety and comfort of walking. For immigrants without car access, having destinations within walking distance adds to their quality of life.

Issues and Strategies

Our findings point to two general strategies for improving the degree to which the needs of California's immigrants, particularly those from Mexican, are met. The first strategy is to make car travel more attainable, the other is to enhance the quality of transit service.

- Make car travel more attainable. In most neighborhoods cars are the preferred mode of travel as they allow convenient access to numerous destinations. Yet many immigrants arrive in California having had little driving experience or without the ability to obtain a driver's license. Particularly in neighborhoods outside of the central city, automobiles provide immigrants with better access to jobs and services and should be promoted.
- Enhance the quality of transit service. Public transit is a critical service in helping new immigrants transi-

tion to life in the U.S.; many immigrants enter the U.S. through ports of entry located in the central city where public transit works best. In these neighborhoods that transit agencies may see the need for additional service. In less densely population areas, transit service is still important to immigrants whose access to cars is limited.

These strategies are not necessarily incompatible, and indeed efforts in both areas would only improve conditions for immigrants. However, if lean budgets should limit these efforts, then there are reasons to give priority to transit service. Transit commuters are disproportionately immigrants; without them, the number of transit commuters in California would be at least half of what it is today. But transit agencies may be likely to face a decline in transit ridership in the future due to (a) the projected slowing of immigration to California combined with (b) the assimilation of current immigrants to auto use. Declines in ridership make it hard to maintain quality of service, let alone improve it. But improving transit service is important not just from the standpoint of meeting the needs of immigrants. The combination of rising gas prices and new environmental policies (such as the California Global Warming Solutions Act) magnify the importance of providing alternatives to driving for all residents of California.

These alternatives should include walking and bicycling as well, both important modes for immigrants and often used in conjunction with transit. All of these modes need supportive land use patterns to be viable. Many communities in California have adopted policies that help to change land use patterns in ways that are more supportive of transit, walking, and bicycling. Examples include smart growth policies and transit-oriented development programs. These efforts, though directed at much broader societal and environmental concerns, may help to address the mobility needs of immigrants as well. In addition, communities might consider land use strategies targeted specifically to immigrants. ☼

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