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Advanced technologies in public transportation
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I.   Introduction

New information, telecommunications and electronics technologies provide valuable tools to public transit agencies working to improve service quality and safety, reduce costs and increase ridership. In the 1990s, transit agencies began taking advantage of the many opportunities available, enthusiastically embracing some new technologies and moving cautiously forward with others. Smart cards, the Internet, geographic information systems, global-positioning systems, wireless communications, and other advanced technologies – all important components of "intelligent transportation systems" (or ITS) – have begun changing the ways transit agencies do business and transit users get around.

The adoption of new technologies allows transit agencies to respond to the demographic and economic changes that have favored automobile transportation over mass transit in the recent decades. That advantage has contributed to a drop in transit use by 1995 to just 2.2% of all urban passenger trips, down from 5% in 1969. Private autos' share of urban passenger trips, on the other hand, rose to 88% from 78% during the same period. (Pucher, Evans et al. 1998)

The most significant change has been the rising affluence of American society that has led to higher auto ownership and, thus, more frequent use of private cars for work, personal business, social and other types of trips. Ownership is a critical factor in the U.S. because the fixed costs of private auto use (e.g. purchase price, insurance, and registration) make up over 75% of the total costs of using a car (Litman 2000). Therefore, once an individual owns a car, he or she has had strong incentives to use it over other forms of transportation.

Other demographic and economic changes in American society have also contributed to the declining share of transit in total trips. There are more women in the workforce today than in past decades and they are making more daily trips, often with multiple destinations and purposes that make trip-chaining via a car simpler and faster. What is more, today's elderly are driving more and longer than past cohorts of senior citizens did; they established driving habits in their youth, whereas their elders did not. Finally, residences and jobs have both suburbanized, spreading out at lower densities, making efficient transit service difficult to provide.

The automobile's success, however, has led to increasing traffic congestion, longer commutes and negative environmental impact in American metropolitan regions, creating conditions that could lead commuters and other travelers to reconsider transit. By capitalizing on assets unique to public transit (e.g. fixed guideways, bus-only freeway lanes, large potential economies of scale), transit agencies are working to provide service that is more reliable, more convenient and more affordable. In short, transit agencies are striving to compete more effectively with cars and other modes of transportation.

Their efforts are proving to be successful, at least in part. Transit ridership nationwide has grown at a faster rate than population growth since 1993, finally reversing a long-lived counter-trend. (U.S. Department of Transportation 2000) California's 200+ transit operators alone provide over 1 billion passenger trips a year. [California State Controller Office, 1998 #170] And transit service continues to be critically important to low-income populations, particularly those households that own no cars at all, and to Hispanics and blacks, who respectively use transit 4 and 5 times as much as whites. (Pucher, Evans et al. 1998) This last point has become particularly important as public assistance reforms have reduced welfare rolls and increased the ranks of low-income job-seekers and workers.

Transit service competitiveness need not depend solely on new technologies – several strategies could be used to improve service and reduce costs. Public policy changes to curb motorists' auto use could make private cars less attractive and transit more so. Higher gasoline taxes and motor vehicle registration fees, charging more for parking, subsidizing transit passes for people who choose not to drive, and establishing transit-only lanes on highways and arterials are methods used in many countries to do just this. Most such policies, however, provoke strong opposition in the U.S. and, where they have been implemented, have not been very effective at reducing car use and increasing transit ridership.

Rather, in the U.S. decision makers have relied more often on technological changes to achieve transportation policy goals (see Howitt and Altshuler 1999 for a detailed discussion). Air quality, for example, has improved in the U.S. for most of the major Clean Air Act Amendment criteria pollutants through technological advances, despite vastly higher levels of driving. Accordingly, public transit providers are increasingly willing to explore the potential that advanced technologies have opened up for achieving goals for greater efficiency and effectiveness.

To help define what the available technologies are and the intended benefits they should provide, the Federal Transit Agency created an Advanced Public Transportation Systems Stakeholders Forum in 1998, consisting of transit agencies, technology developers, manufacturers and consultants. The organization has documented eight principle categories of technologies: fleet management, electronic fare payment, traveler information, transit safety and security, transportation demand management, intelligent vehicle components, bus rapid transit, and communications-based train control. See the graphic on the following page for the complete list of technologies covered by the stakeholders forum and the Web site at http://web.mitretek.org/its/aptsmatrix.nsf for more information.

This report cannot cover each and every technology application available for use by public transit agencies. Instead, it assesses four representative technology applications that transit providers have adopted in recent decades. Some, like traffic signal priority systems have been in use for thirty years or more. Others, like dynamic rideshare matching, are still new and have not been widely implemented. The four technology applications assessed are:

- Traffic signal priority systems
- Transit operations and management systems
- Advanced traveler information systems
- Dynamic rideshare matching
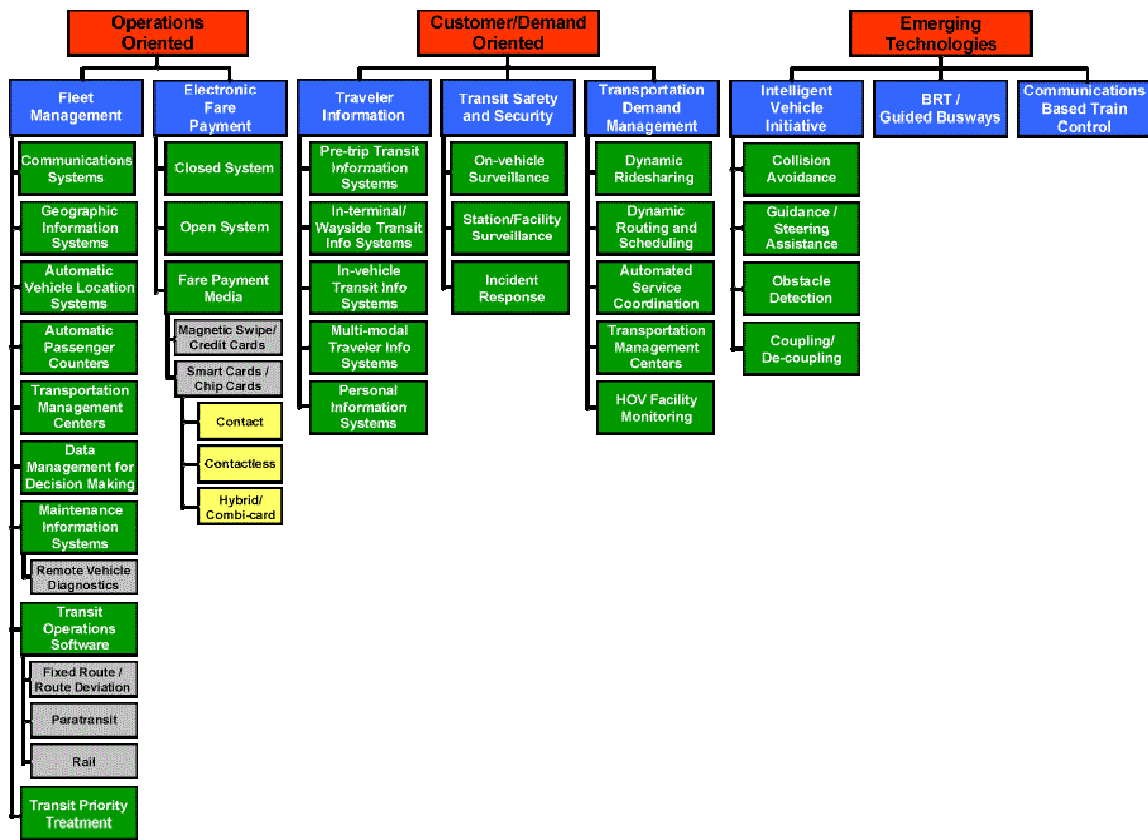
List of Intelligent Transportation Systems technologies for transit by the Federal Transit Administration's Advanced Public Transportation Systems (APTS) Stakeholders Forum (source: http://web.mitretek.org/its/aptsmatrix.nsf)

These four were chosen to cover a variety of technological applications and types of public transit. The first two – traffic signal priority systems and transit operations and management systems – relate to traditional transit systems and are relatively well developed and widely adopted technologies. Advanced traveler information systems are becoming common too and are geared toward all travelers, not just bus and rail users. The last technology – dynamic rideshare matching – is newer, more experimental and, to date, less effective at meeting large numbers of transit users' needs. But it points to applications and a form of transportation that may grow in importance in the near- and medium-term future. A final technology that is effective in improving transit service and lowering costs – electronic fare payment – is not covered in this report because it is covered in detail in another report in this series.

II. **Traffic signal priority systems**

Description of the technology

   Transit buses are, by nature of the service they provide, slow at proceeding down a street. Because of their size, they accelerate and decelerate more slowly than private automobiles. They must stop frequently in curb lanes to pick up and drop off passengers. Their dwell time can be lengthy, depending upon the number of passengers getting off and on, the method of fare payment, and whether the driver is called upon to answer questions. When boardings are completed, transit buses may have difficulty reentering moving traffic, further impeding their progress.

   For all these reasons, transit buses are at significant disadvantage to private cars, particularly on arterial streets equipped with timed traffic signals. One method of giving transit buses a slight edge is to allow them some control over the timing of traffic lights through "traffic signal priority systems." Such systems permit communication with signal controllers that recognize the approach of transit buses and extend green lights or shorten them on cross-streets so that transit buses spend less time waiting at red lights. In some cases, these systems allow buses to proceed down a street 20-25% faster than they could otherwise.

   Engineers, researchers and transit operators have worked on traffic signal priority systems for transit since the 1960s. The first full implementation of such systems occurred in the 1970s, but with only limited success. With the rapid development of computer and telecommunications technologies in the 1980s and 1990s, traffic signal priority systems have become more sophisticated, more effective and more widespread. They are no installed in cities throughout North America and Europe and, to a lesser extent, in other parts of the world.

How it works

   Traffic signals can give priority to transit buses passively or actively. Passive priority is granted via traffic signal coordination and improved signal timing for all arterial traffic to favor transit buses. Such modifications of traffic signal timing is based on the expected intensity of bus traffic deduced from historical measurements of traffic flow and can be accomplished with adjustments of traffic signal cycle timing and area-wide timing plans. Street design – such as turning prohibitions and bus-only traffic lanes – can also help in passively granting transit vehicles priority. These options have the benefit of being relatively low cost and easily implementable, but can sometimes be of limited effectiveness, particularly where traffic volumes are very high.

   Active traffic signal priority is granted by remote detection of buses or by bus driver actuated signals. Active priority technology has existed since the early 1970s with the development of 3M's Opticom System, which uses strobe light pulses triggered by a vehicle driver that are recognized by a receiver on the traffic light. About the same time, the Philips Corporation developed the Vetag system, which uses magnetic detector loops in the pavement, activated by programmable transponders on transit vehicles.

   In the late 1980s, Philips improved the technology by redesigning the on-board equipment to receive as well as send messages, renaming their system Vecom. Two-way communication is important because a traffic signal priority system does not always give priority to transit buses, depending upon whether it is designed to grant full or conditional priority upon receipt of a request. In systems programmed to give conditional priority, the

preferred method in the United States, computer software algorithms take into account the actual phase of a traffic signal, historic traffic volumes, coordination with other traffic signals in the network and a bus's actual location to determine whether or not to extend or speed up a green light. Priority can also be denied if a transit bus is ahead of its schedule or is travelling with few or no passengers.

If priority is granted to a transit bus and a traffic signal's normal timing phases are disrupted, subsequent cycles can be adjusted. Usually, within three or four signal cycles a traffic light can return to its normal phasing within the overall traffic network.

Additional technologies that are incorporated into bus signal priority and preemption systems are automatic vehicle classification techniques that use inductive loops or electronic axle sensors and automatic vehicle identification technologies that enable vehicles to be uniquely identified through a communication link between an on-board transponder and a roadside reader unit. License plate scanners have also been proposed as technology capable of regulating transit vehicle priority at traffic signals, but performance has not been accurate enough yet to permit their use in the field. Infrared beams or digital radio communication are other potential technologies that could be used. Finally, GPS (global positioning systems) and DGPS (differential GPS, a more precise technology) are now being used to determine vehicle positions and speeds for the purpose of activating traffic signal priority, where appropriate.

It is important to recognize the difference between traffic signal priority and preemption (or "full" priority, as mentioned above). Preemption systems give vehicles equipped with the appropriate communication device complete control over a traffic signal, changing it to green regardless of the signal's actual phase, traffic volumes or time of day. In most cases, only emergency response vehicles – police, ambulances, and fire-fighting – have preemption capability. If emergency and transit vehicles using traffic signal priority / preemption systems arrive at an intersection at the same time, emergency vehicles are given absolute priority.

Intended benefits

In the short-run, a transit system can improve the reliability of its service through the use of a traffic signal priority system. Individual buses can adhere more strictly to their schedules, maintain proper headways between vehicles to avoid bunching, and provide passengers with greater confidence in the timing of arrivals, departures and transfers. Vehicle emissions can be reduced, as the time spent decelerating, idling and accelerating can be shortened significantly. In addition, safety can be improved as transit vehicles can be assured of full green lights as they pass through an intersection.

In the long-run, traffic signal priority systems could speed up bus service as schedules could be revised to take into account potential or actual time savings. Both of these improvements could help transit providers compete more effectively with private auto use by providing higher quality service to passengers. If the service improvements are evident to people using other forms of transportation, there could possibly be increases in transit ridership and accompanying decreases in traffic congestion.

Applications to date – examples

Traffic signal priority systems have been installed and are operational in hundreds of cities throughout North America and Europe. Actual systems vary, as several different

technologies and vendors are in competition, as do configurations and conditions of priority service. See Jellison 1998 for a discussion of the Vicenza, Italy traffic signal priority system, Furth and Muller 2000 for an example from the Netherlands and Gifford, et al 2001 for a case study of signal priority systems in the Washington D.C. metropolitan region. Each of these reports provides detailed information about the technologies used and the observed benefits and costs of the systems.

In California, four transit traffic signal priority systems were operational in 1998: two for light rail systems in the Los Angeles and San Jose metropolitan areas and two for fixed-route buses in Napa and Santa Rosa. At the same time an additional 15 transit agencies in places like San Francisco and Sacramento, Redding and Visalia were in the planning stages for traffic signal priority systems (see Casey 1999).

Barriers to implementation

Despite the growing number of traffic signal priority systems in operation throughout the world, several significant barriers prevent or delay their adoption in other cities. First is the financial burden of purchasing and maintaining the systems. While costs for buying and maintaining them have come down and the hardware has become more durable, they still represent a major investment for a municipality. The TEA-21 funding mechanisms contain several programs, such as the Congestion Mitigation / Air Quality program, that could be used in some cases, but competition for those funds is strong (TEA-21 is the Transportation Efficiency Act for the 21st Century, the federal transportation funding legislation for 1997-2003).

Technologically, there are sometimes conflicts between traffic signal timing systems and traffic signal priority systems, particularly on high-volume arterials where transit priority holds greatest potential to provide benefits to transit operations and users (Skabardonis 2000). New intelligent bus priority software algorithms are being developed to minimize the conflicts, but results so far have been mixed (see Balke, Dudek et al. 2000).

In addition, inter-jurisdiction coordination can complicate implementation of a traffic signal priority project where a targeted arterial crosses through two or more municipalities. Metropolitan Planning Organizations can help facilitate collaboration, but the barriers can sometimes be significant (see Gifford, Pelletiere et al. 2001 for a more detailed discussion of such barriers).

What is more, coordination within a single municipality can sometimes be complicated because public works officials, police, firefighters, planners, transit operators, mayors and city council members should all be involved in the process. Each of these stakeholders may have different priorities for a traffic signal priority system. Police and firefighters are usually in favor, as long as emergency vehicles are guaranteed absolute priority. Elected officials may favor or oppose such systems, depending upon their expectations of impacts on transit, motorists and non-motorized traffic. Normally, traffic signal priority systems working on a conditional basis can be programmed to have minimal impact on motorists. But where congestion is high, this is not always the case.

References
(Balke, Dudek et al. 2000)
(Furth and Muller 2000)

(Gifford, Pelletiere et al. 2001)
(Jellison 1998)
(Skabardonis 1994)
(Skabardonis 2000)
(Taylor and Al-Sahili 1995)

III. **Transit operations and management systems**

[To be added later]

<u>Description of the technology</u>

<u>How it works</u>

<u>Intended benefits</u>

<u>Applications to date – examples</u>

<u>Barriers to implementation</u>

<u>References</u>

IV.   **Advanced traveler information systems**

Description of the technology

        Uncertainty is a major difficulty that transit providers must deal with in attracting and keeping riders. Often, would-be riders have insufficient information about the transit options available to them or have insufficient confidence that transit providers will adhere to scheduled service (whether for reasons within or beyond their control). Current riders also frequently lack confidence that service will be reliable and may compensate for this, if they have no better options, by imposing higher costs on themselves (by arriving at transit stations earlier than should be necessary, for example).

        Providing more accurate, complete, and up-to-date information to current riders and future riders is, therefore, an important objective for transit providers and has been for decades. Printed schedules and telephone information services are two simple ways that have long been used by transit providers. Though advanced technologies are now improving the effectiveness and efficiency of these tools, they have not been indispensable in providing basic schedule and routing information. Nevertheless, transit agencies are learning that the latest in telecommunication, computer and electronic technologies – coupled with increasingly complicated inter-agency collaboration and coordination – can help them provide travelers with detailed, reliable, high-quality, real-time travel information that significantly improves on traditional transit information systems.

How it works

        Advanced traveler information systems can provide information to meet a wide variety of needs. They inform travelers both prior to and during a trip and whether they already know they want to take public transit or are still comparing the personal costs and benefits of one transportation mode over another (for example, private auto vs. bus vs. taxi). The media that advanced traveler information systems utilize, moreover, are diverse: printed brochures and leaflets, telephone, Internet, e-mail, pager, and electronic displays and automated announcements in transit stations, public locations like shopping malls, office building lobbies and park-and-ride lots, and in transit vehicles.

        The components of an advanced traveler information system can also vary quite a bit, depending upon a transit agency's goals and resources. The most sophisticated systems use automated vehicle location technologies that permit transit managers to pinpoint the location of every vehicle in their system in real time. Global positioning system (GPS) units installed in buses and trains,[1] for example, can provide location, direction and speed information through wireless telecommunications to central data processors that calculate how closely vehicles are following scheduled routes. Vehicle locations can then be displayed using GIS (geographic information systems) software that automatically codes vehicle symbols according to how closely they are following their schedules. Such real-time data also directly feed into information systems that display time and location information to riders on transit vehicles or customers consulting telephone, in-station or Internet transit information databases. Finally, this real-time

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[1] See Casey 2000 for more details on the role of such "automatic vehicle location systems."

information processing also permits managers to control a vehicle fleet's operations more effectively.

Similar systems can be developed using less sophisticated technology that do not rely on GPS units. For example, voice communication between a central dispatching unit and bus and train operators (using cellular telephone or older radio communications equipment) can be used to regularly update the information provided to transit passengers through telephone operators, public displays and announcements and the Internet. The drawback to such systems is that location, direction and schedule adherence information needs to be input to a computer system by a dispatcher, rather than automatically through GPS units, introducing delays and possible errors into the information system.

Whatever the system of data collection, data-processing technology is being used by some transit agencies to provide information in ways that meet the personal preferences of their customers. Many Internet traveler information systems allow users to specify how far they're willing to walk to a transit stop and whether they would like to optimize a trip for speed, lowest fare or fewest transfers. Some transit agencies are now expanding the services their information systems offer by selling transit passes or providing links to train and airline ticketing agencies. Further improving the versatility of traveler information systems is the more and more frequent coordination between transit agencies with adjacent or overlapping service areas (such as AC Transit, San Francisco Muni and BART in the San Francisco Bay Area) and between transit agencies and other transportation services and modes, such as rideshare programs, taxi and limousine companies, highway traffic monitors and even bicycle and pedestrian programs.

Intended benefits

The primary objective of advanced traveler information systems is to increase transit use by reducing the stress inherent in making transportation choices (and, when having chosen public transit, making transfers). Advocates of advanced traveler information systems argue that they confer multiple advantages that support this overall goal. An effective traveler information system can reduce riders' waiting time by allowing them to arrive at a stop immediately before a vehicle arrives. Where multiple transit routes are available, they are meant to help riders make better choices through more complete and timely details. Backers argue that safety and security are enhanced as well because of reduced wait times at transit stops and the immediate communication link that exists between vehicle operators and central dispatchers. Advocates of the technology also predict that in the medium- and long-term, fewer telephone center operators will be required, reducing personnel costs, and that customer complaints will decrease substantially.

Ultimately, if advanced traveler information systems successfully make transit users more confident in transit services, proponents believe ridership and farebox revenue will increase, overall fuel consumption and single-occupancy vehicle traffic will decrease and, consequently, positive environmental benefits will be realized. It seems reasonable to expect that more accessible, accurate and timely information will improve rider confidence in transit services and make operation and management of transit systems

more effective, perhaps eventually leading to the results that backers predict. Still, the actual levels of impact have not been clearly documented yet.[2]

<u>Applications to date – examples</u>

Fifteen California transit agencies had operational automated transit information systems in 1998 and another 13 agencies were actively planning such systems (see (Casey 1999)). The Los Angeles County Metropolitan Transportation Authority (or MTA, for short), for example, had in-vehicle, in-terminal and pre-trip information systems available for both its fixed-route buses and its light and heavy rail transit systems. Since 1998, many more transit agencies have not only developed their own traveler information systems but have coordinated their systems with other transit providers and transportation agencies to provide comprehensive regional traveler information systems. See, for example, the following Internet Web sites:

- San Francisco Muni, AC Transit, BART and other San Francisco Bay Area transit and transportation agencies coordinate travel information via an online trip planner at http://www.transitinfo.org/cgi-bin/taketransit;
- Los Angeles Metro Rail's Internet Web site includes an automated "Metro Trip Planner" at http://mtaweb5.mta.net/; and
- San Diego Transit agencies have developed an online trip planner at http://www.sdcommute.com.

Outside of California, transit agencies are also developing advanced traveler information systems. See, for example, the English and Spanish language online trip planners for Portland, Oregon's 3-county transit agency, Tri-Met (http://www.tri-met.org). Tri-Met is also providing real time transit information via the Internet, in 50 rail stations, and at 250 bus stops and automating its in-vehicle stop announcements. King County Metro Transit, in the Seattle, Washington metropolitan region, has not yet completed development of its online trip planner (see http://transit.metrokc.gov/bus/trip-planning.html). It has, however, coordinated the information obtained from automatic vehicle location technology in its buses with an online "Busview" software program. This program displays an online map of the locations of Metro buses currently in service and allows users to set online alarms to alert them when a bus they wish to take is approaching their stop (see http://transit.metrokc.gov/bus/busview.html).

<u>Barriers to implementation</u>

Several important barriers to advanced traveler information systems can delay or prevent transit agencies from using them. Technological problems are no longer a significant difficulty – GPS units, the required computer hardware and software, and communication equipment are all well-tested and well-known technologies. Choices remain to be made, of course, in terms of specific companies and vendors to hire and makes and models of equipment to buy. But successful examples of advanced traveler information systems are becoming common throughout the industry, with successful examples just a click away on the Internet (see examples above).

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[2] See Levine, et. al. 2000 for an example of a report on positive, but still preliminary results of an advanced public transportation system demonstration project that incorporates a traveler information system in Ann Arbor, Michigan.

A more difficult question arises as to how to balance capabilities of a desired system and the expense. Systems with all the "bells and whistles" – automatic vehicle location devices, two-way wireless communications, fully integrated data collection, processing and dissemination, video kiosks, Internet Web sites, automated telephone information systems, and more – can be very expensive. Tri-Met in Portland, Oregon, for example, has budgeted almost $19 million in fiscal years 2002-06 for ITS technologies, of which just $4 million comes from other sources such as grants (see http://www.tri-met.org/its.pdf for details). Equipping a single bus with automatic vehicle location equipment costs an average of over $15,000 (see Casey 2000: 7). Less sophisticated systems, of course, need not be so expensive and basic improvements (Internet Web sites, for example, with online trip planners) can be made with simple upgrades to existing technologies.

Another barrier to implementing a comprehensive system can be the necessity to coordinate multiple transit and transportation agencies. The Take Transit Trip Planner for the San Francisco Bay Area, for example, currently coordinates 7 different transit agencies' route and scheduling information, while an additional 38 agencies provide transit services in the region. Coordinating so many different organizations can be extremely difficult, given that information has to be collected, processed and disseminated in a compatible way. The institutional challenge can be significant.

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(Casey 2000)
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(Wolcott and Lai 1999)

V.   Dynamic rideshare matching

[To be added later]

<u>Description of the technology</u>

<u>How it works</u>

<u>Intended benefits</u>

<u>Applications to date – examples</u>

<u>Barriers to implementation</u>

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