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Intelligent Transportation Technology Elements and Operational Methodologies for Shared-Use Vehicle Systems

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There has been significant interest and activity in shared-use vehicle systems as an innovative mobility solution. Shared-use vehicle systems, that is, carsharing and station cars, consist of a fleet of vehicles used by several different individuals throughout the day. Shared-use vehicles offer the convenience of a private automobile and more flexibility than public transportation alone. From the 1990s to today, varying degrees of intelligent transportation system technologies have been applied to shared-used systems, providing better manageability and customer service. Many shared-use vehicle service providers today include some degree of advanced technologies (online reservations, vehicle tracking, smart card access) in their operations. Currently, there is a developing need for interoperability among shared-use vehicle service providers (e.g., smart card access among carsharing organizations) and transit operators (e.g., transit fare collection via smart cards). Interoperability will likely result in higher customer satisfaction and use, leading to greater market penetration. Similarly, some standardization will likely unfold for overall operational techniques (online reservations and insurance policies), customer interactions, and to some degree vehicle interfaces. Because shared-use vehicles systems are still a relatively new mobility concept, an industrywide standardization approach is still premature. Nevertheless, there are attempts to identify many of the important issues that will play a significant role in interoperability discussions among shared-use vehicle providers and the development of industry standards in the future. There are key elements in intelligent shared-use vehicle system operations and trade-offs encountered during the pioneering stage of shared-use vehicle system developments. Topics to discuss include vehicles, user-system interactions, user-vehicle interactions, and system operations.

There has been significant interest in shared-use vehicle systems over the last several years as an innovative mobility alternative. The general principle of shared-use vehicle systems is that individuals can access a fleet of shared vehicles (ranging from cars to bikes and scooters) on an as-needed basis, rather than using their personal vehicles for all trips. There are many potential advantages of shared-use vehicle systems, including better use of vehicles—leading to higher transportation efficiency—cost savings to the user, energy and emissions benefits, and improved access to established transit operations.

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For further information on the history and benefits of shared-used vehicle system, see Shaheen et al. (1) and Whitelegg et al. (2).

Over the last several years, numerous shared-use vehicle services have developed that reflect different operational models (or market segments) and purposes. A classification system for categorizing shared-use vehicle system models, ranging from neighborhood carsharing to station car systems, was developed in 2002 (3). The predominant shared-use vehicle model is neighborhood carsharing, whereby individuals in dense metropolitan areas access shared-use vehicles distributed throughout neighborhood lots. Indeed, this is the prevailing approach in Europe and commercial shared-use services in North America. Station car systems are another model, whereby vehicles are closely linked to transit stations to enhance access. Station cars are often shared, although not always. 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 (3). As of July 2002, U.S. carsharing programs collectively claimed 12,098 members and operated 455 vehicles, and station car programs included 163 members and 121 vehicles (4).

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. Several ITS technology user services (5) can be applied:

- Dispatching and reservation systems so that users can obtain system information, check out vehicles, and make reservations over the web, by telephone, by kiosk, and so forth;
- Smart card technology to assist with vehicle access control;
- Onboard navigation and travel information to assist system users; and
- Intelligent communication and tracking systems to provide vehicle location and identification, emergency messaging, and electronic debiting.

Much of this advanced technology has been developed and applied in shared-use vehicle research programs, such as the UCR IntelliShare testbed (6) and the CarLink II program (7).

Commercial carsharing organizations in North America have limited technology penetration in their systems, in which 39% of U.S. shared-use vehicle organizations have advanced operations, 17% provide partially automated services, and 44% offer manual services (4). In Canada, 40% of the carsharing organizations have partial automation, and 60% have manual operations (8). In Shaheen et al.'s (2003) technology analysis (4), manual operations include operator

telephone services and in-vehicle trip logs; partially automated systems are automated reservations via Touch-Tone telephone or Internet or both; and advanced operations involve smart card access, reservations, billing, automated vehicle location, and cellular and radio frequency communications. As shared-use vehicle systems continue to expand and multiply, the penetration of ITS technology use will only increase as manually managing larger fleets and more diverse user markets (e.g., one-way trip rentals) becomes more difficult with increased scale. The primary reason to date that most commercial shared-use vehicle organizations have not employed a high degree of technology is the initial cost of establishing such systems.

As shared-use vehicle services continue to grow, the need will grow for interoperability among shared-use vehicle systems and providers. Furthermore, in September 2002, the California Transportation Commission (CTC) awarded the California Department of Transportation \$3.6 million to implement a 2-year statewide car-sharing program. In adopting this program, CTC required that organizations that are selected to receive these funds make their services interoperable with those of other providers, so that individuals can use multiple shared-use vehicle services statewide via the same smart card access device. Such requirements will likely have an impact on three aspects common to all shared-use vehicle system models: customers, system operations, and vehicles [from Barth and Shaheen (3)]. Following is a discussion.

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 single access mechanism, for example, a smart card or key fob, 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 important, so that customers do not have to relearn different operational procedures.

Operational Standards

It is inevitable that system operations will be different among shared-use vehicle systems, depending on their functional model, such as purpose and location. Thus, it is difficult to introduce operational standards across all models. Nevertheless, there is a strong need to measure shared-use vehicle system effectiveness with a focus on modal connectivity, air quality, energy efficiency, economic viability, and insurance risks. Operational standards could specify the minimum set of data collection required to document vehicle usage, net benefits, and claims histories. Such standard practices would allow for consistent determination and comparison of system effectiveness and the establishment of an insurance risk class. Currently, shared-use vehicle services have not yet been assigned a risk class, that is, probability of expected loss, within the insurance industry.

There are several disadvantages associated with an unclassified insurance status. First, policies vary widely among carriers, who interpret shared-vehicle risks differently, making it difficult for organizations to predict vehicle premiums; there is no standard. Sec-

ond, insurers are less likely to explore new markets, so shared-use vehicle organizations have fewer options and less consumer power due to decreased competition. Third, unknown risks and the expense of developing a new classification category are reflected in higher premiums. Indeed, during 2001 and 2002, most U.S. shared-use vehicle organizations reported a 50-percentage-point increase in renewal rates. To develop a premium for a new class of shared-use vehicle providers, an underwriter needs a credible historical data set to characterize risks across time and factors. Credible data require a large sample size over at least 3 years. Thus, operational standardization as it relates to insurance documentation will likely require more attention as this nascent market develops (4).

Vehicle Standards

Many automobile standards are already in place for safety, consistent operation, and interoperability of components. With the addition of shared-use onboard electronics, some standards will likely emerge so that automobile manufacturers can produce vehicles that more easily integrate and more consistently operate among many shared-use vehicle programs. As an example, shared-use vehicles might have a common interface (connector) for onboard 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, such as smart card readers placed in vehicles.

Shared-use vehicle systems are still a relatively new mobility concept, and introducing standards at this point is premature and too restrictive in many respects. It is important that standards do not stifle new, innovative operational methods. Thus, the emphasis in the near term should be on establishing system interoperability, developing standard reporting requirements to demonstrate benefits and support an insurance classification for shared-use vehicles, and promoting some standard operational procedures to minimize barriers to customer use, for example, similar processes for reservations and billing and for vehicle access.

As a prelude to technology interoperability among shared-used vehicle systems, this paper describes common technology issues and operational methodologies that have been emerging in the shared-use vehicle arena. The discussion spans the elements of vehicle management and system operations. In this discussion, various trade-off issues are described and qualitative benefits are compared among system designs.

VEHICLE MANAGEMENT

Before describing operational methodologies at various levels of technology application, it is first necessary to address several issues associated with shared-use vehicles themselves. Automobiles are almost always considered to be the vehicle in a shared-use system (3). However, this is not necessarily true, for 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. Nevertheless, for purposes of this paper, the authors look to the automobile as the primary vehicle in a shared-use system.

Depending on the shared-use vehicle system model, the vehicle fleet may consist of identical vehicles (homogeneous fleet) or many different kinds (heterogeneous fleet). A homogenous fleet has sev-

eral advantages (e.g., system management). All the vehicles are expected to operate in the same way, integration of onboard vehicle electronics is consistent, and the vehicle selection process can be based on vehicle parameters such as optimally matching fuel level to the requested trip. However, for many shared-use vehicle systems, having a variety and choice of vehicle types is an important aspect of matching a vehicle to the trip purpose. As an example, a customer may want to select a pickup truck for transporting large cargo items that could not be transported in a passenger vehicle. Having a heterogeneous fleet makes the fleet management problem somewhat more difficult, because each vehicle type will have different characteristics, and dealing with multiple vehicle parameters can complicate management algorithms.

As described in Barth and Shaheen (3), most shared-use vehicle systems are considered as a short-term rental system, in which they are typically used for short periods of time and travel relatively short distances. For this reason, many practitioners have seen a complementary match between battery electric vehicles (EVs) and shared-use systems (6, 9, 10). EVs are plagued by a limited range. They can be driven only relatively short distances between charges, compared with regular internal combustion vehicles, and they require longer periods to recharge. These limitations are somewhat alleviated in a shared-use vehicle situation, because trips are often shorter and vehicles can be recharged when idle at holding locations.

Given the synergy possible through clean-fuel vehicles, carsharing, and station car programs, in 2001 the California Air Resources Board (CARB) proposed to award additional zero-emission vehicle (ZEV) program credits for low-emission cars introduced into shared-use vehicle systems (11, 12). As part of the proposed Transportation Systems program, clean-fuel vehicles linked to transit, employed in carsharing systems using advanced technology, or both, would be eligible for additional credits. The ZEV program requires large-volume automobile manufacturers in California to produce clean-fuel vehicles for sale, starting in 2003. CARB's linkage of technology and demand-management strategies is based on its belief that a significant environmental benefit can arise from shared-use vehicle systems, particularly when low-polluting vehicles (e.g., battery electric, compressed natural gas, and hybrid electric) are introduced into transportation systems, such as carsharing systems linked to transit. However, dealing with vehicles that have relatively short range and require long periods to recharge pose additional shared-use vehicle management issues, as discussed in the following section.

It is important to note that the types of vehicles used can play a significant role in marketing shared-use vehicle systems. If the vehicles are unique, new, and fun to drive, those features can be valuable in marketing tools toward encouraging members to join a shared-use vehicle system.

SYSTEM OPERATIONS: SHARED-USE TECHNOLOGY ELEMENTS

In a generic shared-use vehicle system operation, a user first joins the system organization, perhaps paying an initial registration fee, and after that pays a monthly fee. Once a user is a member, the following steps can be followed to make a trip in a shared-use vehicle:

1. If the trip is planned in advance, a reservation system can be used to hold a vehicle for a specific time and location. In contrast, the shared-use vehicle system may allow an on-demand check-out of a vehicle from a user who wants to make a trip at the spur of the

moment, something that can occur at any time during system operation. Some systems may allow both reservations and on-demand access to the vehicles. An on-demand request can be considered as a reservation made for the very near future, for example, anywhere from 1 to 15 min.

2. When it is time to access the vehicle for the requested trip, there are many variations on how to carry out vehicle access.

3. When the user is inside the vehicle and driving it, information may be flowing between the vehicle and system, for both driver assistance and improved fleet management. Much of such information depends on onboard vehicle electronics and communication architecture.

4. When the trip has been completed, trip information is collected (usually time and distance) and the system management can record the data, perform appropriate accounting and billing, and execute any other back-office functions to best manage the overall system.

Reservation Systems and On-Demand Vehicle Requests

In the simplest of systems, that is, 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 vehicles 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 telephone, entering data via a Touch-Tone pad, and from the Internet. For shared-use vehicle systems, it is a natural fit to have both telephone-based and 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 online automated reservation systems show a calendar with dates and times for which there are available vehicles, and they 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 use throughout the day. For multinodal shared-use vehicle systems in which one-way trips are common [see Barth and Shaheen (3)], reservations can play an important role in maintaining a proper distribution of vehicles at all stations throughout the day. Advance knowledge of the travel demand, through reservations, makes it possible to estimate when a lack of vehicles may occur at any one station and then take corrective action (13). With reservations, three general steps are taken:

1. Reservations are submitted online or by telephone.
2. At the time of the trip, a user approaches the vehicle and obtains access.
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.

Although reservations can provide user trip security and can enhance system operations, many vehicle trips in our lives are not planned well in advance. Often there is a need for a vehicle on a walk-up, on-demand basis. On-demand access to shared-use vehicles provides much convenience to users; however, it places an additional

burden on system management to satisfy user demand. Pure on-demand shared-use vehicle systems exist today—that is, systems operating without any reservation capability—that rely on historical trip information to anticipate vehicle demand. For example, the UCR IntelliShare system has been operating for 3 years providing only on-demand service (6). In a pure on-demand system, the reservation process is replaced by a check-out process in which the users use a kiosk terminal located near the shared-use vehicles. As an example, Figure 1 shows a touch-screen kiosk terminal located in a small building near shared-use electric vehicles. The check-out process in this case usually involves going through a few input data screens that are required for checking out a vehicle. Once the check-out request is complete, the user can go to the appropriate vehicle, obtain access, and carry out the trip as requested. In some shared-use vehicle systems, a kiosk terminal may not be necessary. In that situation, the user simply approaches an available vehicle and performs the check-out and vehicle access process in one step. Doing so is possible if the vehicles have the ability to show that they are available for use. For example, a small green light displayed in the rear window of a shared-use vehicle could indicate that the vehicle is available for use.

For the on-demand check-out of vehicles, going first to a kiosk terminal may seem like an unnecessary step in the overall process. However, there are several cases in which a station-based kiosk terminal proves valuable:

1. If there is a fleet of homogeneous vehicles located at a station, then the kiosk computer, running system management algorithms, can play an important role in the vehicle selection process. If all vehicles are the same and can satisfy trip needs, then other factors can be used in the vehicle selection process, for example, choosing the vehicle with the most appropriate fuel level or rotating vehicle use so that all vehicles are used approximately equally over time.
2. If vehicles have a limited range and are slow to refuel, such as EVs, then a kiosk-based check-out becomes valuable, even when reservations are also used. When the fuel level (state-of-charge in an EV) varies widely depending on previous trips and different charging durations, it is best to select the vehicle just previous to starting the trip. The vehicle selection algorithm employs user estimates

FIGURE 1 Touch-screen kiosk terminal, located inside small building, used to check out shared-use vehicles—electric pickups and electric city cars.

when choosing a vehicle that has enough fuel or energy to satisfy the time and distance of a trip. Even when there is a reservation system, it is difficult to predict what the fuel level will be for any one vehicle well in advance. Thus, vehicle selection made at a station kiosk at the time of the trip is advantageous. When one is reserving EVs with a limited range and slow refueling characteristics, it is possible to skip a station-based kiosk check-out process by introducing a time buffer around each reservation, to ensure that the vehicles have time to recharge sufficiently before their use as reserved. However, operating in this way does not maximize vehicle use.

The process of going to a kiosk before accessing a vehicle can be circumvented through the use of wireless-enabled personal digital assistants (PDAs) or Internet-capable cell telephones. In that situation, a user would simply access a website that performs the check-out process.

Many existing shared-use vehicle systems accommodate on-demand use by allowing users to place reservations several minutes before the trip. Indeed, many reservation-only shared-use vehicle systems report that anywhere from 50% to 75% of their reservations are for trips on the same day.

To maximize vehicle use in a shared-use vehicle system, a combination of reservations and on-demand use can be implemented. The objective is to minimize total unused time for the vehicles and achieve a balance between reservations and on-demand use. Pricing strategies can be used to maximize vehicle use by controlling this balance. This is the current practice for obtaining train and airline seats: walk-up customers are usually charged a higher price than other passengers are, to limit the number of on-demand users. If a plane is overbooked, passengers are sometimes offered financial incentives to take a later flight. Many algorithms can be developed to manage this supply and demand problem and maximize vehicle use and financial revenue. The balance between reservations and on-demand use should be considered on both short-term and long-term bases. Short-term controls can be dynamic to adjust to different daily travel demand. However, it is important to maintain customer satisfaction over the long term to maintain significant levels of use.

Vehicle Access

In addition to reservations and on-demand check-out procedures, there are several ways to control vehicle access. Some methods have been developed in shared-use vehicle system models:

- **Lockbox.** 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 various vehicles are available. Many systems have taken this a step further by using common smart cards to access the lockboxes. An example is the Carsharing Organization and Communication System, or COCOS.
- **Common key.** With this method, all of the shared-use vehicles are rekeyed 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. An example is CarLink II.
- **Smart card open access to all vehicles.** Instead of a common key, onboard electronics—that is, a card reader secured to a door lock mechanism—can be used to read smart cards issued to the users. In this scenario, all vehicles could be unlocked with the use of any smart card in that system. Once the user is in the vehicle, a permanently mounted or tethered key would be used to start the vehicle. Or there

could be an ignition pop-up key, as featured in Honda's Intelligent Community Vehicle System program in Singapore. This method, along with the common key and lockbox methods, depends on users' following an honor system in regard to enforcing reservations, because any user could access a vehicle at any time.

- Smart card exclusive access for specific users. In a method similar to the one just mentioned, smart cards are issued to users. Each smart card has a specific code, and when vehicle access is requested, only the designated smart card, with the associated personal identification number (PIN) code, would release the requested vehicle for use. This method of vehicle access control requires that the smart card code be transmitted to the vehicle before 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.

- Smart card exclusive access for specific users, with PIN confirmation. This method is like the one in which smart card codes are used to enable specific user access for each trip. However, an additional step is required. Once the user is in the car, he or she has to enter a PIN on an input device (or message display terminal, typically mounted on the dashboard) to enable the ignition system. This method is similar to that used in bank automated teller machines, to help prevent the fraudulent use of lost or stolen cards.

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

All of these vehicle access solutions have trade-offs in convenience, security, and cost. Figure 2a illustrates qualitatively how each access method compares in 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, because any lost key could be found and used for an entire fleet of vehicles. The smart card open-access method provides a small increase in security, because a person who finds a lost card will not necessarily know how to use it. The smart card exclusive-access method provides significantly more security but at the cost of requiring the ability to communicate smart card codes to the vehicle. The smart card exclusive-access method with PIN provides the most security but has the added cost of requiring a PIN input device inside the vehicle.

Figure 2b illustrates the trade-off between user convenience and cost. The lockbox method detracts from user convenience in that users must perform the step of accessing a lockbox that may be inconveniently located. The common key method is very convenient for the user, but there is some cost involved in having all vehicles rekeyed. The smart card open-access and exclusive-access methods are equally convenient to the user. The smart card exclusive-access method with-PIN requires an extra step before starting the car and is therefore somewhat less convenient.

Onboard Vehicle Electronics and Communication Architectures

When applying ITS technology to shared-use vehicle systems, much can be gained by equipping vehicles with onboard electronics. There are four primary functions that onboard electronics can provide:

FIGURE 2 Trade-off of cost for different vehicle access methods and (a) security and (b) user convenience.

1. Vehicle access controls;
2. Trip and vehicle performance (e.g., state of charge) data acquisition;
3. Automated vehicle location (AVL) capability; and
4. Onboard navigation and user-system messaging.

In general, each of these functions is integrated into a single black box that is installed and interfaced in the vehicle. This section presents the benefits and trade-offs of different functionalities. Various communication architectures are also discussed.

Onboard Vehicle Electronics

Vehicle Access Control As discussed previously, having some type of vehicle access control improves user convenience and system security, potentially leading to lower insurance premiums. Minimum hardware elements that are required for smart card-based vehicle access control include a card reader (e.g., AWID system, which is used by several of the largest U.S. carsharing organizations) and an

interface to the door lock circuitry of the vehicle. When a user waves his or her smart card by the reader, and the card is recognized as valid, the vehicle doors unlock. That simple functionality can be implemented with discrete hardware components, not requiring any processor. However, if a smart card exclusive-access method is used, then the sophistication of the hardware increases. In that situation, user codes must be transmitted between the system and vehicles so that only valid users can access the vehicles at the proper times. With that added level of sophistication, a microcontroller or microprocessor is typically required to store code variables and carry out preprogrammed state machines to carry out proper sequencing. Adding a dashboard-mounted keypad system for PIN entry does not significantly complicate the microcontroller system, other than adding an additional hardware component to the overall onboard electronics.

Data Acquisition of Trip and Vehicle Performance Another important function that onboard vehicle electronics can provide is automatic recording of trip data, which can be used at a minimum for billing purposes and vehicle performance data (e.g., state of charge). In manual systems, users typically complete a trip log or diary, recording the time checked out and checked in, and trip mileage. Collecting and entering these data can be time consuming for operations. Furthermore, this system relies on a customer honor system. Onboard electronics can be programmed to automatically record the same parameters by interfacing with the vehicle's odometer signal and using an onboard real-time clock. These data can simply be stored and downloaded later by system management personnel (e.g., once every several weeks), such as done by the City CarShare system. Alternatively, this trip information can be transmitted back to the system via wireless communications. If electronics are placed on board for this minimum set of trip parameters—trip duration and distance—it is relatively straightforward to extend the data set to include other useful pieces of information. Additional parameters may include fuel level, auxiliary battery voltage, door open and close sig-

nals, gear selection, and others. Another valuable data parameter, particularly for multinodal shared-use vehicle systems, is location information. It should be noted that in the early stages of shared-use vehicle system deployment, it is often desired to collect a wide range of data to document net benefits to the system.

Automated Vehicle Location Capability In some shared-use vehicle system models, it is very useful to have information on location. For example, in multinodal systems in which there are many one-way trips, having knowledge of vehicle locations at any time as well as past trajectories is valuable for keeping the number of vehicles balanced across multiple stations. Furthermore, recording location information on errand destination can be valuable in determining where new stations should be placed. Location information can be acquired using Global Positioning System (GPS) receivers on the cars or by using other techniques such as land-based radio triangulation. The location and trajectory data need not necessarily be transmitted in real time. It may be sufficient to record the data to be downloaded later (e.g., ignition on and off). AVL systems are often used on buses to help manage the fleet. However, there are certainly privacy issues associated with AVL systems installed on semiprivate or private vehicles—those that are part of a shared-use system. Care must be taken to separate private user data from vehicle location data in any type of analysis.

Onboard Navigation and System Messaging Functionality can be added to onboard electronics, such as integrating onboard navigational devices that assist drivers with directions to their destinations and fueling locations. Also, it can also be beneficial to have system messaging capabilities so that users can send messages to the system to get help in emergencies, such as a flat tire or running out of fuel, or to extend a reservation. Such added functionality can be beneficial for users and overall system operations.

As shown in Figure 3, significant system management benefits and customer convenience can be gained with the introduction of onboard

FIGURE 3 Trade-off between system management benefit and cost of onboard electronic functionality.

vehicle electronics. The functionalities as described can be implemented separately or integrated into a single package. It is possible to have only the vehicle access control functionality without any other functions. Similarly, it is possible to have only trip data acquisition without the other functionalities. Usually, however, both vehicle access control and trip data acquisition are packaged together, providing a large benefit for system management at a reasonable cost. The AVL, navigation, and system messaging functionalities typically are not implemented without existing vehicle access control and data acquisition capabilities. These capabilities improve overall system functionality and user convenience, though at a greater cost.

Wireless Communication Architectures

From the 1990s to today, there has been a tremendous amount of activity in the wireless communications arena. In many ITS applications, communication linkages have been developed for a variety of purposes, such as safety, remote diagnostics, maintenance, traffic management, and advanced vehicle control. Activity in this arena is often referred to as telematics. Wireless communications can play a significant role in shared-use vehicle systems, particularly in communicating information between users, the system, and vehicles.

As previously discussed, it is possible to install onboard electronic hardware to automate the acquisition of trip data and implement basic vehicle access control methods. However, much can be gained by providing wireless communications between the system and vehicles. For example, exclusive-user vehicle access control can take place in which the system sends the user's code to the specified vehicle to be used. The vehicle electronics can then store that code, waiting to match it to a code from its card reader. When the codes match, signals will be sent to unlock the doors. Such a lock-out feature will be increasingly important as systems expand in size and into more diverse markets such as employer-based fleets. Furthermore, transmitting trip data from the vehicles to the system via wireless communication receivers is much more convenient and cost-effective than manually downloading data loggers every few weeks. Many shared-use vehicle systems are using wireless communications for these purposes. Other shared-use vehicle functions can make use of wireless communications, such as AVL functionality, short text messaging between the system and users, and Mayday signaling.

Several wireless communication architectures can be implemented for shared-use vehicle systems. The design of a wireless communication architecture depends on the shared-use vehicle system model, the system purpose, and funding availability. Several of the common communication architectures are outlined as follows.

Local Communication Architecture A generic local communication architecture is shown in Figure 4a. As described in the section "Reservation Systems and On-Demand Vehicle Requests," users can make shared-use vehicle reservations and potentially check out vehicles over the Internet. These requests are handled by a system management server. When shared-use vehicles are idle at stations or parking lots, dedicated short-range communication (DSRC) techniques can be used to download access information from the system to the vehicle. Similarly, when a shared-use vehicle returns from a trip, trip information can be uploaded from the vehicle back to the system management server. In the ITS arena, DSRC is used primarily between vehicles and the roadside for applications such as electronic toll collection, vehicle identification, and so forth. That type of communication is characterized by a short

range (approximately 100 m) with high data reliability and speed. This type of architecture is beneficial when vehicle status information is not required from the vehicles while they are away from their "home"—that is, the station or parking location. Communications between the vehicles and system occur only when the vehicles are within a very short range. This kind of short-range communication does not require licensing, and there are no monthly subscription costs. Once a dedicated short-range communication unit is installed at a location and connected to the system server (via the Internet or dedicated line), no additional costs are involved.

Wide Area Communication Architecture It is also possible to design the communication architecture using a wide area wireless network. A generic wide area communication architecture for shared-use vehicle systems is shown in Figure 4b. In this case, vehicles are not required to be at a designated location to communicate with the system. Instead, cellular based communications can be used to send messages between the system and vehicles. Cellular digital packet data (CDPD) and general packet radio service (GPRS) communications, considered to be wireless Internet protocol networks, are now widely accepted standards in North America. They primarily provide packet data service for mobile users by automatically using idle cellular telephone channels to send packet data traffic. Accordingly, CDPD and GPRS have been the primary target of ITS applications that require wide area data communications. A mobile end system communicates with the CDPD or GPRS network via a 19.2 kilobits/s or greater raw duplex wireless link, which is shared by several mobile end systems. Packets from network to end systems are broadcast, thus establishing a connectionless downlink. For the reverse direction or uplink, CDPD follows traditional slotted, nonpersistent Digital Sense Multiple Access protocol. Additional intelligent wireless techniques such as frequency hopping, radio service code, roaming, and dynamic channel relocation are used to provide a fairly robust data channel (14). In the implementation of such a wide area communication architecture, a monthly subscription fee must be paid. Furthermore, a wide area cellular system will always have a certain degree of data packet loss and data packet latency, situations that might affect the operations of shared-use vehicle system [see Barth et al. (15)].

Hybrid Communication Architecture To maximize the advantages of the local short-range and wide area communication architectures, it is possible to design a hybrid communication architecture for shared-use vehicle systems, as shown in Figure 4c. This type of system is particularly well suited for the multinodal shared-use vehicle system model, in which short-range communications are used for checking out and checking in vehicles, and wide area communications are used for relaying vehicle status information (including position) back to the system (15). Data packet loss and latency problems become less important in this architecture, because there are redundant communications at the stations. Further details on this type of architecture are given in Barth et al. (15).

There can be many variations of the generic communication architecture as just presented. The general advantages and disadvantages of these architectures are given in Table 1.

System Management

The heart of any advanced-technology shared-use vehicle system is the system management component. This component carries out various functions, depending on the model of the shared-use vehicle

FIGURE 4 Communication architectures: (a) generic local; (b) generic wide area; and (c) generic hybrid.

TABLE 1 Advantages and Disadvantages of Communication Architectures for Shared-Use Vehicle Systems

Communication Architecture	Advantages	Disadvantages
Local, Dedicated Short-Range Communications (Figure 4a)	<ul style="list-style-type: none"> • Low cost • Low data packet loss • Low latency • High bandwidth 	<ul style="list-style-type: none"> • Vehicles can only communicate at stations • AVL and system messaging are not possible
Wide Area, Cellular Communications (Figure 4b)	<ul style="list-style-type: none"> • Communications over large areas • AVL and system messaging are possible 	<ul style="list-style-type: none"> • Monthly subscription fee required • Non-trivial data packet loss • Non-trivial data latency • low bandwidth
Hybrid Communication Architecture (Figure 4c)	<ul style="list-style-type: none"> • Communications over large areas • AVL and system messaging are possible • Redundant communications at stations 	<ul style="list-style-type: none"> • Monthly subscription fee required

system. Central to system management is usually a database consisting of authorized users, vehicles, trip reservations, and trip information. Various functions that act on this database include, but are not limited to, reservations management, check-out and check-in processing, trip data logging, vehicle management (and maintenance), and accounting. Not all of these functions are required, and many of the functions may be spread out across different computer platforms. Furthermore, in some systems, all of the functions may be tightly integrated automated processes, whereas in other systems, some functions may be loosely coupled or nonautomated, or both.

Reservation Management

As described earlier, automated reservations can be handled over the telephone or via the Internet. An online system typically includes a calendar with dates and times of vehicle availability. Reservations are usually stored as a database of reservation requests, indexed by time. Other software modules of the system server can then access this database to carry out various functions.

Vehicle Check-Out Processing

The system management component handles vehicle access control through a specified shared-use vehicle check-out process. A check-out may simply consist of conveying information to the vehicle(s), stating which user is expected at what time. This type of communication may happen once a day, once every hour, or once for every user check-out event. If a kiosk terminal is used, as described earlier in the section "Reservation Systems and On-Demand Vehicle Requests," the system management component may invoke additional algorithms based on user inputs. As an example, a vehicle allocation algorithm may be used to select a vehicle from a homogeneous fleet, based on requested trip information and the state of each vehicle.

Trip Data Logging

When a vehicle completes a trip, it is necessary for the vehicle to convey trip information to the system management component. This

type of communication may happen once a day (downloading information on all trips), once every hour, or once for every user check-in event. The trip data are then stored as a database that can be used for evaluation and billing. At a minimum, trip distance and trip time are recorded. However, richer data sets are often recorded, containing information on vehicle status, vehicle trajectories, and so forth, that can be used for subsequent data analysis.

Vehicle Management and Maintenance

In the data logging process, it is often important to track vehicle status information, particularly for limited-range vehicles such as EVs. In regard to management, it is often desired to add or subtract vehicles from the fleet, which can be handled via a vehicle management interface. Algorithms can also be integrated that alert system management personnel when regular vehicle maintenance is required.

Accounting

An important part of system management is the ability to access the trip data logs for billing purposes. Furthermore, it may be necessary to evaluate trips specific to a vehicle, group of vehicles, or specific user groups. Various queries and filters can be designed to quickly sort vehicle trip data. User billing can be handled as a standard back-office operation, which is prevalent on today's Internet.

Additional Processes

Other analyses can be performed employing the system's database, such as calculating overall efficiency and supplying historical data needed to establish insurance risks. These processes are not important to short-term system operations. However, they can be quite helpful in supporting industry developments. The majority of these system management functions are carried out via software. The cost for hardware is not high, for usually a high-end PC with high network bandwidth is sufficient to execute many of these tasks. It is possible to implement a minimum set of functions, such as vehicle check-out processing, data logging, and simple billing. However,

online reservations, which must be integrated into overall system management, are an increasingly important feature of the largest U.S. carsharing service providers. Vehicle management and maintenance software modules are not critical for short-term operations, for typical vehicles. Yet such features are likely to prove valuable in the long run as systems grow in size and spatial scale.

SUMMARY AND CONCLUSIONS

In this paper, the authors described many of the generic elements of intelligent shared-use vehicle operation, including reservation systems, on-demand vehicle requests, vehicle access methods, onboard vehicle electronics, communication architectures, and system management functions. Various aspects of technology penetration and common operational methodologies for systems developed to date were also explored. The benefits of intelligent technology approaches were evaluated qualitatively in light of current operational methods. Currently, U.S. shared-use vehicle providers are moving from low-technology manual operations to more advanced, centralized, and remotely managed systems. This trend toward more advanced electronics allows for improved functionality with respect to

- Vehicle security,
- User convenience,
- Trip recording accuracy,
- Vehicle management,
- Accounting methods, and
- System efficiency.

Historically, shared-use vehicle systems were initiated through a collaborative effort of individuals wishing to share a common resource. This grassroots origin did not require high security or optimal convenience. As shared-use vehicle services continue to grow and compete with the convenience of private automobiles, increasing levels of reliability, responsiveness, and efficiency will be required by the common public. The technology discussion outlined in this paper examines ITS technologies currently available and applicable to various shared-use vehicle models. The natural evolution of advanced electronics will improve on today's technologies. That improvement in turn can lead to more responsive and efficient shared-use vehicle systems, which come closer to matching the convenience of a personally owned vehicle. In the interim, shared-use vehicle providers will need to focus on making their systems, such as smart card access, interoperable for users among transit and other carsharing operators. Such an approach will increase customer satisfaction, system usage, and market growth. Furthermore, standardization in the areas of insurance, performance measurement, and service operation will foster market developments.

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