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Authors
Barth, Matthew
Todd, Michael
Shaheen, Susan

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Matthew Barth

Michael Todd

Susan Shaheen

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Matthew Barth, Michael Todd, and Susan Shaheen

ABSTRACT

As an innovative mobility solution, there has been significant interest and activity in *shared-use vehicle systems*. Shared-use vehicle systems (i.e., carsharing, station cars) consist of a fleet of vehicles that are 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. In recent years, 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 (e.g., online reservations, vehicle tracking, smartcard access) in their operations. At present, there is a developing need for interoperability among shared-use vehicle service providers (e.g., smartcard access among carsharing organizations) and transit operators (i.e., transit fare collection via smartcards). Interoperability will likely result in higher customer satisfaction and use, leading to greater market penetration. Similarly, some degree of standardization will likely unfold for overall operational techniques (e.g., online reservations and insurance policies), customer interactions, and to some degree vehicle interfaces. However, shared-use vehicles systems are still a relatively new mobility concept, thus an industry-wide standardization approach is still premature. Nevertheless, this paper 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. This paper focuses on key elements of intelligent shared-use vehicle system operations, describing many of the tradeoffs that have been encountered during the pioneering stage of shared-use vehicle system developments. Key topics include vehicles, user/system interactions, user/vehicle interactions, and system operations.

Keywords: shared-use vehicle systems, carsharing, station cars, ITS technology, interoperability, standardization

INTRODUCTION

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 utilization of vehicles (leading to higher transportation efficiency), cost savings to the user, energy/emissions benefits, and improved access to established transit operations. For further information on the history and benefits of shared-used vehicle system, see *(1)*, and *(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 different 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, where 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, where 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: 1) *dispatching and reservation systems* so that users can obtain system information, check-out vehicles, and make reservations over the web, by phone, by kiosk, etc.; 2) *smartcard technology* to assist with vehicle access control; 3) *on-board navigation and travel information* to assist system users; and 4) *intelligent communication and tracking systems* to provide vehicle location/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, where 39 percent of U.S. shared-use vehicle organizations have advanced operations; 17 percent provide partially automated services; and 44 percent offer manual services. *(4)*. In Canada, 40 percent of the carsharing organizations have partial automation and 60 percent manual operations *(8)*. In Shaheen et al.'s (2002) technology analysis, manual operations include operator phone services and in-vehicle trip logs; partially automated systems are automated reservations via touch-tone telephone or Internet or both; and advanced operations involve smartcard access, reservations, billing, automated vehicle location, and cellular/radio frequency communications. As shared-use vehicle systems continue to expand and multiply, the penetration of ITS technology 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 haven't employed a high degree of technology is due to the initial cost of establishing such systems.

As shared-use vehicle services continue to grow, there will be an increasing need 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 two-year statewide carsharing 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 smartcard access device. Such requirements will likely impact three aspects common to all shared-use vehicle system models, namely customers, system operations, and vehicles (from *(3)*):

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

***Operational Standards*—**it is inevitable that system operations will be different among shared-use vehicle systems, depending on their functional model (i.e., purpose, location, etc.). 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. At present, shared-use vehicle services have not yet been assigned a risk class (i.e., expected loss probability) 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 (i.e., there is no standard). Second, 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 2001-2002, 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 three 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 on-board electronics, some standards will likely emerge so that automakers can produce vehicles that more easily integrate and operate more consistently among many shared-use vehicle programs. As an example, shared-use vehicles might have a common interface (i.e., connector) for on-board monitoring and control electronics. Shared-use vehicle technology manufacturers could also benefit by adopting some uniform components for the growing shared-use vehicle market segment (e.g., smartcard readers placed in vehicles).

Shared-use vehicles 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 prematurely. Thus, the focus in the near-term should be on establishing system interoperability, developing standard reporting requirements to demonstrate benefits and support a shared-use vehicle insurance classification, and promoting some standard operational procedures to minimize barriers to customer use (e.g., similar reservations/billing and vehicle access processes).

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. This 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 different system designs.

VEHICLE MANAGEMENT

Prior to describing a variety of operational methodologies at various levels of technology application, it is first necessary to address several issues associated with shared-use vehicles themselves. As mentioned previously *(3)*, automobiles are almost always considered to be the "vehicle" in a shared-use system. However, this is not necessarily true—these systems can include other transportation modes such as bicycles and scooters. In fact, shared-use bicycle systems often come to mind when individuals are first introduced to the carsharing concept. Nevertheless, for purposes of this paper, the authors focus on 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 (i.e., homogeneous fleet) or many different kinds (i.e., heterogeneous fleet). There are several advantages (primarily for system management) when dealing with a homogeneous fleet in that all the vehicles are expected to operate the same way, integration of on-board 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 couldn't be transported in a passenger vehicle. Having a heterogeneous fleet makes the fleet management problem somewhat more difficult since each vehicle type will have different characteristics and dealing with multiple vehicle parameters can complicate management algorithms.

As described in Barth & Shaheen, 2002, most shared-use vehicle systems are considered as a "short-term rental" system, where 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 *(9)*, *(10)*, and *(6)*. Electric vehicles are plagued by limited range issues: They can only be driven relatively short distances between charges (relative to a regular internal combustion vehicle) and require longer periods to recharge. These limitations are somewhat alleviated in a shared-use vehicle scenario, since trips are often shorter and vehicles can be recharged when idle at holding locations.

Given the many synergies among 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 automakers in California to produce clean fuel vehicles for sale, starting in 2003. CARB's linkage of technology and demand-management strategies is based on their belief that a significant environmental benefit can arise from shared-use vehicle systems, particularly when low-polluting (e.g., battery electric, compressed natural gas, and hybrid electric) vehicles are introduced into transportation systems (e.g., 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, this can be used as a valuable marketing tool to get members to join a shared-use vehicle system. The next section focuses on shared-use vehicle system operations and intelligent technologies that are commonly employed to facilitate management.

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 thereafter a monthly subscription fee. Once a user is a member and wants to make a trip in a shared-use vehicle, there are various steps in the process:

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, which can occur at anytime 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, e.g., anywhere from one to 15 minutes.) *Reservation systems and on-demand check-outs* are discussed in the following section.

2) Once it is time to access the vehicle for the requested trip, there are many variations on how to carry out *vehicle access*, described in that section below.

3) When the user is in and driving the vehicle, information may be flowing between the vehicle and system for both driver assistance and improved fleet management. Much of this depends on any *on-board vehicle electronics* and developed *communication architecture*.

4) Once 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. This is described in further detail below.

This section explores each of the intelligent shared-use vehicle technology elements outlined in the steps above.

Reservation Systems and On-Demand Vehicle Requests

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

Reservations provide users with the comfort and security of knowing that a vehicle is available for them at a specific time and place. Reservations are also useful for system management, allowing the system to maximize vehicle usage throughout the day. For multi-nodal shared-use vehicle systems where one-way trips are common (see *(3)*), reservations can play an important role in maintaining a proper distribution of vehicles at all stations throughout the day. By knowing the travel demand ahead of time via reservations, it is possible to estimate when a lack of vehicles may occur at any one station and corrective action can take place *(13)*. With reservations, three general steps taken are: 1) reservations are submitted (on-line or phone); 2) at the time of the trip, a user approaches the vehicle and obtains access; and 3) the user carries out the trip. At the completion of the trip, trip data are recorded (either manually or via communication between the vehicle and system).

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 high convenience to users; however, it places additional burden on system management to satisfy user demand. Pure on-demand shared-use vehicle systems exist today (i.e., systems operating without any reservation capability) that rely on past historical trip information to anticipate vehicle demand (e.g., the UCR IntelliShare system has been operating for three years providing only on-demand service *(6)*). In a pure on-demand system, the reservation process is replaced by a "check-out" process where the users use a kiosk terminal located near the shared-use vehicle(s). As an example, Figure 1 shows a touchscreen 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 requested trip. In some shared-use vehicle systems, a kiosk terminal may not be necessary; in this case, the user simply approaches an available vehicle and performs the check-out and vehicle access process in one step. This is possible if the vehicles have the ability to show that they are available for use (e.g., a small green light displayed in the back window of a shared-use vehicle could signal 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 when 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 of the vehicles are the same and can satisfy trip needs, then other factors can be used in the vehicle selection process, e.g., 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 limited range and are slow to refuel (e.g., electric vehicles), then a kiosk-based check-out becomes very valuable, even when reservations are also used. When 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 the trip start. The vehicle selection algorithm utilizes user estimates when choosing a vehicle that has enough fuel or energy to satisfy trip time and distance. Even with a reservation system in place, it is difficult to predict what the fuel level will be for any one vehicle well in advance; thus carrying out vehicle selection at a station kiosk at the time of the trip is advantageous. When reserving electric vehicles with 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 prior to their reserved use. However, operating in this way does not maximize vehicle usage.

The process of going to a kiosk prior to accessing a vehicle can be circumvented through the use of wireless-enabled personal digital assistants (PDAs) or internet-capable cell phones. In this case, a user would simply access a web-site that performs the check-out process without going to a stationary kiosk terminal.

Figure 1. Touchscreen kiosk terminal (located inside small building) used to check-out shared-use vehicles (electric pickups and electric city cars).

Many existing shared-use vehicle systems accommodate on-demand use by allowing users to place reservations several minutes prior to the actual trip. Indeed, many reservation-only shared-use vehicle systems report that anywhere from 50 to 75 percent 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 with train and airline seats: walk-up customers are usually charged a higher price to limit the number of on-demand users. Even when a plane is overbooked, passengers are sometimes offered financial incentives to take a later flight. Many algorithms can be developed and used 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 both on a short-term and long-term basis: 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 usage levels.

Vehicle Access

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

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

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

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

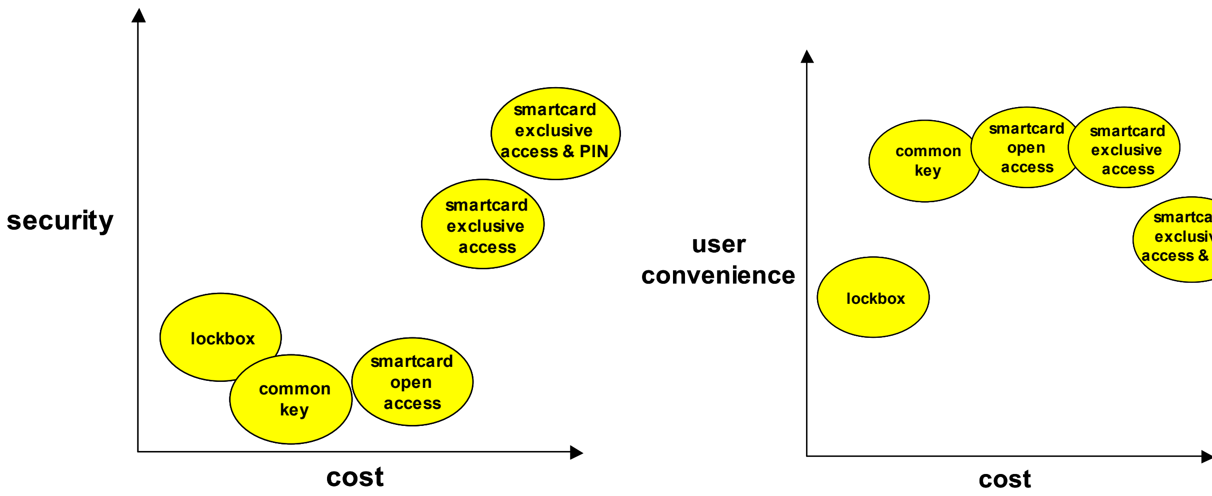
Smartcard Exclusive Access for Specific Users: Similar to that above, smartcards are issued to users. Each smartcard has a specific code, and when vehicle access is requested, only the designated smartcard (with the associated PIN code) would release the requested vehicle for use. This vehicle access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

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

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

All of these vehicle access solutions have tradeoffs in convenience, security, and cost. Figure 2a illustrates qualitatively how each access method compares in terms of security and cost. The lockbox technique provides a small amount of security in that users have to go through an extra step to gain access to the vehicle keys. The common key method is the least secure method, since any lost key could be found and used for an entire fleet of vehicles. The smartcard-open-access method provides a small increase in security since a person who finds a lost card won't necessarily know how to use it. The smartcard-exclusive-access method provides significantly more security but at the cost of requiring the ability to communicate smartcard codes to the vehicle. The smartcard-exclusive-access-with-PIN provides the most security and has the added cost of requiring a PIN input device inside the vehicle.

Figure 2b illustrates the tradeoff between user convenience and cost. The lockbox method deters 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 re-keyed. The smartcard-open-access and exclusive-access are equally convenient to the user. The smartcard exclusive access-with-PIN requires an extra step prior to starting the car and is therefore somewhat less convenient.



A. B.

Figure 2. A: Tradeoff between security and cost for different vehicle access methods. **B:** Tradeoff between security and cost for different vehicle access methods.

On-Board Vehicle Electronics and Communication Architectures

When applying intelligent transportation system technology to shared-use vehicle systems, much can be gained by equipping vehicles with on-board electronics. There are four primary functions that on-board electronics can provide, namely: 1) vehicle access controls, 2) trip and vehicle performance (e.g., state of charge) data acquisition, 3) automated vehicle location (AVL) capability, and 4) on-board navigation and user/system messaging. In general, each of these functions are integrated into a single black "box" that is installed and interfaced in the vehicle. In this section, the authors discuss the benefits and tradeoffs of different functionalities. Various communication architectures are also discussed.

On-Board 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 smartcard-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 vehicle's door lock circuitry. When a user waves his/her smartcard by the reader, and the card is recognized as valid, the doors unlock. That simple functionality can be implemented with discrete hardware components, not requiring any processor. However, if a smartcard-exclusive-access methodology is used, then the sophistication of the hardware increases. In this case, 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, typically a microcontroller or microprocessor is 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 on-board electronics.

Trip and Vehicle Performance Data Acquisition—another important function that on-board vehicle electronics can provide is automatically recording 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 along with the trip mileage. Collecting and entering these data can be time consuming for operations. Further, this system also relies on a customer honor system. On-board electronics can be programmed to automatically record the same parameters by interfacing with the vehicle's odometer signal and using an on-board real-time clock. These data can simply be stored and downloaded at a later time by system management personnel (e.g., once every several weeks), such as the City CarShare system. Alternatively, this trip information can be transmitted back to the system using wireless communications. If electronics are placed on-board for this minimum set of trip parameters (i.e., trip duration and trip distance), it is relatively straightforward to extend this data set to include other useful pieces of information. Additional parameters may include fuel level, auxiliary battery voltage, door open/close signals, gear selection, etc. Another valuable data parameter, particularly for multi-nodal shared-use vehicle systems, is location information, described below. 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 system benefits.

Automated Vehicle Location Capability—In some shared-use vehicle system models, it is very useful to have location information. For example, in multi-nodal systems where 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. Further, recording errand destination location information 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 at a later time (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 (semi-) private vehicles, i.e., 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.

On-Board Navigation and System Messaging—additional functionality can be added to on-board electronics, such as integrating on-board navigational aids that assist drivers with directions to their destinations and fueling locations. Also, it can also be beneficial to have system messaging capabilities so users can send messages to the system for emergency reasons (e.g., "flat tire", "out-of-fuel") or to extend a reservation. This 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 on-board vehicle electronics. The functionalities described above 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 only have 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 improve overall system functionality and user convenience, however at a greater cost.

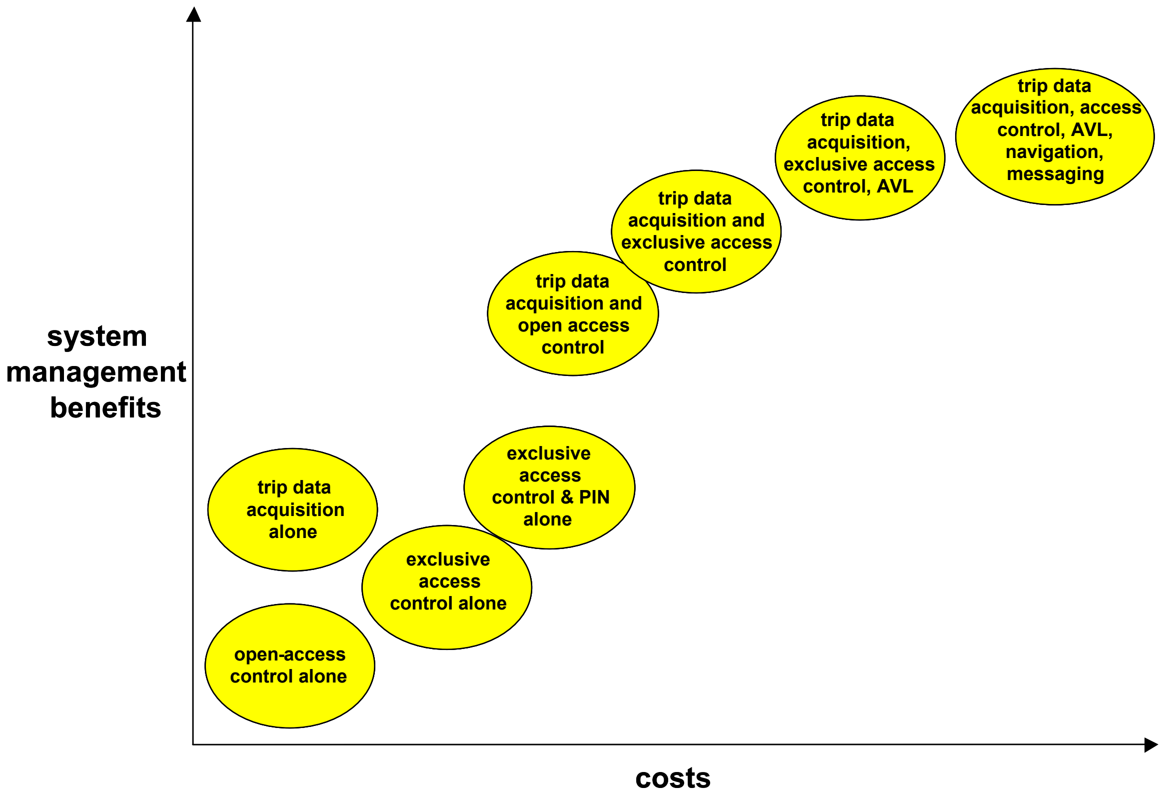


Figure 3. Tradeoff between system management benefit and cost of on-board electronic functionality.

<u>Wireless Communication Architectures</u>

In recent years, there has been a tremendous amount of activity in the wireless communications arena. In many intelligent transportation system applications, there have been many communication linkages 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 described in the previous section (On-Board Vehicle Electronics), it is possible to install on-board electronic hardware to automate trip data acquisition 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 with the system sending the user's code to the specified vehicle of use. 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 (e.g., employer-based fleets). Further, 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 utilizing 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 emergency mayday signaling.

There are several wireless communication architectures that 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 below.

Local Communication Architecture—a generic local communication architecture is shown in Figure 4. As described in "Reservation Systems and On-Demand Vehicle Requests" section, users can make shared-use vehicle reservations and potentially check-out vehicles over the Internet. These requests are handled by a system management server (described below in "System Management" section). 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, etc. This type of communication is characterized by short range (approximately 100 meters) 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", i.e., station or parking location. Communications between the vehicles and system only occur when they within a very short range. This type 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), there are no additional costs involved.

Wide-Area Communication Architecture—somewhat different from a local communication-based 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 5. 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 as wireless IP networks, are now widely accepted standards in North America. They primarily provide packet data service for mobile users by automatically utilizing idle cellular phone channels to send packet data traffic. As such, 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 per second or greater raw duplex wireless link, which is shared by several mobile end systems. Packets from network to end systems are broadcasted, thus establishing a connectionless downlink. For the reverse direction or uplink, CDPD follows traditional slotted, non-persistent Digital Sense Multiple Access protocol (DSMA/CA). Additional intelligent wireless techniques such as frequency hopping, RS code, roaming, and dynamic channel relocation are used to provide a fairly robust data channel *(14)*. When implementing such a wide-area communication architecture, a monthly subscription fee must be paid. Further, a wide-area cellular system will always have a certain degree of data packet loss and data packet latency, which might affect shared-use vehicle system operations (see *(15)*).

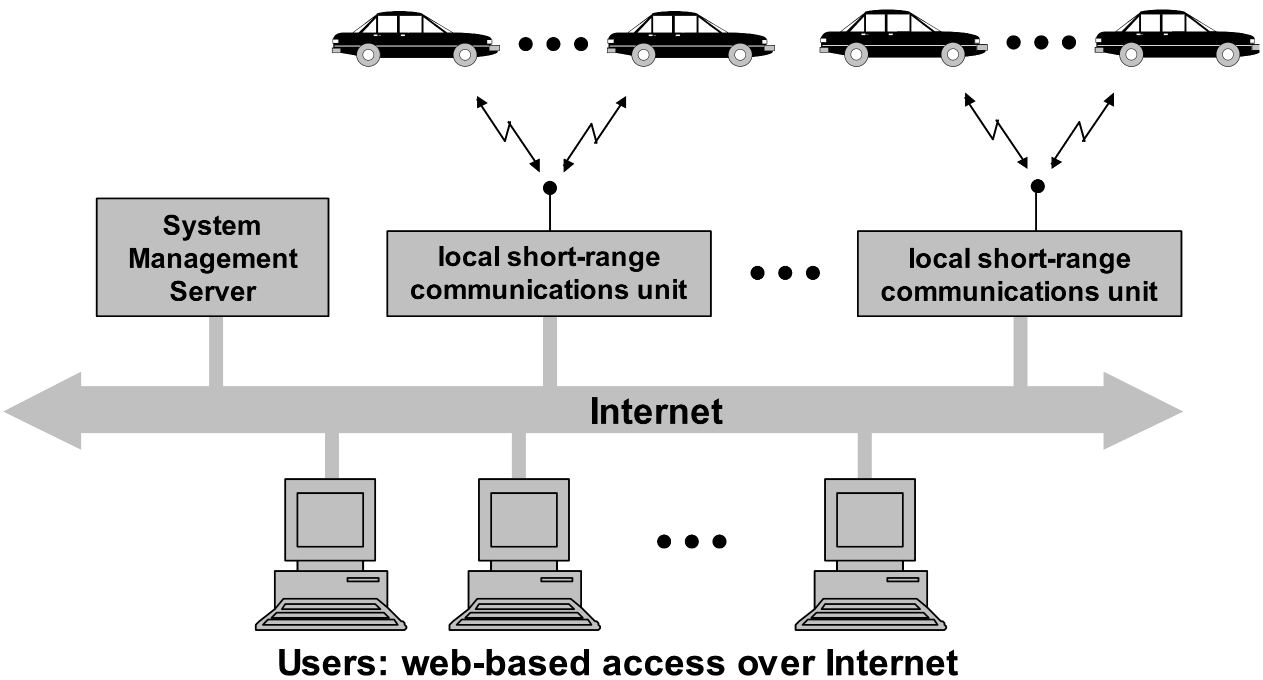


Figure 4. Generic local communication architecture.

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 is shown in Figure 6. This type of system is particularly well suited for the multi-nodal shared-use vehicle system model, where short-range communications is used for vehicles checking-out and checking-in, and wide-area communications is used for relaying vehicle status information (including position) back to the system *(15)*. Data packet loss and latency issues become less important in this architecture since there is redundant communications at the stations. Further details on this type of architecture is given in *(15)*.

There can be many variations of the generic communication architecture examples given above. In general, the pros and cons of these architectures are given in Table 1.

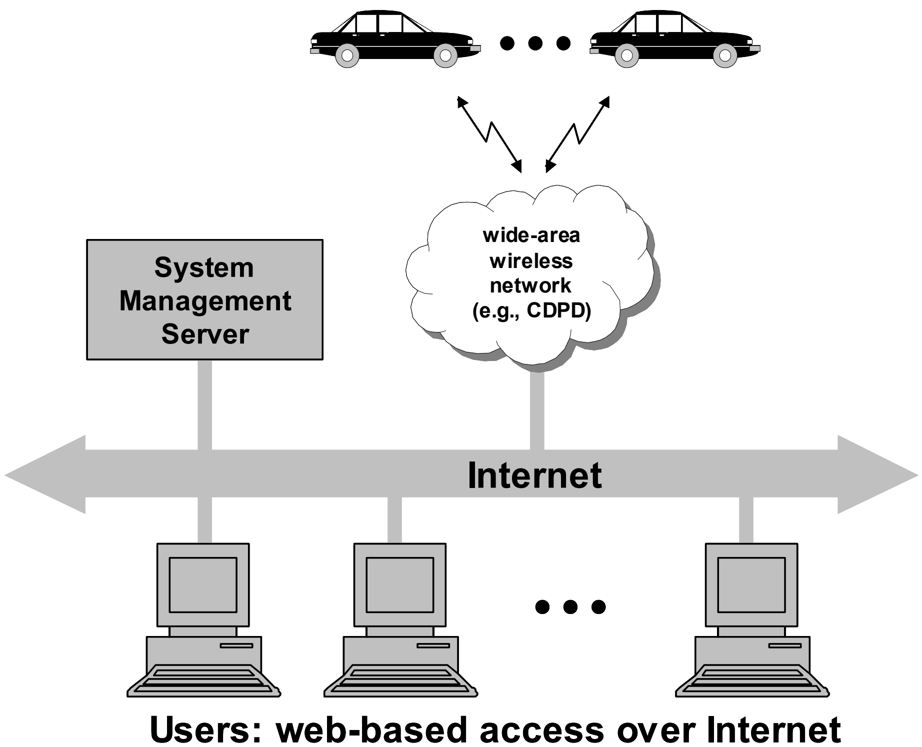


Figure 5. Generic wide-area communication architecture.

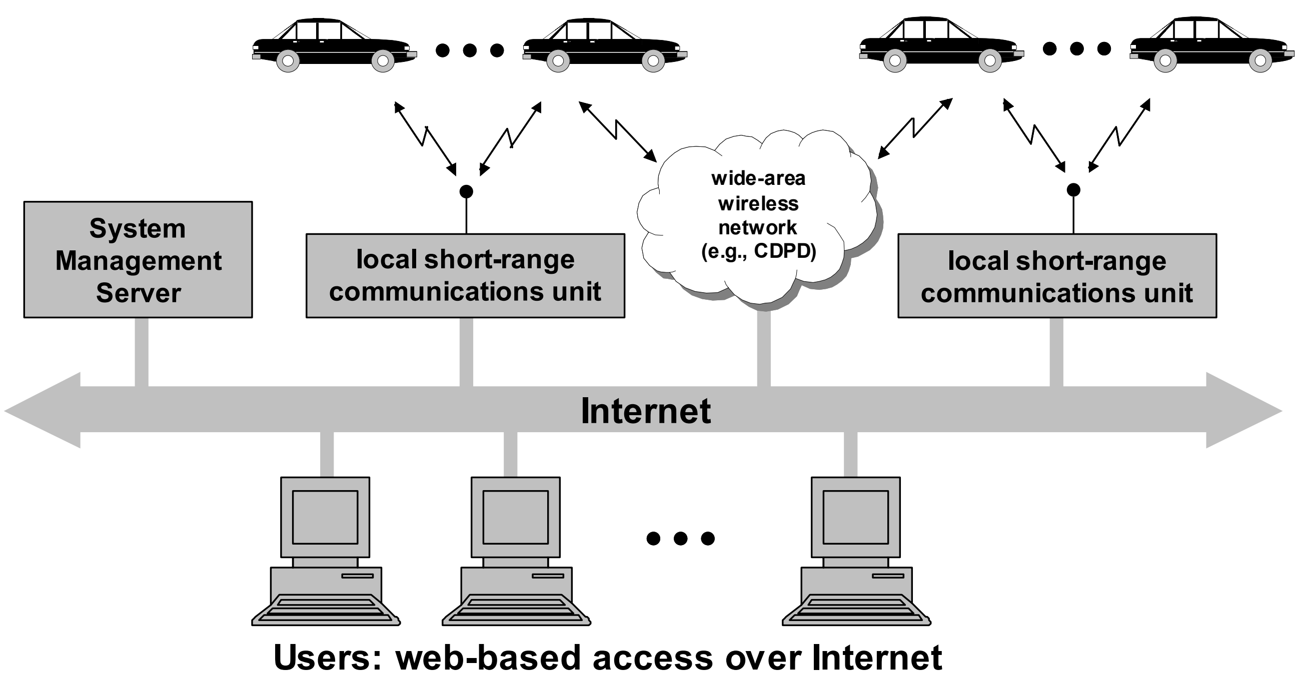


Figure 6. Generic hybrid communication architecture.

Communication Architecture	Advantages	Disadvantages
Local, Dedicated Short-Range Communications (Figure 4)	• low cost • low data packet loss • low latency • high bandwidth	• Vehicles can only communicate at stations • AVL and system messaging are not possible
Wide Area, Cellular Communications (Figure 5)	• Communications over large areas • AVL and system messaging are possible	• Monthly subscription fee required • Non-trivial data packet loss • Non-trivial data latency • low bandwidth
Hybrid Communication Architecture (Figure 6)	• Communications over large areas • AVL and system messaging are possible • Redundant communications at stations	• Monthly subscription fee required.

Table 1. Advantages and disadvantages of shared-use vehicle system communication architectures

System Management

The heart of any advanced-technology shared-use vehicle system is the *system management component*. The system management component carries out various functions, depending on the shared-use vehicle system model. 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), accounting (i.e., billing). Not all of these functions are required, and many of the functions may be spread out across different computer platforms. Further, all of the functions may be tightly integrated automated processes while in other systems, some functions may be loosely coupled and/or non-automated.

Reservation Management—as described earlier, automated reservations can be handled over the phone or via the Internet. An on-line 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 "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, etc. that can be used for subsequent data analysis.

Vehicle Management and Maintenance—as part of the data logging process, it is often important to track vehicle status information, particularly for limited-range vehicles such as electric vehicles. In terms of management, it is often desired to add or subtract vehicles from the fleet; this 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. Further, 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. There isn't a high cost for hardware; 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, on-line reservations are an increasingly important feature of the largest U.S. carsharing service providers, which must be integrated into overall system management. Vehicle management and maintenance software modules are not critical for short-term operations (for typical vehicles); however, such features will likely to prove to be 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, on-board vehicle electronics, communication architectures, and system management functions. Various aspects of technology penetration and common operational methodologies for systems developed to date also were explored. The benefits of intelligent technology approaches were evaluated qualitatively in light of current operational methods. At present, U.S. shared-use vehicle providers are moving from low-technology manual operations to more advanced, centralized and remotely managed systems. This trend towards 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 grass roots origin did not require high security or optimal convenience. As shared-use vehicle services continue to grown and compete with the convenience of the private auto, 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 upon today's technologies. This 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 (e.g., smartcard 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 also foster market developments.

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