Implications of Technological Developments for Demand Responsive Transit

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The initial development of demand responsive transit (DRT) in the early 1970s was highly ambitious technologically at the time. In fact, many of the early problems with dial-a-ride related to the cost and performance of the computer hardware and software technologies in use 20 years ago. As experience was gained with DRT, the technology for delivering this service became much simpler and relied much less—and in many cases not at all—on computers. In addition, during the past 10 years there has been a strong trend toward advance scheduling of trips on DRT systems, with ridership restricted to certain groups. This represents a fundamental shift away from the original premise of DRT, which was to provide an immediate response local transportation mode for the general public. Recent technological developments offer promise that DRT may be able to return to its technologically sophisticated roots, albeit at a much superior level of performance and cost-effectiveness. The advent of low-cost, high-performance computer hardware, generic data base systems, moderately priced scheduling and dispatching software, mobile computers, inexpensive card readers, hand-held data transfer devices, off-the-shelf automatic vehicle location technology, and electronic mapping software makes possible the development of DRT systems that are much more capable than the typical current system and yet are also relatively affordable. A few systems are now beginning to experiment with these new possibilities. As these efforts, and others, proceed along the development path, how DRT is organized and delivered is likely to change significantly, though gradually, from the current practice.

Demand responsive transit (DRT), when introduced into the public transportation arena in the early 1970s, represented the first major transit service innovation in many decades. Before DRT, public transit consisted of services that were fixed in space and time. Such services require that users find their own means of accessing the transit system, and service is provided only where the fixed routes of the system go. Dial-a-ride—as DRT was then usually referred to—was designed to access users and deliver them to the desired destination. This was to be accomplished by accepting trip requests—consisting of origin point, destination point, and desired pickup or arrival time—from users over the telephone and then dynamically scheduling and routing vehicles to service many of these trip requests simultaneously. The objective was to establish a shared-ride service of moderate productivity providing a level of service substantially better than conventional fixed-route transit, offering the promise that it could compete for some trips being made by automobile.

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In addition to representing a radical departure from traditional public transit services, DRT was the first transit innovation premised explicitly on computer technology (*1*). Accordingly, the initial dial-a-ride demonstration projects made extensive use of computer and other electronic technologies to collect and store customer trip information, schedule vehicles for passenger pickups and deliveries, and dispatch trip orders to vehicles. In all likelihood, DRT would not have been conceived without the digital computer, because the complexity of the real-time scheduling and routing problem was such that it was naturally adaptable to computer solution.

The returns from the first few years of DRT implementation called into question the technological basis of this innovation. Whereas computer technologies were an integral element of the most visible projects (Haddonfield, New Jersey; Ann Arbor, Michigan; Rochester, New York; and Santa Clara County, California), it turned out that most DRT systems—at least those that did not have many vehicles—operated successfully with little or no computer technology. Moreover, it quickly became apparent that the cost of full automation of the DRT control system was quite high and not usually cost-effective (*2*). Finally, the market appeal of DRT was far less than had been anticipated. The high level of assumed market penetration, however, had led to estimates of a ridership level that could only be adequately served by full automation of the DRT control system.

Fortunately for the dial-a-ride concept, experience with DRT has demonstrated that it has the capability of being "reinvented" by implementors to adapt to changing needs and circumstances (*3*). The technological underpinning of DRT was one of the first attributes to undergo reinvention. As the evidence accumulated of the lack of need for and relatively unfavorable cost-effectiveness of full computer automation of DRT, there was a strong trend toward technologically simpler DRT systems. Between 1975 and 1990, there were only a handful of attempts to implement technologically sophisticated DRT systems. In fact, the system implemented in Orange County, California, about 1980 is still the most technologically sophisticated DRT system in the country.

Not only did the technology of DRT become much simpler, the very nature of the service also underwent reinvention during the late 1970s and the 1980s. Whereas almost all implementations of DRT before 1975 featured immediate response service for the general public, most DRT systems implemented during the 1980s required users to reserve trips at least 1 day in advance and restricted ridership to certain population groups (elderly, handicapped, or clients of particular agencies). Advance reservation systems represent a significantly different type of DRT operation from immediate response systems.

As a result of these two major changes in DRT operations over the past 20 years—the virtual abandonment of full automation of the control system and the strong trend toward advance reservation systems—the technology of the typical DRT system today is different from that envisioned by the developers of this mode. With the exception of the Orange County DRT system, the state-of-the-art technology for DRT consists of computerized reservations and scheduling software of varying degrees of sophistication, primarily oriented toward meeting the requirements of advance reservation systems. Whereas the computer hardware is vastly more powerful than that used 20 years ago, the software is better written, and the user interface of the software is undoubtedly easier to work with, in virtually all other respects the typical computerized DRT system today is significantly less technologically sophisticated than the Rochester dial-a-ride system implemented in 1976. [Wilson and Colvin (*4*) describe the computerized DRT system implemented in Rochester.]

Recent developments in hardware and software, however, have created the potential for another technological reinvention of DRT, which would return this mode to its technological roots at a vastly improved level of cost-effectiveness and performance. This potential to "reengineer" DRT, using what is essentially off-the-shelf hardware combined with incremental improvements in software, is stimulating renewed interest in DRT technologies and is the subject of this paper.

TECHNOLOGICAL BASIS OF DRT

The developers of DRT had a vision of how this public transit mode would operate. Figure 1 shows that vision as it existed in the early 1970s. [The source document for the original vision of DRT was prepared by Roos et al. (*1*)].

A computerized reservation, scheduling, and dispatching system served as the heart of the DRT operation. An advanced telephone system would link the patron to an order taker, who would enter the relevant trip information into the computer. A sophisticated algorithm in the computer software would determine the best vehicle to assign to the trip, taking account of the effects of the trip assignment on previously assigned passenger trips. An estimated arrival time for the vehicle would be generated and communicated to the patron. The trip order would be transmitted digitally via radio frequency to the vehicle to which it had been assigned, where it would be displayed on a terminal or printed on a printer. The driver would be able to communicate digitally with the control room through some sort of keyboard/terminal device. It was hoped that an automated system for keeping track of the location of all the vehicles in the system could be included, although the precise nature of the vehicle locator technology was not specified. All information entered into or generated by the system would be stored in data bases, from which it would be retrieved to generate reports on the operation of the system.

To summarize, the originators of DRT anticipated that the following technologies would be used:

- Digital computers,
- Scheduling/dispatching software,
- Digital communication between control room and vehicles via radio frequency,
- In-vehicle video terminals or printers,
- Vehicle location system, and
- Data base systems to store information and generate reports.

This vision of DRT was never fully implemented during the early 1970s, although the Rochester system, which became operational in 1976, contained some form of all of these features except automated vehicle location. The Orange County Transit District's (OCTD's) DRT system, implemented beginning in 1980, also corresponds reasonably well to the above description, again with the exception of automated vehicle location technology. Only the OCTD system is still operational; it represents the sole example in the United States of a DRT system with sophisticated technological features (although the computer hardware and software it uses are antiquated by current standards). The cost of the Rochester project was $3.6 million (not all of this was for technology), and the cost of developing the OCTD system was $2.6 million. In both cases most of the cost was borne by the federal government.

DEEMPHASIS OF AUTOMATED TECHNOLOGIES FOR DRT

There were three primary reasons why the initial vision of DRT did not achieve widespread acceptance. First, it proved much more difficult and expensive to develop the system outlined above than the originators of DRT had anticipated. The computer technology—both hardware and software—of 20 years ago was much less sophisticated and far more costly than that of today. Today, a desktop computer costing less than $3,000 can outperform the computers used in the early DRT systems, which had costs in the range of hundreds of thousands of dollars. Moreover, the software for computerized DRT systems had to be custom developed, including all of the data base and reporting systems.

Second, experience with real DRT systems quickly demonstrated that they did not require sophisticated technologies to operate successfully. Manually scheduled and dispatched systems in Michigan and California achieved system productivities of six to eight passengers per vehicle service hour, which exceeded the productivity level of the computerized systems in Rochester and Haddonfield.

Third, and perhaps most significant, the disappointing ridership of actual DRT systems made technological sophistication both unnecessary and cost-ineffective in most cases. Put simply, DRT did not generate enough demand to warrant systems with large numbers of vehicles, and absent this requirement there was no compelling reason to invest in computer and other electronic technologies for the DRT system (*2*).

As a result of the experiences in the 1970s, the technology of DRT was sharply downscaled. Manual scheduling and dispatching and the use of voice radio communications became the standard mode of operation, and few systems evidenced any serious interest in computerization of functions (other

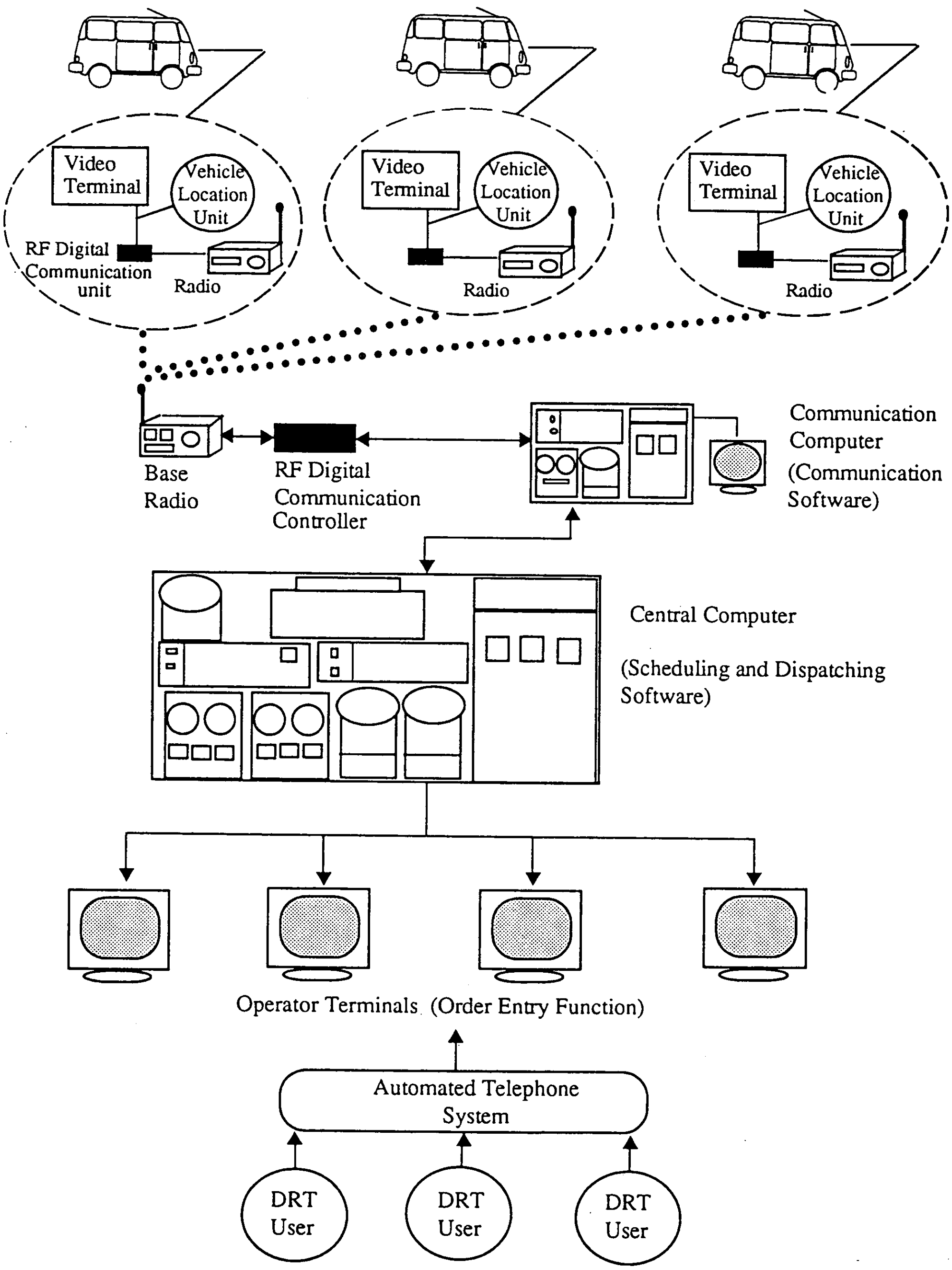

FIGURE 1 Concept of DRT, about 1970.

than record keeping). By the early 1980s, DRT had become a technological backwater.

NEW ERA OF TECHNOLOGICAL POSSIBILITIES

DRT has only recently begun to emerge from its technological hiatus. Several developments during the 1980s proved instrumental in restoring interest in automating various aspects of DRT operations.

One key development was the strong trend toward advance reservation systems. Ironically, even though this represented an abandonment of the cornerstone of the original dial-a-ride concept—real-time scheduling and dispatching of trip requests—it eventually created new needs for computerization. Promoted in part as a method for simplifying the scheduling and dispatching tasks of a DRT operation, advance reservation systems sufficiently complicated the DRT scheduling problem that, beginning in the mid-1980s, DRT systems turned to software solutions. Currently, there appear to be at least 100 to 150 DRT systems that have installed computer software to automate at least some of the reservations/scheduling/dispatching function. None of these systems, however, is as sophisticated as the OCTD DRT operation implemented more than a decade ago.

The second major reason why automation returned to DRT was that it became much more affordable. Because of the revolution in computer hardware that occurred in the 1980s, the hardware platforms for the DRT scheduling packages—primarily personal computers—cost only a small fraction of their 1970 counterparts. Moreover, DRT scheduling software became much less expensive, with some packages selling for as little as $5,000 for a single-computer version and $15,000 for a networked-computer version.

Developments in the taxi industry have also rekindled interest in DRT automation. After resisting computer control of their operations during the 1970s and early 1980s, a number of large taxi companies purchased computerized dispatch systems during the late 1980s. These systems feature automated assignment of vehicles to trip requests, full data base and reporting capabilities, and digital transmission via radio of dispatch messages and other information to in-vehicle data terminals (usually referred to as mobile data terminals). These systems have proven cost-effective in performing the dispatching function for large taxi operations.

Because the algorithms that control the taxi dispatching systems are vastly simpler than those used in DRT scheduling/dispatching software, they are not directly transferable to DRT operations. Nonetheless, they have demonstrated to the paratransit industry the benefits of automation of the control function.

TECHNOLOGIES FOR REENGINEERING DRT

Although the gap between actual practice and current technological possibilities remains large, it has become clear that currently available technologies offer the potential for another major reinvention of DRT. Since the prospective changes involve a return to the original technological foundation of DRT, it is perhaps more accurate to refer to this process as reengineering rather than reinvention. This reengineering holds the promise that large numbers of DRT systems will eventually operate as the developers of this mode intended, but in a much more cost-effective manner than was possible previously.

The most important technologies involved in this reengineering are the following:

- Computer hardware systems,
- Mobile computers and data terminals,
- Radio frequency (RF) data communication devices,
- Vehicle locator devices,
- Mapping software,
- Relational data base systems, and
- Card-based data storage and transfer media.

These seven technologies represent the foundation on which a new generation of DRT systems is likely to be built during the remainder of the 1990s. The key developments in these areas are examined below.

Computer Hardware Systems

Improvements in performance, reductions in cost, and ease of connectivity of computer hardware have become so commonplace that it is easy to underestimate their significance for DRT. The improvement in cost-effectiveness of computer hardware for DRT is in the range of one to two orders of magnitude (i.e., between 10 and 100 times). A handful of networked microcomputers have significantly more computing power than the computer hardware used in the Rochester and OCTD systems and cost less than 10 percent as much. By networking personal computers or UNIX workstations, enough processing power can always be made available for even the most complex scheduling/dispatching software. Consequently, the cost of computer hardware is hardly ever a serious constraint on automation and improved functionality for a DRT system of any significant size.

Mobile Computers and Data Terminals

The revolution in computer hardware has also made possible the development of relatively powerful and inexpensive in-vehicle computers. In-vehicle computers, also referred to as mobile computers, usually have the computing power of at least an 8086-class microprocessor (IBM-XT class) but are approximately the same size as a car radio and can now be purchased for less than $2,000. An in-vehicle computer has a keypad with varying number and types of keys, a display terminal, possibly a built-in or attached printer, and some type of communications link to the central computer, possibly an on-line real-time communications connection. In-vehicle computers can also usually be connected to other devices useful in the transportation environment, such as automatic vehicle location units and card reader/writers.

When used in a DRT application, in-vehicle computers collect data generated in the course of operations, process data, display messages to drivers, and communicate digitally with a host computer system. Mobile computers can also be hand-held computers. Rather than being mounted in the vehicle, a hand-held computer is simply used inside the vehicle. General purpose hand-held computers are currently in the same general price range as in-vehicle computers, although they typically lack connections to printers.

The advantage of mobile computers is that by placing computing power directly in the vehicle, it becomes possible to create more robust and flexible applications—and to support automation of functions without being in continuous communication with the central computer. In an advance reservation DRT system, for example, a day's worth of schedules can be loaded into an in-vehicle computer at the beginning of the day, and the driver can then work independently of central control, except for changes or additions to the schedule, which are communicated via an RF modem link.

Mobile data terminals have also become widely available and are now extensively used in the taxi industry with computerized dispatching systems. Because these data terminals cannot function effectively without being in communication with the central computer, they either contain a built-in RF modem or are connected to such a device. They can hold several dispatching messages and can usually transfer a small amount of data—sometimes no more than a few bytes of status information—from the vehicle to the central computer. Although less powerful and versatile than in-vehicle computers, simple mobile data terminals are nonetheless adequate for certain DRT applications. Moreover, they are less expensive than in-vehicle computers, typically costing less than $1,000 per vehicle.

RF-Based Data Communications Systems

A revolution is occurring in data communications systems with the development of so-called wireless networks. These are data communications systems that rely on RF channels (including cellular radio frequencies) for local transmission rather than physical connections such as telephone lines. For longer-distance transmission, additional telecommunications infrastructure is used. Wireless technologies allow computers and other communication devices to exchange data without being physically connected to a data communications network and thus represent a quantum increase in the flexibility of data communications systems.

The wireless revolution is the backdrop against which developments in RF modem technology are occurring. Currently, RF modems work on the same principle as telephone modems. Digital information (the 0's and 1's of binary data) is encoded by a device into an analog signal, which can then be transmitted over some communications medium to a decoding device at the other end of the channel, where it is converted back into digital data. An RF modem differs from a telephone modem in that it uses radio waves to carry the signal from one location to another. Because RF channels are inherently "noisier" than telephone channels and because of regulatory restrictions on the bandwidth of the carrier signal, RF data transfer is invariably a slower, more error-prone mode of data communication than using telephone lines or direct connections. Most RF modems operate at data transfer rates of 4,800 baud or less, whereas telephone modems typically communicate two to four times faster.

Although RF modems are slower and more expensive than telephone modems (whose price has dropped to below $100 for basic versions), they are becoming increasingly available at reasonable costs and at relatively high speeds. RF modems of 4,800 baud can be purchased for less than $1,000, and RF modems of 1,200 to 2,400 baud cost a few hundred dollars. The latter price is substantially less than the cost of the radio with which the modem will interface. Thus high cost is no longer a serious barrier to the use of digital data communication for DRT operations. In addition, digital cellular modems are just being introduced and may become a viable option if cellular transmission prices are significantly reduced in the future.

Digital RF communication can also occur via digital radios, which are radios with modems integrated into the internal circuitry. Because these radios are specifically designed for digital communication, they are able to operate at higher speeds (e.g., 8,000 baud) than separate RF modems. Their disadvantage is that they cannot also support voice communications, and this limits their utility for DRT applications.

The advantage of digital data transmission for DRT is that it makes much more efficient use than voice transmission of the limited capacity radio channel in transmitting dispatch messages from the control center to the driver in the vehicle. In addition, if real-time data are to be efficiently returned from the vehicle to the control center, digital data communication is essential. The developments in RF technology, therefore, complement developments in the area of mobile computers and data terminals.

Vehicle Locator Devices

The ability to precisely locate vehicles can be of significant value to DRT systems using computerized scheduling and dispatching. By knowing the exact location of vehicles at the time a passenger trip is assigned to a vehicle, it may be possible to improve system productivity, since the proximity of a new trip request to a vehicle's current location on its tour can be better exploited. Until recently, however, vehicle location technology was expensive, and no DRT system to date has used so-called automated vehicle location (AVL) technology.

AVL technology has become markedly more cost-effective during the past year as the result of two developments. First, a U.S. government system of geopositioning satellites (GPSs) has now achieved adequate coverage of the continental United States. This satellite system continuously broadcasts highly accurate positioning information; the satellite signals can be received by any antenna tuned to the appropriate frequencies. The use of these signals is absolutely free, since the U.S. government provides the entire GPS infrastructure.

Second, the cost of GPS receiver units has declined significantly during the past 2 years. A complete GPS receiver can now be purchased for less than $1,000, and a GPS antenna costs an additional $100 to $150. More significantly, circuit board GPS units (which actually contain all of the logic components of the GPS receiver) can now be purchased for $300 to $500 in quantity and can be readily interfaced to an in-vehicle computer to provide the same functionality as a full GPS receiver.

These developments make AVL technology affordable. An end user can purchase the in-vehicle component of AVL technology (mapping and control software is also necessary for a functional system) for only a few hundred dollars per vehicle when the GPS receiver unit is interfaced with other in-vehicle components. AVL systems based on GPS technology have begun to appear in the market and will in all likelihood become the dominant AVL technology. Whereas other types of AVL technology exist, they are usually superseded in accuracy and cost-effectiveness by systems based on GPS.

Mapping Software

An AVL system is only as good as its mapping interface. Simply obtaining locational information is of little value unless that information can be displayed on an electronic map of the service area and manipulated on command. Recent developments in mapping software have fundamentally altered the cost-effectiveness and ease of development of these mapping interface systems, to the pronounced advantage of DRT operations.

As recently as 2 to 3 years ago, most mapping interface systems were expensive pieces of software running on UNIX workstations or minicomputers and using expensive full-function geographic information systems as their foundation. Such systems could cost $100,000 or more when linked to applications software such as computer-assisted dispatch of public safety vehicles.

Today, the leading desktop mapping software package costs approximately $1,000 and runs on a standard personal computer, an application development system can be purchased for a few hundred dollars more, and Census Bureau–based electronic maps of any county in the United States cost less than $250 each. A relatively robust map-based application can be developed in a few weeks by a single programmer. The mapping software can be integrated with a microcomputer-based relational data base system that uses industry standard file formats. Consequently, mapping software and applications using this software have become cost-effective and available to virtually any organization.

For DRT, the major application of electronic mapping is for map-based interfaces to computer-assisted dispatching and for vehicle location systems. The DRT dispatcher can observe on a computer terminal precisely where vehicles are located at the time a trip request is assigned to a specific vehicle.

Relational Data Base Systems

Over the past several years, the data processing industry has adopted a standard data base technology, which now dominates data base systems on computers ranging from mainframes to personal computers. This is the relational data base system. Virtually unused 10 years ago, this technology has rapidly become the industry standard because of its technological superiority over competing types of data base systems.

With relational data base systems, complex applications can be created that are relatively inexpensive. They provide impressive functionality and can be readily modified. Moreover, many applications can be ported to different operating systems and hardware platforms without undue effort and expense. DRT software constructed using these systems as the foundation—as is increasingly done for scheduling/dispatching software—can thus be much more user friendly, powerful, and cost-effective than was the case several years ago. In fact, commercial relational data base systems were simply unavailable at the time of the early implementations of computerized DRT systems.

Card-Based Data Storage and Transfer Technologies

Just as the magnetic stripe card has fundamentally altered the way individuals and businesses conduct their financial transactions, a new generation of card-based technologies may have a similar impact on consumer transactions. This new generation of card technologies is generally referred to under the rubric of "smart cards." This loosely used term refers to three different types of card technologies, all of which can store and alter data but differ in their ability to process the data.

At the low end of the spectrum is the simple stored value memory card. The data on this card can be both read and altered, but the memory is extremely simple and essentially supports a single type of data. In Europe and Japan, telephone stored value memory cards are widely used; a display unit on the telephone indicates to the user how much value remains on the card. The stored value fare cards used in the BART and WMATA rail transit systems are more basic uses of this technology.

More complex memory cards, which can store much more data (as much as 1 megabyte or even more) as well as different types of data on different locations on the card, are available. Such memory cards have been used by public transit operators in Germany to transfer data from the vehicle to the central computer and vice versa.

A "true" smart card is one containing an embedded microprocessor as well as an area for data storage. Most current smart cards can store 8,000 to 24,000 bits (approximately 1,000 to 3,000 bytes) of data. The embedded microprocessor is what gives the smart card its "smarts"—it can actually process data on the card. Relatively few smart card applications to date, however, have taken advantage of this capability, other than for simple functions such as incrementing and decrementing numeric data stored on the card. Another important attribute of the smart card is the additional security it provides compared with conventional magnetic stripe technology—it is possible both to encode data and to prevent unauthorized access to the data on the card.

There are three fundamental advantages of smart cards over magnetic stripe cards. First, they can store much more information. Second, and more important, the data stored on the card can be altered. Third, the embedded microprocessor can execute computer programs that operate on the data on the card.

The major disadvantage of smart cards is their cost. They require a much more complicated card reader—which is actually a reader/writer—than do magnetic stripe cards, and this device costs a few hundred dollars per unit. In contrast, a magnetic stripe card reader costs less than $25. In addition, the cards themselves are relatively expensive, currently costing $6 to $10 each, depending on features (such as photo ID), for cards of 8K to 16K bits.

Because the performance advantage of smart cards comes at a relatively high price, they are likely only to be used where the application requires the ability to alter the data on the card at the time the consumer interacts with the system. To date, the only public transportation implementation of smart cards in the United States has been in the Chicago Transit Authority's paratransit system for the disabled, where smart cards are used both as an electronic purse and to transfer passenger information to hand-held computers in the vehicle.

FUNCTIONAL REQUIREMENTS FOR REENGINEERED DRT SYSTEMS

DRT was developed as a "real-time" public transportation mode, that is, a means of transportation that could be configured at every moment to the requirements of its users. Consequently, the key functional requirements of a reengineered DRT system revolve around real-time assignment of vehicles to trip requests and real-time data communication between the control center and the vehicle. At the same time, a reengineered DRT system must support all three major types of trip requests: immediate response, standing orders (subscription), and advance reservation. The vehicle-scheduling algorithms must be capable of inserting prebooked trips into vehicle tours that are developed in real time.

To most efficiently use the RF communication channel, information must be transmitted digitally from central site to vehicle and vice versa. This includes dispatching messages sent to the vehicles and data and status information sent back to the central site. Voice communication must also be available. In most cases, the driver's routing decisions should be determined by the computer software; stop sequencing should be under system control. Messages displayed on the terminal in the vehicle should direct the driver to the next location (street level routing can be left to the driver or suggested by the computer).

There should be a simple, efficient, and reliable means of obtaining data about users and their specific trips at the time they access the system (i.e., board the DRT vehicle). A system in which DRT users carry cards containing passenger and fare information is most efficient for this purpose, but this requirement must also be met in systems where passengers do not use cards. This requires communication between the central computer and some type of intelligent in-vehicle device. In addition, the central computer should be able to determine the status of any vehicle or passenger at any time; passengers should be automatically tracked as they move through the system.

Finally, a reengineered DRT system should support any reasonably complex fare structure (e.g., based on zones, straight line mileage, time of day, etc.), a fully automated accounting/billing system allowing multiple funding sources to be billed for different users for different types of trips, and a comprehensive and fully automated data analysis and reporting system. Both data collection and the system of data flows should be fully automated. Participants in the system should not have to write down information or enter data into the computer after the fact; all information should be obtained in real time and stored in computer data bases, either in the vehicle or at the central site.

To summarize, the functional requirements of a fully reengineered DRT system are the following:

- Real-time scheduling and dispatching of trips;
- Ability to handle advance reservation and subscription trips;
- Real-time digital data communication between vehicle and central site;
- Voice radio capability for nonroutine circumstances;
- Computer control of vehicle routing (stop to stop) decisions;
- Computer monitoring of vehicle and driver activities;
- Automated in-vehicle collection of data on passenger trips;
- Automated tracking of passengers in system;
- Automated determination of approximate or exact location of any vehicle in system;
- Automation of all routine data collection and analysis activities;
- Automated fare calculation, billing, and financial accounting capability;
- Automated generation of management and government reports; and
- On-line access by system administrator to continuously updated information on all aspects of system operations.

PROFILE OF A REENGINEERED DRT SYSTEM

On the basis of the preceding functional requirements and the actual availability of hardware and software, it is possible to describe the operation of a reengineered DRT system. The only element of this system that cannot be implemented using off-the-shelf technology is the real-time scheduling/dispatching software. The other components of the system are already operational, often in numerous settings—although not usually DRT systems.

Figure 2 shows an overview of this reengineered DRT system. Not surprisingly, this figure bears a great deal of resemblance to Figure 1, the vision of DRT of 20 years ago. The major differences are the addition of the in-vehicle computers (which had not even been conceived of in 1970) and the downsizing of the computer hardware at the central site. The mapping interfaces to the AVL and vehicle dispatch systems also represent new features compared with the system of 20 years ago. What cannot be seen in the comparison of Figures 1 and 2 is the dramatic improvement in cost-effectiveness and performance of the component technologies over the past 20 years.

Most of the operations in this hypothetical but realistic DRT system are fully automated. A user calls on the telephone to place a trip order, and as soon as the order entry clerk has entered the individual's last name, the computer supplies the passenger record. This includes a list of the five most frequent trips (origin and destination addresses) made by this user. The order entry clerk finds that one of these previous trips is exactly the same as the current trip request and simply moves to that trip and enters it into the system. The computer calculates a fare for this trip. After a wait of a few seconds, during which the computer determines which vehicle to assign this trip to and calculates the new vehicle schedule, the computer informs the order entry clerk that the vehicle will pick up the passenger 35 min from now, with a window of 5 min before and 10 min after the promised pickup time. The order entry clerk informs the passenger of the pickup time window and the fare, and the trip booking transaction is complete.

Behind the scenes, the scheduling/dispatching software generates a dispatch message and sends it over the network to the communications computer. The communications computer transforms this dispatch message into an encoded data packet and delivers the packetized message to the network controller RF modem, which deciphers the message to determine to which vehicle to send it and then transmits the data packet to that vehicle using the RF channel. The modem in the vehicle receives the data packet, checks for errors, and, on determining that the data are correct, returns an acknowledgment to the network controller modem. The communication computer is informed that the message has been successfully delivered to the vehicle.

Back at the vehicle, the modem transmits the data packet to the in-vehicle computer, which decodes the data and then displays the text message on the display terminal. The driver acknowledges acceptance of this trip by pressing a button on the display terminal, and the trip acknowledgment is sent back to the central computer. Software in the in-vehicle computer places this trip request into the proper order of stops, making adjustments to the current stop sequencing if necessary.

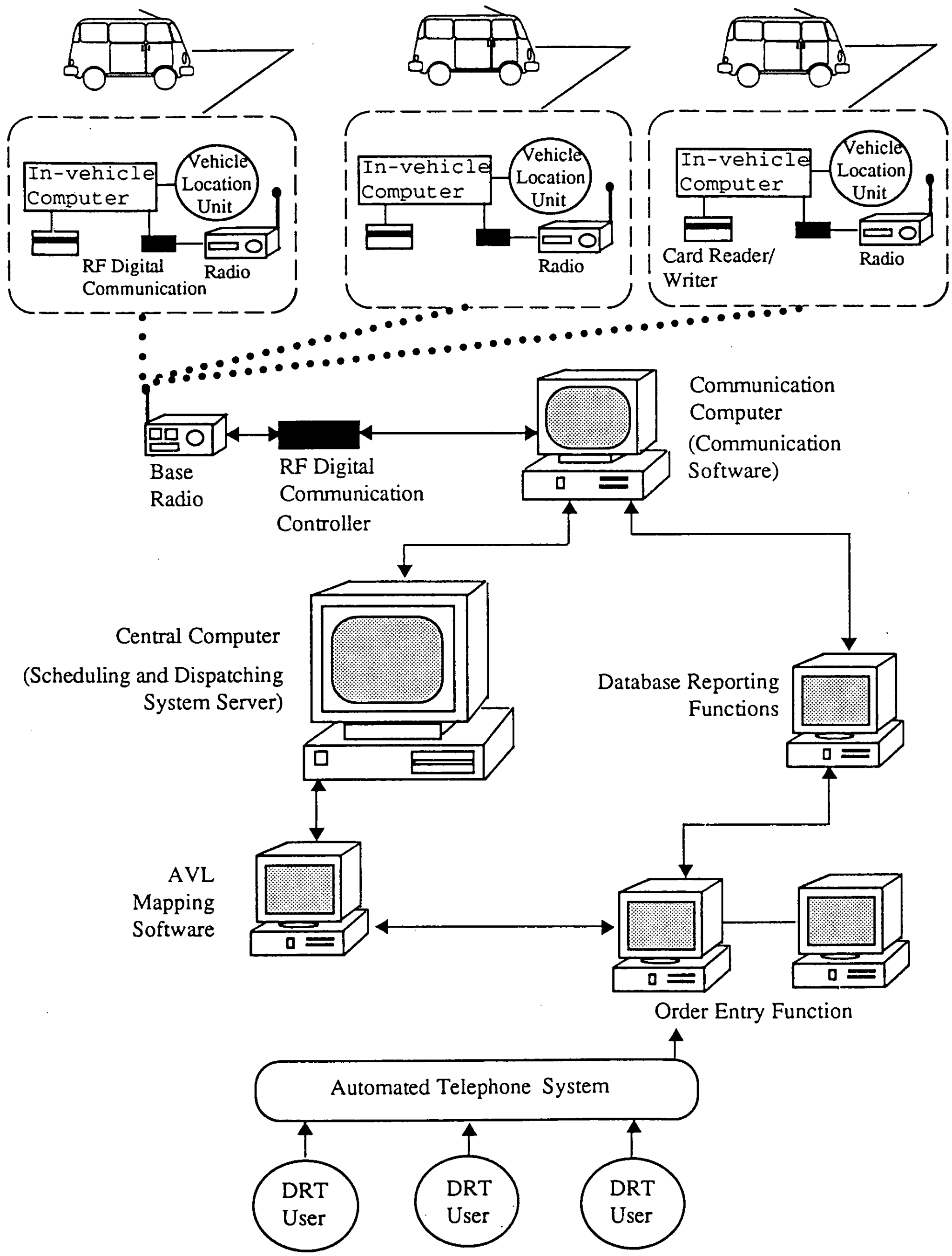

FIGURE 2 Concept of reengineered DRT.

In some cases, the software in the central computer decides to use the AVL system to obtain precise information on the location of the vehicles that are candidates to serve the trip. It requests the communications computer to poll the in-vehicle computers in the vehicles selected as the best candidates for trip assignment. A request is sent to each of these in-vehicle computers to transmit its current location, which is being continuously updated by the GPS receiver unit. Within a few seconds, the locational data are delivered back to the central computer, where the scheduling algorithms use them to assign a vehicle to the trip request.

The in-vehicle computer directs the driver how to proceed along the vehicle tour. At each stop, the display terminal informs the driver where to proceed next; the driver can also scroll through the next two or three stops. As changes are made to the vehicle's schedule, they are eventually reflected in the in-vehicle computer's directions to the driver.

Automation also encompasses passenger processing in the vehicle. On boarding the vehicle, the passenger hands a combination identification/fare payment card to the driver, who inserts it into a card reader/writer where passenger and fare information is extracted. The in-vehicle computer now knows that this passenger is on board and will track the trip. On arriving at the destination, the passenger again hands the card to the driver for insertion into the card reader/writer, the appropriate fare is calculated and deducted from the stored value remaining on the card, and the passenger's trip record is completed. The in-vehicle computer now contains a complete record of the passenger's trip, including boarding and alighting times and odometer readings, the fare paid, and the payment medium. This data record can be sent by the in-vehicle computer back to the central computer as soon as the passenger trip is completed or whenever the system requests it. The in-vehicle computer is also continuously recording information about vehicle operations (speeds, time spent at stops, etc.) and driver activities, which is transmitted to the central computer on request.

During the course of the day, the dispatch supervisor in the DRT control center is able to monitor the status and performance of the system from a computer terminal. The central computer is continually receiving data from the in-vehicle computers about events occuring in the system.

At the end of the day, all of the data generated by the day's operations are loaded into the central computer's data base system from the in-vehicle computers, the scheduling/dispatching system, and the communications computer (many of the data are loaded during the day as transactions occur). Management reports are then generated as well as reports needed by government agencies that finance the DRT system. In addition to uploading data to the central computer, each in-vehicle computer is at this time loaded with a new list of customers who will have their fare cards replenished the next time they access the system. Any changes to system parameters are also downloaded to the in-vehicle computers. The system is ready for the next day's operations.

This is merely an overview of how a reengineered DRT system would operate. Many features of such a system have been ignored in this description, but it indicates the level of automation available for DRT operations.

COST-EFFECTIVENESS OF REENGINEERED DRT

This reengineered DRT system would cost surprisingly little compared with the normal capital costs of a DRT system. The in-vehicle component of this system could be purchased for less than $4,000 per vehicle, the data communications component for $10,000 or less (exclusive of the in-vehicle RF modems), and the central site software probably for $50,000 to $100,000; the latter estimate is the most uncertain due to the current absence of a real-time-oriented scheduling/dispatching software package. If computer-assisted dispatching software were used, the cost of the central site software would almost certainly be less than $50,000.

Reengineering a 20-vehicle DRT system would cost about $130,000 (exclusive of certain smart card system costs). Costs for each vehicle would be $3,100 to $3,600, categorized as follows: in-vehicle computer and software, $1,800; GPS receiver unit, $600; smart card reader, $300; and RF modem, $400 to $900. Other system costs would total $60,000: communications software and hardware, $10,000; data base reporting software, $5,000; AVL software, $10,000; scheduling/dispatching software, $25,000; and computer hardware upgrade, $10,000.

Reengineering a 75-vehicle system would cost somewhat more, assuming a higher price for the fully automated scheduling/dispatching software and the need for more high-performance computer hardware. Assuming that the central site software would cost $50,000 more and that hardware would cost an additional $10,000, the cost for reengineering this system would be $190,000.

The cost of smart cards and smart card processing software is not included in these estimates due to the large variation in cost depending on number of cards issued, features of the cards, and functionality of the smart card system. The additional cost could range from $25,000 for the 20-vehicle system to $150,000 or more for the 75-vehicle system.

To put these costs in perspective, the capital costs for vehicles for the 20-vehicle system would be at least $500,000 (assuming $25,000 per vehicle) and for the 75-vehicle system would be $1,875,000. The computer and electronic components would have a useful service life at least as long as the vehicles, so they can be amortized over the same time period. Thus reengineering adds 26 percent (and 30 percent or more when all smart card system costs are included) to the capital costs of the 20-vehicle system and about 10 percent (and as much as 18 percent with all smart card system costs) to the capital costs of the 75-vehicle system. The benefits from reengineering—in reduced labor costs for data collection and reporting and improved system productivity, to cite the most obvious—would almost certainly outweigh these additional costs over a 5-year period, and probably much sooner.

Seen from another perspective, the amortized cost of reengineering the 20-vehicle system is $0.125 to $0.150 per passenger trip (depending on smart card system costs) using a 5-year life, 8 percent interest rate, 300 service days per year, 10 service hr per day, and 4.5 passengers per vehicle service hour. For the 75-vehicle system, the cost of reengineering is $0.05 to $0.09 per passenger trip. The most productive DRT systems in the United States have passenger trip costs of $3 to $4; more typical costs are $5 to $8 per passenger trip, and some systems have cost levels exceeding $10 per passenger trip.

From this perspective, the cost of reengineering DRT is extraordinarily low, particularly if the result is improved vehicle productivity. If reengineering improved a system's productivity by merely 5 percent, this alone would pay for the additional cost within 1 to 2 years. And this does not include the labor cost savings made possible by automating the entire data collection, analysis, and reporting function. Developments in technology over the past decade have thus made the initial technological vision of DRT a highly cost-effective alternative to a typically configured current system.

ACTUAL DEVELOPMENTS AND FUTURE PROSPECTS

The DRT system outlined above does not exist today. Nonetheless, some actual or planned systems contain several of the features of this system. The Chicago Transit Authority's paratransit system for the disabled, for example, uses smart cards and hand-held computers. Although it is 12 years old, the OCTD DRT system uses in-vehicle data terminals, digital data communication, and real-time scheduling and dispatching software. The Los Angeles County Transportation Commission is moving toward the development of an AVL system for all public transportation vehicles in Los Angeles County, including paratransit, and is considering equipping at least some of the paratransit vehicles in the county with in-vehicle computers or data terminals. Several other large transit agencies are considering equipping their paratransit fleets (or those of their contract operators) with in-vehicle computers or data terminals. In Medford, Oregon, a Federal Transit Administration–funded demonstration encompassing 30 vehicles includes requirements for in-vehicle computers or data terminals, RF-based digital data communications, and a smart card system.

These developments indicate that reengineered DRT is not merely a technological possibility, but also an increasingly attractive option to the government agencies responsible for organizing and funding DRT services. Transit planners are beginning to discover that the technologies for a new generation of DRT systems are both available and affordable and that technologically simplistic DRT is not necessarily more cost-effective than technologically sophisticated DRT. Moreover, vendors are now marketing these technologies specifically to the paratransit industry. And real-time scheduling/dispatching systems are beginning to be seriously discussed again. These are other indicators that a DRT technology shift may be near.

It is ironic that at a time when DRT appears to have finally achieved widespread acceptance as a transit mode, the typical DRT system is quite backwards technologically compared with the initial vision of DRT, a vision stimulated by technological developments that occurred more than 20 years ago. Nonetheless, as the paratransit industry becomes educated about the operational and cost-effectiveness advantages of these technologies, and as the results of actual experiences with them become widely known, it is likely that increasing numbers of DRT systems will find it advantageous to reengineer their operations.

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