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### Publication Date

2004-04-01

CALIFORNIA PATH PROGRAM  
INSTITUTE OF TRANSPORTATION STUDIES  
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# **Personalized Demand-Responsive Transit Service**

**Randall Cayford  
Y.B. Youngbin Yim**

**California PATH Research Report  
UCB-ITS-PRR-2004-12**

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department of Transportation, Federal Highway Administration.

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Final Report for Task Order 4102

April 2004

ISSN 1055-1425

# **Personalized Demand-Responsive Transit Service**

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## **Abstract**

Providing easy access to the public transit service is the goal of the California transit agencies. Many travelers cannot take an express transit because they often cannot park and ride. Smart DRT (demand responsive transit) Feeder is a system that collects transit riders from neighborhoods and takes them to transit stations. This system will use APTS (Advanced Public Transit System) technologies to make the feeder service convenient and reliable. The concept is very simple. When demand is high, Smart Feeder will use the fixed-route fixed-schedule service. When demand is low, it will use the on-demand service. For the on-demand service, customers will use an automated dial-a-ride system or the Internet for making a reservation or receiving a confirmation. Feeder vehicles will be equipped with Automated Vehicle Location (AVL) and on-board wireless computer devices. The first part of this paper describes the results of a user survey on the demand for and on the desired characteristics of a Smart Feeder system for the city of Millbrae. The second part of the paper describes the resulting design and implementation of the automated dial-a-ride system that will be used for the demand responsive transit service. The system uses an automated phone-in system for reservations, computerized dispatching over a wireless communication channel to the bus driver, and an automated callback system for customer notifications. User requests for pickup are collected and a computerized scheduling system acts as a broker between the multiple user requests and the transit agency to determine the optimal departure time and route that minimizes customer wait time and maximizes the number of passengers per trip. The system requires no dispatchers and operates in real time without requiring advance reservations.

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## Introduction

Transit access is an important transportation issue in California. BART and Caltrain in the Bay Area have identified finding solutions to transit access problems as being high priority. Although BART access modes vary greatly by station, over 80% of BART riders drive to and from the station in suburban communities. While express transit is gaining ridership, consumers are increasingly experiencing limited access to transit due to saturated parking at and around stations and inadequate local transit services. Local transit services can provide critical access by gathering and distributing local residents to and from express transit stops. In low density or low demand neighborhoods, however, fixed route / fixed schedule buses are inefficient as they make many circuits with few, or no, passengers. Demand responsive transit (DRT) services are a proposed solution for local transit in such neighborhoods. A widely held perception, however, is that these services are unavoidably expensive. The high cost of on-demand trips is a result of the inability “to maximize the use of vehicles and personnel by spreading the cost of a given trip over a greater number of passengers.”

The smart feeder/shuttle is an alternative travel mode to personal vehicles; it provides easy access to express transit services and local activity centers. Smart-feeder/shuttles can fulfill the criteria of the ADA (Americans with Disabilities Act), which require demand responsive transit services. The project designed a smart feeder/shuttle system to replace AC Transit Route 87 in Castro Valley. The smart-feeder concept is that by integrating new technologies into local transit, services can be made more efficient, lowering costs, and more responsive, increasing customer satisfaction. The key technologies to be integrated include automatic vehicle location (AVL) using global positioning satellite (GPS) positioning, computerized dispatching, wireless communications between drivers and operators, variable message signs, and customer notification systems.

This project consisted of two phases. The first phase examined the user demand for a DRT type system in the city of Millbrae, California. The study focused on the demand for different kinds of systems and on operational parameters, such as hours of operation, for a DRT service. The second phase of the research focused on the design and implementation of an automated DRT system where real-time scheduling of transit service is determined by user demand. This DRT system uses an automated phone-in system for reservations, computerized dispatching over a wireless communication channel to the bus driver, and an automated callback system for customer notifications. User requests for pickup are collected and a computerized scheduling system acts as a broker between the multiple user requests and the transit agency to determine the optimal departure time and route that minimizes customer wait time and maximizes the number of passengers per trip. The system requires no dispatchers and operates in real time without requiring advance reservations. The next phase of this project will coordinate with AC Transit to operate a one year field test of the DRT system, develop additional software modules for transit management and performance measurement, examine institutional and community issues raised by the introduction of DRT service, and conduct before and after studies measuring the effectiveness and reception of the service.

## Background

Transportation diversity, including a variety of demand responsive transit services, is highly desirable because increased transportation diversity increases alternatives to automobile use. Current subsidies to maintain transport options indicate society's willingness to pay for improved transport diversity, transit subsidies average about 50 cents per passenger-mile and are higher in lower-density, suburban areas where such subsidies are justified almost entirely by equity and option value. Even with subsidies, transit services are limited, sometimes uncomfortable and often stigmatized. Thus, transit subsidies do not reflect total transportation option value. Society would be willing to subsidize transit even more if it provided a higher level of service. Society should similarly value other modes that provide comparable equity and option value benefits, such as rideshare programs that improve mobility for non-drivers. The value of transportation diversity is the incremental financial savings from improved transportation options. Households in automobile dependent US urban regions devote more than 20% of household expenditures to surface transportation (over \$8,500 annually), while those in communities with more balanced transportation systems spend less than 17%, under \$5,500, annually (1). Among the benefits of transportation diversity are: improved access for people who are economically, physically or socially disadvantaged, increased transportation affordability, cost savings for users and public agencies, increased mobility if another component of the transportation system fails (2).

Demand responsive transit includes a diverse set of services both public and private. Much of the past focus on demand responsive transit services has been on paratransit services. In the 1970s, paratransit was thought to be the answer to providing transit service for all users in low-density and low-demand areas where the conventional transit services were not cost-effective. This thought was based partially on the assumption that computerized control would make paratransit efficient. Unfortunately, the technology of that time did not meet the challenge. In 1990, the Americans with Disabilities Act of 1990 (ADA) required communities to provide access to the elderly and handicapped population. The ADA put all public transit operators into the paratransit business. Because transit funds are limited, paratransit became the only public transportation in many small cities. Since the federal mandate came without additional funding, there has been a great deal of work on the search for cost-effective methods to operate paratransit services. Research has been conducted on rider training and on new ways to market transit services. Paratransit requires changes to organizational structure, internal procedures, and the use of technology in transit agencies and research has been done in all these areas. Investigation into future systems has examined the deployment of a range of services in different geographic areas, at different times of day or days of week, and with differentiated pricing structures to make public transit more attractive while increasing overall system efficiency. (3)

Successful examples of demand responsive transit are available; some are expanding their operation and others are discontinued because supply cannot keep up with demand. In Summit County, a low cost paratransit service was successfully deployed to improve the mobility of senior citizens and visitors; the program is accessible to disabled persons to meet the ADA requirement as well as to the traveling public. Summit Stage Paratransit began with



one dedicated vehicle operating seven days a week and has recently added another vehicle in response to increased demand. Drivers use radio contact with fixed route transit so that if necessary a transfer may be arranged. The service is very popular with its clients and is widely accessible to disabled persons. The service began in 1993 and it continues to expand. (4)

Another success case of demand responsive service is in Santa Clara County, California. In 1978, the nation's largest dial-a-ride mass transit system with door-to-door service, which was regarded as an innovative model, was abolished within six months after its opening. "Curiously, it failed not because it proved the popular axiom that mass transportation can't compete with the automobile, but because it was more successful in luring riders than its originators expected it to be." The county supervisors found that more than twice as many buses and double the original budget were necessary to make it work; the county thought it cost too much to keep the service. With a telephone call, any of the county's 1.2 million residents could reserve a bus to come and pick him up. Computers were used to identify which of dozens of buses were cruising closest to the caller's home. Then, the bus took the caller to the doorstep of his destination if it was not far away. (5)

In 2000, Yim investigated the consumer response to personalized demand responsive transit (PDRT) service (6). Six focus group meetings were held in three communities in the San Francisco Bay Area. Subsequently, a Bay Area-wide telephone survey was conducted among randomly selected households. The question was why a personalized transit system appeals to commuters. The focus group and telephone survey showed that the idea of the DRT system holds a lot of appeal to commuters. Overall, people liked PDRT for exclusivity and personal attention to their needs. They liked the idea of a service that would be tailored to their own schedules, giving them the flexibility to go to work a half hour later or stay a half hour later, or leave work earlier if they needed to. That aspect of the service felt very convenient to them, and represented an opportunity to lessen the stress in their lives by making their commute more pleasant. They liked a service that is limited to only a few passengers per van, being driven by a safe and professional driver who is taking them door-to-door. Some parents even said they would consider the service as a safe and convenient way to provide transportation to their older children, who often need to be picked up from school or from after-school activities. They also believe the van would pick up other people in their own neighborhood, giving them an additional sense of comfort and security about their fellow van passengers. Another appeal of the system for the Park and Ride participants is that it would prevent them from having to deal with big crowds and rushing to ride public transit. For the Drive Alones, many of them liked the idea of having someone else drive, and saving the wear and tear not only on their car, but also on themselves. Sitting in traffic every morning and evening is stressful, and being able to sit in a comfortable seat and read the newspaper while being driven to their destination definitely appeals to many of these people. The survey showed that 15% of the 1000 telephone survey participants were very interested in taking a shuttle to work or to their desired destinations. Sixty percent said that they would consider using a demand responsive shuttle service.

## **Project Objectives**

Demand responsive services are suitable to low density and low demand neighborhoods. A widely held perception, however, is that these services are unavoidably expensive. The high cost of on-demand trips is a result of the inability “to maximize the use of vehicles and personnel by spreading the cost of a given trip over a greater number of passengers.” A coordinated system provides the ability to link trips and passengers between various agencies and expands the pool of potential riders. There is a need to develop an innovative demand responsive system to provide easy access to potential transit riders.

Transit access is an important transportation issue in California. BART and Caltrain in the Bay Area have identified the access problem as being high priority. Although BART access modes vary greatly by station, over 80% of BART riders drive to and from the station in suburban communities. While express transit is gaining ridership, consumers are increasingly experiencing limited access to transit due to saturated parking at and around stations and inadequate local transit services. Over 70% of BART riders are commuters and all BART stations have parking problems. Many commuters have decided to drive to and from work because park and ride becomes increasingly difficult and local transit service is inadequate. The Bay Area surveys showed that 15% of the respondents would take BART if easy access were provided.

A smart-shuttle/bus is an alternative travel mode to personal vehicle; it provides easy access to express transit services and to local destinations. The smart-feeder/shuttles may also replace ADA required demand-responsive transit services where appropriate. Our innovative shuttle concept includes the following features:

- 1) Shuttles collect express transit riders from neighborhoods and take them to transit stations. Conversely, shuttles will also pick up express transit riders and distribute them to neighborhoods.
- 2) Shuttles provide a combination of fixed and flexible services. During peak hours or high demand periods, the shuttles will be operated with fixed route and fixed schedule services. During off-peak hours and low-demand times or locations, the shuttles will be operated with flexible routes and schedules. Many variations of these routing and schedule schemes are available (Cedar and Yim 2002). The selection of appropriate schemes depends on the demand and characteristics of each community.
- 3) Shuttles provide convenient transfers between a shuttle and BART by synchronized schedule and transit coordination.
- 4) The computerized dispatching system determines optimal scheduling in order to accommodate all riders and minimize trips.

Shuttle operations rely on advanced public transit system (APTS) technologies. These include an automated vehicle location (AVL), advanced traveler information system (ATIS), and automated dial-a-ride (ADART) system. The schedule synchronization between transit modes will be done by coordinating real-time arrival/departure of transit modes through advanced communication systems.

Originally, three potential field test sites were selected to conduct an analysis of the smart feeder system (7). The sites were Castro Valley in Alameda County, Glen Park in San Francisco, and the City of Millbrae. The city of Millbrae was selected as the site for conducting a latent demand study. Routing strategies and synchronized transfers between main and collector transit systems were developed for both Millbrae and Castro Valley. Castro Valley was selected as the best choice for a field test of the DRT system and a feeder system was designed and developed to serve that area as a replacement of the existing Route 87 bus line.

## **Part 1: Millbrae Demand Study**

The first part of the project was an examination of the potential for a smart shuttle service for the City of Millbrae. The city offers multi-modal opportunities to its residents and employees. There is a Caltrain station in Millbrae; adjacent to it is the new BART station, which is scheduled to be opened in December 2002. An airport shuttle between the Caltrain/BART stations and SFO is expected to attract many travelers besides the residents of Millbrae.

A growing concern for public transportation is its inability to encourage people to switch their mode of transportation from solo driving to shared driving. As cities expand, transit ridership decreases while auto ownership increases. Although overall transit ridership is declining in cities, an encouraging trend is an increased ridership in long-haul express bus or rail transit. When long-haul express transit systems were built in the 1970s and 1980s in California, parking facilities were also provided for the riders to park their cars and ride a train. The concept of “park and ride” was readily accepted by the public and a large number of commuters preferred to take an express bus or train to avoid rush hour traffic and high parking costs. As the regional economy grew and more jobs became available, commuters increasingly relied on the express transit service. Bay Area Rapid Transit (BART) is a good example. In 1999, BART carried 285,000 commuters each weekday, compared to 255,000 in 1992 (an 11.7% growth over seven years). Automobiles continued to be the major access mode to BART. Approximately 80% of the park and ride BART customers parked in the BART parking lots while the remaining 20% parked off-site around the BART stations on residential streets.

A smart-shuttle is an alternative travel method to personal vehicle or bus transit for short-haul feeders. The smart shuttle concept has the potential for improvement of transportation accessibility for those who may not want to drive or take a bus to express transit stations. It would also provide transportation services for those elderly and handicapped who need to make trips to downtown Millbrae or to other activity centers for business or shopping.

The potential of a smart shuttle system to serve the needs of Millbrae was evaluated by conducting a latent demand study (or market study) to estimate the potential riders of the smart shuttle. Also examined were possible routing strategies to attract transit customers.

In April and May 2002, a two-page questionnaire was sent out to the residents of Millbrae via their utility bills. Of the 6,000 questionnaires distributed, 900 residents have responded. We were able to obtain a 15% of return rate, which is typical of this type of survey. In August 2002, a survey of employees was conducted by distributing a similar survey questionnaire to employees. Of the 300 questionnaires distributed, 904 employees have responded. The return rate was 30%.

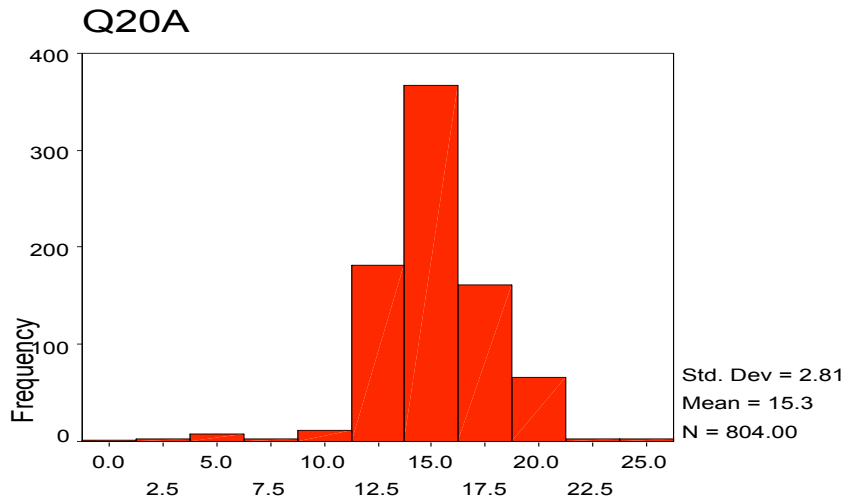
## Survey Results

The survey results are presented in two parts: responses obtained from 900 households and 904 responses obtained from employee working in the City of Millbrae. Reported are demographic characteristics of the respondents and the willingness to use the smart-shuttle service.

### Household Survey Results

Demographically, the sample was highly educated (Figure 1) and financially well off. This part of San Mateo County is among the middle and upper-middle income communities in the Bay Area and commuters typically are driving to well paying professional or highly specialized jobs in San Francisco. The sample is a representation of those who live in the suburbs of San Francisco Bay Area.

Figure 1. Education (years of education completed)



Q20A

Years of Education Completed (median=16 years)

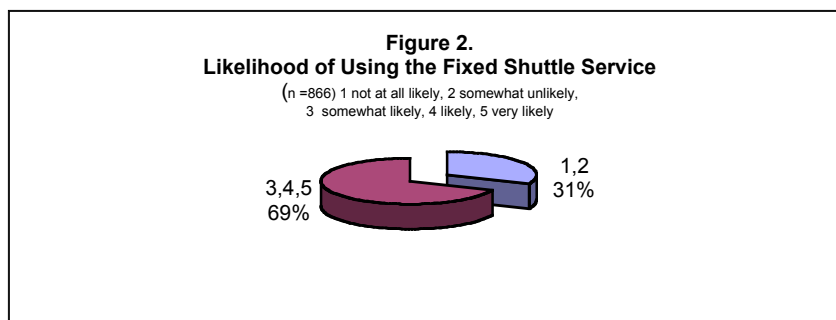
(Q20A = survey question number)

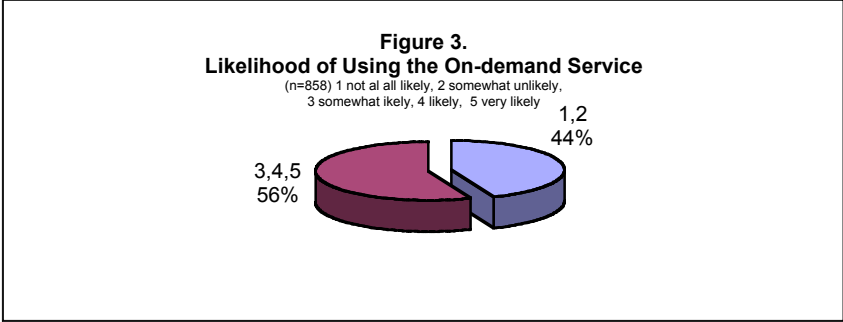
Approximately half of the participants (48.5%) commuted to work or school. Of those, 54% made five or more trips per week, 23.2% made three to four trips per week and 22.5% made one to two trips a week. The vast majority (79.5%) of the commuters drove to work alone. Only 3% of them carpooled while 6.2% took public transit. Nearly half of the respondents said that they have two cars in their household. The sample is representative of adults (18 years old or older) living in the City of Millbrae.

### Demand for a shuttle service

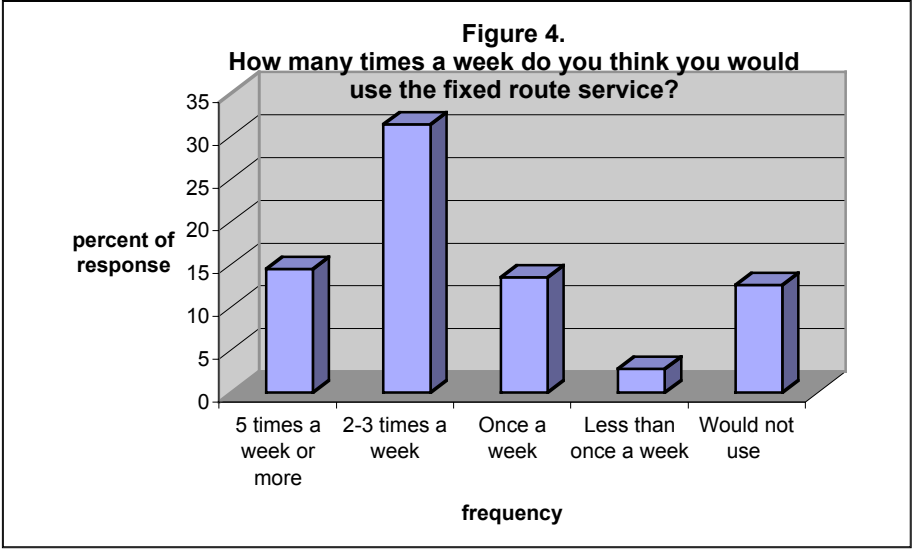
Two types of shuttle services are being considered: an on-demand service, which would require a customer to make a reservation to be picked up at a specific time, and a fixed route service, which would operate on a schedule and stop at specific locations much like a public bus service. Assuming that the shuttle service is offered at a fare that is acceptable to City residents, with acceptable wait, travel, and scheduling times, and pick-up and drop-off locations, survey questions were how likely would the customers be to use the on-demand or fixed service and how frequently would they use the service?

Using the one-to-five scale; five being very likely and one being not at all likely, 69% of the respondents said that they are likely or somewhat likely to use the fixed route service while 56% said that they are likely or somewhat likely to use the on-demand service (Figures 2 and 3). These percentages include the scale of three (somewhat likely), four (likely), and five (very likely). The cross-tabulation showed that only 9.1% are “very likely” to use both on-demand and fixed services. It also indicated that customers who are likely to use the fixed route service are not likely to use the on-demand service ( $p < .05$ ).





When asked how many times a week do you think you would use the fixed route service, 14.5% of the respondents said that they would use a shuttle five times a week, 31.4% said two to three times a week, 13.5% said once a week, 2.8% said less than once a week and 12.6% said they would not use the shuttle at all (Figure 4).



When asked how many times a week do you think you would use the on-demand service, 7.7% of the respondents said that they would use a shuttle five times a week, 21.8% said two to three times a week, 14.2% said once a week, 37.2% said less than once a week and 19.2% said they would not use the shuttle at all (Figure 5).

When asked how many people in your household are likely to use a shuttle, over one third of the respondents said that two persons in their household would use it while one third said that only one person would use it. The median number of people likely to use a shuttle per households is two persons (Figure 6).

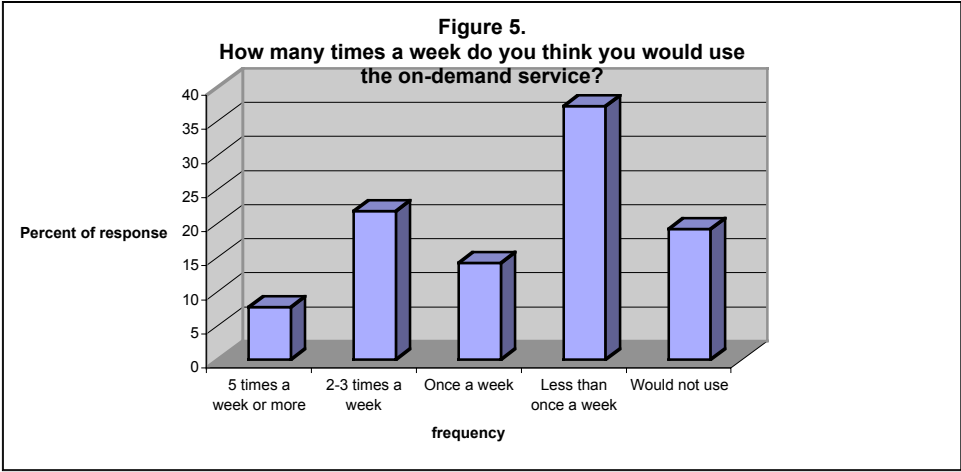
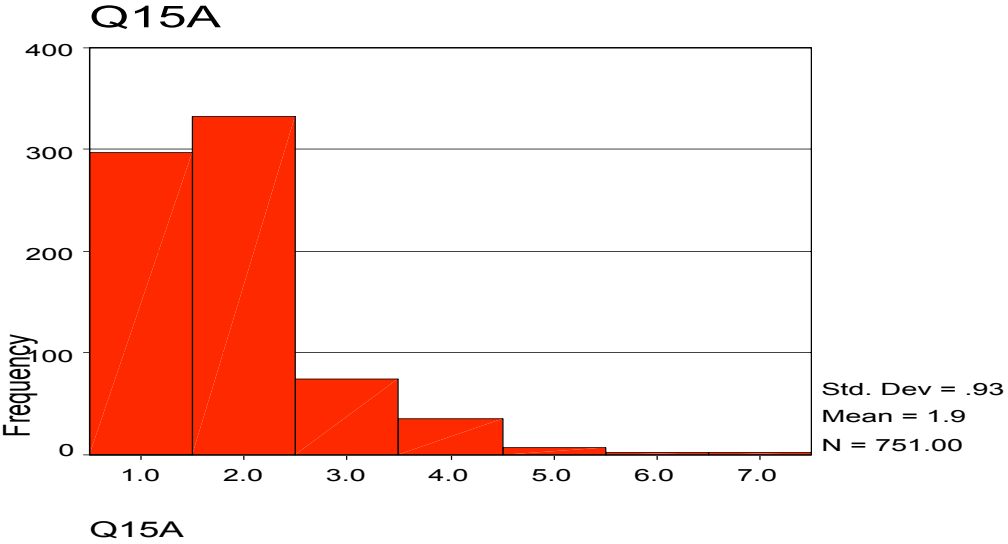


Figure 6. Number of people likely of using a shuttle per household



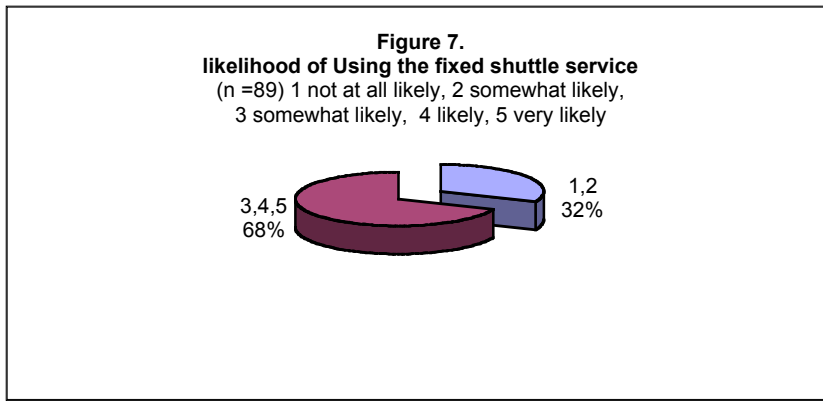
Number of people (median = 2)

(Q15A= survey question number)

## Employee Survey Results

The employees survey shows that the vast majority of the people working in the City of Millbrae are employed full time (92.9%). The number who responded was evenly split between male and female. The median education of these employees is college graduate or higher and the median age group is between 45 –54. The median number of cars per employee’s household is two vehicles.

As in the case of the Millbrae residents, most employees commute to work by their personal vehicles. Of those surveyed, 82.1 drive alone, 2.4% carpool, and 7.1% take transit. Most employees commute five or more times a week.



### Demand for a shuttle service

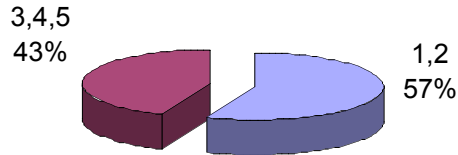
Responding to two types of shuttle services, an on-demand service and a fixed route service, the fixed route service is far more favorably received than the on-demand service. Using the one-to-five scale; five being very likely and one being not at all likely, 67.9% of the employee respondents said that they are likely to use the fixed route service and 42.8% said that they are likely to use the on-demand service (Figures 7 and 8). These percentages include the scale of three (somewhat likely), four (likely), and five (very likely). Similar to the City residents’ responses, the cross-tabulation showed that 41.7% are likely to use both on-demand and fixed services. The cross tabulation also showed that people who are likely to use the fixed service are different from those who are likely to use the on-demand service among employees ( $p < .05$ ).

When asked how many times a week do you think you would use the fixed route service, 21.5% of the employee respondents said that they would use a shuttle five times a week, 33.3% said two to three times a week, 6% said once a week, 16.7% said less than once a week and 16.7% said they would not use the shuttle at all (Figure 9).

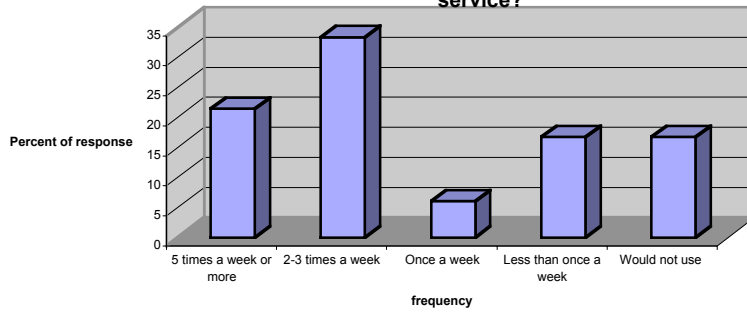


**Figure 8.**  
**likelihood of Using the on-demand servic**

(n=858) 1 not at all likely, 2 somewhat unlikely,  
 3 somewhat likely, 4 likely, 5 very likely

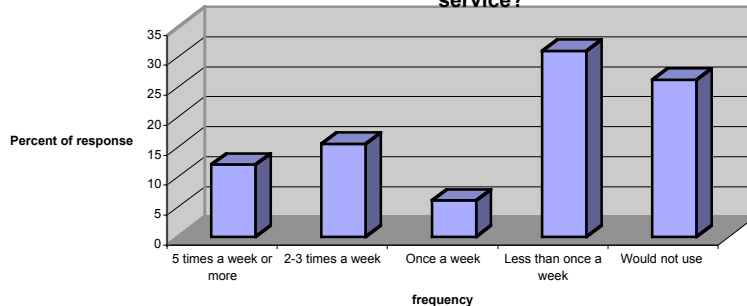


**Figure 9. How many times a week do you think you would use the fixed route service?**



When asked how many times a week do you think you would use the on-demand service, 12 % of the employee respondents said that they would use a shuttle five times a week, 15.5% said two to three times a week, 6 % said once a week, 31% said less than once a week and 26.2% said they would not use the shuttle at all (Figure 10). The survey suggests that employees were somewhat less likely to use the on-demand service than the City residents were.

**Figure 10. How many times a week do you think you would use the on-demand service?**



## Forecasting Demand for a Shuttle Service

Demand for a shuttle service is related to several factors. These factors include consumer interest in using a shuttle, service attributes, and demographic and trip characteristics of the community including origin and destination of individual trips and modal split of travelers. The logistic regression model has been commonly used as a tool to estimate latent demand for a transportation mode. In logistic regression, we estimate the probability of an event occurring. Therefore, the probability of an event occurring (i.e., mode choice of taking a shuttle) can be written as:

$$\text{Prob (taking a shuttle)} = \frac{1}{1 + e^{-(B_0 + B_1X_1 + B_2X_2 + \dots + B_pX_p)}} \dots\dots\dots(1)$$

Where

$B_0, B_1, B_2, \dots, B_p$  = coefficients estimated from data

$p$  = number of independent variables

$e$  = the base of the natural log (2.718)

Alternatively the logistic regression model can be written as:

$$\text{Prob (taking a shuttle)} = \frac{1}{1 + e^{-Z}} \dots\dots\dots(2)$$

For example, if:

$$Z = -1.784 - 1.182(\text{auto/licensed drivers/HH}) - 0.571 (\text{age 45-54}) - 0.562 (\text{commute distance}) + 0.19(\text{income}) + 0.903 (\text{auto/licensed driver}) - 0.927 (\text{commute})$$

$$Z = 1.582 + 1.261(1) - 0.571 (1) - 0.562 (1) + 0.19 (1)^1 + 0.903 (1) - 0.927 (1) = 1.876 \dots\dots(3)$$

Then,

$$\text{Estimated Prob (taking a shuttle)} = \frac{1}{1 + e^{-(1.876)}} = 0.386 \dots\dots\dots(4)$$

Based on this estimate, we can predict that the people in this group are likely to take a shuttle with the estimated probability of 0.39. The probability of not taking a shuttle is 0.61 (that is 1-0.39).

What's shown above is an example that we can estimate the number of people likely to use a shuttle using the logistic regression model. However, this type of modeling requires an extensive statistical analysis and trial and error exercises in order to ensure that data would fit

well with the model. Therefore, a simpler model is used to estimate shuttle demand for this report. It is our intent that the survey data will be analyzed using the logistic regression model later.

The model used for the preliminary estimate of the daily shuttle patrons can be expressed as:

$$P = LH \left( D + \frac{1}{2}S + \frac{1}{5}N \right) \dots\dots\dots(5)$$

$P$  = the number of daily shuttle patrons

$L$  = the percent of respondents who are very likely to use a shuttle

$H$  = the number of total households in Millbrae

$D$  = the percent of respondents who would like to use a shuttle five times a week or more

$S$  = the percent of respondents who would like to use a shuttle 2-3 times a week

$N$  = the percent of respondents who would like to use a shuttle once a week

Using this model, the estimated demand for the fixed-route service amongst households is:

$$0.24 * 8,234 \left( 0.14 + \frac{1}{2}(0.31) + \frac{1}{5}(0.14) \right) = 637 \text{ persons} \dots\dots\dots(6)$$

We assumed that only one fifth of the estimated demand would be realized in Phase One.

Therefore, the estimated daily fixed-route shuttle patrons among households are 125 Persons

The estimated demand for the on-demand service amongst households is:

$$0.19 * 8,234 \left( 0.08 + \frac{1}{2}(0.22) + \frac{1}{5}(0.14) \right) = 254 \text{ persons} \dots\dots\dots(7)$$

The estimated daily on-demand shuttle patrons among households = 50 (one fifth of 254)

If we consider that fixed-route and on-demand customers are somewhat mutually exclusive; we can say that the daily estimated shuttle patrons ( $R = 125 + 50$ ) among households are 175

persons. These numbers would increase as the service is better known to consumers and is perceived as being both efficient and convenient.

Using the same model, latent demand for employees can be estimated. The estimated demand for the fixed-route service among employees is:

$$0.25 * E \left( 0.21 + \frac{1}{2}(0.33) + \frac{1}{5}(0.06) \right) = 39 \text{ persons} \dots\dots\dots(8)$$

Assuming that  $E = 400$  employees

$E$  = number of employees working in the City of Millbrae

The estimated daily fixed-route shuttle patrons among employees are 39 persons.

The estimated demand for the on-demand service among employees is:

$$0.14 * E \left( 0.12 + \frac{1}{2}(0.15) + \frac{1}{5}(0.06) \right) = 11 \text{ persons} \dots\dots\dots(9)$$

The estimated daily on-demand shuttle patrons among employees are 11 persons.

The estimated daily patrons ( $E'$ ) among employees are 50 persons.

Since Phase One routing schemes cover the commercial districts, activity centers, and multiple residential areas, the total estimated daily patrons ( $P$ ) of the shuttle service are approximately 100 persons. The multiple residential areas cover 30% of the total housing units.

$$\begin{aligned} P &= 0.30 \times R + E' \dots\dots\dots(10) \\ &= (0.30 \times 175) + 50 \\ &= 102.5 \longrightarrow \text{approximately 100 daily patrons} \end{aligned}$$

Note: Total housing units in the City of Millbrae 8,238  
 Single family housing units 5,644; multiple family housing units 2,591

*Shuttle Routing Strategies*

Developing routing strategies involves field surveys and potential route investigation. Currently, there is no shuttle service provided to the city. A site observation was conducted

in August 2002 from which the base network was created and alternative routing schemes were developed.

It is recommended that the Millbrae shuttle service be developed incrementally; the first phase of the shuttle service is to cover activity centers, commercial districts, employment centers, and multi-family neighborhoods. The shuttle service can be expanded into residential neighborhoods as the service becomes better known and well utilized.

The alternative routing schemes shown in Figure 11 serve activity centers, commercial districts, employment centers, and multi-family neighborhoods. All routing schemes are considered to initiate at the Caltrain/BART station. Alternative routing schemes are developed using the information from land use maps, site visits and the City staff. Routing schemes in the residential districts will be considered in the next phase of the shuttle service planning. The first phase of the routing schemes are described as following:

Alternative 1 routing scheme: A → B → E → D → F → A 10:30 minutes

A shuttle starts at the Caltrains/BART station and travels through the El Camino business district, then runs around the multifamily residential district, then travels to the City Hall and major shops and the senior center on Magnolia Street, then travels on Millbrae Avenue and returns to the Caltrain and BART stations. The trip takes 10:50 minutes without counting boarding and alighting times.

Alternative 2 routing scheme: A → B → C → D → F → A 8:30 minutes

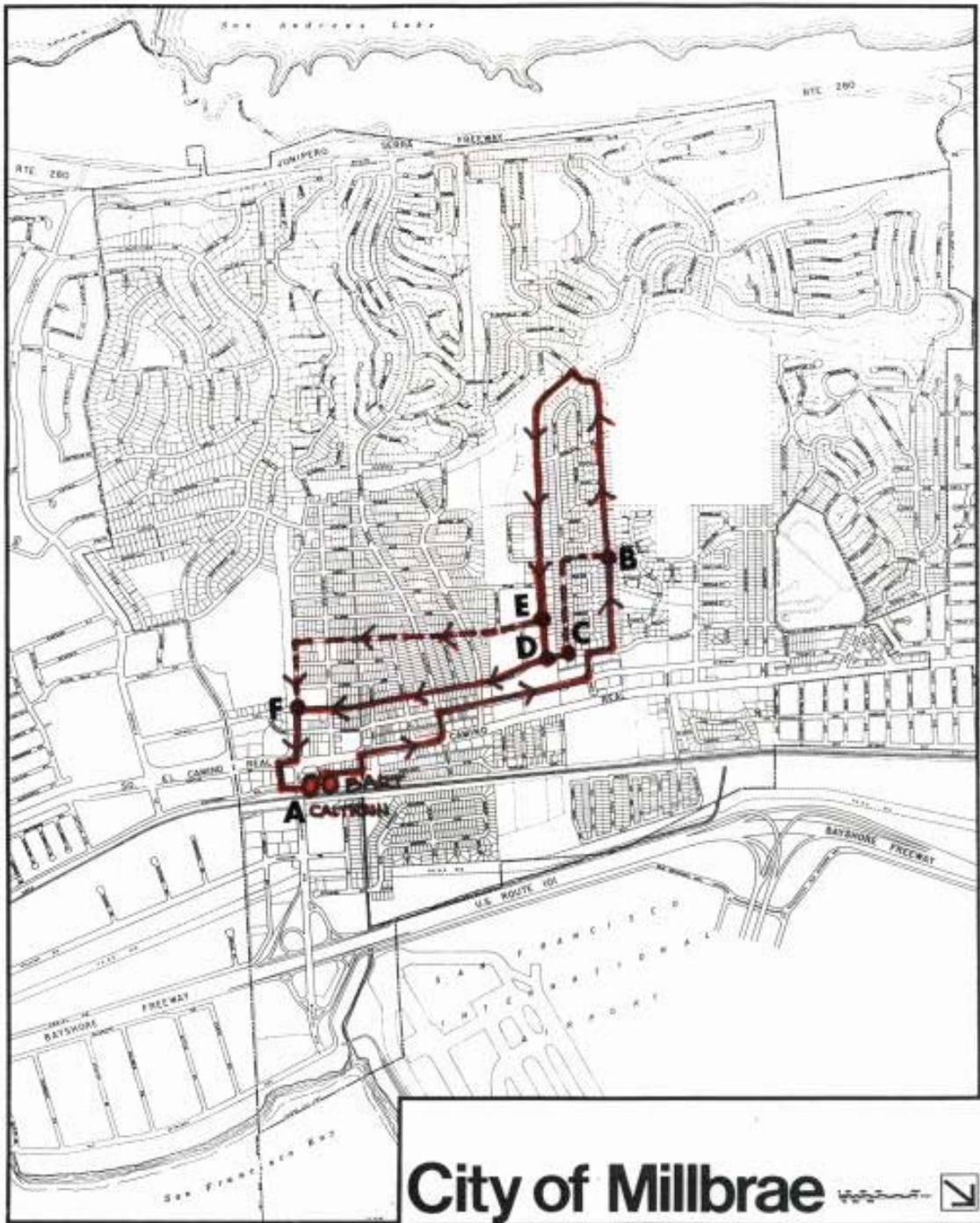
In this scheme, only a portion of the residential neighborhood will be covered. The shuttle trip will take 8:30 minutes without considering boarding and alighting times.

Alternative 3 routing scheme: A → B → E → F → A 11:30 minutes

This is a scheme to provide a shuttle service to a school on Magnolia Avenue via residential streets. The shuttle trip will take 11:30 minutes without considering boarding and alighting times.

Alternative 4 routing scheme: A → B → C → D → E → F → A 10:10 minutes

This scheme is similar to Alternative 2, but the routing will go to the school site. The shuttle trip will take 10:10 minutes without considering boarding and alighting times.



**Alternative Smart Shuttle Routes**

Alternative 1: A → B → E → D → F → A	10:50 minutes
Alternative 2: A → B → C → D → F → A	8:30 minutes
Alternative 3: A → B → E → F → A	11:30 minutes
Alternative 4: A → B → C → D → E → F → A	10:10 minutes

**Figure 11. Smart Shuttle Routing Alternatives**

## Part 2: Design and Development of the DRT system

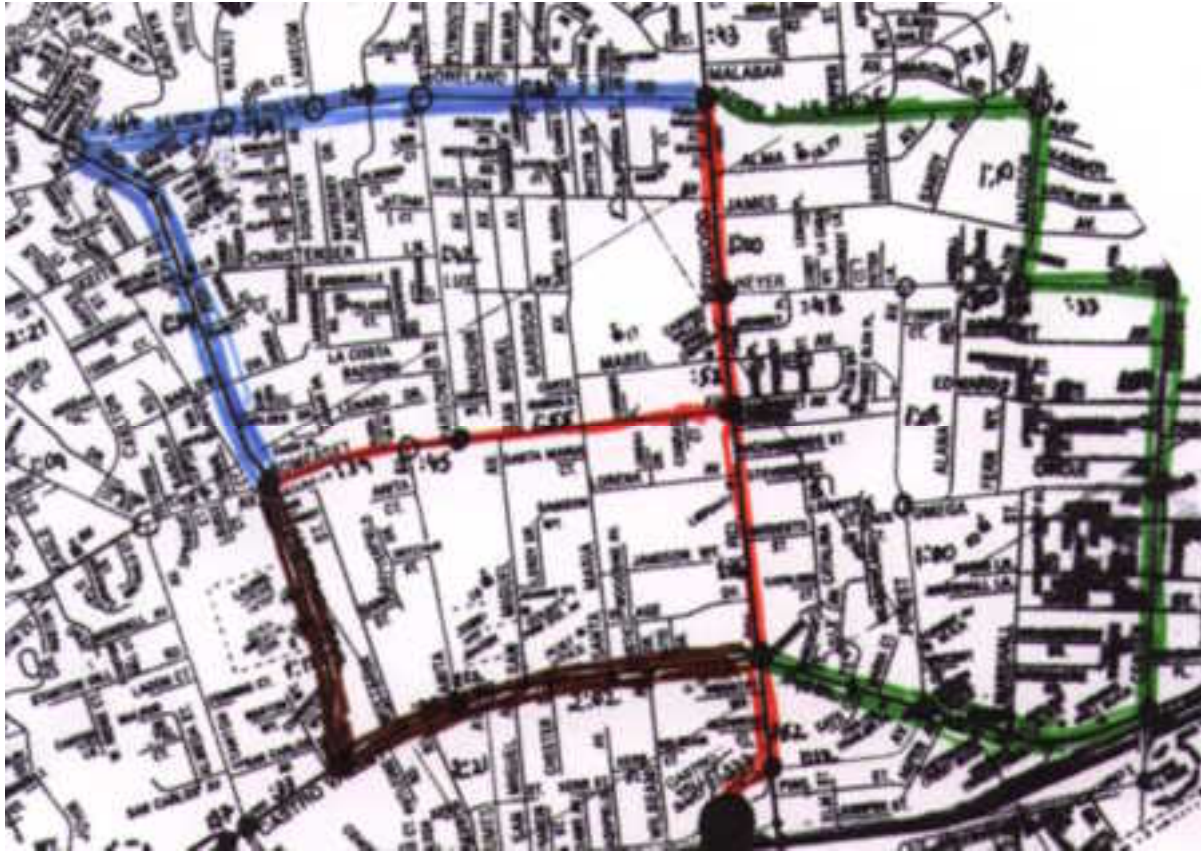
The city of Millbrae was the initial choice for a planned field trial of a smart feeder DRT system. Budget constraints on the part of the city, however, made implementation of a DRT field system very unlikely, at least in the short term. Consequently, the focus of the project shifted to Castro Valley, a small city in the San Francisco bay area. The proposed route for a DRT system follows the existing line, Route 87, which is a roughly square trip around downtown Castro Valley, including a BART station, and takes approximately 30 minutes. A significant use of the line is as a feeder service to the BART rapid transit station. There are two major streets bisecting the square that allow the route to be divided into three subsections.



**FIGURE 12 Existing Route 87 in Castro Valley.**

A series of meetings was held with AC Transit, the transit operator for Castro Valley. These resulted in an initial specification of a DRT system for a future field trial. Figure 12 shows the route of the current bus, Route 87. This line operates well during morning and evening peak periods but is very underutilized during the rest of the day. Based on this, the decision was made to implement a mixed fixed schedule/fixed route service during peak periods and a flexible schedule/fixed route service at all other times. Key requirements of the system were:

- No operators – fully automated reservations and scheduling
- Seamless transition between fixed schedule and flexible schedule operation
- Pickup and drop-off at existing stops only
- Ability to serve walkup (no reservation) customers
- Follow existing route except for three defined shortcuts (see Figure 13)



**FIGURE 13 Proposed DRT Route With Shortcuts.**

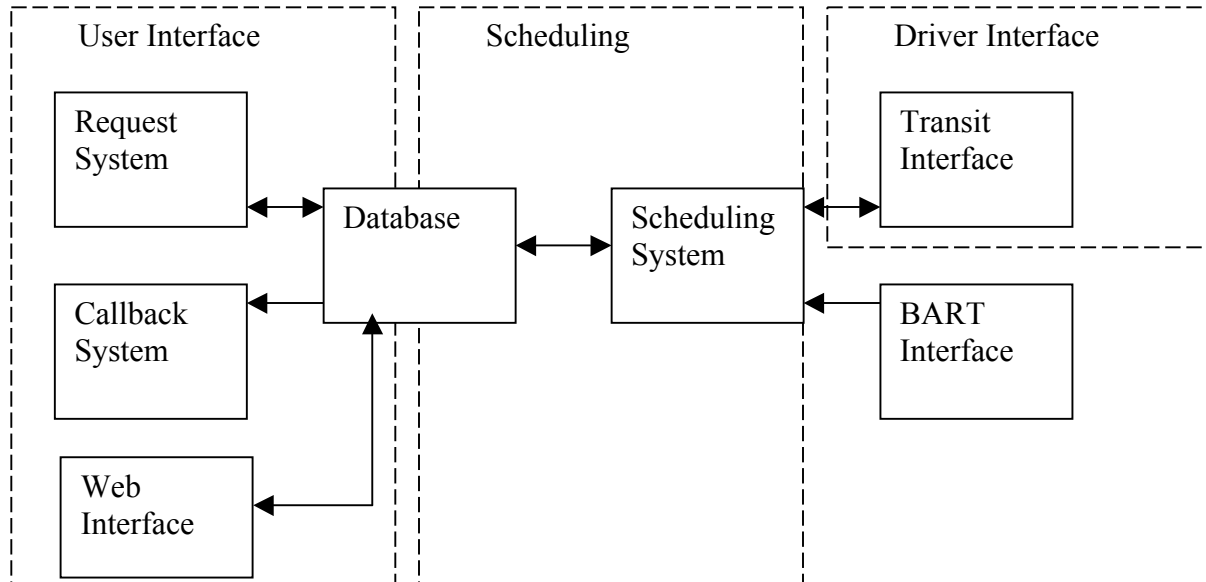
### **Overview of the User Driven Scheduling System**

The demand responsive system developed for this project takes a set of customer requests for pickup and drop-off at a preferred time, together with a variable time window around the preferred time, and schedules bus departures and routes to accommodate the set of requests. Once determined, departure and route information is transmitted to the bus driver. Figure 14 shows a block diagram of the major components of the system.

User requests for transit service are collected either through an automated phone entry system or through a web page. Each request has a stop number where the rider will be picked up, a preferred time and a call back phone number as well as additional information. As each request arrives, the scheduling system builds a set of trips, both routes to follow and departure times for the managed buses, which best accommodates that request and all prior



requests. Shortly before the bus is scheduled to depart, the schedule for that bus is frozen and the route and departure information is transmitted to the driver. Once the schedule is fixed, a confirmation call is made to the users who will take that bus specifying the expected arrival time at their stop.



**FIGURE 14 System Components Block Diagram.**

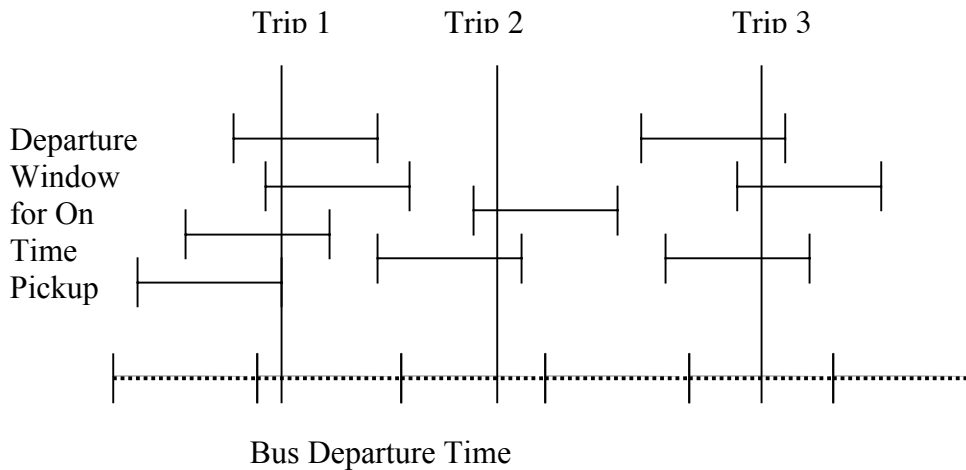
There are two user (customer) interfaces, a web interface and a phone interface. Both provide the same functionality though the web interface allows quicker data entry and better access to additional information. The phone interface uses a customized touch-tone menu system to collect information from the user. The web page uses a form-based web application.

The user enters information about their proposed travel: the route, the origin and destination stops, their preferred departure time and a call back number. The scheduling system will try to schedule a bus to arrive at their stop within 15 minutes plus or minus of the preferred time. If this cannot be done given the set of prior user requests, the closest available time is calculated and the user is given a chance to modify their preferred time.

As each request enters the system, the scheduling component attempts to build a provisional trip table that will accommodate all outstanding requests, including the new one. The scheduler generates trips and assigns users to trips based on their preferred times. The 30-minute time window around the preferred time allows the scheduler to shift the bus departure time and the expected arrival times at the user stops to group user requests onto a single trip. Figure 15 shows an example of this process. Each request has a time window and the scheduler attempts to add trips and shift the starting departure time so as to intersect as many of the request time windows as possible.

The scheduling process requires that all requests be gathered before the schedule is determined. This means that the arrival time at the stop for the first user request will not be

known until long after the phone call in which the request is entered. At the time of the request, all the user will know is that a bus will arrive at their stop somewhere within 15 minutes of their requested time. This requires that there be some way to notify the user once the actual arrival time has been determined.



**Figure 15 Scheduling Algorithm.**

User notification is primarily handled by an automated call back system. Once a trip has been finalized, the riders for that trip are called and informed of the expected arrival time at their stop. The call back is done at least 15 minutes prior to the expected arrival time to allow the rider time to walk to the bus stop. For users who cannot be called back, the web site shows the expected arrival times for each trip or the automated phone system can be used to query schedule information.

Once the departure time has been determined for a particular trip, the bus driver is notified. The driver interface uses a custom application running on a handheld Personal Digital Assistant (PDA) though some of the newer cellular phones are also sufficiently capable to be used. The PDA has wireless communications through the cellular phone network and provides two-way communication with the driver. Information flowing to the driver includes the departure time, the route, and the expected riders along with their stops and the times they are expecting to be at the stop. To accommodate walk up passengers, such as those standing at stops as the bus arrives, the driver interface allows the bus driver to enter information into the system about the passenger needed for the scheduler to deal with them. Figure 3 shows the entry screen for a walk up passenger on the Castro Valley route. Very little information about the passenger is needed - only destination information. Information sent to the driver only needs to be sent before the trip starts. Information sent by the driver is only sent as the passenger boards the bus. No information needs to be exchanged while the bus is in motion, which eliminates driver distraction issues.

The scheduling system determines, based on the origin and destination stops of the riders, which of the three subsections the bus will need to traverse. If there is no need to traverse one of the sections, the bus will take a shortcut back to the BART station rather than traversing the unnecessary portion of the route.

### **Components of the User Driven Scheduling System**

Figure 14 shows a block diagram of the major components of the DRT system. The components of the system can be grouped into three primary systems, components that provide the user interfaces, components for storage and scheduling, and the component for communicating with the bus driver. The system consists of the following basic components:

- A voice menu, touch-tone driven call in system for taking customer requests for pickup
- A call back system that notifies customers of expected bus arrival time
- A web application that provides an alternative reservation and notification interface
- A database for storing the requests, schedules and bus status
- A scheduling program which analyzes the requests and schedules bus runs
- A transit interface that communicates with the bus driver
- A BART interface that pulls in schedules and estimated arrival times of trains.

#### User Interfaces

The DRT system has two phone components: a touch-tone based call-in reservation system and an automated callback system. Both functions will be provided by a commercial software package. There are several commercial packages available that can be customized to support a DRT system. These are generally marketed as call center software. While voice navigation of the menu tree may be possible, the initial planned system would use touch-tones as a more reliable method of navigation.

The call-in reservation system is used to collect time and stop information for transit riders. While primarily for pick-up scheduling, it can also be used for scheduling drop-offs. The basic operation of the system consists of a menu tree of voice prompts that the user navigates by way of touch-tones. This is a standard interface for many customer/provider relationships so should be relatively familiar to many users. The phone script would run similar to:

#### Greeting

To request pickup press 1, Cancel pickup press 2, help press 9

Specify bus line by route number press 1, help 9

Enter bus line by number followed by the pound key

To enter the stop # press 1, To hear a list of stops press 2, help press 9

Enter stop # followed by the pound key

If you are traveling to the BART station press 1, if you would like to enter a drop-off stop press 2, help press 9

<present current scheduled arrival time if any>

Would you like to make the next possible pickup press 1, enter desired pickup time press 2, help press 9

Enter time as HHMM using leading 0s

<present results of schedule if available>

<present expected BART arrival times for both directions, if available>

Would you like a call back? Yes press 1, no press 2, help press 9

How many minutes prior to arrival would you like to be called? Enter MM#

Enter a phone number to reach you at, including the area code xxx-xxx-xxxx

Closing

The data collected from the user is, at a minimum, the bus stop or stops they wish to go to and the preferred time they wish to be picked up. Additional information such as a call back phone number may be collected if desired. Any information which may affect travel decisions, such as expected BART arrival times may be presented as well.

Once the user has successfully entered a reservation into the system, the entered data is written to the central database. The bus schedule is determined by the scheduling algorithm based on all entered reservations.

The second phone system is the automated callback system. This component notifies the customer once the final schedule for the bus has been determined and the arrival time at the desired stop has been set. The callback system uses the customer entered callback number and calls either at a pre-determined number of minutes before the bus is scheduled to arrive or calls a user-specified number of minutes prior. Allowing the user to specify how much in advance to be called allows for variable walking times from the user's location to the bus stop. There needs to be a maximum allowed prior time for the call-back because once a user has been called, no further changes should be made to the bus schedule. The assumption is that once the user has received the call, they leave for the bus stop and can no longer be reached. Thus, it is important that the arrival time at the user's stop not change.

A web application provides another interface to the reservation system. The web provides much quicker reservation entry and richer information about departure times and routes than can be provided through a phone system. However, its applicability is limited to a relatively small group of users and limited to use almost exclusively in their homes or offices. It is a supplement to the phone system but cannot be a replacement until mobile web access is much more universal, if ever.

## Database and Scheduling Components

The scheduling algorithm depends on a set of database tables, some static and some dynamic. There are two primary tables that must be produced as part of the initial deployment of the DRT system. These tables are the Path table and the stop table. There are two dynamic tables: the pickup Request table, which holds the customer data, and the schedule table, which holds the bus departure and route information.

A basic concept within the system is a route that is identified by a route number and consists of a set of sequentially numbered stops. Within the route there may be any number of subroutes. A subroute is produced when shortcuts are added to a route and consists of a subroute number, a starting stop number, an ending stop number, and, optionally, a sequence of road segments which can be used to describe the route in text (or auditory) form.

The path table in the database holds the definition of all possible subroutes in the system. The main route as a whole is also counted as a subroute. The subroute is the unit used for scheduling – the departure information passed to the bus driver will consist primarily of the time to depart and the subroute (path) to follow.

Each physical location at which a bus may stop is stored in the stop table as a set of records. A single location may be a stop on several different bus routes. In addition, a single physical location has a separate record for each of the subroutes on which it appears. A stop consists of a route number, a stop number, a subroute number, a transit time based on the time to reach this stop from the start of the route and a time variability factor.

The scheduling algorithm depends heavily on the requirement that while customers request a specific pickup time, the actual scheduled pickup time will fall into a 30 minute time window around the requested time. Without this scheduling flexibility, the first one or two callers would fix the schedule for most trips. For Castro Valley, since the total loop time of the full route is 30 minutes, all user requests can be accommodated within a 30-minute time window. Longer routes will either require larger time windows or result in user requests that cannot be met within the time window. The departure time and route for a trip can be finalized 30 minutes prior to the provisional departure time.

As each caller enters their preferred pickup time, the scheduler recalculates all prior reservations and any external constraints and reassigns the departure times and routes of all scheduled trips. This determines whether the requested pickup can be made within the time window and the caller is informed immediately as to whether or not the request can be met. The rescheduling is done in real time by calculating overlaps in the time windows of all prior reservations plus the current request. Figure 15 illustrates the technique used. The travel time to each stop is subtracted from the bounding times of the window around the preferred pickup time to produce a time window that represents the possible departure times for the bus to reach the stop at the appropriate time. This operation is repeated for each reservation. Starting with the first trip which has not yet departed, specific bus trips are assigned to the earliest departure time windows by specifying the departure time which meets the maximum number of overlapping windows while still allowing the bus to reach each requested stop

within the customer requested time window. Trips are assigned until either all reservations, including the newest one, have been satisfied or until it reaches a point at which a request cannot be satisfied. If a set of trips which can accommodate all reservations cannot be created the current request is rejected and the caller is so informed. If a set of trips satisfying all constraints can be created, the reservation is accepted. Thus, as each reservation is made, the system will always at least one set of trip schedules which can accommodate all prior requests.

The scheduling algorithm imposes a partial first come, first served strategy on the system. The first caller will always be accommodated. Subsequent callers either will be accommodated or will be informed that they cannot be accommodated. This limits the ability of the scheduler to optimize the trip schedules somewhat. It was felt that the small loss in efficiency was outweighed by the need to always give a definite answer to the caller as to whether or not their reservation would be honored. To call a customer back later to tell them that the bus trip they had been expecting to make was cancelled presented large usability problems for the DRT system.

#### Driver interface

Several features of a DRT system require two-way communications with the bus driver in order to operate reasonably. The departure time must be conveyed to the driver in flexible schedule systems. The route must be conveyed in flexible route systems. While pickups can be established through the automated reservation system, the DRT system needed to be able to handle passengers who walk up to the bus either at the resting location or at stops along the regular route as the bus passes by. These passengers will not be part of the scheduling and routing system so must be added by the driver through some kind of two-way communication system.

There are several possible channels for driver to DRT system communications. AC Transit, and other transit systems in the bay area, have installed consoles manufactured by Orbital Systems in some of their busses. These use a dedicated radio link between the bus and the operations center. For agencies with this type of equipment, the DRT system can be integrated into the Orbital System and messages passed back and forth between the driver and the scheduling system.

There are alternative communication devices and methods available, however. Cellular phones are cheap and easily available. While issues of driver distraction and usability would likely preclude having the driver place and receive calls as the primary communication method, cellular phones are being adapted to provide always on data network connectivity. CDPD based devices have been available for several years and are used for dedicated wireless communications with field controllers. In addition, GPRS has become available in the last two years in most metropolitan areas. GPRS provides always connected data transfer for phones from T-Mobile, ATT and Cingular. A competing data network technology, 1xRTT is in the process of being deployed in 2002-2003 and is available for phones from Sprint and Verizon. Nextel also provides its own data network system based on 1xRTT.

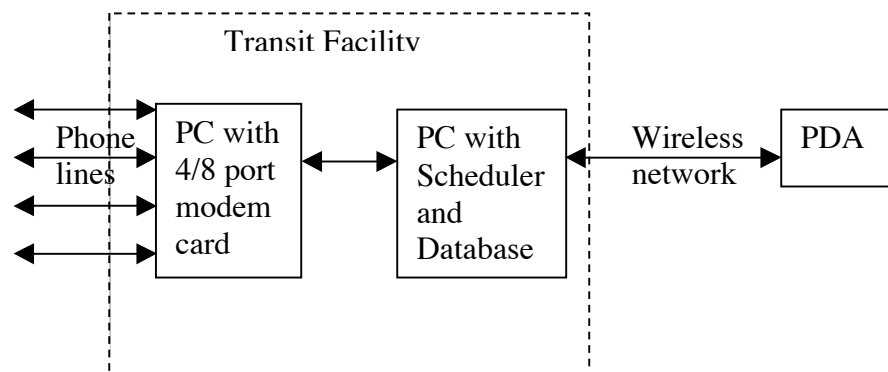
Beyond phones, WiFi (IEEE 802.11b) wide area networks are starting to appear in many cities. This communications technology has been adopted as the standard for vehicle to roadway communications in the Federal ITS program. Except in limited cases, however, the deployment of WiFi networks are unlikely to be useful for DRT systems for many years due to limited and sporadic coverage.

Both phones and handheld PDAs, which are incorporating phone network connectivity technologies, can provide a reasonable user interface to support a DRT application. Status messages, departure times and routes, can be easily passed to the device. Driver input can be gathered through simple menu or touch screen applications residing on the phone. Scheduler to driver communications can be handled by a small set of text messages. Driver to scheduler communications can be handled by having the driver select one of a very small set of messages that are sent back to the scheduling system.

**FIGURE 16 Driver Interface for Unscheduled Walk Ups.**

A handheld PDA was chosen for the first implementation of the DRT system. A preliminary design of the driver interface is shown in Figure 16. The actual interface was not developed during the course of the project, however. Design work was done in consultation with AC Transit during which it was determined that the requirements of the driver interface were much greater than those strictly required to implement the envisioned DRT system. A number of issues were raised by AC Transit regarding monitoring driver performance and providing confirmation of system operation, such as on-time arrival at scheduled stops. Time and resource constraints limited work on the driver interface to basic conceptual designs with the expectation that a more complete implementation which satisfied all the requirements of the transit agency would need to be done prior to a field test of the system.

The basic hardware requirements for the system are shown in Figure 17. A single computer containing multiple modems accepts the incoming calls, manages the caller interactions and makes the outgoing calls. A second computer stores the reservations, handles all scheduling tasks, and handles the interactions with the bus driver.



## **FIGURE 17 Hardware Configuration.**

### **Next Steps**

The DRT system described is part of a multi-year research project. The next phase of the project, which will start in October 2003, will be a field operational test with AC Transit. Application of demand responsive transit in the provision of disabled access has been widely studied. However, DRT applied to regular transit operations represents a significant shift in how transit services are provided. The goals of the field test will be to evaluate the impact of DRT service using a variety of different metrics. Special access service can be evaluated based on the quantity of trips provided per potential users. Mobility-to-work service can be evaluated based on the convenience, reliability, trip times and cost of commute trips by workers. The evaluation criteria may include:

- Number of trips provided per potential users
- Proportion of requested trips that are satisfied
- Average response time
- Price for an average trip relative to user's income
- Comfort, safety, reliability, and courtesy of service
- Number of problems reported by users.

Access measurement based on:

- The number of daily patrons of the smart feeder service compared to patrons of Route 87.
- The number of daily or weekly ADA patrons carried by the smart feeders.
- The number of daily patrons of BART riders before and after the field test.
- On-time performance of the smart feeder service compared to Route 87 performance.
- Consumer satisfaction with smart feeders compared to Route 87.
- Responsiveness of the bus service to on-demand service
- The condition of the vehicle
- The number of patrons per smart feeder miles versus bus miles Route 87.
- Deadhead miles

System effectiveness measurement based on:

- Time savings (access to transit, waiting for vehicle arrival, waiting to board vehicle, in-vehicle on transit, transfer into another vehicle or mode)
- Service reliability
- Service quality
- Flexibility
- Convenience
- Safety and security
- Cost savings.



The field trial in Castro Valley will deploy only a limited DRT system involving only one or two busses on a single route. One of the primary goals of the field test is to gather information to guide the next steps in DRT research and deployment. For transit agencies, a major benefit of a DRT is the perceived possibility of cost savings from decreasing deadhead miles traveled while still providing service comparable to the existing fixed route/fixed schedule system. Clearly the field trial involving a single bus on a single line will not produce significant cost savings. It will, however, produce a great deal of information on the use of a DRT system in a public implementation and on the public perceptions and attitudes toward the proposed DRT system.

The next step beyond the single bus/single route system is to enhance the scheduling system to manage multiple busses across multiple lines. This would allow a pool of busses to serve a larger pool of lightly used routes. This can be done through improvements in the scheduling system with little or no change in the public interface between the customers and the system or the drivers and the system. Steps beyond that will add short trip diversions to fixed routes. This will fully integrate the paratransit systems and the fixed route systems, which are currently operated and managed separately in many transit agencies.

## **Conclusions**

The first part of this project compared possible customer acceptance of a demand responsive transit system with traditional fixed route transit system. While the demand was generally lower for most demographics for a DRT system than for a fixed schedule system, the demand was sufficient for the city of Millbrae to make a DRT system a feasible solution for a downtown feeder service.

The second part of this project developed a user-driven scheduling system for local transit using an automated phone-in system for reservations, computerized dispatching over a wireless communication channel to the bus driver, and an automated callback system for customer notifications. The DRT system is designed to follow a fixed route with demand driven scheduling of departures and route variation. The route variation is limited to skipping over portions of the fixed route where there is no demand during a particular trip.

Future changes to the scheduling system will support the scheduling of more buses covering multiple routes over a larger area. Additional changes to the scheduling and routing system will be developed to support flexible routing involving short diversions from a fixed route. This will lay the groundwork for the extension of the DRT system to encompass the integration of ADA riders as well as traditional transit riders into a single automated dispatch on demand service.

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