A Benefit-Cost Evaluation of Smart Transit Features at Small Scale Transit Operations

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Abstract

This study evaluates the benefits and costs of smart transit technologies at San Luis Obispo Transit, a small transit operation. In 2001, the California Department of Transportation test-deployed its new program entitled "Efficient Deployment of Advanced Public Transportation Systems (EDAPTS)". The purpose of the field study was to make low-cost, Intelligent Transportation System (ITS) technologies readily available to small and medium size transit properties. The system developed applies digital communications links, open source designs, solar powered real-time arrival signs, and innovative data links to improve transit service and safety at a total investment of $150,000 (2007 dollars). An evaluation was undertaken in 2007 to determine the economic justification of the program and assess the case for commercialization.

Benefit-cost analyses were conducted for 5-, 7-, and 10-year service lives of EDAPTS components using discount rates of 5%, 7% and 10%. A conservative analysis excluded consumer surplus as benefits and shows benefit-cost ratios of 3.7 to 6.1. With consumer surplus, the ratios range from 4.5 to 7.5. This indicates that $1 invested in EDAPTS resulted in nearly $4 of benefits to constituent groups. Since the benefit-cost ratios substantially exceed 1.0 in all cases, results confirm that EDAPTS provides an economically sound smart transit solution for small and medium size transit properties seeking low-cost easily deployed ITS solutions.

Key Words

Public Transit, Smart Transit, APTS, ITS, Benefit-Cost Ratio

Contents

1. INTRODUCTION

1.1 Background

In late 1990, the California Department of Transportation (Caltrans) embarked on a research program entitled "Efficient Deployment of Advanced Public Transportation Systems (**EDAPTS**)." The objective of the program was to make low-cost, easily deployed Intelligent Transportation System (**ITS**) technologies readily available to small and medium size transit properties.

In early 2001, the first EDAPTS ITS system was installed, tested and began operation at San Luis Obispo (**SLO**) Transit. The system applies innovative digital communications links, open source designs, solar powered real-time arrival signs, and innovative data links to improve transit services and safety for passengers and drivers.

1.2 Objective

This evaluation was undertaken to determine if the EDAPTS program as implemented at SLO Transit is economically justified and thereby inform the case or lack thereof for commercialization. A successful system test that is also evaluated to be economically sound for small and medium size transit providers would support commercializing EDAPTS. While it was envisioned that the deployment of EDAPTS at SLO Transit could offer many potential benefits, it was not known at the beginning of the effort whether it would have an overall benefit-cost (**B/C**) ratio sufficiently high to warrant consideration for widespread deployment and commercialization.

A B/C ratio substantially greater than 1.0 could be interpreted as an argument supporting a positive recommendation on commercialization and encouraging small transit properties to deploy low-cost ITS solutions of EDAPTS. If the B/C ratio were less than 1.0, it would be important to document lessons learned from the test deployment and make recommendations regarding the possible need for modifications and continued research activities into EDAPTS.

1.3 Commercialization

EDAPTS is an open source Smart Transit System that the transit community as a whole may benefit from, using its advanced transit management and other features that may be developed within the industry. EDAPTS was developed to be consistent with the National ITS Architecture and Transit Communications Interface Profiles (TCIP) Standards. No rigid path towards commercialization has yet been forged, although Cal Poly San Luis Obispo is working jointly with the California Center for Innovative Transportation (www.calccit.org) to achieve this goal. Results of this effort will be made public in Spring 2009. The final project reports, existing EDAPTS source code, and hardware designs are available at http://itrans.calpoly.edu/EDAPTS. Interested parties may download all materials from this web site. The availability of this technology is being disseminated to the transit industry for awareness.

2. STUDIES OF SMART TRANSIT SYSTEMS

Advanced Public Transportation Systems (**APTS**) technologies have been developed and increasingly deployed by transit properties as a means of: (a) increasing the efficiency and safety of transit services; (b) offering users easy access to real-time information about transit operations; and (c) providing reliable customer service. Review of existing literature revealed that there were two types of research efforts relevant to benefit-cost evaluation of APTS. One type was centered on *identifying* the specific benefits and costs associated with the implementation of APTS systems and on the *framework* for evaluating these benefits and costs. The benefits and costs are typically grouped into six categories: safety, mobility, productivity, efficiency, energy and environment, and user satisfaction. The other type of effort was aimed at developing appropriate *methodologies* for measuring benefits and costs that are not easily quantified.

In a typical benefit-cost evaluation, costs are usually straightforward and are more easily identified and measured while benefits are much more difficult to identify and quantify. With this consideration, the literature review emphasized the search not only for tools and procedures to identify benefits and costs but also for methodologies that can potentially help in the economic assessment of the EDAPTS system at SLO Transit.

2.1 Evaluations of APTS Applications

Since the inception of ITS technologies in public transit, researchers have conducted a number of benefit-cost assessment studies on APTS applications for various transportation agencies throughout the nation (*1*, *2*). In these studies, researchers have related the use of APTS technologies to improvements in transit operations and services and found that APTS technologies can be beneficial to transit properties with large fleets. However, there have been few benefit-cost analyses of APTS applications in small or medium sized transit properties. These few publications acknowledge the difficulty of measuring particular benefits of APTS systems. Some of the findings are summarized in the following paragraphs.

Gomez et al. (1998) evaluated the benefits of Automatic Vehicle Location (**AVL**) systems in public transit and their implementation in the U.S (*3*). They concluded that AVL applications in public transit systems offer many benefits to transit agencies and riders, including improving on-time performance, raising productivity, enhancing security, and increasing ridership. AVL can provide real-time information about bus locations, running speed and other information. Transit dispatchers can use real-time information for bus scheduling and transit planners can use real-time information for adjusting transit routes and stops. Transit users can benefit from improved on-time performance and schedule reliability, as well as real-time information to reduce waiting time and anxiety. The researchers asserted that transit riders are extremely sensitive to schedule reliability and the improved reliability of arrival-time arising from the use of AVL could potentially increase transit ridership and improve satisfaction with service.

Wallace et al. (1999) assessed the impact of several transit safety and security enhancements based on a 1998 survey of transit riders in Ann Arbor, Michigan (*4*). The safety and security enhancements evaluated included on-board video surveillance, emergency phones, video cameras at transit centers, enhanced lighting at transfer centers and increased police presence. Surveys of riders on randomly selected routes at random times during weekday service found that camera systems were the safety enhancement most often noticed by respondents. When respondents rated the degree to which improvements increased their sense of security, police presence showed the greatest influence, followed closely by increased lighting. Emergency phones and video cameras had smaller impacts.

Furth and Muller (2000) measured the effectiveness of a transit signal priority system installed in the City of Eindhoven (population 300,000), in the Netherlands (*5*). The signal priority system was installed on all local transit vehicles. The adherence of the vehicle to its planned schedule was monitored. “Early” or “late” status was communicated to the vehicle operator. Video cameras were mounted on utility poles at the busiest intersections in order to measure the impacts of the signal priority system on overall traffic delay. Also, buses were equipped with onboard computers and wireless communications to track schedule adherence.

The effectiveness of the transit priority system was determined by measuring the difference in the deviation of individual vehicles from their schedules as they passed through signalized intersections. The project compared the on-time performance of vehicles when the transit priority system was in use with periods when the system was not in use. Performance data on schedule deviation, run times, and delay were evaluated against schedule adherence and bus delay.

This research showed that vehicular delays for traffic under conditional priority (or the priority to a bus running behind schedule) were about the same as those for traffic with no bus priority. The absolute priority (the policy to provide a green phase to each bus regardless of whether or not it was running behind schedule) caused large increases in overall traffic delay. This research also found a strong improvement in deviation from schedule during periods with conditional priority compared to periods with no priority and no delay for 90 percent of all buses under absolute priority.

Gillen and Sullivan (2000) conducted a preliminary evaluation of the potential impacts of EDAPTS on riders and services provided by San Luis Obispo (SLO) Transit (*6*). They evaluated bus operations prior to and after the deployment of the EDAPTS ITS technologies and conducted an opinion survey of riders. Using limited operational data, they were able to identify a set of positive system benefits to the transit operator, employees, riders, and the community at large. Efforts did not include dollar-quantification of benefits.

Mikko and Kulmala (2002) evaluated a pilot project designed to provide real-time passenger information and signal priority to tram and bus lines in the City of Helsinki, Finland (*7*) where Automated Vehicle Location (AVL) and Computer Assisted Dispatch (CAD) systems were installed. Their study showed that the system had positive effects on the level-of-service for tram and bus services. Based on their test ride observations, in-vehicle studies and ticket sales information, the pilot project showed: (a) increases in on-time performance and ridership; and (b) reductions in travel time, fuel consumption and mobile emissions; as well as (c) improvements in user satisfaction.

Daigle and Zimmerman (2003) did a Field Operational Test (FOT) on the deployment of ITS traveler information on shuttle buses at the Acadia National Park in Maine (*8*). ITS technologies that were evaluated by the study included Automated Vehicle Location (AVL), real time electronic arrival signs, automated in-vehicle announcements, automated in-vehicle passenger counting systems, and website and telephone traveler information services. These technologies were deployed as a way to disseminate more accurate and timely information to more than two million park visitors each year. The primary goal of the study was to measure the impact of ITS on the "quality of visitors' experience" in terms of customer satisfaction and mobility. Visitors were asked about their awareness, use and experience with ITS in the park.

Findings indicate that ITS helped: (a) the free shuttle bus service, Island Explorer, improve operations; (b) reduce parking lot congestion; and (c) improve aesthetics and safety by decreasing the number of vehicles parked alongside roads. ITS also enhanced the growing tourist economy through improved mobility.

Zhong-Ren et al. (2005) investigated the use of AVL systems to enhance transit performance, management and customer services in two medium-sized transit agencies (*9*). The investigation was based on surveys conducted in Racine and Waukesha, Wisconsin before and after AVL implementation and in Manitowoc, Wisconsin, a small city without AVL. The research found that features like improving on-time performance, knowing when the bus will arrive, knowing that another bus will be dispatched in case of breakdown were valued as important to transit users. The research also observed that transit systems with AVL have improved schedule adherence and on-time performance. The researchers concluded that passenger trips would increase if better information was offered to users.

The various evaluation studies showed that APTS applications provided a variety of benefits including the improvement of on-time performance, the reduction of users' wait time and anxiety, and the improvement of user satisfaction. However, many of these studies did not focus on the comparison of quantified benefits and costs of APTS applications. Few studies measured benefits and costs in dollars and calculated benefit-cost ratios for APTS applications.

It was concluded from the review of existing APTS evaluation studies that the challenges associated with economic evaluation of APTS applications were likely to be related to the lack of effective evaluation methods for placing dollar values on benefits that are not easily quantified. Quantifying benefits in dollar values requires creative assumptions and revealed or stated preference surveys. These topics were subsequently investigated in the literature review.

2.2 Review of APTS Evaluation Methods

Few evaluation methods and tools show high potential for dollar-quantified assessment of APTS applications. These methods and tools are grouped in this paper into two categories: Conventional Methods and Market Study Methods.

2.2.1 Conventional Methods

The ITS Deployment Analysis System (IDAS) is regarded a conventional project evaluation method. IDAS was developed by the Federal Highway Administration (FHWA) and has been widely used in planning for ITS deployments. This method integrates evaluation of benefits and costs of ITS investments with existing transportation planning models, comparing and screening ITS deployment alternatives, and estimating the impacts and traveler responses to ITS (*10*).

The IDAS method provides a set of default values for benefits and costs. These default values are the initial factors for evaluating travel time, fuel consumption and other impacts in dollar values, making the IDAS method a tool for true benefit-cost evaluation of ITS applications. However, it has certain limitations when used for evaluating APTS-specific applications. A test conducted by the Chicago Area Transportation Study (CATS) in 2003 showed that IDAS provides a set of reasonable analysis methodologies for highway networks and is well suited for evaluating ITS deployments on highways (*10*). Due to the fact that IDAS cannot perform transit network assignments, it can only analyze benefits and costs of transit services at an aggregate (zonal) level. Also, the IDAS method requires a substantial level of effort in preparing all the necessary data inputs. In addition, some of the IDAS default values might not be applicable to APTS applications. It was apparent that making direct use of the IDAS model was not appropriate for the SLO Transit evaluation.

2.2.2 Market Study Methods

Market study methods offer potential for the evaluation of APTS applications. Two types of approaches for B/C evaluations are hedonic pricing models and contingent valuation methods (*11*). Hedonic pricing models measure imputed values in the revealed preferences of consumers.

Contingent valuation methods measure stated preferences of consumers. In general, these two types of market study methods use information about people's behavior to measure their willingness to pay (**WTP**) for services and/or technologies when faced with situations of choice.

Hedonic Pricing Models

A hedonic pricing model was considered a potential tool for measuring benefits associated with EDAPTS because, as Williams (1991) asserts, "it can be used as a means to value indirectly non-market effects." (*12*) Many of the benefits of the EDAPTS approach are envisioned to be indirect and not readily measurable. Hedonic pricing models are based on the concept that goods comprise bundles of attributes that combine to form objectively measurable characteristics or utility-affecting attributes that consumers value (*13*). For instance, in the real estate market, where much of the literature on hedonic models is published, the hedonic method uses information on people's choices to estimate their WTP for attributes related to housing location, structure or amenities, and neighborhood (see for instance *13, 14, 15, 16*). It is discernible that these attributes are both quantitative and qualitative.

Contingent Valuation Methods

Studies of existing markets using hedonic price models are limited because only choices actually made by consumers can be used to infer the values of the attributes of goods. Stated preference surveys can apply contingent valuation (**CV**) or ranking of attributes to estimate the benefits of actions or policies that place people beyond the range of their choice-making experience (*11, 17, 18, 19*). Applied in this study therefore SLO Transit riders were asked to value features of EDAPTS by considering situations that they never experienced.

3. STUDY APPROACH

3.1 Overview

An evaluation procedure was developed that relied on stated preference analysis to quantify the intangible benefits of the system. This method used the principle of *willingness-to-pay* to provide an aggregate measure of what surveyed passengers were willing to forego to obtain a given ITS feature. It is an adaptation to APTS analysis since available literature did not include applications that quantified benefits of ITS technologies using the stated preference evaluation method.

3.2 Benefit and Cost Measures

Critical tasks in the benefit-cost analysis were the identification, measurement and quantification of benefits and costs. This was accomplished through a process of brain-storming and discussions of the features of EDAPTS.

The benefits considered for this study consist of both tangible and intangible measures. They were formulated from the perspectives of riders, drivers, dispatchers, system managers, and the community at large. Most measured benefits fall into three main categories: (1) those that accrue to passengers riding SLO Transit buses, (2) those that accrue to the SLO Transit agency; and (3) those that accrue to SLO Transit bus drivers. In addition, benefits such as those arising from reduced parking demand in the community were considered. Table 3-1 shows the benefit measures of performance.

Table 3-1: Benefit Measures of Performance

Constituent	Measure of Performance
Passengers	▪ Value of reduced response time due to GPS in the event of a bus breakdown ▪ Value to passengers of knowing arrival times so that passengers experience reduced stress, improved certainty regarding bus services, and easier planning of trip activities ▪ Value of more reliable trip times from improved schedule adherence and coordination ▪ Benefit from increased trip making induced by faster and more reliable performance ▪ Value of reduced trip times due to faster boarding operations (due to card-swipe technology)
SLO Transit	▪ Administrative cost reduction from less cash handling and easier accounting for fares ▪ Value to SLO Transit of panic button, ability to summon help quickly in an emergency ▪ Impact of GPS in monitoring drivers' job performance and improved supervision ▪ Value of reduced response time from GPS data in the event of a bus breakdown ▪ Benefit of increased revenue from having traveler information and more reliable performance ▪ Running time savings from electronic fare collection ▪ Value of real-time operational data in improved dispatch operations and system efficiency ▪ Value of reduced vehicle operating & maintenance costs ▪ Value of accident reduction due to schedule control and no need for aggressive driving to return to schedule ▪ Value of reduced complaints about service
Drivers	▪ Value to drivers in reduced stress from ability to more easily stay on schedule and allow passengers to make transfers ▪ Value to drivers of panic button, ability to summon help quickly in an emergency ▪ Avoidance of penalties due to improved on-time performance
Community	▪ Indirect benefit to university and community due to increased ridership (less parking capacity needed)

The cost measures were obvious, consisting of items that quantify capital, operating and maintenance costs related to the installation and operation of EDAPTS. Table 3-2 shows the cost measures of performance. Because EDAPTS implementation at SLO Transit was a pilot demonstration project, many of the listed costs were covered by the project grant, but under normal conditions all of these costs would fall upon the transit operator. Annual maintenance costs listed in the table incorporate occasional equipment replacement due to failures, accidents or vandalism. Costs of power for operating on-board units and computers are ignored.

Table 3-2: Cost Measures of Performance

Cost Category	Cost Items
Capital	▪ On-board driver console and fare paying units – Manufacture ▪ On-board driver console and fare paying units – Installation ▪ Street-side displays – Manufacture ▪ Street-side displays – Installation ▪ System control, data acquisition console ▪ Operator consoles (dispatch)
Operation and Training	▪ System operating costs ▪ Front-end system setup, calibration ▪ Initial driver training in EDAPTS operation ▪ Continuing driver training in EDAPTS operation ▪ Initial office personnel training in EDAPTS operation ▪ Continuing training of office personnel
Maintenance	▪ Setup and recalibration for bus system changes (quarterly) ▪ On-board unit maintenance ▪ Street-side display maintenance ▪ Maintenance of system control and dispatch consoles

3.3 Surveys of Benefit and Cost Items

The study used a variety of primary data collection methods to gather the data regarding benefit and cost measures. Results of these surveys are presented in subsequent sections.

3.3.1 Benefit Items

Four distinct data-gathering tasks were performed to collect information on the benefits that are identified in Table 3-1:

1. An on-board self-administered survey of passengers to measure how passengers' travel behaviors may have changed due to improvements to bus services enabled by the EDAPTS ITS technologies, and how much value, in dollar terms, passengers attribute to resulting travel changes and to the improved bus services generally.
2. On-board observations to measure passenger boarding-times on buses with and without EDAPTS technologies. The boarding time survey was conducted without direct interaction between surveyors and riders. Some passengers might not have realized these observations were being made, while others might have noticed. The approach was to time how long it took riders using various fare media to complete payment transactions.

   A Visual Basic (VB) computer program was developed to record the time each boarding passenger first stepped on the bus floor and the time that same passenger completed boarding by crossing the yellow line just behind the bus driver. Also recorded was whether passengers had to wait in queue before paying and the fare medium used. The seven fare media choices are: (a) Cal Poly ID Card; (b) Monthly pass or ticket or transfer; (c) Paper currency; (d) Coins or token; (e) Flash card; (f)) Other; and (g) Not a valid boarding transaction, that is, the observation is to be excluded. This permitted estimating the potential benefits from reduced boarding times due to EDAPTS card-swipe units that read Cal Poly IDs, which are used by the majority of SLO Transit riders to pay their fares.

3. Structured interviews with bus drivers
4. Structured interviews with SLO Transit administrators.

3.3.2 Cost Items

For the cost items identified in Table 3-2, the study collected cost data (in 2007 dollars) from a survey of typical prices for the various components used in the design of EDAPTS. The survey included online price checks, visits to local retail establishments and calls to manufacturers and vendors of specialized items. The "best" prices of individual subcomponents were included in the cost data. Labor time estimates were based on the times spent previously and in other ongoing EDAPTS projects in the installation of EDAPTS components and software programs.

3.4 Benefit-Cost Procedure

The procedure of the benefit-cost analysis included the following steps:

Step 1: Determine the service life of the project and the discount rate applicable to the project. For sensitivity analysis, three service lives were analyzed corresponding to 5, 7 and 10 years. The study also applied three discount rates of 5%, 7%, and 10%. The 7% rate is recommended by the federal Office of Management and Budget (OMB), 5% was the typical bond interest rate in 2007, and 10% is an arbitrary high value set to twice the typical bond rate.

Step 2: Identify, measure, and quantify the benefits of the project and discount them to annualized values. These quantified benefits are presented in subsequent sections.

Step 3: Identify, measure, and quantify the costs of the project and discount them to annualized values. These quantified costs are presented in subsequent sections.

Step 4: Calculate the benefit-cost ratios by dividing the annual benefits by annualized costs. This was done for the range of discount rates and service lives that were assumed for annualizing project capital costs.

4. ESTIMATION OF BENEFITS

4.1 Willingness to Pay Estimates from On-Board Passenger Survey

The survey of SLO Transit passengers was used to quantify a number of parameters used in calculating some of the EDAPTS system benefits identified in Table 3-1. These parameters reflect passengers' expressed "willingness to pay" for service improvements and other features that are provided through EDAPTS. Willingness to pay observations were also used to estimate behavioral parameters such as values of time. The key findings from the survey are summarized in the following subsections.

Willingness to Pay for Arrival Information

The majority of survey respondents (79%) are not willing to pay anything to have the bus arrival time display information. The remainders express willingness to pay ranging from $0.50 to $8. Table 4-1 shows the distribution. The modal amount of dollars riders are willing to pay is $1. The average amount they are willing to pay is $0.25 per trip. Note that there are a few passengers who claimed in the survey that they are willing to pay a substantial fee for real time bus arrival information, which seems difficult to believe. If the $6 and $5 observations are eliminated as suspect, the average willingness to pay falls to $0.21. If the $4 observations are also eliminated, the average falls to $0.19. In all cases, the stated willing to pay for this information results in rather similar levels of benefits.

Table 4-1: Willingness to Pay for Displays at Bus Stops

WTP Amount ($)	Total	Percent	WTP?	Total $
$0.00	517	79%	N	$0.00
$0.50	37	6%	Y	$18.50
$1.00	64	10%	Y	$64.00
$2.00	9	1%	Y	$18.00
$3.00	8	1%	Y	$24.00
$4.00	3	0%	Y	$12.00
$5.00	3	0%	Y	$15.00
$6.00	2	0%	Y	$12.00
Other	8	1%	N	$0.00
Total Respondents	651	100%		$163.50
Average WTP per trip				*$0.25*

Willingness to Pay for Shuttle Service

More than half of survey respondents (53%) are not willing to pay anything for a replacement shuttle for their trips. The rest express willingness to pay ranging from $0.50 to $6 for a replacement shuttle service in lieu of a 10-minute delay to the bus service. Table 4-2 shows the distribution. The modal amount riders are willing to pay is $1. The average amount they are willing to pay is $0.76. This was used to estimate the average passenger value of time of $0.76 for ten minutes, or $4.56 per hour.

Table 4-2: Rider Willingness to Pay (WTP) for Substitute Shuttle Service

WTP Amount ($)	Total	Percent	WTP?	Total $
$0.00	347	53%	N	$0.00
$0.50	62	9%	Y	$31.00
$1.00	132	20%	Y	$132.00
$2.00	39	6%	Y	$78.00
$3.00	33	5%	Y	$99.00
$4.00	6	1%	Y	$24.00
$5.00	20	3%	Y	$100.00
$6.00	6	1%	Y	$36.00
other	9	1%	N	$0.00
Total Respondents	654	100%		$500.00
Average WTP				*$0.76*

Willingness to Pay for Alternative Taxi Service

More than half of survey respondents (58%) are willing to pay something for an alternative taxi service for their trips in case of a bus service shutdown. Their expressed willingness to pay ranges from $0.50 to $6. Table 4-3 shows the distribution. The modal amount riders are willing to pay is $1. The average amount they are willing to pay is $1.08. This is the value used in the analysis for the average passenger value of a trip.

It is interesting to note the logical outcome that more people are willing to pay for a substitute ride when faced with a service shut-down than for a substitute ride when service is simply delayed. It is also notable that people are willing to pay about 40% more on average for a substitute ride when faced with service disruption than with a delay. It is revealing to note that the typical rider in all these cases is only willing to pay as much for a substitute ride as the cost of a one-way bus fare.

Table 4-3: Rider Willingness to Pay (WTP) for Taxi Alternative to Bus

WTP Amount ($)	Total	Percent	WTP?	Total $
$0.00	272	42%	N	$0.00
$0.50	57	9%	Y	$28.50
$1.00	163	25%	Y	$163.00
$2.00	46	7%	Y	$92.00
$3.00	51	8%	Y	$153.00
$4.00	8	1%	Y	$32.00
$5.00	35	5%	Y	$175.00
$6.00	10	2%	Y	$60.00
Other	8	1%	N	$0.00
Total Respondents	650	100%		$703.50
Average WTP				*$1.08*

4.2 Findings from Passenger Boarding Time Survey

The passenger boarding time survey was undertaken to measure the extent to which the EDAPTS card-swipe devices reduce boarding times, as a basis for estimating the corresponding user benefits. In an attempt to increase the sample size of passengers paying with cash, observations were made on both SLO Transit buses, all equipped with the EDAPTS devices, and the RTA (Regional Transit Authority) county buses, which were not EDAPTS-equipped. However, observations varied greatly between the two bus services due to wide differences in fare structures, and it was therefore decided to estimate time savings for CP-Cards based only on the data from SLO Transit, despite concerns about small sample size. Highlights of the findings are summarized in the following subsections.

Type of Payment vs. Time to Pay Fares

Examination of the time taken to pay fares when using the various payment types reveals that, on average, the Cal Poly ID swipe card, an EDAPTS feature, exhibits a clear time advantage over all other payment media. Swiping the Cal Poly ID card (CP-Card) takes less than half as long as most alternative methods, except for the flash card, which is close.

Table 4-4 and Figure 4-1 compare the lengths of elapsed fare paying times by payment medium stratified by whether or not the passenger had to wait in queue to pay. Note that the average times shown represent only the times required to pay the fares, not the time spent waiting in queue for one’s turn to pay.

Table 4-4: Average Fare-Payment Times by Payment Type

		In Queue?	
	Medium	No	Yes
SLO Transit	Currency	6.4	6.0
	Coin	7.1	5.7
	CP-Card	3.0	2.1
	Flash Card	4.3	2.8
	Pass	8.3	6.9
	All Media	4.4	3.0

An interesting comparison appears in relation to whether or not a passenger is required to wait in queue before paying his or her fare. There is a consistent and, in some cases, rather large time advantage if the passenger must first wait in queue. One explanation for this is that moving-up time is generally not counted for passengers in queue, while it is included in the fare-payment time when no queue is present. A second likely explanation is that, while waiting in queue, passengers can use the time by preparing to pay the fares quickly.

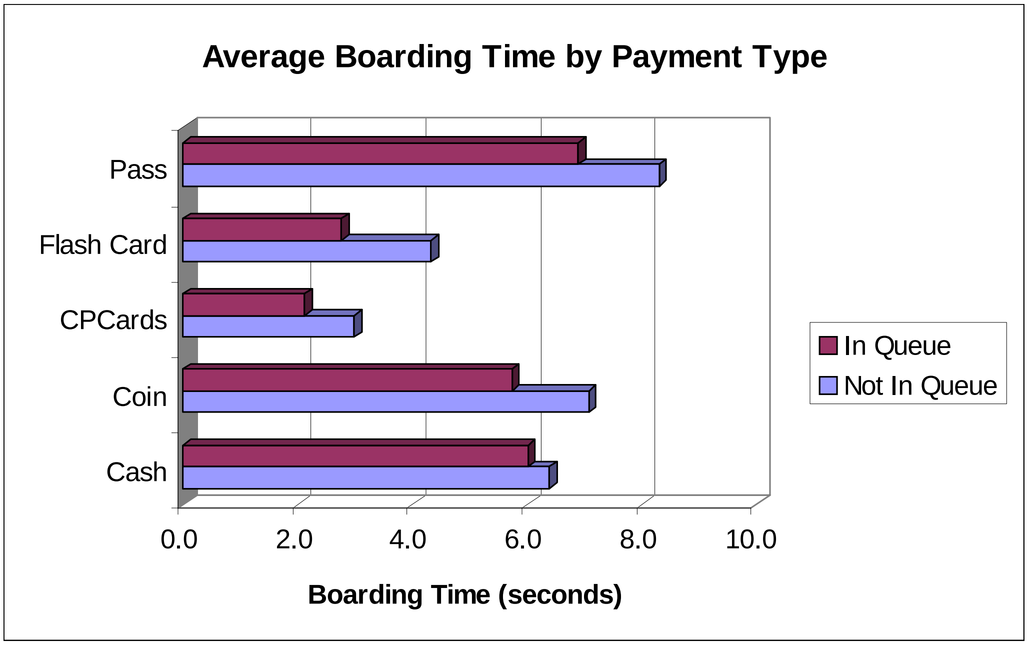

Figure 4-1: Average Fare-Payment Times by Payment Type (SLO Transit)

Boarding Time Savings Due to EDAPTS

Using the data from Table 4-4, a simple calculation is made to determine the average boarding time savings from using the EDAPTS card-swipe system. This calculation appears in Table 4-5 below. Note that, for the reasons previously discussed, only data from SLO Transit buses are used in this calculation.

Table 4-5: Calculation of Average Boarding Time Saved by EDAPTS

Average non-CP-Card time without queue =	6.92
Average non-CP-Card time with queue =	5.99
Average CP-Card time without queue =	2.97
Average CP-Card time with queue =	2.12
CP-Card savings without queue =	3.95
CP-Card savings with queue =	3.87
% of SLO fares without queue =	60.8%
% of SLO fares with queue =	39.2%
Weighted average CP-Card savings =	3.9
Percentage of valid boardings w/ CP-Card =	75%
Average boarding time savings per passenger =	2.9

As seen in the table, the average fare-paying time for passengers using CP-Cards is either 2.97 or 2.12 seconds, depending on whether or not the passenger waits in queue. This compares to weighted average delays of 6.92 and 5.99 seconds for the other payment types combined. The savings from the card-swipe system are therefore just about 3.9 seconds, whether or not a queue is present. Since 75% of SLO Transit passengers use CP-Cards, this corresponds to 2.9 seconds saved for the average passenger, whether or not he or she is a CP-Card user.

The average savings of 2.9 seconds per boarding is used in a subsequent section to calculate the travel time benefits to passengers from the use of the EDAPTS card-swipe system.

4.3 Estimation of Annual Benefits

Table 4-6 presents the summary of quantified benefits derived from the survey data. Two categories of benefits are considered: conventional benefits and benefits with consumer surplus. Conventional benefits are the benefits directly measured using the "willingness to pay" principle for existing passengers, as well as for drivers and SLO Transit administrators. Consumer surplus captures the differences between the prices consumers (passengers) are willing to pay and the actual price charged by SLO Transit.

Table 4-6: Summary of Quantified Benefits

Benefit Components	**Quantified Benefit**	**Units**	**Beneficiary**
(Part a) Benefits with Consumer Surplus			
Quantified benefits of **electronic fare collection**	$44,351	$ per year	Passengers
Quantified benefits of increased **schedule reliability**	$2,873	$ per year	Drivers
Quantified benefits of having **real-time information signs**	$98,477	$ per year	Passengers
Quantified **increase in fare revenue due to real-time information**	$36,765	$ per yr	SLO Transit
Quantified **consumer surplus due to real-time bus arrival information**	$42,647	$ per year	passengers
Quantified benefits due to **avoided parking costs**	$1,468	$ per year	Community
Total Benefits including Consumer Surplus	**$226,581**	**$ per year**	**All Beneficiaries**

(Part b) Benefits without Consumer Surplus			
Quantified benefits of **electronic fare collection**	$44,351	$ per year	Passengers
Quantified benefits of improved **schedule adherence**	$2,873	$ per year	Drivers
Quantified benefits of having **real-time information signs**	$98,477	$ per year	Passengers
Quantified **increase in fare revenue due to real-time information**	$36,765	$ per yr	SLO Transit
Quantified benefits due to **avoided parking costs**	$1,468	$ per year	Community
Total Benefits Excluding Consumer Surplus	**$183,934**	**$ per year**	**All Beneficiaries**

The total quantified annual benefits shown in Table 4-6 (part a) add up to approximately $226,600. They include conventional benefits and consumer surplus estimated for passengers who receive real time bus arrival information from EDAPTS. If consumer surplus is not considered, the estimate of total benefits would decrease to approximately $184,000, as shown in Table 4-6 (part b).

It is noteworthy that all benefits and consumer surplus were quantified using year 2007 dollars since surveyed passengers, riders, and SLO Transit personnel answered the “willingness to pay” questions in 2007. In addition, it was assumed that the quantified benefits and consumer surplus remain unchanged within the life cycle of the EDAPTS components. In other words, ridership growth is assumed to be zero. This assumption provides a conservative estimate of the benefit-cost ratio since benefits and consumer surplus would be expected to increase over time from increased ridership.

5. ESTIMATION OF COSTS

5.1 Unit Cost Estimates

Cost data collected for the benefit-cost analysis fall into two main groups: fixed and recurring costs. Table 5-1 lists the various components (*20*) and associated per unit costs. Year 2007 prices were used in this analysis to correspond with the year 2007 benefits data. The total fixed cost for the configuration of the SLO Transit EDAPTS system is just over $145,000 at 2007 unit prices.

5.2 Estimation of Annual Costs

Table 5-2 presents a representative cost summary at 7% discount rate associated with implementation of EDAPTS at SLO Transit. Operating and maintenance costs, considered recurring costs, are in 2007 dollars. The capital costs, considered fixed costs, were annualized at discount rates of 5%, 7% and 10% over five-, seven-, and ten-year periods. (Results for the other discount rates appear later.) The three terms (5-year, 7-year and 10-year) were applied for sensitivity analysis. EDAPTS components implemented in the SLO Transit system were anticipated to last for at least five years, but some components could last much longer. The five-year life cycle represents the most conservative analysis scenario.

Capital cost (C_1) data for various EDAPTS components were converted to equal annual payments (*AC*) over each assumed life cycle (*n*) for each discount rate (*i*). The equation for equalized annual capital costs is as follows:

$$AC = C_1 * \frac{i(1+i)^n}{\left[(1+i)^n - 1\right]}$$

Where:

AC is the equalized annual capital cost;
C_1 is the estimated capital cost of the proposed improvement;
i is the assumed discount rate per year;
n is the economic life cycle of the improvement in years.

Table 5-1: Prices of EDAPTS Cost Components

Component	SLO Transit Quantities	Current Per Unit EDAPTS Component Cost Estimates (2007)	Current Per Unit EDAPTS Component Construction Labor Time Estimates in hours (2007)	Current Per Unit EDAPTS Installation Labor[2] Time Estimates	Current Per Unit EDAPTS Annual Maintenance Labor Time Estimates	SLO Transit EDAPTS Total Component Cost Estimates (2007)
Fixed Costs						
Mobile Data Terminal with mounts, GPS antenna, and magnetic stripe card reader	15	$1,747	7.00	3.50	6.00	$37,615.88
Smart Transit Sign with paging receiver and solar power equipment	9	$3,179	16.00	9.00	2.00	$44,912.25
Smart Transit Sign engineered post with installed foundation	7	$2,350	2.00	4.00	0.00	$19,492.90
Radio and radio-modem set with installation in vehicle	15	$1,700	$0	2.50	1.00	$28,216.88
Central Dispatch Workstation	2	$700	$0	0.75	0.00	$1,508.68
Central Dispatch Server	1	$1,700	$0	1.25	2.00	$1,790.56
Software	1	$0	$0	160.00	88.00	$11,592.00
Total Fixed Cost						$145,129.20
Recurring Costs						
Radio service (per bus)[1]	18	$17 /mo.				$3,726.00 /yr.
Pager service	1	$55 /mo.				$660.00 /yr.

Notes:

[1] *Cost is for single radio channel. Current EDAPTS installation in San Luis Obispo share existing voice channel, effectively providing free data communications. A separate dedicated channel is recommended.*

[2] *Labor rate assumed to be $72.5 per hour*

Table 5-2: Summary of Annualized Costs

7% Discount Rate	5-Year Life	7-Year Life	10-Year Life	Units
Total Fixed Costs	$42,568	$34,102	$27,836	$ annualized
Mobile Data Terminal with mounts, GPS antenna, and magnetic stripe card reader	$9,609	$7,414	$5,790	$ annualized
Smart Transit Sign with paging receiver and solar power equipment	$11,099	$8,479	$6,539	$ annualized
Smart Transit Sign engineered post with installed foundation	$4,754	$3,617	$2,775	$ annualized
Radio and radio-modem set with installation in vehicle	$6,954	$5,308	$4,090	$ annualized
Central Dispatch Workstation	$368	$280	$215	$ annualized
Central Dispatch Server	$582	$477	$400	$ annualized
Software	$9,203	$8,527	$8,026	$ annualized
Total Recurring Costs	$4,386	$4,386	$4,386	$ annualized
Monthly radio service (per bus)	$3,726	$3,726	$3,726	$ annualized
Monthly pager service	$660	$660	$660	$ annualized
Total Costs	**$46,954**	$38,488	$32,222	**$ annualized**

For simplicity, EDAPTS components were not assumed to have any residual values at the end of their economic lives.

Table 5-2 shows that the total fixed cost of $145,130 (in 2007 dollars) incurred in implementing EDAPTS at SLO Transit translates to $42,570 in annualized costs over 5 years, assuming a 7% discount rate. There is an additional annual recurring cost of $4,390.

Annual operating and maintenance costs were calculated in constant (2007) dollars. Maintenance costs were assumed to be 1.0% per year of total capital costs. For each component, the annualized capital cost and the annual operating and maintenance costs were added to obtain the total cost per year over the duration of each economic life cycle analyzed. They add up to a total annualized cost of $46,954 per year (assuming a 5-year life cycle for a 7% discount rate).

6. BENEFIT-COST SUMMARY

6.1 Base Case Analysis

Table 6-1 presents a summary of the benefit-cost ratios associated with implementation of EDAPTS at SLO Transit for the representative discount rate of 7%. For each term, two ratios are presented corresponding to whether or not the consumer surplus is included among user benefits. The most conservative analysis excludes consumer surplus and shows ratios of approximately 3.9 to 5.7. This means that every dollar invested in EDAPTS at SLO Transit generally resulted in at least four dollars of benefits to the constituent groups each year. Including consumer surplus causes the ratios to increase to between 4.8 and 7.0.

Table 6-1: Summary of Benefit-Cost Ratios (7% Discount Rate)

	5-Year Term	**7-Year Term**	**10-Year Term**	**Units**	**Constituent**
Including Consumer Surplus					
Total Annual Benefits	$226,581	$226,581	$226,581	$ per year	All beneficiaries
Total Costs	$46,954	$38,488	$32,222	$ per year	transit agency
Benefit-Cost Ratio	4.8	5.9	7.0		
Excluding Consumer Surplus					
Total Annual Benefits	$183,934	$183,934	$183,934	$ per year	All beneficiaries
Total Costs	$46,954	$38,488	$32,222	$ per year	transit agency
Benefit-Cost Ratio	3.9	4.8	5.7		

6.2 Sensitivity Analysis on Discount Rates

Table 6-2 presents the results of sensitivity analyses for three discount rates over three terms. Including consumer surplus, ratios range from 4.5 to nearly 7.5. Without consumer surplus, ratios range from 3.7 to 6.1. It is notable that ratios depict step increases from the shortest to the longest economic lives (or life cycles) tested. As discount rates increase, ratios decrease more slowly than with changes in life cycle length. The findings depict that ratios substantially exceed 1.0 thereby justifying the economic efficiency of the ITS technologies of EDAPTS.

Table 6-2: Sensitivity Analysis of Benefit-Cost Ratios

	5-Year Term	**7-Year Term**	**10-Year Term**
Including Consumer Surplus			
5% Discount Rate	5.0	6.2	7.5
7% Discount Rate	4.8	5.9	7.0
10% Discount Rate	4.5	5.5	6.4
Excluding Consumer Surplus			
5% Discount Rate	4.1	5.0	6.1
7% Discount Rate	3.9	4.8	5.7
10% Discount Rate	3.7	4.4	5.2

7. CONCLUSIONS

The following findings from this research provide a basis to recommend the deployment of ITS technologies of EDAPTS to small and medium size transit agencies:

1) Passengers of SLO Transit, as indicated by the questionnaire survey, perceived substantial benefits in the ITS features of EDAPTS. For example, 16% of respondents concurred that the bus arrival time displays did affect their decisions to ride. Survey results indicated that there would be an 8.4% reduction in rides (or trips) overall if there were no bus arrival time displays at stops. This indicated that the presence of the bus arrival time displays at stops indeed generated benefits in terms of ridership retention and gain. Available historical data revealed that ridership declined by 9 percent within a year from 2000 to 2001 before EDAPTS was installed (*21*). The installation may have helped to arrest the decline with a modest ridership gain of 1 percent between 2001 and 2006. Over the same period, fare revenue increased by 13 percent in nominal dollars.

2) Not all ITS features of EDAPTS were found to be consistently beneficial to passengers, drivers and SLO Transit management. For instance, passengers were largely unaware of the Global Positioning System (GPS) receivers on buses, and drivers and dispatchers preferred the use of radios in emergencies over GPS. However, the GPS data did provide real-time information to SLO Transit in dealing with dispatching, schedule adherence, emergency responses, and passenger complaints. In this regard, drivers expressed some willingness to pay for this feature, indicating that aiding in schedule adherence which facilitates better job performance yields a modest but tangible dollar-quantifiable benefit.

3) Surveys of passenger boarding times on buses indicated that boarding times vary among different payment methods. On average, the Cal Poly ID swipe card, an ITS feature of EDAPTS on SLO Transit, exhibited a clear time advantage over other payment media by an average of 3.9 seconds per boarding. This indicated that using the Cal Poly ID swipe card to board buses can save, on average, substantial boarding times and in the long run facilitate schedule adjustments that reduce overall bus running times. This results in a substantial value of time savings to passengers and possibly some operating cost savings to the transit administration, depending on the nature of its operating contracts.

4) At a total initial investment cost less than $150,000, small and medium-size transit agencies can deploy ITS features of EDAPTS relatively inexpensively, as demonstrated by the test deployment at SLO Transit. The annualized capital, operating and maintenance costs in this case ranged from $30,000 to $50,000 for EDAPTS with a service life ranging from 5 years to 10 years.

5) The total benefits generated by the EDAPTS ITS system as deployed at SLO Transit ranged from $185,000 to $225,000 per year. These do not include possible additional benefits (such as reduced emissions and increased civic pride) that could not be quantified in the context of this study. The annual benefits substantially outweigh the annual costs.

6) The ratios of total benefits to total costs are at least 3.7:1 for EDAPTS at SLO Transit. This suggests that the ITS technologies of EDAPTS are economically viable. A $1 investment in EDAPTS can generate about $4 or more in benefits to a transit agency and its customers.

In summary, this paper presents a comprehensive benefit-cost evaluation of ITS technologies of EDAPTS at SLO Transit. The findings lead to the conclusion that ITS technologies such as EDAPTS are indeed low-cost, easily deployed, economically sound ITS solutions for small and medium size transit agencies.

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