Impacts of Management Practices and Advanced Technologies on Demand Responsive Transit Systems

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Abstract

Over the past 10 years, operating expenses for Demand Responsive Transit (DRT) have more than doubled as demand for this mandated service has expanded. The DRT systems that we studied consist of dial–a–ride programs that transit agencies use for point–to–point pickup and delivery of the elderly and handicapped. Many advanced technologies and management practices have been proposed and implemented to improve the efficiency of the service; but, evidence for the effectiveness of these actions has been based upon projections or small pilot studies. We present the results of a nationwide study involving 62 transit agencies. Our analysis indicates that the use of Paratransit Computer Aided Dispatching (CAD) system and Agency Service delivery provide a productivity benefit while the use of financial incentives has a detrimental impact on productivity. Also, the use of Advanced Communication technology has a beneficial impact on operating cost while the use of financial incentives has a detrimental impact.

1 Introduction

Demand Responsive Transit (DRT) systems are the means by which ‘comparable transportation services’ are provided to mobility impaired individuals. The DRT system that we focus on consists of the dial-a-ride programs that transit agencies provide for point–to–point pickup and delivery of the handicapped and elderly. The Americans with Disabilities Act (ADA) mandates that all transit agencies receiving federal funds must provide such services. Since the enactment of the ADA in 1991, DRT has expanded from a national total of 42.4 million passenger trips for the year to a total of 73.2 million passenger trips in 2000. Over the same period, the annual operating expense for DRT has gone from less than 3% to more than 6% of the total for public transportation services nationally, becoming a $1.2 billion industry in 2000 (Federal Transit Administration 2000).

In the last ten years, many advanced technologies have been proposed to improve the performance of DRT systems. Computers and advanced algorithms have been offered to improve the dispatching and scheduling of paratransit systems (Stone, Nalevanko, and Gilbert 1994). The implementation of Automatic Vehicle Location (AVL) and advanced scheduling has been credited as the primary factor in increasing efficiency by 10.3% for Houston's METROLift Service (Higgins, Laughlin, and Turnbell 2000). Use of the Internet has also been discussed as a means to improve productivity (Stone, Ahmed, and Nalevanko 2000).

There have been studies that outline the impact of Advanced Public Transportation Systems (APTS) on service productivity and cost. A study sponsored by the U.S. Department of Transportation quantifies expected benefits of APTS based on future forecasts (Goeddel 1996). A survey of paratransit customers in southeastern Michigan concludes that APTS has ample potential to increase customer satisfaction when reserving a trip (Wallace 1997). A study in Santa Clara County, California, reports the productivity gains realized by of use of APTS technology (Chira–Chavala and Venter 1997). However, the deployment of APTS may place additional stress on transit employees due to the need to learn how to use the new technology (Schweiger and McGrane 1999).

In addition to technological implementations, a variety of management practices such as type of service, use of financial incentives for good performance, and use of ridesharing have been discussed as methods to influence productivity, efficiency levels, and costs. There are numerous paratransit delivery methods such as single contracts, multiple contracts, or direct service (Simon 1998). A Federal Transit Administration Study found that 7.6% of total expenditures by transit operators was spent on purchased transportation (Gilbert and Cook 1999). A case study in Portland, Oregon, showed that the service cost for demand responsive transit decreased by a half when switching from direct service to contract service primarily due to labor cost differences (Rufolo, Strathman, and Peng 1997).

However, the evidence for the effectiveness of these technologies and practices has been based either upon projections or small pilot studies. We present the results of a nationwide benchmarking study involving an analysis of data from 62 transit agencies serving large and medium sized urban areas. Our intent is to evaluate the impact of several advanced technologies and management practices upon the productivity and operating cost of DRT systems. The advanced technologies that we consider include advanced communications, automated vehicle location, automated fare payment, automated transit information, and paratransit Computer Aided Dispatching (CAD) systems. The management practices that we consider include financial incentives, financial penalties, ridesharing, agency administration, contracted administration, agency service delivery, contracted service delivery, and consumer choice.

The performance measures used in this study relate to agency/operator objectives, rather than the objectives of a customer. We identify differences in productivity and operating cost performance between agencies who have implemented a practice and agencies who have not. The impact of the investigated practices upon a customer's perception of service attributes is outside the scope of the paper. The performance measures that we studied are Passenger Miles per Vehicle, Passenger Trips per Vehicle, Operating Expense per Passenger Trip, and Operating Expense per

Passenger Mile. Notice that none of the performance measures relies on the Revenue Mile, a measure commonly used in the industry. Our analysis of productivity measures based upon the Revenue Mile reveals a substantial flaw in the definition of the Revenue Mile, as it relates to assessment of productivity. Consequently, we select alternative productivity measures for use in this work. We also discuss the need for a data source that addresses the flaw in the Revenue Mile.

Throughout the study, we have sought to make use of existing data sources, such as the National Transit Database (NTD), where possible, and collect new data only as necessary. The intention of the study has been to obtain information regarding operational characteristics from a sample of transit agencies serving urban areas in all parts of the United States and to identify statistically significant relationships between technologies/practices and performance. In Section 2, we describe the steps taken to assure that the data used is representative of the industry and indicative of performance. In Section 3, we present the analysis of the performance data. In Section 4, we summarize our conclusions from the analysis.

2 Design of the Benchmarking Study

Data regarding the performance of DRT systems is available online from the NTD. For this study, we used NTD data for the three most recent years available at the beginning of the study: 1997, 1998, and 1999. A survey regarding the implementation of APTS technologies had been reported (John A. Volpe National Transportation Systems Center 1999). However, the survey only included implementations as of the fall of 1998 by agencies listed in the 1996 NTD. Also, little information was available regarding implementation of management practices. In order to obtain information regarding technology and practice implementations that coincided with the most recent performance data, a new survey of transit agencies was required.

2.1 The Implementation Survey

The 1999 NTD lists 413 transit agencies that report providing a DRT service to their constituents. Of these agencies, 180 serve urban areas with a population of 200,000 or more. The 180 agencies that serve these so–called large and medium sized urban areas provided 97% of all Passenger Trips reported (includes modes other than DRT). To concentrate on agencies providing the vast majority of service, we selected these 180 agencies as the target organizations for our survey.

The initial distribution of the survey was conducted via the U. S. Postal Service. Survey forms were mailed during the first week of July 2001 and agencies were requested to reply to the survey by July 20, 2001. Follow–up contact with non–responsive agencies was conducted via electronic mail. By the end of September 2001, we had received responses from 62 agencies.

A survey with self–selecting respondents can produce biased results. To combat this problem, we designed a strategy of segmenting the surveyed agencies according to industry demographic variables and focusing our e–mail follow–up activities on obtaining responses from agencies belonging to under–represented segments. The demographic variables that we selected are the Population Density of the urban area serviced by an agency and the Passenger Trips per Capita.

The Population Density is determined as the ratio of the population to the square miles for the agency's service area. Passenger Trips per Capita is the ratio of unlinked passenger trips for the DRT service to the population of the service area. The number of unlinked passenger trips is reported as the number of passengers who board DRT vehicles. A single request for service would generate more than one unlinked passenger trip if more than one person boarded the vehicle at

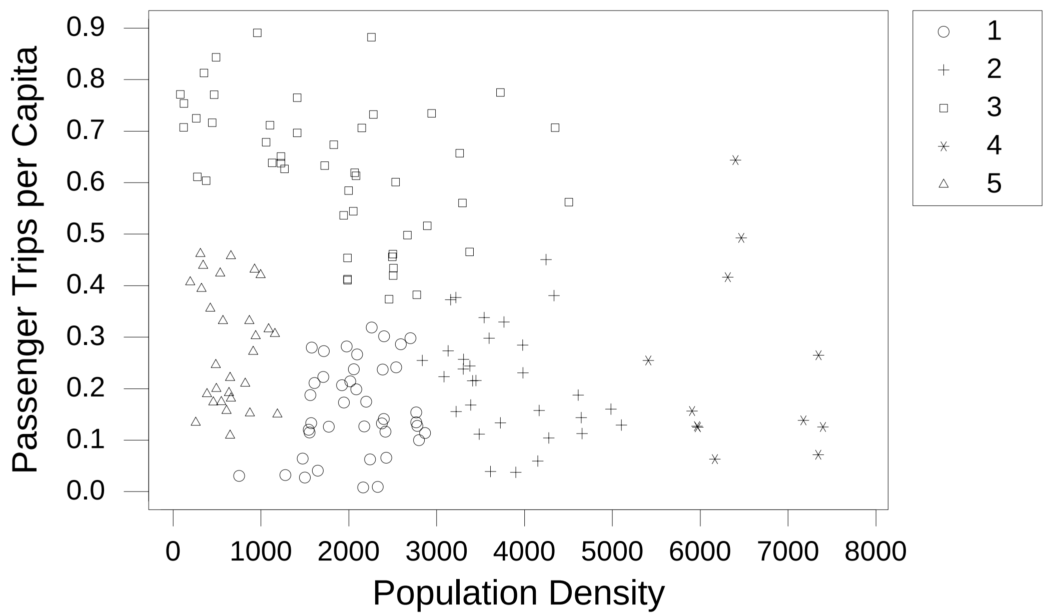

Figure 1: Clusters of Surveyed Agencies

the pick–up location. A passenger would also be counted as making more than one unlinked trip if transfers between vehicles occurred during a journey from origin to destination.

Figure 1 shows the results of a cluster analysis for the surveyed agencies' demographic variables. We arbitrarily chose to create five clusters from the agencies represented in the figure. The plotting symbols indicate the characteristics of the agencies within each of the five groups. The clusters were formed using the average linkage method of agglomerative hierarchical clustering (Massart and Kaufman 1983, SAS Institute 1988). The similarity measure was the Euclidian distance based upon values of the demographic variables that had been scaled by their mean and standard deviation. There are an additional 19 agencies not represented in the figure that were considered outliers for the cluster analysis: 12 agencies have ridership greater than 0.99 Passenger Trips per Capita and 7 agencies serve areas with Population Density greater than 8000 persons per square

Table 1: Responses by Segment

Segment	Surveyed	Responses
Cluster 1	41	15
Cluster 2	31	9
Cluster 3	48	20
Cluster 5	29	9
Cluster 4 and Outliers	31	9

mile. The clusters were used as the basis for the segmentation of the survey group.

Table 1 shows the number of surveyed agencies in each of the demographic segments. Our goal for the survey was to achieve 30% response rate, both overall and for each segment. By focusing the e–mail follow–up messages to agencies in under–represented segments, we were able to achieve our response rate goal.

The management practices and advanced technologies that we investigated through the survey are described in Tables 2 and 3. An additional concern regarding the characteristics of the responding agencies was related to their history of implementing the management practices and advanced technologies. If an overwhelming majority of the responding agencies had not implemented a particular technology or practice, it would not be possible to evaluate the performance impact because there would be too little evidence of the performance after implementation. A similar problem would occur if an overwhelming majority of agencies had implemented a technology or practice. There would be too little evidence in the 1997-1999 NTD of performance prior to implementation. Table 4 shows the state of technology/practice implementations, as reported by agencies responding to the survey. For the Consumer Choice management practice, as well as the Automated Vehicle Location, Automated Fare Payment, and Automated Transit Information technologies, the number of implementations is so few that a large difference in average performance would be required to demonstrate statistical significance. For the Contracted Service

Table 2: Management Practices Investigated

Factor	Definition
Financial Incentives	Payments to contractors, in addition to the base fee, that are contingent upon service performance results
Financial Penalties	Charges to contractors, deducted from the base fee, that are contingent upon service performance results
Ridesharing	A vehicle simultaneously serves trip requests from more than one customer by use of a carpooling strategy
Agency Administration	The agency named on the survey performs the following functions: determines ADA eligibility, arranges for use of vehicles and services of drivers, monitors service performance, and distributes funds in payment for transportation
Contracted Administration	The agency named on the survey contracts another organization(s), most likely a private operator, to perform the functions listed above
Agency Service Delivery	The agency named on the survey directly operates vehicles that fulfill trip requests
Contracted Service Delivery	The agency named on the survey contracts another organization(s) to fulfill trip requests
Consumer Choice	Customers are allowed a selection of providers (among the agency and its contractors) to service a trip request

Delivery practice, the number of agencies that have not implemented the practice is so few that demonstration of a statistically significant impact on performance may also be problematic.

A correlation analysis (Draper and Smith 1981) of the practice/technology implementations was performed to determine whether or not agencies tend to implement pairs of practices or technologies concurrently. If a large portion of the responding agencies implement two practices or technologies concurrently, then it is not possible to separate the impacts of the two on performance via the regression techniques that we use. The correlation analysis revealed that the implemen-

Table 3: Advanced Technologies Investigated

Factor	Definition
Advanced Communications	A digital radio or wireless personal communication system used to transmit voice and/or data between the vehicle and the dispatch center
Automated Vehicle Location	A computer–based tracking system that includes a method of determining vehicle location (such as global positioning system, active signposts, ground–based radio) and a method of transmitting data from the vehicle to the dispatch center
Automated Fare Payment	A system that allows customers to use magnetic stripe cards, smart cards, credit cards, or debit cards for fare payment via in-vehicle readers, telephone, or the internet
Automated Transit Information	A computer-based system for disseminating real–time information (such as vehicle location or anticipated arrival times) to customers via kiosks, the internet, or interactive telephone systems
Paratransit CAD System	A single software package, or integrated collection of software products, that provides Computer Aided Dispatching capabilities used to deliver transit service to individuals in accordance with the requirements of the ADA. The system is capable of performing one or more of the following automated functions: administration, reservations, scheduling, routing, dispatching, or reporting.

tation of Financial Incentives and Financial Penalties is inter–related. Among the 26 agencies that use Financial Incentives, 25 also use Financial Penalties. As a result, it is not possible for us to determine the impact of using Financial Incentives in the absence of Financial Penalties. All other pairwise combinations of the practices and technologies are uncorrelated. Their impacts upon performance can be assessed independently.

A final issue connected to implementation history was the timing of the implementation. If a practice/technology was implemented during the time frame of our performance evaluation, the

Table 4: Implementation by Responding Agencies

	No	Yes	Implemented 1996-1999
Management Practices —			
Financial Incentives	36	26	12
Financial Penalties	25	37	14
Ridesharing	25	37	2
Agency Administration	19	43	7
Contracted Administration	37	25	1
Agency Service Delivery	39	23	0
Contracted Service Delivery	6	56	0
Consumer Choice	57	5	1
Advanced Technologies —			
Advanced Communications	33	29	8
Automated Vehicle Location	57	5	2
Automated Fare Payment	58	4	3
Automated Transit Information	61	1	0
Paratransit CAD System	29	33	16

performance measures reported during the transition could not be considered to be representative of typical pre– or post–implementation performance. Consequently, as part of the survey we solicited information from the responding agencies regarding the year of implementation for each practice/technology in use. If a practice/technology had been implemented within the 1996-1999 time frame, the performance measures for the year of implementation were removed from the analysis. Table 4 shows the amount of data loss for this cause.

2.2 The Performance Data

The selection of performance measures required some preliminary analysis of data available from the NTD. We preferred using existing data from the NTD for two reasons: (1) to reduce the amount of information requested in the survey and (2) to allow the selection of performance measures based upon a review of information describing all of the surveyed agencies. Our first task was to identify a set of performance measures that could be associated with the characteristics of productivity and operating cost. While we did consider measures reported in the National Transit Profiles, we also considered additional measures of our own design. The preliminary analysis determined the number and formulation of performance measures to be used.

The first performance measures that we considered dealt with the productivity of the DRT service. Initially, we proposed four productivity measures: Revenue Miles per Vehicle ($RevMil/Veh$), Revenue Miles per Total Vehicle Mile ($RevMil/VehMil$), Passenger Miles per Revenue Mile ($PassMil/RevMil$), and Passenger Trips per Revenue Mile ($Trip/RevMil$). Revenue Miles represent the distance traveled by a vehicle while available to carry passengers, whether or not a passenger is actually in the vehicle. Total Vehicle Miles include both Revenue Miles and deadheading. Deadheading is defined as the distance from a dispatch location to the first passenger pick–up location or the distance from the final passenger drop–off location back to a dispatch location, as well as any distance traveled between dispatch, storage, and maintenance locations. The number of Vehicles used is the number reported as the maximum actually operated to provide service on an average weekday. Passenger Miles are the total of distances traveled by each passenger.

A principal components analysis (Johnson and Wichern 1992) was performed separately for each year of NTD data (1997, 1998, and 1999). The three analyses produced consistent results. The results revealed that these measures were most naturally arranged into two groupings. The first group, consisting of $RevMil/Veh$ and $RevMil/VehMil$, we interpreted as representing the portion of miles traveled by the vehicle that was productive. We refer to this characteristic as mileage productivity. The second group, consisting of $PassMil/RevMil$ and $Trip/RevMile$, was interpreted as representing the number of passengers travelling simultaneously in the vehicle. We refer to this characteristic as people loading productivity.

An initial analysis of the impacts of practices and technologies upon mileage productivity produced counter–intuitive results. Upon further study, we discovered that the definition of the Revenue Mile was inconsistent with the concept of mileage productivity, see the Appendix. Consequently, we concluded that it was necessary to create a revised set of productivity measures.

The revised productivity measures are Passenger Miles per Vehicle ($PassMil/Veh$) and Passenger Trips per Vehicle ($Trip/Veh$). We interpret $PassMil/Veh$ as being related to mileage productivity, and $Trip/Veh$ as being related to people loading productivity.

While the formulation of the revised productivity measures was inspired by the concepts of mileage productivity and people loading productivity, we must admit that neither measure can be said to represent solely one or the other characteristic. For example, $PassMil/Veh$ can be increased by shortening trip segments when the vehicle carries no passengers, thereby allowing the vehicle to service more requests over the same number of total miles. But, $PassMil/Veh$ can also be increased by carrying more than one passenger at a time, thereby multiple counting the miles when the vehicle is carrying passengers. Similarly, one could argue that both effects can influence the $Trip/Veh$ measure.

Ultimately, it would be useful to have access to information such as the Loaded Miles or the Trip Requests Serviced. The Loaded Miles would indicate the number of miles traveled when the vehicle contained one or more passengers, with no multiple counting of miles when the vehicle carries more than one passenger. The Trip Requests Serviced would indicate the number of calls for service satisfied, irrespective of the number of passengers per request. These measures would help to clarify the productivity picture. Measures defined as Loaded Miles per Total Vehicle Mile or Trip Requests Serviced per Vehicle would clearly represent the mileage productivity concept.

A measure defined as Passenger Miles per Loaded Mile would clearly represent people loading productivity.

However, without incorporating Loaded Miles and Trip Requests Serviced within a mechanism such as the NTD Reporting Requirements, it is unlikely that academic researchers relying on voluntary reporting would be able to obtain this information for a large number of agencies. Policy makers interested in evaluating system productivity on a national basis should support the inclusion of these new variables in the NTD Reporting Requirements.

With regard to operating cost, we considered two performance measures: Operating Expense per Passenger Trip ($OpExp/Trip$) and Operating Expense per Passenger Mile ($OpExp/PassMil$). A principal components analysis of these measures indicated that both represent the same performance characteristic. Consequently, an Average Operating Cost (AOC) measure was defined, see Equation 1 for an example based on the 1999 data. The AOC was formulated as the mean of the scaled performance measures. The values \$18.692 and \$9.909 are the mean and standard deviation of $OpExp/Trip$ for the 180 agencies surveyed. The values \$2.3992/mile and \$1.2946/mile are the mean and standard deviation of $OpExp/PassMil$.

$$AOC \equiv \left(\frac{OpExp/Trip - 18.692}{9.909} + \frac{OpExp/PassMil - 2.3992}{1.2946} \right) \div 2 \tag{1}$$

A principal components analysis of $PassMil/Veh$, $Trip/Veh$, and AOC, indicates that the productivity and operating cost measures do represent separate performance characteristics. Having formulated the performance measures, the next step is to identify statistically significant relationships between the performance measures and the practices/technologies.

Table 5: Passenger Miles per Vehicle Regression Results

y: $(ScaledMiles + 3)^{0.2}$

	1999		1998		1997	
Term	Coeff. Est.	p–value	Coeff. Est.	p–value	Coeff. Est.	p–value
Paratransit CAD	0.07	0.003	0.05	0.034	—	—
Financial Incentives	−0.05	0.064	—	—	—	—

3 Main Survey Results

We began by analyzing relationships to the $PassMil/Veh$ productivity measure. Linear regression techniques were used to evaluate statistical significance. The method was similar to that used for the initial productivity analysis, described in the Appendix. The first step was to scale the measure using its mean and standard deviation, see Equation 2 for the 1999 data example. A Box–Cox power transformation was applied to the scaled measure to improve the normality of the regression residuals. Table 5 shows the results of the regression analysis. The table shows all model terms found significant at the 10% level.

$$ScaledMiles = \frac{PassMil/Veh - 40429}{19334} \tag{2}$$

The strongest relationship to $PassMil/Veh$ is with the implementation of Paratransit CAD technology. This relationship was observed in both the 1999 and 1998 data. The sense of the relationship is positive, i.e. agencies that implement Paratransit CAD have a greater $PassMil/Veh$ value than agencies that do not. For the 1999 data, responding agencies that had implemented Paratransit CAD had a mean $PassMil/Veh$ value of 48700 miles/vehicle, while the responding agencies that had not implemented CAD technology had a mean value of 35800 miles/vehicle. For the 1998 data, the mean values are 48600 miles/vehicle for implementers versus 37000 miles/vehicle for non–implementers.

A relationship of marginal statistical significance is also observed in the 1999 data between $PassMil/Veh$ and use of Financial Incentives in contracts for service delivery. The sense of this relationship is negative, i.e. the agencies that use financial incentives have a lower average $PassMil/Veh$ value than those that do not. The mean values are 45600 miles/vehicle for non–implementers versus 38200 miles/vehicle for implementers.

The next analysis was for relationships to the $Trip/Veh$ productivity measure. The scaling for the 1999 data is shown in Equation 3. The regression results are shown in Table 6. The observed relationships both deal with the selection of providers for service delivery. The sense of the relationship to the use of Contracted Service Delivery is negative, i.e. agencies that do use contractors had a smaller mean $Trip/Veh$ value than those who did not. The sense of the relationship to use of Agency Service Delivery is positive, i.e. agencies that deliver the service themselves had a greater mean $Trip/Veh$ value than those who did not. For the 1998 data, responding agencies that do deliver service themselves had a mean $Trip/Veh$ value of 5620 trips/vehicle, while those that do not deliver service directly had a mean value of 4310 trips/vehicle. The impacts of Contracted Service Delivery in 1999 and 1997 are larger than the 1998 impact of Agency Service Delivery. However, since there is only a small number of the responding agencies that do not contract any delivery, we choose to exercise caution towards overstating the impact of these relationships.

$$ScaledLoading = \frac{Trip/Veh - 4948.8}{2050.6} \tag{3}$$

Table 7 shows the regression results for relationships to the AOC measure, defined in Equation 1. The strongest relationship is that observed in the 1998 data with use of Advanced Communications technology. The sense of this relationship is negative, i.e. agencies that use advanced

Table 6: Passenger Trips per Vehicle Regression Results

y: $(ScaledLoading + 3)^{0.5}$

	1999		1998		1997	
Term	Coeff. Est.	p–value	Coeff. Est.	p–value	Coeff. Est.	p–value
Contracted Service Delivery	−0.30	0.006	—	—	−0.26	0.018
Agency Service Delivery	—	—	0.16	0.034	—	—

Table 7: Average Operating Cost Regression Results

y: $(AOC + 3)^{-0.75}$

	1999		1998		1997	
Term	Coeff. Est.	p–value	Coeff. Est.	p–value	Coeff. Est.	p–value
Financial Penalties	−0.04	0.082	—	—	—	—
Advanced Communications	—	—	0.05	0.032	—	—

communications technology have a smaller mean AOC value than those that do not. The mean AOC value for responding agencies that use the technology translates to a mean $OpExp/Trip$ value of \$13.50/trip, and a mean $OpExp/PassMil$ value of \$1.75/mile. The mean AOC value for agencies that do not use the technology translates to a mean $OpExp/Trip$ value of \$16.50/trip, and a mean $OpExp/PassMil$ value of \$2.20/mile.

A marginally significant relationship between AOC and the use of Financial Penalties in service delivery contracts was observed in the 1999 data. The sense of this relationship is positive, i.e. agencies that use financial penalties in their contracts have a greater mean AOC value than those that do not. The mean AOC value for agencies that reported use of financial penalties translates to a mean $OpExp/Trip$ value of \$16.20/trip, and a mean $OpExp/PassMil$ value of \$2.08/mile. The mean AOC value for agencies that do not use the practice translates to a mean $OpExp/Trip$ value of \$14.00/trip, and a mean $OpExp/PassMil$ value of \$1.78/mile.

The results of the analyses above are summarized in Table 8.

Table 8: Summary of Analysis

	Performance Impacts		
Significant Factors	*PassMil/Veh*	*Trip/Veh*	*AOC*
Paratransit CAD	positive		
Financial Incentives	negative		
Financial Penalties			positive
Contracted Service Delivery		negative	
Agency Service Delivery		positive	
Advanced Communications			negative

4 Conclusions

We have conducted a survey of transit agencies providing DRT service in medium sized and large urban centers throughout the United States. The survey has provided information regarding the implementation of advanced technologies and management practices for 62 agencies that responded. We have evaluated the impact of the implemented technologies/practices on productivity and operating cost measures derived from information available in the 1997-1999 NTD.

First, the Revenue Mile was found to be a poor representation of service output, as related to evaluation of productivity. Productivity measures based upon the Revenue Mile should be avoided. Policy makers should support the inclusion of Loaded Miles and Trip Requests Serviced in the NTD Reporting Requirements.

Our analysis indicates that use of a Paratransit CAD system provides a productivity benefit of approximately 12000 passenger miles per vehicle annually. However, there is no corresponding operating cost benefit. Since the majority of CAD implementers reported using their systems for the automated scheduling and automated dispatching functions, we interpret this productivity impact as being related to improvements in these functions. These results suggest that policy makers should continue to implement Paratransit CAD systems, but should also monitor operating cost impacts that offset the expected benefits from productivity improvement.

Agency Service Delivery was also found to have a beneficial impact on productivity of approximately 1300 passenger trips per vehicle annually. The $Trips/Veh$ regression results indicate that agencies that directly operate at least a portion of the service provided to their customers have a more productive overall service. This could be a result of the methods by which trip requests are directed to contractors. If requests are first handled by a central call receiving facility and then passed along to the contractors, it may not be possible for the contractors to effectively schedule the service. Alternatively, contracts may call for vehicles to be available for service, even in periods of low demand. Finally, this productivity impact may be a result of the relative priority given to DRT requests by contractors providing service at pre–negotiated rates. In any case, policy makers should be aware that there is an overall productivity benefit to agencies electing to directly operate DRT service. Here again, there is no corresponding operating cost impact. Policy makers should consider the decision between direct operation and contracted service to be operating cost neutral, and should consider other factors when making the decision.

The use of Advanced Communications technology was found to have a beneficial impact on operating cost of approximately $3.00 per passenger trip in 1998. Operating cost in transit services is primarily related to labor and fuel. It is most likely that the AOC impact of Advanced Communications is related to a reduction in labor cost. Since there is no corresponding productivity impact, we interpret the labor cost reduction as a reduction in supervisory or dispatch labor. The cost benefit observed for Advanced Communications in the 1998 data is not evident in the 1999 data. A closer look at the 1999 data reveals that the sense of the relationship between AOC and Advanced Communications remained the same as that in 1998. The relationship is no longer statistically significant because the size of the impact diminished somewhat and the overall variability of the operating cost measure increased due to the rising impact of Financial Penalties. Consequently, policy makers should be alert to increasing costs that offset the benefits of Advanced Communications.

The use of Financial Incentives was found to have a detrimental impact on productivity of approximately 7000 passenger miles per vehicle annually. Many agencies use of financial incentives is linked only to on–time pick–up performance. It is possible that contractors are dispatching vehicles in a relatively unproductive way in order to satisfy the on–time performance criteria established in their contracts. Incentives based upon a single performance metric can induce this type of performance trade–off. Even so, an analysis of voluntarily reported on–time performance data from our survey indicates no relationship between on–time performance and any of the practices/technologies. Furthermore, the use of Financial Penalties was found to have a detrimental impact on operating cost of approximately $2.00 per passenger trip. This indicates that policy makers should assume that contractors will either avoid conditions that result in activation of financial penalty clauses or will bid at base rates that cover expected losses. Policy makers should exercise caution when using these practices in contracts for service.

As important as those practices/technologies that do demonstrate relationships to AOC are some of those that do not. For example, implementation of Paratransit CAD technology has been shown to improve productivity, but there is no commensurate impact on operating cost. This indicates that the operating cost benefit of improved productivity is being offset by an additional operating expense associated with introduction of the CAD systems. One might assume that this operating cost is related to initial operator training, and will not be present with continued operation. However, policy makers should continue to evaluate the operating cost impact of CAD implementations. Also, Agency Service Delivery has shown a beneficial impact on productivity, but demonstrates no statistically significant impact on operating cost. This indicates that there is no significant difference in operating cost between Contracted Service Delivery and Agency Service Delivery. Policy makers should base the decision to contract rather than directly operate on factors other than operating cost.

As a final remark, the cost and productivity factors considered in this study are only one part of the total picture of benefits and costs derived from the efforts to improve service. For example, our study does not consider the effect on customer perceptions or preferences. Furthermore, the derived impacts are based on national averages and may vary from agency to agency based on local conditions such as cost of living.

5 Acknowledgement

Funding for this project was provided by California Partners for Advanced Transit and Highways (PATH) under a grant from Caltrans. We would also like to thank the anonymous referees for their helpful comments in improving the paper.

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Appendix

An Average Mileage Productivity (AMP) value was calculated for each of the responding transit agencies, for each year of NTD data. As an example, Equation 4 shows the calculation for 1999. First, an agency's $RevMil/Veh$ and $RevMil/VehMil$ values were separately scaled. The values 30498 miles and 11559 miles represent the mean and standard deviation, respectively, of $RevMil/Veh$ for all 180 of the surveyed agencies. Similarly, 0.8431 and 0.1092 are the mean and standard deviation of $RevMil/VehMil$. Then, the AMP was defined as the mean of the scaled performance measure values.

$$AMP \equiv \left(\frac{RevMil/Veh - 30498}{11559} + \frac{RevMil/VehMil - 0.8431}{0.1092} \right) \div 2 \tag{4}$$

Linear regression techniques were used to evaluate the statistical significance of the relationships between the AMP and the practices/technologies. A Box–Cox power transformation of the AMP was used to improve the normality of the residuals (Draper and Smith 1981, Myers and Montgomery 1995). Separate maximum likelihood estimates of the power transformation exponent were calculated for each year of NTD data. The estimates were found to be consistent; so, a single value for the exponent ($\lambda = 2$) was selected for uniform application across all years of NTD data. Finally, a stepwise regression procedure was used to select the terms in the model for each year.

Table 9: Average Mileage Productivity Regression Results

y: $(AMP + 3)^2$

	1999		1998		1997	
Term	Coeff. Est.	p–value	Coeff. Est.	p–value	Coeff. Est.	p–value
Ridesharing	−2.74	0.020	−2.77	0.024	−2.82	0.021
Financial Penalties	4.58	0.002	—	—	2.17	0.071
Financial Incentives	−3.09	0.037	—	—	—	—

Table 9 shows the results of the regression analysis. The terms in the models are indicator variables representing implementation of the respective management practices. The terms shown are the only ones found to be significant at the 10% level. Since the purpose of these models is to identify statistically significant relationships between the AMP and the practices/technologies, the intercept estimates are omitted from the table.

The results shown in Table 9 were troubling to us because the sense of the relationship between AMP and ridesharing is negative. In other words, the data indicate that agencies that have implemented ridesharing have a smaller portion of productive miles traveled than those agencies that do not use ridesharing. This result did not agree with our intuition regarding the likely impact of ridesharing. However, upon further investigation, we came to understand the nature of the result.

Figure 2 shows alternative methods of servicing requests from two customers. Nodes P1 and P2 represent the pick–up points for each of the customers. Nodes D1 and D2 represent the drop–off points. The pick–ups are relatively close to each other, as are the drop–offs. However, the drop–off points are relatively far from the pick–up points. This is a typical case where ridesharing should be a productive practice. The arcs depicted with solid lines fall within the definition of Revenue Miles (Federal Transit Administration 1999, pp. 240-241). The values along the arcs that connect the nodes indicate distance traveled. The side calculations show that the revenue miles fraction has decreased for the diagram 'with rideshare'. This is the same impact observed in the regression analysis. It is due to the fact that, in the 'no rideshare' diagram, the Revenue Miles definition admits the segment of the trip between D1 and P2, even though the vehicle is carrying no passengers.

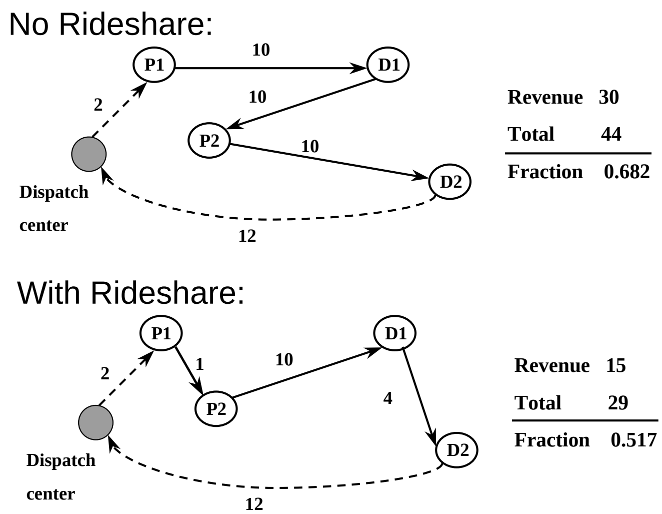

Figure 2: Revenue Miles Explanation

Clearly, the diagram 'with rideshare' shows a more productive method of servicing the customers than that shown in the 'no rideshare' alternative. In the 'with rideshare' diagram, both requests are satisfied while the vehicle travels a much shorter total distance. For the purpose of measuring productivity, performance measures that use the Revenue Mile to indicate system output are obviously misleading. Policy makers wishing to improve productivity should not rely on measures such as $RevMil/Veh$ or $RevMil/VehMil$ to gage the success of their efforts.