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BENEFIT-COST ANALYSIS OF INTEGRATED PARATRANSIT SYSTEMS
Volume 5: The Impacts of Technological Innovation

Multisystems, Inc.
Cambridge MA 02138

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Trans

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16. Abstract

This study systematically estimates potential impacts of a range of integrated transit/paratransit options and policies in a variety of settings and compares them with impacts of transportation alternatives.

The study concludes that, in general, integrated paratransit with fares closer to fixed-route transit than exclusive-ride taxi will result in net paratransit operating deficits. However, in some instances, the benefits of integrated paratransit options in terms of improved service levels and mobility, reduced auto expenditures and other impacts appear to offset these operating deficits. Necessary factors for this include high paratransit productivities, possibly achieved by implementing hybrid, fixed-route/demand responsive service; and low operating costs, possibly achieved by contracting with private operators. Integrated paratransit was found to have a positive but insignificant impact in reducing automobile usage and ownership, but no measurable impact on vehicle miles travelled, fuel consumption, or emissions. Promising locations for paratransit implementation are those areas with population densities between 3,000 and 6,000 persons per square mile and limited existing transit service. The most promising paratransit concepts appear to be checkpoint many-to-many service, route deviation service, automated doorstop service with high vehicle densities and vanpool service. The results of the study further suggest that paratransit service demand is sensitive to fare; fare increases above $.25 were determined to be counterproductive, while free transfers from feeder services to line haul became an inducement to use paratransit. The study also concluded that digital communications and automated dispatching systems are potentially cost-effective technological innovations.

This is the fifth volume of the six volume series documenting this study. This volume contains the analysis of the impacts of technological innovations on integrated paratransit systems.

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PREFACE

Integrated paratransit (IP) service is a concept which involves the integration of conventional fixed-route transit services with flexible, demand-responsive services in order to best serve emerging urban development patterns. Despite the emphasis that has been placed on the analysis and demonstration of paratransit concepts in recent years, there is still considerable confusion and disagreement concerning the impact of paratransit service deployment. To learn more about the capability of IP to meet the transit needs in the urban/suburban environment, the Urban Mass Transportation Administration sponsored a study to identify and define the benefits due to and the costs associated with the deployment of various hypothetical IP systems. The work was performed by Multisystems, Inc. in association with Cambridge Systematics, Inc., and Applied Resource Integration Ltd. under contract to the Research and Special Programs Administration's Transportation Systems Center. Richard Gundersen was Technical Monitor of the study. The Final Report was edited by Larry Levine.

The results of the study are documented in a Final Report which consists of the following six volumes:

Volume 1 - Executive Summary
Volume 2 - Introduction and Framework for Analysis
Volume 3 - Scenario Analyses
Volume 4 - Issues in Community Acceptance and IP Implementation
Volume 5 - The Impacts of Technological Innovation
Volume 6 - Technical Appendices.

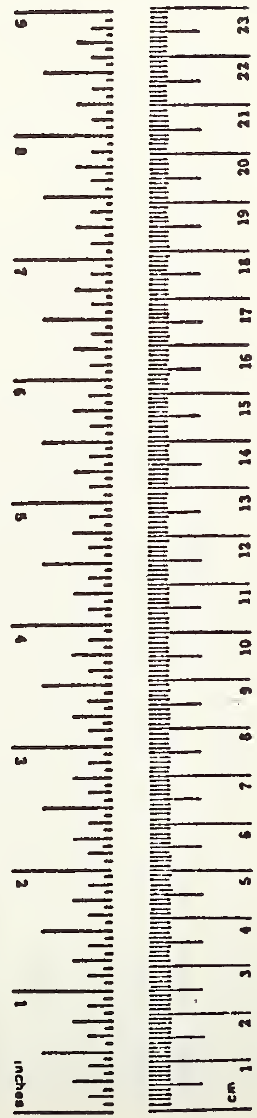
This is Volume 5 - The Impacts of Technical Innovation. Multisystems, Inc. had sole responsibility for this segment of the analysis. This volume summarizes the analysis of the impacts of technological innovations on IP systems.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

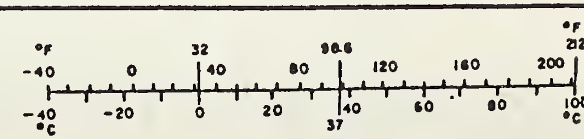
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



SUMMARY

A number of new technologies have been implemented with or proposed for paratransit systems. As part of the overall IP benefit-cost study, the potential impact of two such technologies, digital communications and computer dispatching, have been analyzed in detail and are reported here. In addition, some preliminary analyses have been conducted on the potential impacts of computer-aided dispatching, computer control of radio channels, automated control-to-passenger communications, automated passenger information systems, automatic vehicle monitoring, and a new paratransit vehicle. The results of these assessments are summarized below.

Digital Communications

Digital communications involves the transmission of data digitally, rather than by voice. Digital communications systems hae been implemented in the Rochester, N.Y. and Ann Arbor, Mich. IP systems. Potential benefits of digital communications are reduced vehicle fleet size or hours of service, reduced frequency requirements, and reduced control room staffing requirements.

The analysis indicated that digital communications may be cost-effective for dynamic dispatch, many-to-many DRT systems with as few as 8 vehicles serving 6 demands per vehicle per hour. Annual dollar savings could be as high as $188.000 for a 32 vehicle system (which would have a base annual operating cost of about $2.2 million).

Computer Dispatching

Computer, or automated dispatching involves the use of a computer to make routing and scheduling decisions. Fully computerized dispatching systems have been implemented in IP systems in Haddonfield, N.J. and Rochester, N.Y. In both of these cases, automation reduced passenger wait time and the variability of wait and ride time. Potential benefits of computer dispatching are reduced vehicle fleet size or hours of service, reduced control room staffing requirements, and improved reporting capability.

The results indicate that the combination of computer dispatching and digital communications is more benefical than automated dispatching alone. The combination may be cost-effective in a dynamic dispatch, many-to-many DRT system with vehicle fleets of about 12 vehicles serving 8 demands per vehicle hour. The net benefits of the technology tends to increase with increasing system size. With 32 vehicles, up to a $444,406 annual cost reduction may be observed for a system with a base annual operating cost of $2.2 million.

Computer Control of Voice Radio

This technology involves the use of a computer to ensure that only the desired (first on line) vehicle receives messages. The concept appears to have limited application to IP systems, but is more promising for an exclusive-ride taxi operator, where there may be a problem of dispatcher favoration or driver "pirating", and where a "first-in first-out" dispatching formula can be more readily followed.

Computer-Aided Dispatching

With this technology, a computer is used to assist in the dispatching or scheduling process, but does not make any scheduling decisions. The primary economic benefit of this innovation is probably in the area of improved reporting capabilities. However, continued experimentation is needed to help estimate benefits.

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16. Abstract

Integrated paratransit (IP) service is a concept which involves the integration of conventional fixed-route transit services with flexible, demand-responsive services in order to best serve emerging urban development patterns. To learn more about the capability of IP to meet the transit needs in the urban/suburban environment, the Urban Mass Transportation Administration sponsored a study to identify and define the benefits due to and the costs associated with the deployment of various hypothetical IP systems. This study systematically estimates potential impacts of a range of integrated transit/paratransit options and policies in a variety of settings and compares them with impacts of transportation alternatives. This study concludes that, in general, IP with fares closer to fixed-route transit than exclusive-ride taxi will result in net paratransit operating deficits. However, in some instances, the benefits of IP options in terms of improved service levels and mobility, reduced auto expenditures and other impacts appear to offset these operating deficits. Necessary factors for this include high paratransit productivities, possibly achieved by implementing hybrid, fixed-route/demand responsive service; and low operating costs, possibly achieved by contracting with private operators. IP was found to have a positive but insignificant impact in reducing automobile usage and ownership, but no measurable impact on vehicle miles traveled, fuel consumption, or emissions. Promising locations for paratransit implementation are those areas with population densities between 3,000 and 6,000 persons per square mile and limited transit service. The most promising paratransit concepts appear to be checkpoint many-to-many service, route deviation service, automated doorstop service with high vehicle densities, and vanpool service. The results of the study further suggest that paratransit service is sensitive to fare. Fare increases above $.25 were determined to be counterproductive, while free transfers from feeder services to line haul became an inducement to use paratransit. The study also concluded that digital communications and automated dispatching systems are potentially cost-effective technological innovations.

This volume, Volume 5, contains the analysis of the impacts of technological innovations on integrated paratransit systems.

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Automated Control-to-Passenger Communications

The only system of this sort to receive considerable application to date is an interactive tape recording system. The primary potential for this technology would appear to lie with exclusive-ride taxi operators, where this component of communications is usually fairly straightforward.

Automated Passenger Information System

The type of technology would go somewhat beyond that of the previous one, by providing information on service characteristics, general dynamic system status, vehicle schedule at specific stops, and passenger-specific status in the queue. Given the present state-of-the-art, only simple technologies based on tape recorders, are likely to be reasonably inexpensive. Passenger specific status information would not be available from such single technologies.

Automated Vehicle Monitoring (AVM)

AVM, in which vehicles locational information is provided on a continuous basis, is presently receiving a thorough testing by UMTA in a fixed route application. Preliminary consideration suggest that an increase in productivity of up to 5% may be achievable in a many-to-many DRT system, but further experimentation or analysis must be undertaken before this benefit can be verified.

Paratransit Vehicle

A new paratransit vehicle could potentially reduce paratransit operating costs and hence local and federal subsidies, decrease fuel consumption, and improve service reliability. Based on ballpark estimates of IP penetration, it was estimated that a new vehicle could eventually save $3.2-10.7 million in subsidy annually on a national level, and reduce fuel consumption by 3.2-10.7 million gallons.

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Chapter 1

Introduction

Introduction to the Study

For the most part, paratransit and integrated paratransit services have represented low cost, low capital intensive options. In contrast to downtown people movers and other innovative urban transportation concepts, IP systems do not depend on the development of sophisticated hardware. IP systems represent near-term alternatives which are highly labor intensive; it is typically possible to implement the systems fairly quickly, without worrying about the performance of sophisticated technologies.

This need not imply, however, that there are not, or have not been various technologies associated with the deployment of IP systems. On the contrary, a number of fairly new technologies have been implemented (or proposed) along with IP systems. These technologies almost uniformly have a common objective: to allow IP systems to operate in a more cost-effective manner.

Because IP systems are labor intensive, the majority of the technologies deal with the elements of vehicle control, including communications, scheduling, dispatching and information. One, but by no means the only, goal behind implementing these technologies is to reduce the number of personnel needed to provide IP service. Perhaps the only area of technology not included in this group would be the area of new vehicles, which would be designed to reduce operating costs and increase system reliability.

An analysis of the benefits and costs of IP systems, particularly systems which will be implemented sometime in the (near) future, would not be complete without at least addressing the area of new technology, and attempting to determine the type of impact that new technologies can have on the costs and benefit of IP Service.

This area of investigation is worthy of its own study. Because it represents only a small part of the overall study, it is not possible to address, in-depth, all of the new technologies which may be associated with IP. Instead, only two technologies, both of which have been successfully tested and shown promise, are selected for detailed case studies. Other technologies will be described briefly, with some indication of the possible impacts on IP operation. All of these new technologies are identified in the next section.

Types of Technological Innovation

In the course of this study, the following technological innovations have been identified as having been proposed for, or implemented with, IP Services:

1. Computerized dispatch - The use of a computer to make all the routing and scheduling decisions for a demand-responsive service. The computer can then also be used for management reporting.

2. Computer-aided dispatch - The use of a computer to assist the dispatcher in the scheduling of vehicles by storing and arranging passenger request and vehicle status information. The computer can be used for a variety of functions, including record-keeping and reporting.

3. Digital communications - The use of digital, rather than voice communications between the control center and the vehicles. A digital communications link can be integrated directly with the computer in the case of computer dispatch, resulting in complete automation.

4. Computer control of radio channels - The use of computers to control and increase the capacity of voice radio channels.

5. Automated control to passenger communication - The use of a variety of technologies to reduce the need for call-takers.

6. Automatic vehicle monitoring systems - To pinpoint the location of vehicles, thus allowing better scheduling decisions.

7. Automated passenger information systems - To replace the role of an information operator or requirement of request takers to also give out general information.

8. Paratransit vehicles - UMTA is considering the development of a vehicle specifically designed for paratransit, which would be more reliable and less costly to operate than presently used vehicles.

Of these innovations, only the first three have seen significant experimentation to date. Computerized dispatching has been implemented in Haddonfield, New Jersey, Rochester, New York and planned for Orange County, California. Computer-aided dispatching has been implemented in the Ann Arbor IP system, the Cleveland TH paratransit system, and taxi systems in Davenport, Iowa, Los Angeles, California, and Ottawa, Ontario, as well as in other places. Digital communications have been implemented in the Rochester, New York and Ann Arbor, Michigan IP systems. The remaining innovations, however, have seen only limited implementation, at best. Computer control of radio channels has been tried only in Montreal, Canada. Automated passenger to control communications has been tested only in the form of interactive tape recording systems (rather than more sophisticated computer systems), and only for exclusive-ride taxi services. Automated vehicle monitoring is first receiving complete testing new under an UMTA demonstration, and thus far only for fixed-route operation. Automatic passenger information systems are being used in Portland Oregon and Mississagua, Ontario, but also applied only to fixed route service. Finally, UMTA has not yet decided on whether to pursue the development of a paratransit vehicle.

Clearly it is easier to assess the potential impacts of a new technology if it has already been tested. For this reason, it was first decided to focus on items 1, 2, and 3. In addition, since fully automated dispatching has a greater potential impact (both costs and benefits) than computer-aided dispatching, it was decided to limit the in-depth analysis to computerized dispatching and to digital communications. However, the possible impacts of each of the other innovations will also be discussed.

The impacts of digital communication on IP service are discussed in Chapter 2. The impacts of automated dispatching are discussed in Chapter 3. Finally the remaining innovations are discussed briefly in Chapter 4.

Chapter 2
Digital Communications

Technological Concept

Digital communication involves the transmission of data digitally, rather than by voice, over a regular voice radio channel. On the transmission end, the data are digitally coded in some manner. On the receiving end, the data are than encoded and displayed in some form. There are a variety of technologies available for coding, encoding, and display of the data. For the most part, the details of the technologies themselves will not be discussed in this report, since it is only the impacts of the technologies that are of concern.

There are a number of potential advantages of digital communications. First, and foremost, is increased communication speed. Because digital communications are significantly faster than voice communications, the following impacts are possible:

1 - More messages can be transmitted on a single frequency, thus reducing the need for additional frequencies. This can be extremely important in larger urban areas where there is serious radio frequency "congestion".

2 - A single dispatcher may be able to dispatch more vehicles.

3 - Vehicle response time is reduced, thus increasing the effective vehicle speed.

Two other potential advantages of digital communications are typically cited in the literature. First is a reduction in error, since voice transmission (particularly of items such as addresses) can often be misinterpreted. Second is improved safety, since drivers do not have to write down the information, which sometimes is done while a vehicle is in motion. Note that elimination of the need to stop to write down information serves to increase effective vehicle speed.

2.1 Application of Digital Communications to Paratransit

Digital communications equipment have been used by a number of police departments around the country for about 10 years. The first application within the transit industry came in November, 1972, when Ford Motor Co. conducted a one-month test of digital communications in the Batavia, New York "B-Line dial-a-bus" service. (Guenther, 1973) The system tested involved the use of mobile teleprinters on board a number of vehicles. Information was encoded and printed out in hard copy format. A cathode ray tube (CRT) terminal was used in the control room to input the data. The terminal was interfaced with a "central translator" which coded and transmitted the data.

The results of this test were inconclusive, given its brief nature, but suggested that the digital communications equipment would work. The data suggested that digital communications actually resulted in a 4-11% increase in vehicle productivity.

The first full-scale implementation of digital communications came 8 months later in the dial-a-bus system in neighboring Rochester, a system operated by the same regional transit authority. This system utilized the same teleprinters and central translator. In place of the input terminal, however, a card reader was used. Call-takers keypunched passenger information directly onto computer cards; the dispatcher then arranged the cards in the appropriate order after assignment, and fed them through the card reader for transmission to the appropriate vehicles. This procedure eliminated the "double effort" experienced in Batavia, where the call-takers wrote the passenger information on slips of paper and the dispatcher had to then type the same information into the terminal. The Rochester system also resulted in a permanent record of passenger requests in machine-readable form.

The Rochester system utilized two-way digital communications. Each vehicle was equipped with a device that transmitted a single "message" (vehicle ID number). The drivers were instructed to transmit the message each time they reached a stop. A display in the control room displayed the vehicle number, informing the dispatcher that the vehicle has completed its next assignment. A hard copy printout of the date, vehicle number, and time was also produced.

The control-to-vehicle communications link proved to be extremely reliable and helpful.[1] On the other hand, the vehicle to control communications did not prove overly useful, since drivers often forgot to activate their transmitters. Unfortunately, since the communications system was implemented at the same time as the overall service, no data could be developed on the impact of digital communication.

The next phase in the utilization of digital communications technology also took place in Rochester. As part of an UMTA sponsored demonstration which involved automated dispatching, the mobile teleprinters and associated equipment were replaced with a system that includes:

1. Mobile terminals that have soft-copy "plasma" displays and a keyboard with a number of functions. (For vehicle-to-base communication of a few pre-coded messages.)

2. A control room minicomputer which serves as an interface with the radio transmitter and the dispatching computer.

The switch to soft copy displays was motivated by the anticipated need for additional speed; soft copy displays take considerably less time than teleprinters to print out the message. A number of different soft copy display technologies are available on the market. These devices can display from one to eight lines of information (the Rochester system displays seven); each has a buffer memory which can store additional (in some cases up to 32) lines of information.

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[1]The equipment failed occassionally, but the manufacturer always responded with immediate repairs. During the latter part of the initial demonstration, however, after plans had been made to purchase new equipment from a different manufacturer, the equipment failed and was not repaired. Since the control room staff had been trained primarily on digital communications, the 6-week switch to voice communications proved to be chaotic.

Under the present Rochester system there is no manual interaction at all. Dispatching decisions are made by computer (see Chapter 3), and then transmitted digitally. Drivers inform the computer of their status directly through the use of their keyboards. Voice communications is used only for special instructions or as a back-up.

A communication system similar to that in use in Rochester was implemented in mid-1978 by the Ann Arbor, Michigan, IP system. Digital communications has also been proposed for a taxi system in Ottawa, Ontario, and a dial-a-ride system in Missisagua, Ontario.

2.2 Benefits and Costs of Digital Communications

Digital communication has been shown to be a viable concept for paratransit applications. To date, however, there has been no concerted effort made to actually compare the benefits of digital communications with its costs. This analysis is performed in this section.

To determine the maximum possible benefits of digital communications, it has been decided to consider only dynamic dispatched, many-to-many service. Since this type of service requires pick-up and drop-off information to be sent to the drivers on a dynamic basis, it requires the most communication. The results of this analysis is intended, therefore, to serve as an upper bound on the potential benefits of digital communications.

Although there are some data available on the impacts of this technology, the data are somewhat limited. As such, the analysis must be based on a variety of assumptions regarding communications speed, etc. To incorporate a sensitivity analysis, the analysis is parametric, i.e., key assumptions are varied. The analysis is also parametric with respect to such factors as service area size, demand rate, vehicle fleet size, and operating costs.

In this chapter the impact of automation on the communications function only is considered; in Chapter 3, the impacts of combined communication and scheduling/dispatching automation will be addressed.

2.2.1 Costs

For the purposes of the analysis it has been assumed that all digital communication equipment is purchased, rather than leased. The lifetime of the equipment is unknown, since most systems have been in operation for only a short time. A five year lifespan has been assumed; given the fact that most radio systems last upwards of 15 years, this is probably a conservative estimate.

Costs have been computed for two technologies which represent lower and upper bounds on digital communication cost and capability. The first, simpler system would involve one-way digital communications using mobile teleprinters. Control room equipment would include a central translator (coder), card-reader and interface, and keypunches for each call-taker. The second system would involve two-way digital communications, with a soft copy display. Vehicle-to-base communications is in the form of a number of prespecified functions. In the control room, the call-takers are equipped with terminals, while the dispatcher has a terminal, CRT display, and display of vehicle status, with a minicomputer used for data manipulation. Costs were provided by a number of manufacturers over the telephone (June, 1978). All costs are marginal, based on the assumption that voice radio equipment is in place in any event. Annual operating costs include hardware maintenance and, in the simpler case, keypunch leasing and card purchase. All costs are displayed in Table 2.1.

2.2.2 Benefits

In terms of benefits, only strictly economic benefits are estimated. The following, specific impacts have been considered:

1. The increase in effective vehicle speed increases achievable productivity (at a constant level of service), and thus decreases vehicle requirements.

2. The increase in communications speed reduces frequency requirements and hence radio equipment costs.

Table 2.1

Digital Communications Cost

Capital Costs	Teleprinter Technology		Display Technology	
	Total Cost	Annual Cost	Total Cost	Annual Cost
Mobile unit: per vehicle	$1,500	$300	$3,800	$ 760
Central translater (per frequency)	10,000	2,000	10,000	2,000
Card reader	8,000	1,600	-	-
Computer (incl. printer, software, and interface)	-	-	18,000[1]	3,600
Dispatcher terminal and display (per dispatcher)	-	-	4,000	800
Vehicle-base display & printer	-	-	2,500	500
Call-taker terminal (per position)	-	-	2,000	400
Operating Costs				
Equipment maintenance	-	12% of total (depends on number of vehicles, call-takers, dispatchers)	-	12% of total
Keypunch (per call-taker position)	-	1,800	-	-
Keypunch cards (per call-taker position)	-	200	-	-

[1] A micro-computer may be able to perform this task at about ½ the cost.

3. The use of digital communications equipment speeds up the dispatching process and decreases control room staffing requirements.

The increase in effective vehicle speed results from eliminating the need for drivers to record passenger address information; as such, this benefit is basically independent of the technology used. On the other hand, control room dispatch time is dependent upon the control room set-up. For the purpose of this analysis, it is assumed that the call-takers input the information either on computer cards or in a terminal; in either case, the dispatcher would have no responsibility for inputting any further information. Since the difference in time requirements on the part of either the call-takers or the dispatchers of these alternatives is felt to be slight, control room requirement impacts are also assumed to be technology independent.

The calculation of the benefits is discussed below.

A. Impact On Vehicle Requirements

It is possible to consider the time taken by drivers to record passenger pick-up and drop-off information as part of the passenger "dwell" or delay, time. If dwell time is reduced, through digital communications, the effective vehicle speed is increased and either service levels are improved or it becomes possible to serve the same number of passengers with fewer vehicles (without sacrificing service quality). To provide the impact of digital communications with an economic interpretation, we have considered the latter possibility.

Using the descriptive many-to-many supply model (described in Volume 6, Appendix 1 of this series of reports) it was possible to compute the potential vehicle fleet (or vehicle hours of service reduction) achievable through reduced dwell time, at different area size, vehicle fleet size, and demand level combinations. An example of this is provided in Figure 2.1. Unfortunately, no hard data exists on the dwell time impacts of digital communications. We have, therefore, performed the analysis using different possible impacts, where the "post-digital communications" level is based on data from Rochester

The first scenario from Table 2.2 has base characteristics of:

4 sq. mile area,
4 vehicles
4 passengers per vehicle-hour (productivity), and
2.5 minutes pickup and dropoff time.

Using the descriptive many-to-many supply model, the level of service components produced by this service are:

9.8 minutes wait time
7.9 minutes ride time
17.7 minutes of wait and ride time

If the pickup and dropoff time is reduced to 1.5 minutes, and the vehicle fleet size is reduced by 9% to 3.6 vehicles on average (thereby increasing the productivity to 4.4 passengers per vehicle hour), the level of service produced is:

10.0 minutes wait time
7.7 minutes ride time
17.7 minutes wait and ride time

(The 9% reduction in vehicle hours which resulted in equivalent service level was found by decreasing vehicle hours in 1% increments).

Therefore a 9% reduction in fleet size can be achieved and still provide the patrons with the same overall wait and ride time.

Figure 2.1

Example of Vehicle Savings Resulting From Reduced Dwell Time (for combined pick-up and drop-off dwell time) and "pre-level" is based on trial estimates (conducted as part of this study) of the time which would be needed by a driver to record the necessary information (assuming the vehicle is delayed at a stop until the information is recorded). The results of this analysis are presented in Table 2.2.

Note that these results, which suggest possible vehicle reductions in the range of 3% - 13%, closely parallel the results reported by Ford Motor Co. for the Batavia tests. Note also that, as should be expected, the impact increases with increasing productivity.

Reduced vehicle fleet size requirements can impact costs in two ways. First, it can reduce capital costs. However, given the relatively small vehicle fleet sizes considered (for a single system module) and the relatively small percentage decrease in vehicle requirements, only a few of the systems would actually see a reduction in vehicle requirements; the remainder would see only a reduction in vehicle-hours (e.g., an 11% reduction for an 8 vehicle system translates into an ability to eliminate less than 1 full vehicle). The systems which could achieve fleet size reductions savings, and the resulting annual capital cost savings (based on the use of vans costing $16,000 and lasting 4 years), are shown in Table 2.3.

The second, and more significant impact is on operating costs. For this analysis, fleet reduction is measured in reduced <u>vehicle-hours</u>. Costs savings are computed in Table 2.4 for three different situations:

1. Systems which average $8 per (marginal) vehicle hour (e.g., private taxi operated systems);
2. Systems which average $13 per vehicle hour (e.g., low cost transit systems in smaller cities);
3. Systems which average $22 per vehicle hour (e.g., unionized systems in larger cities.)

For this analysis, it was assumed that there are 60 hours of service per week, with all available vehicles used all hours in the "before" case. (i.e., an 8 vehicle fleet records 480 vehicle hours per week, or 24,960 per year)

Table 2.2

Possible Percentage Fleet Size Reduction

Resulting from Digital Communications

System Parameters			Percent Increase in Productivity or Decrease in Vehicle Requirements with Change in Dwell Time		
Area (mi^2)	Vehicles	Before Productivity (Passengers per vehicle-hr.)	Dwell Time (min) Before 2.5 After 1.5	Dwell Time (min) Before 2.5 After 1.5	Dwell Time (min) Before 2.5 After 1.5
4	4	4	9%	5%	9%
4	4	6	11%	5%	11%
8	4	4	7%	3%	7%
8	4	6	9%	5%	9%
8	8	4	9%	5%	9%
8	8	6	11%	5%	11%
8	12	4	9%	5%	9%
8	12	6	11%	5%	11%
8	12	8	13%	7%	11%
12	4	4	7%	3%	7%
12	4	6	7%	5%	7%
12	8	4	7%	5%	7%
12	8	6	9%	5%	9%
12	8	8	11%	5%	9%
16	4	4	7%	3%	7%
16	8	4	7%	3%	7%
16	8	6	9%	5%	9%
16	8	8	9%	5%	9%
16	12	4	7%	5%	7%
16	12	6	9%	5%	9%
16	12	8	9%	5%	9%
16	16	4	9%	5%	9%
16	16	6	9%	5%	9%
16	32	4	11%	5%	11%
16	32	6	13%	7%	13%
16	32	8	13%	7$	13%
16	32	16	13%	7%	13%

* A base vehicle speed of 15 miles per hour is assumed.

Table 2.3

Annual Capital Cost Savings Resulting From Digital Communications

System Parameters Area (mi2)	Vehicles	Prod. (pax/veh.-hr.)	Dwell Time Reduction	Annual Cost Savings
8	12	4	2.5-1.5 or 2.0-1.0 min.	$ 4,000
8	12	6	2.5-1.5 or 2.0-1.0	4,000
8	12	8	2.5-1.5 or 2.0-1.0	4,000
16	12	6	2.5-1.5	4,000
16	12	8	2.5-1.5 or 2.0-1.0	4,000
16	16	4	2.5-1.5 or 2.0-1.0	4,000
16	16	6	2.5-1.5 or 2.0-1.0	4,000
16	32	4	2.5-1.5 or 2.0-1.0	12,000
16	32	4	2.0-1.5	4,000
16	32	6	2.5-1.5 or 2.0-1.0	16,000
16	32	6	2.0-1.5	8,000
16	32	8	2.5-1.5 or 2.0-1.0	16,000
16	32	8	2.0-1.5	8.000
16	32	16	2.5-1.5 or 2.0-1.0	16,000
16	32	16	2.0-1.5	8.000

Table 2.4

Annual Operating Cost Savings From Digital Communication

System Parameters			ΔDwell[1]	Annual Operating Cost Savings at		
Area (mi^2)	Veh.	Prod. (Pax. veh.-hr.)	Time	\$8/hr	\$3/hr	\$22/hr
4	4	4	2.5-1.5 min	$ 8,985	$14,601	$ 24,710
4	4	4	2.0-1.5	4,992	8,112	13,728
4	4	6	2.5-1.5	10,982	17,846	30,201
4	4	6	2.0-1.5	4,992	8,112	13,728
8	4	4	2.5-1.	6,988	11,356	19,219
8	4	4	2.0-1.5	2,995	4,867	8,236
8	4	6	2.5-1.5	8,985	14,601	24,710
8	4	6	2.0-1.5	4,992	8,112	13,728
8	8	4	2.5-1.5	17,971	29,203	49,420
8	8	4	2.0-1.5	9,984	16,224	27,456
8	8	6	2.5-1.5	21,964	35,692	60,403
8	8	6	2.0-1.5	9,884	16,224	27,456
8	12	4	2.5-1.5	26,956	43,804	74,131
8	12	4	2.0-1.5	14,976	24,336	41,184
8	12	6	2.0-1.5	32,947	53,539	90,604
8	12	6	2.0-1.5	14,976	24,336	41,184
8	12	8	2.5-1.5	38,937	63,273	107,078
8	12	8	2.0-1.5	20,966	34,070	57,657
12	4	4	2.5-1.5	6,988	11,356	19,219
12	4	4	2.0-1.5	2,995	4,867	8,236
12	4	6	2.5-1.5	6,988	11,356	19,219
12	4	6	2.0-1.5	4,992	8,112	13,728
12	8	4	2.5-1.5	13,977	22,713	38,438
12	8	4	2.0-1.5	9,384	16,224	27,456
12	8	6	2.5-1.5	17,971	29,203	49,420
12	8	6	2.0-1.5	9,984	16,224	27,456
12	8	8	2.5-1.5	21,964	35,692	60,403
12	8	8	2.5-1.5	9,984	16,224	27,456
16	4	4	2.5-1.5	6,988	11,356	19,219
16	4	4	2.0-1.5	2,995	4,867	8,236
16	8	4	2.5-1.5	13,977	22,713	38,438
16	8	4	2.0-1.5	5,990	9,734	16,473

Table 2.4 (Cont.)

Area (mi^2)	Veh.	Prod. (pax. veh.-hr.)	ΔDwell Time[1]	Annual Operating Cost Savings $8/hr.	$3/hr.	$22/hr.
16	8	6	2.5-1.5	17,971	29,203	49,420
16	8	6	2.0-1.5	9,984	16,224	27,456
16	8	8	2.5-1.5	17,971	29,203	49,402
16	8	8	2.0-1.5	9,984	16,224	27,456
16	12	4	2.5-1.5	20,966	34,070	57,657
16	12	4	2.0-1.5	14,976	24,336	41,184
16	12	6	2.5-1.5	26,956	43,804	74,131
16	12	6	2.0-1.5	14,976	24,336	41,184
16	12	8	2.5-1.5	26,956	43,804	74,131
16	12	8	2.0-1.5	14,976	24,336	41,194
16	16	4	2.5-1.5	35,942	58,406	98,841
16	16	4	2.0-1.5	19,968	32,448	54,912
16	16	6	2.5-1.5	35,942	58,406	98,841
16	16	6	2.0-1.5	19,968	32,448	54,912
16	32	4	2.5-1.5	87,859	142,771	241,612
16	32	4	2.0-1.5	39,936	64,896	109,824
16	32	6	2.5-1.5	103,833	168,729	285,542
16	32	6	2.0-1.5	55,910	90,854	153,753
16	32	8	2.5-1.5	103,833	168,729	285,542
16	32	8	2.0-1.5	55,910	90,854	153,753
16	32	16	2.5-1.5	103,833	168,729	285,542
16	32	16	2.0-1.5	55,910	90,854	153,753

[1] Referring back to Table 2.2, it is clear that a 1 minute reduction in dwell time will have virtually the same impact if the dwell time was originally 2.5 minutes as it would if it were 2.0 minutes. For this reason, only the 2.5-1.5, 1 minute dwell time change is considered.

It is quite clear from this table that digital communications may have a significant impact on operating costs, particularly in higher cost systems. Savings of over $100,000 annually are possible with 12-vehicle systems which have an average cost of $22 per hour. Systems with larger fleets see even larger savings.

B. Impact on Frequency Requirements

The transmission of information digitally is significantly faster than the transmission of the same information by voice. This implies that an IP system using digital communications may require fewer radio frequencies; this, in turn reduces both the cost of central radio equipment, the problem of obtaining radio frequencies in congested urban areas.

To develop a rough estimate of the volume of communications that can be handled on a single frequency, using either digital or voice communications, a queuing analysis was performed. The analysis was based on a number of assumptions, described below. The sensitivity of the results to some of the assumptions will be explored later.

1. The system operates with a radio channel consisting of a "frequency pair" (two frequencies extremely close on the spectrum). One frequency is used for base-to-vehicle transmission only, and one for vehicle-to-base only. (this is a standard set-up). The "constraining frequency" (in terms of capacity) is the one use for base-to-vehicle messages.

2. All base-to-vehicle messages are assumed to consist of a single address (pick-up or drop-off) only.

3. Messages are assumed to be randomly transmitted, as requests for service are randomly received and processed.

4. The length of voice messages follows a Poisson distribution with mean 15 seconds (which includes vehicle polling and driver confirmation of address).

5. The length of a digital message is also a Poisson distribution. In the case of mobile teleprinter displays, the mean length is 6.5 seconds; in the case of soft copy displays, the length is 0.81 seconds.[1]

6. No other messages from base to vehicle are required (i.e., this represents an ideal case analysis).

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[1] The time required to transmit a digital message during which the -continued-

Table 2.5

Queuing Delays of Different Communication Systems

Demands Per Hour	Delay waiting for frequency space: Voice	Digital: Teleprinter	Digital: Soft-Copy
40	2.6 sec.	.5 sec.	.007 sec.
80	7.3	1.1	.015
144	22.0	2.3	.028
208	96.0	4.0	.04
272	∞	6.6	.05
336	∞	19.4	.07
500	∞	58.7	1.00
3000	∞	∞	1.63

Based on these assumptions the delay or wait time for frequency space as a function of demand is shown in Table 2.5. Delays of less than 1 minute should have no impact on the system, since it is likely that both the vehicle and the dispatcher can be doing something else during most of the delay. If a delay of 1 minute or more is considered unacceptable, it appears that, under voice control, the system begins to saturate at about 200 demands per hour. For a system with a productivity of 8 passengers per vehicle-hour, at most 25 vehicles could be dispatched on a single frequency. With digital communication using mobile teleprinters, delays ensue at about 500 requests per hour, or 62 vehicles. With soft-copy

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frequency is occupied includes three phases: equipment "warm-up", transmission, and printing. Most of the equipment on the market have about a .1 second warm-up period. Transmission speed is the same regardless of the display technology; the key difference is in printing time. Teleprinters are relatively slow. Each line printed consists of 32 characters, regardless of the length of the message. (e.g., blanks are printed out). This includes a vehicle ID number which must precede each message; thus, each message consists of two lines. Information is transmitted and printed at a rate of 10 characters per second, or 3.2 seconds per line. Claims for soft copy displays include rates of 450-3000 bits per second, or 45-300 characters per second, or .11-.71 seconds per line. To be conservative, we have used the upper bound estimate.

display, it appears that a single frequency can handle over 3000 requests per hour.

The degree to which different assumption will influence these results is evidenced by the following:

1. If two addresses, rather than one, are transmitted at one time, (which is very likely) mobile teleprinters could handle about 1/3 more demands (since the vehicle ID message would only be needed once for each message). The impact on the other technologies would be very small.

2. If the average voice message length is only 10 seconds, delays would first begin at around 300 demands per hour. If the average were 20 seconds, the demand limit would be around 150 demands per hour.

3. Given the fact that the radio system will also be used for other messages and, in particular, will be used for some voice messages in the digital case, all of the upper bounds are somewhat high.

In terms of cost impact, the elimination of a single frequency "saves" about $6,000 in radio base station costs. Thus (assuming 10 year radio equipment life) the marginal annual capital of digital communication equipment is reduced by $600 for "every" 200 demands per hour served. The cost, and hence savings, associated with multiple frequencies is essentially a step function (with respect to the average demand rate). This is illustrated graphically in Figure 2.1.

Note that the Ann Arbor Transportation Authority (Teltran System) which implemented digital communication fully in March, 1978, reports being able to eliminate 1 of 3 frequencies. The Teltran system handles 2000-2500 demand-responsive trips per day, (200-300 per peak hour, although not all dispatched), plus about 4000 fixed route trips.

C. Impact on Staffing Requirements

The use of digital communications clearly reduces the time which must be spent by the dispatcher who communicates with the

[1]Telephone conversation with Henry Bonislawski, June 14, 1978.

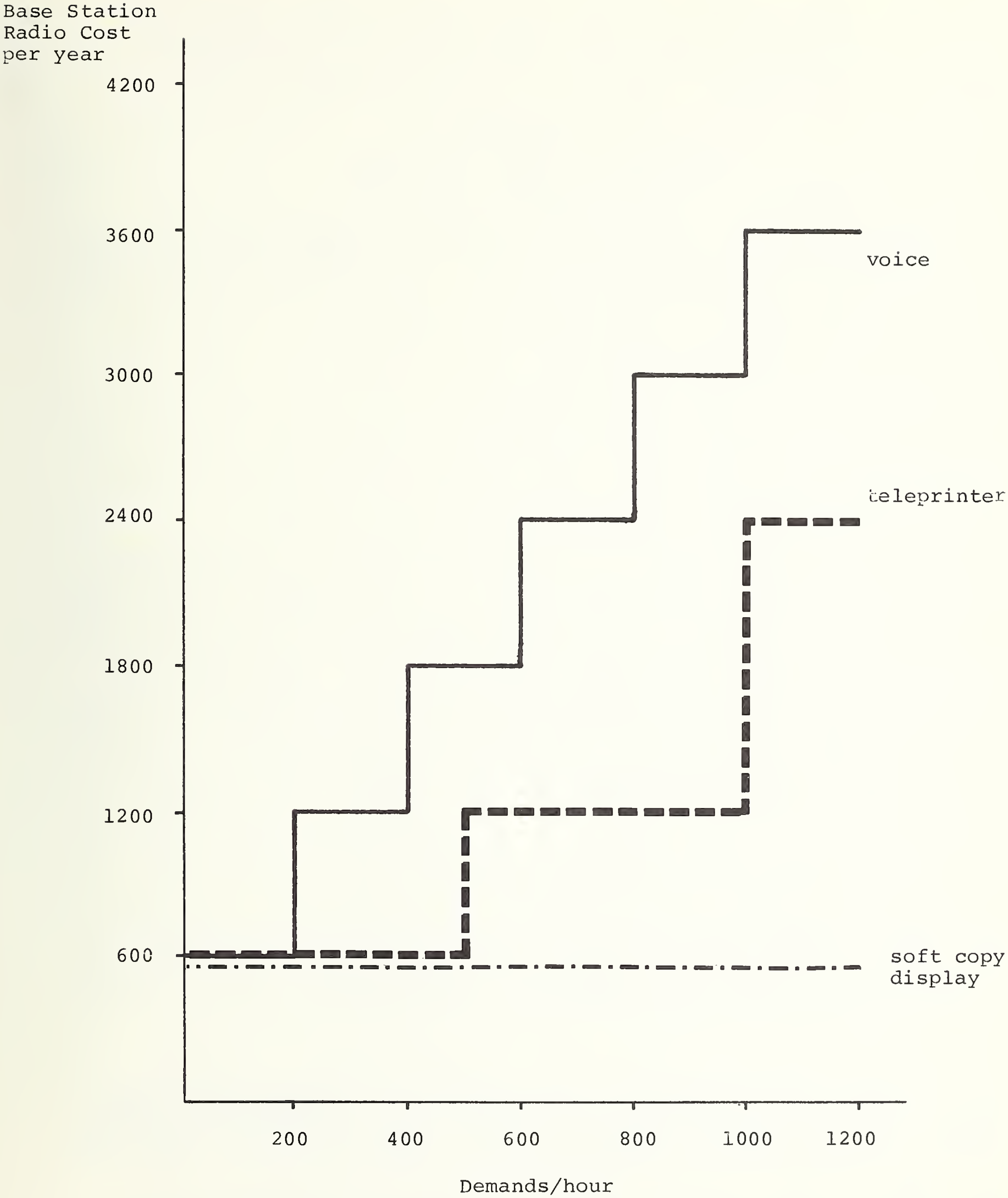

Figure 2.2

Base Station Costs as a Function of Demand Rates vehicles. Unfortunately, no data have as yet been collected to indicate exactly what the time savings are or how they impact staffing requirements. In this section an attempt is made to develop such estimates, using queuing analysis to determine the maximum number of demands that can be handled by a single dispatcher using voice and digital communication.

First, consider the time it takes for a dispatcher to perform his/her tasks. One researcher (Spiller, 1977) has made an estimate of the time requirements, and cites data collected in Ann Arbor (Newman, et-al, 1976) to indicate his estimates are close. However, Spiller's estimates were based on a system which has one person (a scheduler) who is concerned only with vehicle assignments, and one who is concerned only with communication with the vehicle. Experience has suggested that such systems are ineffective, and that a single person can be used for both jobs. This is particularly the case where digital communications is employed, since communications time is so short. Thus, we have attempted to estimate the time requirements for a system in which a single person serves as both dispatcher and scheduler. The tasks and times per request associated with the dispatching function include:

1. vehicle assignment (includes map manipulation) - 30 sec.
2. base-to-vehicle communications: voice - 15 seconds[1]
digital - 5 seconds
3. vehicle to base communication and misc. - 10 seconds

Thus the total time per request is estimated as 55 seconds under manual communications, and 45 seconds for digital communications. Treating this as a "general" distribution[2], and the demand

[1]This estimate is essentially independent of the technology used in the dispatch room, although it does assume that the dispatcher need <u>not</u> type out the information.

[2]The estimate of a queuing delay for a general service time distribution requires an estimate of the standard deviation of the service time. We assumed a value of .3 min. for the voice case and .26 min. for the digital.

rate as a random distribution, the mean dispatch delays at different demand rates are shown in Table 2.6.

Table 2.6

Dispatcher Queuing Delays

Demand Rate	Voice	Digital
30 demands/hour	.2 minutes	.13 minutes
50 "	1.4	.59
70 "	∞	3.5
90 "	∞	∞

This table suggests that a single dispatcher (performing both scheduling and dispatching functions) can handle over 50 (but well under 70) demands per hour using voice communications; this estimate appears confirmable based on experience to date. The maximum demand rate which can be handled by a single dispatcher using digital communications is over 70 (or about 1/3 more).

The potential savings in personnel caused by digital communications is less of a step function than was the savings in base station radio equipment, if it is possible to bring in part time dispatchers. Since demand rates do vary from hour to hour, the number of dispatchers needed may also vary. Thus, we have treated dispatcher requirements as a continuous function with respect to demand rate in order to estimate the economic impacts of digital communications. This analysis, conducted for three dispatcher salary levels ($3.50 per hour, corresponding to the $8/hour operating cost; $5 per hour, corresponding to the $13/hour operating cost; and $8 per hour, corresponding to the $22 per hour operating cost, all including benefits) and under the assumption that no additional call-taking personnel are required (because the data input device is no more time consuming), is summarized in Table 2.7.

Once again, these results appear to be confirmed by the Ann Arbor experience. The Ann Arbor Transportation Authority reports it has been able to reduce its dispatch staff time by 1/3 since the implementation of digital communication.[1] Note that the digital communication system in Ann Arbor is interfaced with the dispatch computer.

Table 2.7

Annual Cost Savings From Control Room Staff Reductions Possible Under Digital Communication

Demand Rate		Savings, given hourly wage of:		
Hourly[2]	Annual[3]	$3.50	$5.00	$8.00
50	156,000	$ 0	$ 0	$0
80	249,600	5,023	7,175	11,480
120	374,400	7,644	10,920	17,472
240	748,800	15,505	22,150	35,440
500	1,560,000	32,543	46,490	74,384

2.2.3 Net Benefits Analysis

In Table 2.8, the total potential benefits of digital communications are compared with the total costs for a number of reasonable sets of system parameters. Included are the benefits of increased vehicle productivity, reduced frequency requirements, and reduced control room staffing requirements. Both hard-copy teleprinter (one-way) and soft-copy display (two-way) technologies are considered. To remain conservative, only the smaller potential impact on dwell times (.5 minutes) has been considered.

The results suggest that digital communications is cost-beneficial, even for fairly small systems. For systems costing $13 per hour or more, the teleprinter technology becomes cost-effective with vehicle fleets as small as eight, serving 124,800 trips per year. Even the soft-copy display technology

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[1] Telephone conversation with Henry Bonislawski, Ann Arbor Transit Authority, June 14, 1978.

[2] Savings for other demand rates within this range can probably be reasonably approximated by interpolation.

[3] Assumes 60 hours of service per week, 3120 hrs. of service per year.

is cost-effective for that system in the case of $22 per hour operating costs.

At higher demand levels, digital communications becomes even more cost-effective. For example, in a system with 32 vehicles and 8 demands per hour, a teleprinter system could save $46,895 per year (7¢ per trip), given an operating cost of $8 per hour, and $164,673 per year (24.7¢ per trip), given an operating cost of $22 per hour.

Thus, digital communications represents a cost-effective technology for systems of approximately 8 or more vehicles and 6 or more demands per vehicle per hour, with the exact break-even point depending upon a number factors, including hourly system operating cost.

Note that, for all of the systems considered, the less expensive teleprinter technology remained more cost-effective than the soft-copy technology. This is in part a reflection of the fact that no advantage was imputed to soft-copy display other than increased speed, and hence reduced frequency requirements. This first actually begins to have an impact at very high demand levels. No direct benefit was imputed to the two-way communications capability. However, for a fully automated dispatching system, two-way communications becomes extremely important (since it bypasses the need for a dispatcher entirely). Thus, the soft-copy display, two-way alternative should be more applicable in a very large scale, automated dispatch system, as will be discussed in the next chapter.

In considering these results, it must be recognized that they are based on a variety of unproven assumptions. Thus, the next step in the deployment of digital communication technology should involve a structured demonstration that allows the various impacts of the technology to be measured. Since the reduction in vehicle requirements represent the major component of the benefits, the impact of digital communications on dwell time and effective vehicle speed should be the focus of the experiments. In addition, there is a need for further analysis of the impact of digital communications on system types other than many-to-many demand-responsive.

Table 2.8

Costs and Benefits of Digital Communications for Selected Systems

System Description				Hourly Oper. Cost	Annual Costs (inc. maintenance)		Capital		Annual Benefits Operating		Total Benefits		Net Benefits (Cost)	
Area	Veh.	Base Prod. (Pass./Veh-hr.)	Annual Rider		Tel.	Display	Tel.	Display	Tel.	Display	Tel.	Display	Tel.	Display
8	4	4	49,920	$ 8	9,680	16,544	0	0	2,995	2,995	2,995	2,995	(6,685)	(13,549)
8	4	4	49,920	13	9,680	16,544	0	0	4,867	4,867	4,867	4,867	(4,813)	(11,677)
8	4	4	49,920	22	9,680	16,544	0	0	8,236	8,236	8,236	8,236	(1,444)	(8,308)
8	8	6	149,760	8	11,600	21,408	0	0	9,984	9,984	9,984	9,984	(1,616)	(11,424)
8	8	6	149,760	13	11,600	21,408	0	0	16,224	16,224	16,224	16,224	4,624	(5,164)
8	8	6	149,760	22	11,600	21,408	0	0	27,456	27,456	27,456	27,456	15,856	6,048
12	8	8	199,680	8	13,600	22,048	0	0	9,984	9,984	9,984	9,984	(8,384)	(12,064)
12	8	8	199,680	13	13,600	22,048	0	0	16,224	16,224	16,224	16,224	2,624	(5,824)
12	8	8	199,680	22	13,600	22,048	0	0	27,456	27,456	27,456	27,456	13,856	5,408
16	12	8	299,520	8	15,520	28,192	4,000	4,000	21,176	21,176	25,176	25,176	9,656	(3,016)
16	12	8	299,520	13	15,520	28,192	4,000	4,000	32,736	32,736	36,736	36,736	21,216	8,544
16	12	8	299,520	22	15,520	28,192	4,000	4,000	55,184	55,184	59,184	59,184	43,664	30,922
16	32	8	798,720	8	33,120	57,632	8,600	8,600	71,415	71,415	80,015	80,015	46,895	22,383
16	32	8	798,720	13	33,120	57,632	8,600	8,600	113,004	113,004	121,604	121,604	88,484	63,972
16	32	8	798,720	22	33,120	57,632	8,600	8,600	189,193	189,193	197,793	197,793	164,673	140,161
16	32	10	998,400	8	48,880	64,672	8,600	8,600	88,453	88,453	97,053	97,053	48,173	32,381
16	32	10	998,400	13	48,880	64,672	8,600	8,600	137,344	137,344	145,944	145,944	97,064	81,272
16	32	10	998,400	22	48,880	64,672	8,600	8,600	228,137	228,137	236,737	236,737	187,857	172,065

Tel = Teleprinter technology

Diplay = Soft-Copy Display

Chapter 3

Computer Dispatching

Technological Concept

Computerized, or automated, dispatching involves the use of a computer to make routing and scheduling decisions which would be made by a dispatcher under a manually dispatched demand-responsive service. By eliminating the need for a dispatcher, automation can potentially reduce control room costs. However, the major potential impact of automation lies in increased service levels and/or productivities. In a manual system, the dispatcher may have difficulties integrating all available information on the system state (e.g., vehicle locations, driver schedules, current vehicle tours, etc.), particularly at higher demand levels. As such, the dispatcher may not always make the "optimum" scheduling decision. On the other hand, a computer can integrate all of the information, regardless of system size. Thus, automating the dispatching function may lead to improved service levels and/or reduced vehicle requirements. In addition, a small, but not inconsequential benefit of automation is improved reporting capabilities. The use of a computer as a management information system may improve overall management and control, and simultaneously reduce the need for clerical personnel.

3.1 Application of Computer Dispatching to Paratransit

The original research into computerized dispatching took place at MIT from 1969-1971 (Project CARS - Computer Aided Routing System). The resulting system was modified by USDOT and MITRE Corporation and implemented in the Haddonfield N.J. Dial-a-Ride demonstration in 1974, using a small, dedicated computer. After a six-month debugging period, the system began functioning satisfactorily. Analysis of the results suggested that automated dispatching reduced mean passenger wait time by about 20%, with comparable reductions in the variability of wait and ride times. (Wilson, et al, 1975).

Following the Haddonfield experiment, two other systems utilizing automation were implemented. The first, introduced in Santa Clara, California in 1974, involved almost total automation, but allowed the dispatcher to make final routing decisions. The Santa Clara system was terminated after only a few months of operation, although not due to control system problems. A computer system was introduced in the Ann Arbor TelTran system in early 1976. This system, however, is not fully automated, since the computer does not actually make scheduling decisions. Computer-aided dispatching of this sort will be discussed in Chapter 4.

The next fully automated dispatching system was implemented as part of the UMTA Service and Methods Demonstration Project now being conducted in Rochester, N.Y. This system is also based on the MIT CARS/Haddonfield system, but includes substantial refinement and extension of the control software. The system is operated on a non-dedicated large computer located in Waltham Massachusetts. After a lengthy debugging and development period, the system began functioning satisfactorily in early 1977. The results of this experiment have been even more dramatic than the results in Haddonfield. As shown in Table 3.1, tests indicated that computerization of the Irondequoit Service Area resulted in a 41% reduction in mean wait time for immediate request passengers, plus improvements in a number of other service characteristics.

3.2 Benefits and Costs of Computer Dispatching

At this point in time, the feasibility of automated dispatching appears to have been proven. In addition, fully automated dispatching has been shown to be able to improve the service levels of a many-to-many DRT system, even one which operates on a fairly small

Table 3.1

Impact of Automated Dispatching on Irondequoit Service Level

Measure of Service	Manual	Computer	% Change
Mean wait time	26.69 min.	17.44 min.	- 41% *
Standard deviation of wait time	20.42	10.23	- 50% *
Mean ride time	10.41	10.72	+ 3%
Standard deviation of ride time	5.49	7.19	+ 31% *
Mean delay time[1]	5.51	6.25	+ 13%
Standard deviation of delay time	16.24	8.53	- 47%
Advanced Request			
Mean delay time[1]	7.12	4.24	- 40% *
Standard deviation of delay time	15.29	10.87	- 29% *
Mean ride time	10.60	13.05	+ 23% *
Standard deviation of ride time	7.11	7.27	+ 2%

1 - delay time for immediate request = difference between estimated and actual pick-up delay

delay time for immediate request = difference between scheduled and actual pick-up delay

* - statistically significant difference at 95% level.

Source: Wilson, N. and N. J. Colvin, Computer Control of the Rochester Dial-a-Ride System, M.I.T. Report 77-22, July 1977.

scale.[1] Thus, it is appropriate to attempt to place values on the potential benefits and costs of automated dispatch systems.

As was the case with digital communications, only dynamic dispatched many-to-many service will be considered, since it is clear that automated dispatching also has the greatest potential with this service. In addition, some of the analysis of automated dispatching will also be performed parametrically.

3.3.1 Costs

For the purpose of the analysis, it has been assumed that the system would utilize a dedicated minicomputer. UMTA is currently in the process of converting the Rochester software for use on a minicomputer; this effort is scheduled to be completed in the fall of 1978. Capital cost of the required hardware is estimated in Table 3.2. The cost of additional call-taker stations (terminals) is computed separately. Note that the minicomputer system will be able to control a number of system modules. No allowance is made for a back-up computer; thus, in the event of computer failure, it is assumed that the system reverts to manual control. In a relatively large scale system, where control costs are spread over many passengers, and manual control becomes very difficult, a full back-up system becomes more desirable. This is discussed later.

Annual capital costs are computed based on 5-year straight-line depreciation.

3.2.2 Benefits

The following potential impacts of automated dispatching are considered as part of the benefits analysis:

1 - Improved routing decisions reduce vehicle requirements at constant service levels.

2 - Automation reduces control room staffing.

3 - Automation improves reporting capability and thus, reduces clerical staff requirements.

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[1]The Irondequoit system operated with only about 5 vehicles and productivities of 4 passengers per vehicle hour.

Table 3.2

Capital Costs: Automated Dispatching

	Total Cost	Annual Capital Cost	Annual Maintenance
Computer (with dispatch terminal)[1]	$250,000[2]	$50,000	$30,000
Hard Copy terminal (back-up)	4,000	800	480
Call-taker (or spare dispatcher) terminals[3] (each)	2,000	400	240

[1]Inter-Data 832 + 1 megabyte of additional storage or equivalent.

[2]Software available at no charge from UMTA: installation of software included in total.

[3]Two call-taker terminals needed at a minimum. This should be sufficient for up to 80 demands per hour. Additional terminals would be needed at a rate of about 1 terminal per 40 demands per hour.

A. Impact on Vehicle Requirements

With Voice Communications

The best data available to date on the potential impacts of automated dispatching come from the Haddonfield and Rochester demonstrations. In both cases, automation resulted in improved service levels. Theoretically, had fewer vehicles been placed on the street, the system would have achieved comparable levels of service at comparable ridership levels and reduced costs. As was the case for the digital communications analysis, we have used the descriptive supply model to translate improved service levels into reduced vehicle requirements. This analysis has been performed parametrically, varying service area size, vehicle fleet size, base productivity, and the percent impact on overall level of service.

In the Rochester experiment, automation resulted in a 41% decrease in mean wait time. Therefore, we have taken, as a base level, a 40% reduction. Assuming that wait and ride time are equally onerous to the passenger, we have estimated the comparable vehicle fleet reduction, as shown in Table 3.3. A sample calculation is provided in Figure 3.1. This analysis is for a system with voice communications; the impact of automated dispatcher plus digital communication will be explored later.[1]

The Rochester experience provides only 1 data point, however. In Haddonfield, automation decreased wait time by 20%. Since both the Haddonfield and Rochester systems are relatively small scale systems, automation could conceivably have a greater impact on larger systems. We therefore selected 20% and 60% as lower and upper bound impacts, and developed Table 3.4.

It should be recognized that the wait time reduction values used here were based on only two data points, each taken at a distinct point in time. It is possible that factors other than automation would have an effect on the impact of automation; e.g., the skills of the manual dispatcher. Nevertheless, the Rochester and Haddonfield results are the only data points to date and as such, represent a reasonable basis upon which to estimate the impact of automated dispatching.

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[1] Note that in Rochester, a digital communications system was in place before and after the implementation of automated dispatching.

Table 3.3

Impact of Automation Assuming 40% Wait Time Reduction

System Parameters			% Vehicle Reduction Under Computerization
Area (mi^2)	Vehicles	Productivity (Pax./veh.-hr.)	
4	4	4	18%
4	4	6	15
8	4	4	15
8	4	6	12
8	8	4	16
8	8	6	13
8	12	4	16
8	12	6	13
8	12	8	11
12	4	4	12
12	4	6	10
12	8	4	14
12	8	6	11
12	8	8	10
16	4	4	11
16	8	4	12
16	8	6	10
16	8	8	9
16	12	4	13
16	12	6	11
16	12	8	9
16	16	4	13
16	16	6	11
16	32	4	14
16	32	6	11
16	32	8	9
16	32	10	8

The first scenario of Table 3.3 represents a non-automated system with:

4 vehicles serving
16 passengers per hour in
4 sq. miles with
1.5 minutes pickup plus dropoff time (per passenger)

Applying the descriptive many-to-many supply model to this system produces a level of service of:

9.4 minutes WAIT TIME
6.2 minutes RIDE TIME
15.6 minutes TOTAL TIME

The supply model adjusts for computerization via a wait time adjustment factor. Setting the factor to 1.67 (indicating that computerization reduces wait time by 40%), it can be calcualated that a computerized system serving the same number of passengers in the same area with only 3.33 vehicles on average can provide the following level of service:

7.7 minutes WAIT TIME
7.9 minutes RIDE TIME
15.6 minutes TOTAL TIME

(The vehicle fleet size reduction needed to result in equivalent service levels was found by reducing fleet size in 1% increments.) Therefore, a 17.5% reduction in fleet size (rounded to 18% in the table) can be achieved while patrons are still provided with the same overall wait and ride time.

Figure 3.1

<u>Example Calculation of Vehicle Savings Resulting From Computer Dispatching</u>

Table 3.4

Impact of Different Wait Time Reduction

System Parameters			% Vehicle Reduction with Impact on Wait Time of		
Area (mi^2)	Veh.	Prod. (Pax./Veh.-hr.)	20%	40%	60%
4	4	6	7	15	20
8	4	4	8	15	20
8	8	4	9	16	22
8	8	6	7	13	18
8	12	6	7	13	18
12	4	4	7	12	17
12	8	8	5	10	13
16	8	6	5	10	14
16	12	8	5	9	13
16	32	8	5	9	13
16	32	10	5	8	12

The results of this analysis suggest that automation can have a significant impact on vehicle requirements, ranging from 5% at the lowest to 22% at the highest level. The potential annual capital cost savings of the systems shown in Table 3.4 are computed in Table 3.5, while the potential annual operating cost (at 3 different hourly cost levels) are shown in Table 3.6. It is clear from this table that fairly substantial operating cost savings are projected for the larger systems.

The results described above are somewhat conservative in that it was assumed that a decrease in wait time was no more desirable than a decrease in ride time. Numerous research studies have suggested that wait time is more onerous than ride time, at least to fixed route users. To test whether automation may have an even greater impact than suggested above, since it tends to minimize wait time rather than ride time, we performed the analysis assuming that wait time is 50% more onerous than ride time. The results suggested that up to an additional 4% decrease in vehicle requirements could be achieved under this assumption (since the alternative reduction in wait time would be more heavily valued). To remain on the conservative side, these results are not used for any cost reduction estimations.

With Digital Communications

Next consider the case in which both automated dispatching and digital communications are implemented. Table 3.7 lists the combined impact on vehicle requirements given a (conservative) digital communications impact of reducing dwell time from 2.0 minutes to 1.5 minutes, and a computerized dispatching reduction in wait time of 40%. This analysis is possible since the two technologies impact different aspects of service (although) it is still not possible to simply "add" the percentage impacts). Resulting capital cost and operating cost savings are shown in Table 3.8.

Impact of Automation as a Function of System Size and Productivity

Intuitively, one would expect that automation would have an increasing impact as the number of vehicles and number of demands increase (since the dispatching process becomes more difficult). There are no data available to date, however, to verify this hy-

Table 3.5

Capital Cost Savings from Automated Dispatching

System Parameters				
Area (mi^2)	Veh.	Prod. (Pax./Veh.-hr.)	ΔWT%	Annual Capital Cost Savings
4	4	6	20	-
4	4	6	40	-
4	4	6	60	-
8	4	4	20	-
8	4	4	40	-
8	4	4	60	-
8	8	4	20	-
8	8	4	40	4,000
8	8	4	60	4,000
8	8	6	20	-
8	8	6	40	4,000
8	8	6	60	4,000
8	12	6	20	-
8	12	6	40	4,000
8	12	6	60	8,000
12	4	4	20	-
12	4	4	40	-
12	4	4	60	-
12	8	8	20	-
12	8	8	40	-
12	8	8	60	4,000
16	8	6	20	-
16	8	6	40	-
16	8	6	60	4,000
16	12	8	20	-
16	12	8	40	4,000
16	12	8	60	4,000
16	32	8	20	4,000
16	32	8	60	16,000
16	32	10	20	4,000
16	32	10	40	8,000
16	32	10	60	16,000

Table 3.6

Annual Operating Cost Savings Resulting From Automated Dispatching

System Parameters				Savings given cost of:		
Area (mi^2)	Veh.	Prod. Pax/Veh-hr	ΔWT%	$8/hr	$13/hr	$22/hr
4	4	6	20	$ 6,988	$11,357	$ 19,219
4	4	6	40	14,975	24,336	41,184
4	4	6	60	19,968	32,448	54,912
8	4	4	20	7,986	12,979	21,964
8	4	4	40	14,975	24,336	41,184
8	4	4	60	19,968	32,448	54,912
8	8	4	20	17,971	29,203	49,420
8	8	4	40	31,948	51,917	87,859
8	8	4	60	43,352	71,386	120,806
8	8	6	20	13,977	22,713	38,438
8	8	6	40	25,958	42,183	71,385
8	8	6	60	35,470	57,638	97,542
8	12	6	20	20,966	34,070	57,657
8	12	6	40	38,937	63,273	107,075
8	12	6	60	53,913	87,610	148,263
12	4	4	20	6,988	11,356	19,219
12	4	4	40	11,980	19,469	32,947
12	4	4	60	16,972	27,581	46,675
12	8	8	20	9,984	16,224	27,456
12	8	8	40	19,967	32,448	54,912
12	8	8	60	25,958	42,182	71,386
16	8	6	20	9,984	16,224	27,456
16	8	6	40	19,967	32,448	54,912
16	8	6	60	27,955	45,427	76,877
16	12	8	20	14,976	24,336	41,184
16	12	8	40	26,956	43,805	74,131
16	12	8	60	38,937	63,273	107,078
16	32	8	20	39,936	64,896	109,824
16	32	8	40	71,884	116,812	197,681
16	32	8	60	103,833	168,729	285,541
16	32	10	20	39,936	64,896	109,824
16	32	10	40	63,897	103,833	175,717
16	32	10	60	95,846	155,749	263,576

Table 3.7

Impact of Computerized Dispatching and Digital Communications on Vehicle Fleet Requirements

System Parameters			
Area (mi^2)	Veh.	Prod. (Pax/Veh-hr)	% Vehicle Fleet Reduction
4	4	6	21
8	4	4	19
8	8	4	21
8	8	6	19
8	12	6	20
12	4	4	16
12	8	8	16
16	8	6	15
16	12	8	16
16	32	8	18
16	32	10	18

Table 3.8

Annual Cost Savings Resulting from
Automated Dispatching Plus Digital Communication

Area (mi^2)	Veh.	Prod. (Pax./ Veh-hr.)	ΔWT%	Capital Cost Savings	Annual Operating Cost Savings given Cost/hour of: $8	$13	$22
4	4	6	40	$ 0	$ 20,965	$ 34,068	$ 57,654
8	4	4	40	0	18,968	30,823	52,162
8	8	4	40	4,000	41,932	68,139	115,312
8	8	6	40	4,000	37,939	61,650	104,331
8	12	6	40	8,000	59,903	97,342	164,733
12	4	4	40	0	15,973	25,957	43,927
12	8	8	40	4,000	31,947	51,914	87,855
16	8	6	40	4,000	29,951	48,670	82,364
16	12	8	40	4,000	47,922	77,873	131,786
16	32	8	40	20,000	143,688	233,493	395,142
16	32	10	40	20,000	143,768	233,623	395,362

pothesis. In Rochester, the computer had a fairly sizable impact, despite the small number of vehicles (4-5) and demands served (12-25 per hour). In Haddonfield, where more vehicles (8-10) served more demands (40-60 per hour), automation had a smaller impact. However, the difference might be explained by the fact that the control system implemented in Rochester incorporated many improvements and extensions. It is also important to recognize that the extent of the impact of computerization depends to a large extent on the skill of the dispatcher in the manual system.

The data appearing in Tables 3.3 and 3.4 may seem somewhat counter-intiutive, since they show some systems with higher productivities achieving a smaller percentage decrease in vehicle requirements than smaller scale systems. However, it should be recognized that this was based on the assumption that automation impacts wait time to the same extent (percentage) at all productivity levels. The resulting reduction in vehicle requirements would have been very different if different percentage impacts on wait time were assumed.

In an effort to determine the impact automation might have on a large scale DRT system, an attempt was made to simulate the Little Rock, Arkansas shared-ride taxi system, using the MIT dial-a-ride simulation model. The MIT model was initially designed as part of the development of dispatching algorithms. The model has been incrementally extended over the past decade, and has been validated with data from both Haddonfield and Rochester; it was also used to develop the descriptive supply model described in Volume 6, Appendix 1. Currently the model incorporates the same algorithm being used in Rochester. It was hoped that by comparing the results of a simulation run with actual level of service data from Little Rock, the impact of automation on service levels in a large system could be estimated.

Little Rock, Arkansas has the largest shared-ride taxi system currently in operation in the United States. The system, which is <u>privately owned and profitable</u>, has a total of 75 cabs. Cabs are leased to drivers on a daily (or 12 hour) basis; at most 60-65 cabs are leased on any given day. Productivity averages around five trips per vehicle-hour in service.

Taxi company management and drivers cooperated in collecting data on passenger movements and service levels for a four hour period (averaging both peak and off-peak hours) for one day. Wait and ride times were computed (for a sample of passengers for which drivers recorded sufficient information). Passenger origins and destinations were coded geographically, and the actual demand stream was entered into the simulation.

The results of this analysis was inconclusive; two simulations runs using slightly different constraint parameters (as discussed below) yield slightly different results, neither suggesting any improvement in service levels. The major reasons for the problems were as follows:

1 - Since drivers lease the vehicles, they are free to take breaks whenever they wish, which they do very frequently. The simulation treats service breaks as hard constraints (which they are for hourly employees); the result is a degradation in service with the simulation. Relaxing the constraint improves service levels, but does not truly model the actual system.

2 - Because of frequent breaks, at no point during the analysis period were there more than 25 vehicles in operation. (On some days there apparently may be as many as 50 vehicles operating during 1 or 2 peak hours.) Thus, the system is not quite as large as it appears at first. Total ridership between 6 a.m. and 6 p.m. averages about 1000-1200, which is only 16-24 per vehicle in operation that day.

3 - Only a small portion of all trips are actually assigned by the dispatcher. The remainder are "put out to bid", with drivers who claim they are in the vicinity responding. This makes it very difficult to compare the results of the simulation with actual data.

The disappointing results of this analysis once again point out that the impact of computerization depends to a large extent upon the operating characteristics of the system, as well as the skill of the dispatcher and overall system parameters. Note that, even if computerization did improve service levels and reduce vehicle requirements in Little Rock, the operator would see little benefit. In fact, since he gets paid on a lease per vehicle basis, his overall net revenue may actually decrease. The full benefits of a reduction in vehicle fleet requirements only accrue to systems in which drivers are paid on a hourly basis.

The only conclusion to be reached in this section is that there is still need for experimentation with automated dispatching, particularly in a large scale system.

B. Impact on Control Room Staffing Requirements

In addition to the savings resulting from reduced vehicle requirements, computerized dispatching potentially can produce benefits by decreasing the workload of the control room staff. Such a reduced workload can be translated into direct monetary savings by the reduction in staff necessary to operate the control facilities.

In Rochester, as a result of computerization, the workload on the single dispatcher has been reduced, but no reduction of staff has been noted. Since there is no further data regarding observed impacts of computerization on control room staffing requirements, this section focusses primarily on a theoretical estimation of impacts.

Under manual dispatching procedures, two classifications of workers perform the majority of tasks. These classifications are dispatcher and call-taker. The principal tasks assigned to the dispatcher are:

- receiving requests for service from the call-taker and developing vehicle tours,
- vehicle surveillance to keep track of vehicle position and status,
- communication of pick-ups and drop-offs to vehicle,
- keeping records on vehicle dispatching (such as time of request assignment, vehicle to which it was assigned, etc.)
- handling abnormal situations such as vehicle breakdowns, emergency situations,
- responding to information requests from customers who have placed requests for service,
- aiding drivers in locating and decoding information on pick-up and drop-off locations

The call-taker is responsible for:

- answering telephones
- providing general information regarding service characteristics (i.e., fare, service area, service hours, etc.),
- receiving and recording trip request information, (this includes pick-up location, drop-off location, desired pick-up time, and any other information specific to the paratransit systems operation),
- transmitting trip request forms to the dispatcher for further processing,
- acting as interface between customer and dispatcher in obtaining information regarding status of specific requests for service,
- determining fare and quoting information to customer on systems with complex fare structures, and
- gathering and recording customer request data as required by system managers and planners.

These procedures require, on average approximately 50 seconds per request for service of dispatcher time,[1] and around 50 seconds of call-taker time per call using manual procedures.[2]

Computerization of dispatching and vehicle communications tasks reduces the time required by the dispatcher by handling the majority of tasks assigned to him under manual operation. Some call-taker tasks are also performed by the computer; however, additional demands are placed on call-takers (in terms of increased data intake), which actually decreases their productivity under computerization.

The tasks most likely to be performed by the computer system are: 1) development of vehicle tours; 2) communication of vehicle tours, with digital communications); 3) vehicle surveillance; 4) reassignment of

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[1]This figure assumes voice communications and varies depending on vehicles in service and productivity. A common rule of thumb often applied to the capabilities of a single dispatcher is that he can control up to ten vehicles at one time.

[2]Spiller (1977)

passengers after vehicle breakdown; 5) record-keeping, and; 6) provision of information on status of request for service. These tasks account for nearly 90% of the dispatcher workload and a small portion of call-taker workload.

While potentially reducing the workload of dispatchers significantly, a computerized dispatching system will also create new tasks for both dispatchers and call-takers. New or expanded tasks resulting from computer implementation include increased accuracy and formatting of demand for service information, surveillance of computer operation, and handling of transitional periods from computerized to backup dispatching techniques when software or hardware problems are encountered. The first of these new control room operation requirements may result in an increase of 20% in call-taker workload. Surveillance of computer operations requires some time on the part of the dispatcher, but if things are operating smoothly, this effort should represent only a small fraction of the dispatcher's workload. The final problem of handling hardware and software breakdown may require a significant level of staffing or only a minor increase based on the method used to back-up the base system. At this point, we shall assume that an adequate method of back-up is employed and that no additional staffing (above normal levels) is required to provide the back-up. This issue will be addressed in greater detail after a discussion of potential benefits.

To determine the potential implications of computerization, queuing analysis was used to estimate the number of call-takers required to provide an acceptable response time. In this analysis, a call-taker of a manual dispatch system was assumed to be able to service 72 calls per hour. Under computerization the service rate was reduced to 60 calls per hour. Another assumption made was that 15% - 20% of all calls were for information rather than to request service. Given the service rates and call arrival rates of various systems, the average response time (the time a caller spends waiting for his/her call to be answered) was determined for varying numbers of call-takers.

The acceptable response time was set at between 10 and 15 seconds on average. In some cases, no integral number of call-takers could provide service at the desired response time. As a result, it was assumed that call-takers could be assigned in half units by employing part time labor or by scheduling hours such that more call-takers are available during peak periods. The results of this analysis are presented in Table 3.9.

Table 3.9 also presents an estimate of dispatcher requirements for a fully manual system, automated dispatch/voice communications system, and an automated dispatch/digital communications system for different vehicle fleet sizes and productivities. Again it was assumed that part time dispatchers can be hired and that schedule can be arranged to provide adequate coverage during the peak periods.

Table 3.10 presents the economic implications of these staffing requirements on systems of varying cost characteristics.[1]

The results of this analysis indicate that there are effectively no potential savings in systems with fewer than 10 vehicles. In fact, for some systems which require more call-takers but cannot reduce the number of dispatchers, computerization can result in increased control room labor costs. As systems begin to reach fleet sizes of twelve vehicles (greater than the number that can be handled by a single dispatcher) savings begin to be noted. Once systems expand to greater than 30 vehicles, the annual labor cost savings become relatively significant.

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[1]The following table indicates the wage rates of call takers and dispatchers, and cost per vehicle hours for low, medium, and high cost systems.

Wage Rates

	Low Cost	Medium Cost	High Cost
Cost/Veh-hr ($/veh-hr)	8.00	13.00	22.00
Dispatcher wage ($/hr)	3.50	5.00	8.00
Call taker wage ($/hr)	2.50	4.00	6.00

Table 3.9

Control Room Staffing Requirements

Vehicles	Productivity	Call Takers: Manual	Call Takers: Computer	Dispatchers: Manual	Dispatchers: Computer With Voice Communication	Dispatchers: Computer With Digital Communication
4	4	1.5	1.5	1	1	1
8	6	2	2.5	1	1	1
8	8	2.5	3	1.3	1	1
12	8	3	3.5	2	1	1
32	8	6	7	5	2.5	1
32	10	7	8.5	6.4	3.2	1

Table 3.10

Control Room Savings Under Computer Dispatch

Vehicles	Productivity (passengers/veh-hr)	Cost Structure (Cost/Hour)	Annual Savings (Cost)	
			Computer Plus Voice	Computer Plus Digital
4	4	$ 8	$ -0-	$ -0-
4	4	13	-0-	-0-
4	4	22	-0-	-0-
8	6	8	(3,900)	(3,900)
8	6	13	(6,240)	(6,240)
8	6	22	(9,360)	(9,360)
8	8	8	(624)	(624)
8	8	13	(1,560)	(1,560)
8	8	22	(1,872)	(1,872)
12	8	8	7,020	7,020
12	8	13	9,360	9,360
12	8	22	15,600	15,600
32	8	8	19,500	35,880
32	8	13	26,520	49,920
32	8	22	43,680	81,120
32	10	8	23,244	47,268
32	10	13	31,200	55,520
32	10	22	54,792	109,704

Back-up System

The above analysis assumes that there is no need to worry about a back-up system in case of computer failure. Data from the Rochester experience (Wilson et al, 1977) indicates that a down-time of 2% can be expected. In many systems, an administrator can be brought in to help provide manual dispatch back-up, without substantially disrupting his/her other work. Assuming one such person is available, systems in which automation potentially reduces the control room staff by one person or fewer - including the first four systems considered in Table 3.9 - need not worry about back-up (i.e., can rely on a manual back-up). In the last two systems listed in Table 3.9, control room staff requirements are reduced by "1.5" and "1.7" persons respectively with voice communications and approximately 4 persons in each case given digital communications. With the voice system, the difference can be made up by shifting call-takers to dispatch positions temporarily (assuming they are trained to handle both roles). This would increase passenger telephone delays by about 1 minute, which is probably acceptable for short periods of time. In the case of digital communications, however, shifting a sufficient number of call-takers would result in very long telephone delays, which would undoubtedly cause many persons to seek other means of transportation. The operator would have to decide if this temporary deterioration of service levels (and loss of patronage) is acceptable. If it is not, some other form of back-up is necessary. The options are:

1 - Intentionally overstaff the control room to be able to handle instances of computer failure.

2 - Purchase a back-up computer.

3 - Make arrangements to switch to a service bureau on a time-sharing basis during the period of computer downtime.

It is unclear which of these alternatives is the least expensive: it will depend on system size and the rate available from a service bureau, plus a variety of other factors. For smaller scale systems, the purchase of a back-up computer is likely to be the most expensive option, and reliance on manual back-up the least. The balance would shift as the demand rate grows.

C. Impact of Improved Reporting Capability

The availability of an on-site computer which is used for the dispatching of a paratransit system provides flexibility in terms of data generation and reporting. A significant amount of information, e.g., travel pattern and level of service data, can typically be generated in a paratransit system. Without computer assistance, the time requirements associated with data collection and processing may imply that data are only sampled on an intermittent basis. In an automated system, particularly one in which data are entered into the computer for dispatching purposes, a wide variety of management reports can be readily generated. The uses to which such data could be applied include the following:

1 - Vehicle fleet management - Long term trends can dictate whether more or fewer vehicles are required. On a more micro - level, the data can indicate times of day and days of week when the vehicle supply and demand level are not in equilibrium. On a dynamic basis, reports may indicate that more vehicles are needed immediately. Data can also be generated on driver productivity, which can be important to management.

2 - Revenue control and billing - First, revenue data generated by the computer can be used as a check against revenue actually counted. Second, data on trip characteristics can be used as a measure of the equity of the fare structure. Third, and perhaps most important, in cases where post-payment is allowed, the computer can be used to generate the bills. In cases of third party payment, the computer can automatically assign charges to the correct sponsor, and also be used to screen prospective passengers for eligibility.

3 - Reporting requirements - The operations data that are entered for dispatching purposes can be processed to meet any possible local, state, or Federal reporting requirements. Included would be elements of Section 15 requirements, such as ridership by time of day, which are typically difficult to generate. If the dispatch computer is the only computer available to the operator, it can be used

to help meet all of the system's accounting, management information system, and Section 15 reporting needs.

It is clear that some of the above uses of the computer may result in direct monetary savings; e.g., better vehicle fleet management may lead to improved system productivity. However, it is extremely difficult to estimate the extent of the impact, without any case histories of computers used in this manner. To assign an economic benefit, only reduced (clerical) staffing requirements will be considered. It is assumed that some of the data (e.g., level of service data) needed for the purposes described above would be obtained on a sample basis, with the sampling rate decreasing as the demand rate increases. A relatively high sample rate is used to compensate in part for the fact that potential system efficiencies (from improved management control) and economies from automating the accounting function are not considered. Overall, however, the estimate of benefits should still be on the conservative side.

An estimate of clerical time requirements was based on conversation with operators of a few demand-responsive systems which have some form of automation.[1] For a 100% sampling rate, it is assumed that approximately one clerical hour is needed for every 50 demands. (Clearly this will vary from system to system, depending upon such factors as the extent of postbilling. It has been accepted as an average value for the purpose of this analysis). To reflect the reduction in sampling rate as the demand rate increases, the following relationship between clerical hours and demand rate has been hypothesized:

$$C = .45\sqrt{X} - 2$$

where:

C = clerical hours

X = demands per day ($X \geq 20$)

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[1]Rochester, N.Y., Ann Arbor, Mich., Westport, Conn., and Diamond Cab of Wilmington, Delaware.

The potential economic benefits of automating data processing and reporting for three different cost systems (with clerical wages of \$3, \$4 and \$5 per hour respectively) and varying demand levels are estimated in Table 3.11.

3.2.3 Net Benefits

The overall benefits and costs of automated dispatching alone and in combination with digital communications are shown for a number of systems in Table 3.12. Given the uncertainty associated with the impact of automation on wait time, the base level of 40% (from the Rochester experience) has been selected. Digital communications is assumed to reduce dwell time by .5 minutes.

Note that there are economies of scale associated with implementing both automated dispatching and digital communications. The computer and terminals used for dispatching can also be used for the digital communications system. The only additional communication equipment needed is a central translator (\$10,000) and some hardware/software interface (\$5,000).

Referring to Table 3.12, it is clear that the combination of automated dispatching and digital communications is, in most cases, substantially more beneficial than the implementation of automated dispatching alone. In the latter case, benefits are not seen for systems with fewer than 12 vehicles and with operating costs below \$22 per hour. For the larger systems (32 vehicles), the combined system results is 2-3 times the net benefit for most cost levels.

For computer dispatching and digital communications combined, the "break-even" point appears to be at about 12 vehicles and 96 demands per hour, depending on system cost structure. (Although some benefits are seen for smaller, high cost systems, these benefits are very small and could be made to disappear by small changes in some of the underlying assumptions). At a level of 32 vehicles, automation becomes clearly beneficial.

Table 3.11

Annual Benefit of Automating Data Processing and Reporting

System Demands		Benefit at Wage Level of:[1]		
Daily	Annual	$3/hour	$4/hour	$5/hour
192	49,920	$ 3,300	$ 4,400	$ 5,500
384	99,840	5,300	1,100	8,900
576	149,760	6,900	9,200	11,400
768	199,680	8,200	10,900	13,600
1152	299,520	10,400	13,800	17,300
2304	599,040	15,300	20,400	25,500
3072	798,720	17,900	23,900	29,900
3840	998,400	20,200	26,920	33,700

[1] Figures rounded to nearest $100.

Table 3.12

Costs and Benefits of Automated Dispatching for Selected Systems

System Description					Annual Cap. Costs		Annual Benefits: Capital Cost Savings		Annual Benefits: Oper. Cost Savings		Total		Net Benefits (Cost)	
Area	Veh.	Base Prod.	Annual Rid.	Hourly Oper. Cost	Dispatch only	Dispatch + D.C.	Dispatch only	Dispatch + D.C.	Dispatch only	Dispatch + D.C.	Dispatch only	Dispatch + D.C.	Dispatch only	Dis- patch + D.C.
8	4	4	49,920	8	82,560	88,600	0	0	18,275	22,268	18,275	22,268	(-64,285)	(-66332
8	4	4	49,920	13	"	"	0	0	19,375	23,368	19,375	23,368	(-63,185	(-65232
8	4	4	49,920	22	"	"	0	0	20,475	24,468	20,475	24,468	(-62,085)	(-64132
8	8	6	149,760	8	83,200	92,280	4,000	4,000	28,958	40,939	32,958	44,939	(-50,242)	(-47341
8	8	6	149,760	13	"	"	4,000	4,000	45,143	64,610	49,143	68,610	(-34,057)	(-23670
8	8	6	149,760	22	"	"	4,000	4,000	73,425	106,371	77,425	110,371	(-5,775)	18,091
12	8	8	199,680	8	83,200	92,280	0	4,000	27,843	39,523	27,843	43,523	(-65,357)	(-48757
12	8	8	199,680	13	"	"	0	4,000	41,788	61,254	41,788	65,254	(-41,432)	(-27026
12	8	8	199,680	22	"	"	4,000	4,000	64,440	99,583	68,440	103,583	(-24,760)	11,303
16	12	8	299,520	8	83,840	95,320	4,000	4,000	44,376	65,342	48,376	69,376	(-35,464)	(-25944
16	12	8	299,520	13	"	"	4,000	4,000	66,965	101,033	70,965	105,033	(-12,875)	9,713
16	12	8	299,520	22	83,840	95,320	4,000	4,000	107,031	164,686	111,031	168,686	27,191	73,366
16	32	8	798,720	8	87,040	113,080	8,000	20,000	141,233	197,468	149,233	217,468	62,193	104,388
16	32	8	798,720	13	"	"	8,000	20,000	219,149	307,313	227,149	327,313	140,109	214,233
16	32	8	798,720	22	"	"	8,000	20,000	359,121	506,162	367,121	526,162	280,081	413,082
16	32	10	998,400	8	88,960	114,360	8,000	20,000	107,341	211,236	115,341	231,236	26,381	116,276
16	32	10	998,400	13	"	"	8,000	20,000	161,953	316,063	169,953	336,063	80,993	221,703
16	32	10	998,400	22	"	"	8,000	20,000	264,209	538,766	272,209	558,766	183,249	444,406

DC = Digital Communications

Chapter 4
Other Innovations

Introduction

As noted in Chapter 1, there are a variety of technological innovations, other than those discussed thus far, which have been associated with IP systems. These innovations have not been analyzed in-depth in the course of this study. However, the potentials of these technologies have been considered briefly. A variety of the other innovations are described briefly in this chapter.

4.1 Computer Control of Voice Radio

In 1973, a form of computer-aided dispatching was introduced by the Diamond Cab Co. of Montreal, a taxi "brokerage" with about 1175 cabs. The system was intended to eliminate driver "pirating" (i.e., stealing trips from the cab that is really closest to the calls) and dispatcher favoritism. In this system, drivers indicate that they are free in a given zone by the use of a digital communications link similar to the one used initially in the Rochester system. The dispatcher keys the information into the computer, which "queues" free cabs on a first-in first-out (FIFO) basis. When a request for service is received for a given zone and the dispatcher wishes to assign it, the computer opens up a voice radio link to only the first cab in the queue.

Results claimed for the system are a 20% increase in productivity, as well as a reduction in dispatch time requirements (Lee (1974)). The cost of the system is difficult to gauge, since most of the software was done in-house, while Canadian Marconi picked up the cost of the computer. A rough estimate of $100,000 in total cost has been provided (Thompson (1974)).

This technology appears to be working well. However, the application appears to be limited to exclusive-ride taxi service, where the simple FIFO queuing and assignment of vehicles can be accomplished. The system has positive impacts because it eliminates pirating and favoritism, neither of which are particular problems in integrated paratransit systems.

4.2 Automatic Vehicle Monitoring (AVM)

An AVM system is intended to provide, on a continuous basis, information on the location of vehicles in a mobile fleet. AVM systems have seen limited experimentation to date, most of which has taken place in Europe (although U.S. trials have taken place in Chicago, Dallas, Orlando, and Philadelphia). The Urban Mass Transportation Administration is currently sponsoring a large scale demonstration of AVM in Los Angeles, California.

There are a number of different types of AVM technologies ("sharp signal," "broad signpost," "radio frequency," and "dead reckoning"), all of which have been tested to some extent. AVM systems have been proposed for fixed route bus systems, police departments, taxi companies, and demand-responsive services; i.e., any fleet of continuously moving vehicles. For fixed route bus systems, AVM is intended to facilitate route monitoring and the implementation of schedule correction techniques, thus improving service levels and reducing scheduled layover time. For variable route systems, AVM can help ensure that the correct vehicle is dispatched, thus reducing response time and, potentially, reducing vehicle requirements.

A recent effort (by USDOT/Transportation Systems Center) resulted in a comprehensive cost-benefit analysis of AVM for all applications except demand-responsive transit (Reed, et al, 1977). The exclusion of DRT from consideration was based, apparently, on the lack of suitable tools for measuring system response to improved vehicle location monitoring. That study did address the impact on taxi systems, but found the impact fairly small, since labor "costs" in taxi operation are effectively a function of revenue, rather than vehicle hours.

The impact of AVM on demand-responsive systems may be somewhat similar to that of automated dispatching, in that improved routing decisions lead to improved productivity and hence reduced vehicle requirements. Early M.I.T. simulation experiments (Wilson et al., 1969) suggested a possible 10% improvement with both AVM and automated dispatching. However, the data presented in Chapter 3 suggests that automated dispatching alone can result in more than a 10% improvement. Thus, the potential impact of AVM is still unclear. Certainly, one would expect AVM to have a greater impact in a manually dispatched system, since a dispatch computer is likely to have more accurate locational knowledge than a dispatcher. The present version of the M.I.T. simulation model can probably be used to provide better estimates of the impacts of AVM, since it has a feature which allows a variation of the uncertainty associated with vehicle speeds and hence location at any time point. Intuitively, AVM would have a fairly small impact under automated dispatching. However, under manual dispatching, a productivity improvement in the neighborhood of 5% is not infeasible.[1] The potential financial benefit of this improvement can be determined by referring back to Tables 3.4 and 3.6 and identifying those instances where automated dispatching was projected to have a similar impact.

4.3 Computer-Aided Dispatching

In a computer-aided dispatching system, a computer is used in the dispatching process, but does not make scheduling decisions. Functions a computer can fulfill include:

1. Display of passenger request information to the dispatcher;

2. recording and display of previous vehicle assignments (i.e., listing of planned vehicle tours to aid the dispatcher in making new assignment decisions);

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[1]The AVM cost benefit study noted above projected a 4% to 8% decrease in vehicle deadhead miles for a taxi system.

3. storing and display of advanced requests;

4. vehicle status reporting (e.g., in-service, break, relief required, zone, etc.);

5. print-out of planned vehicle tours at end of day in advanced request system, and;

6. data manipulation and report generation.

These functions can both simplify the scheduling process and, potentially, reduce staffing requirements (particularly clerical). Table 4.1 contains a partial list of computer-aided dispatching systems presently in use and their functions.[1]

Note that a number of the present computer-aided dispatching systems have been implemented for elderly and handicapped services. Since many elderly and handicapped services utilize advance requests, they represent potential markets for lower cost batch software/hardware systems, as well as for on-line systems.[2] In addition, as the concept of coordinated transportation delivery systems (funded by a variety of agencies and funding programs) for the elderly and handicapped grows, the possible applications of an automated management information system also grows.

A quantification of the benefits of computer-aided dispatch system is somewhat difficult, since it is unclear to what extent, if any, such a system can improve scheduling decisions or reduce control room staffing requirements. There is certainly an intrinsic value to the scheduler in terms of easier scheduling. The major economic benefit probably comes from the management information system application of computers. In addition to improving reporting

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[1] Computer-aided systems have also been used by a variety of exclusive-ride taxi systems. This application is ignored in this discussion.

[2] In on-line systems, the computer is available for data input and processing at all times. In a batch system, all input and processing occur at a single point. Thus, for example, in an advanced request system, all service requests may be entered into the computer at the end of the day. This allows the use of a service bureau or some other non-dedicated computer.

Table 4.1: Computer-Aided Dispatch Systems Currently in Operation

Location	Type of Service	Computer Functions
Ann Arbor, Michigan	Integrated paratransit with cycled many-to-one paratransit zones	Identifies possible tours Assigns advanced requests Stores assignment data Generates operations reports
Cleveland, Ohio	Zonal elderly and handicapped advanced request service	Lists vehicle tours Stores assignments Prints vehicle schedules Generates operations reports
Naugatuck Valley, Connecticut	Demand-responsive, primarily for elderly and handicapped	Stores and lists vehicle tours Generates operations reports
Westport, Connecticut	Shared-ride taxi	Stores and prints out advanced requests Generates operations reports

capabilities and management control, such a system potentially reduces administrative and clerical staff requirements. For example, a recent study of a computer-aided dispatch/MIS system (which would also be responsive to Section 15 reporting requirements) for a coordinated elderly and handicapped system in New Haven, Connecticut, estimated a potential annual reduction in staff costs of over $19,000, versus an annual software/hardware cost of only $16,000 (Multisystems, 1978). However, whether or not computer-aided dispatching, on solely economic grounds, is justifiable is still unclear. Continued experimentation with the concept, particularly in a controlled environment allowing before and after testing, is required.

4.4 Automated Control-to-Passenger Communications

The intention behind automating the passenger-to-control communications interface is primarily to reduce the need for call-takers. The technology that has had the most widespread penetration to date is an interactive tape recording system (currently made by only one manufacturer). In this system, pre-recorded taped questions or comments are used to "simulate" a conversation with a prospective passenger. The system is voice activated: "control room" questions and responses follow the completion of passenger sentences. Systems of this sort have been implemented by a variety of taxi companies. The system does have a dispatcher monitoring feature, so that the dispatcher can override the tape in case the passenger questions do not follow the anticipated sequence. These systems have met with mixed results. In some cases, operating procedures made pre-taping a conversation difficult; this was particularly true in the case of a shared-ride taxi system in Westport, Connecticut. (It is apparently easier to use the system in the case of exclusive-ride taxi, where the conservation might be something like: "Yellow Cab; where would you like to be picked up? . . . Thank you.") In some cases, there has been resentment on the part of passengers over having to deal with a tape rather than a person. Nevertheless, a number of taxi companies have expressed satisfaction with the system, indicating both a reduction in staff requirements <u>and</u> an increase in ridership due to increased telephone capacity.

This technology may be less readily applicable to shared-ride services because of the more complex interaction with the passengers (i.e., pickup and dropoff address and the number in the party must be obtained, and there must be a mechanism for identifying and dealing with advanced requests). There may be some application, but no extensive experimentation has as yet been reported. The system sells for approximately $11,000 per call taker position.

A more sophisticated technology that represents just about the state-of-the-art is direct access to the dispatch computer through (touch tone) telephones. Clearly, there would be limitations on the use of this approach, particularly if some response to the passenger is required. This technology has been applied on a limited basis at some banks, but has not been applied in a transportation context. The technology clearly needs further development and evaluation before it can be readily applied to IP systems.

4.5 Automated Passenger Information Systems

There is a range of automated systems which are presently available or in a developmental stage which can be applied for providing information to paratransit passengers. These information systems may serve several purposes, including providing:

- general information on service hours, service area, fare, eligibility, and other static information
- general system status such as expected wait times, or any special information which varies over time
- specific information for passengers at major demand generators, such as time until next vehicle or passenger assignments
- status of individual demands (updates for passengers regarding their specific estimated wait and ride times)

Each of these functions has major benefits to the operator and user. The automation of passenger information tasks can reduce the requirements of call-takers to respond to questions from the public, thus improving their productivity in performing the major task of recording requests for service. In addition to any benefits from reduced labor requirements, a general information system can be operable during hours when the control room is not being staffed. An information service aids the public by keeping them informed about many aspects of system operations. These data allow the patron to derive a greater value from the system through increased utilization of services and improved scheduling of their trips.

The complexity of the technology required to perform passenger information procedures varies by the type of information provided. To provide general information and system status, relatively simple available technologies can be employed. In the simplest case, the requirements are for only a single telephone line plus a tape playback unit which repeats a single message for customers. Other systems could provide alternate tapes which present system status such as average wait times. These systems can be implemented for as little as $1,300 per year[1] for a system which serves over twelve information requests per hour.[2] At this rate, a small system could provide general information for a cost of under 4¢ per call. Since dialogue is required for a request from a call-taker, more time (on the average) would be required for non-automated information services per passenger. At a call-taker rate of $3.50 per hour, representing a low cost system, a manual system would cost about the same as an automated system.

Other information tasks may require significantly greater costs. For example, providing information at a major trip generator requires a display at these locations, some method of transmitting information to the major generator (probably a telephone line), and an interface with the vehicle control center. For a manual system, an individual would be required to update information through a terminal. For a computerized system, an interface and support software would be required. While such a system may produce significant advantages

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[1]For telephone charges, interface, and record/playback equipment.

[2]Assuming a 30-second message and assuring an open line for 90% of all calls.

for the public, little if any reduction in labor costs would be noted since passengers from the major generators are not likely to call and request information.

More complex automated passenger information systems might be interfaced with equipment used for computerized routing of vehicles. A system of this type could be capable of informing an individual passenger the status of his/her specific request for service. Information which could be transmitted to the customer includes: (1) an updated estimate of vehicle time; (2) an updated estimate of ride time, and; (3) confirmation of request. The equipment necessary to perform these tasks would include an interface with the existing computer, telephone lines, a system to receive and translate tones indicating information requested, and a system to translate coded information into voice communications. The cost of the advanced technologies to perform these tasks will undoubtedly prove prohibitive for all but extremely large systems. Requests for this form of information by customers is relatively infrequent and can be handled by call-takers at a rate of 40 per hour. This implies that the paratransit service would have to have a demand rate well beyond 400 demands per hour to justify an annual expenditure on advanced information systems equivalent to one call-taker's wages. A further aspect indicating the unlikely success of such systems in the near term relates to willingness of individuals requesting confirmation to talk directly to a computer rather than a human.

In conclusion, relatively simple technologies are the most likely to prove cost-effective for providing passenger information. The types of information most likely to be transmitted for automated systems are general systems information, overall system status, and information at non-home major demand generators.

4.6 New Paratransit Vehicles

A common complaint from operators of paratransit systems is that there are no vehicles currently available that perform entirely satisfactorily. Unlike the case of standard transit coaches, vehicles used for paratransit service are not designed for heavy stop and go use. A variety of vehicle types have been used for paratransit service, including regular and raised-roof passenger vans, truck body-on-chassis minibuses and mobile home conversions, and vehicles with integrated chassis build from the "ground up" as a small bus (Flusberg et al., 1974). While some operators have been satisfied with the vehicles they have used, no single vehicle has escaped criticism.

In response to concerns expressed about paratransit vehicles, UMTA has sponsored a number of research efforts aimed towards the eventual development of one or more vehicles specifically designed for paratransit service. There are presently plans to fund design efforts by three manufacturers and to test the vehicles thoroughly. The desired output of this effort is a vehicle that could potentially decrease fuel consumption, decrease paratransit operating costs (through reduced fuel and maintenance costs), and increase system reliability (and potentially reduce spare vehicle requirements).

To assist in the assessment of whether to proceed with the development of a paratransit vehicle, a preliminary benefit analysis has been undertaken. Specifically, the impacts of such a vehicle on fuel consumption and operating cost have been estimated, using the following assumptions:

1. A paratransit vehicle averages 14 miles per gallon (as opposed to 8 for a regular van).

2. A paratransit vehicle can reduce the operating cost per mile by 5¢ (fuel and maintenance).

As part of the analysis, the impacts of replacing all van-type vehicles in the scenario framework described in Volume 2 of this series of reports has been determined. Subsequently, the possible ranges of national impacts of an improved paratransit vehicle were estimated, using the ballpark IP penetration rates (as functions of Federal spending levels) hypothesized in Appendix 5 (Volume 6) and shown in Table 4.2. Note that these values are all probably <u>underestimates</u> of the total possible impact, since a paratransit vehicle is likely to be used for such services as airport shuttles and elderly and handicapped services, which were not considered in this study.

Table 4.2: Potential National Impacts of a Paratransit Vehicle

Impact	Level of Federal Funding		
	Low	Medium	High
Annual operating cost savings ($1000) Local	1,602 - 2,332	3,025 - 3,841	4,534 - 5,350
Federal	1,602 - 2,332	3,026 - 3,842	4,535 - 5,350
Total	3,204 - 4,664	6,051 - 7,683	9,069 - 10,700
Annual fuel consumption reduction (000 gallons)	3,252 - 5,000	6,488 - 8,235	9,722 - 10,700

Note that _no_ additional capital costs are projected. It is assumed that the new paratransit vehicles would cost about 25% more than conventional vans but last about 25% longer (thus leaving annual capital costs the same).