A STUDY OF THE COSTS AND BENEFITS
ASSOCIATED WITH AVM

H. David Reed
Mary Roos
Michael Wolfe
Ron DiGregorio

RECEIVED

1977

FCB

FEBRUARY 1977
FINAL REPORT

03894

TK
6570
.M6
S78

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-MA-06-0041-77-1		

4. Title and Subtitle		5. Report Date
A STUDY OF THE COSTS AND BENEFITS ASSOCIATED WITH AVM		February 1977
		6. Performing Organization Code
7. Author's)		8. Performing Organization Report No.
H.D. Reed, M. Roos, M. Wolfe, R. DiGregorio		DOT-TSC-UMTA-77-5

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
U.S. Department of Transportation	UM711/R7716
Transportation Systems Center	11. Contract or Grant No.
Kendall Square	
Cambridge MA 02142	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Final Report
U.S. Department of Transportation	Spring 1976-Winter 1977
Urban Mass Transportation Administration	
Office of Technology Development & Deployment	14. Sponsoring Agency Code
Washington DC 20590	UTD-22

15. Supplementary Notes

16. Abstract

Automatic Vehicle Monitoring (AVM) Technology has long been perceived as a means of increasing the efficiency and productivity of transit operations as well as that of other users such as police and taxi. This study seeks to examine the economic viability of AVM for a range of users and their unique applications. The report examines other installations throughout the North American Continent and Europe to extract empirical evidence needed to substantiate cost saving possibilities both for single and multiple user applications.

17. Key Words	18. Distribution Statement
Technology, Costs, Maintenance, Operations, Bus, Police, Taxi, Control, System Lifetime, Present Values, Sensitivities	DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	256	

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

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
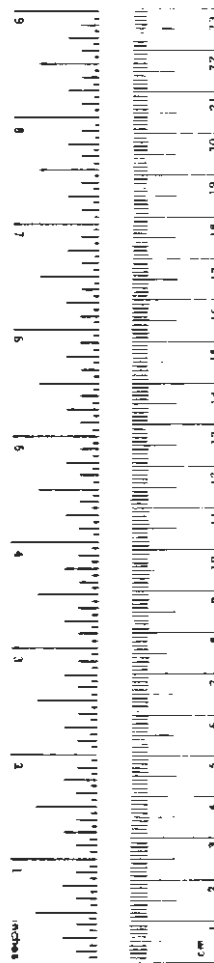
Approximate Conversions from Metric Measures

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

°F							
-40	0	32	40	80	98.6 120	160	200 212
-40	-20	0	20	37 40	60	80	100
°C							°C
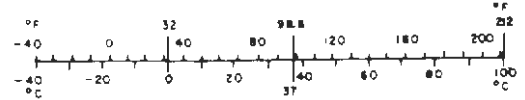
PREFACE

This study of costs and benefits for AVM was conducted at
the U.S. Department of Transportation, Transportation
Systems Center, in Cambridge, Massachusetts. The study is a
small part of a larger UMTA funded project dealing with
Automatic Vehicle Monitoring (AVM) technology.

i

TABLE OF CONTENTS

ii

iii

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY AND CONCLUSIONS

Automatic Vehicle Monitoring (AVM) systems provide real-time
vehicle position location information, thus enabling
managers to apply more exacting fleet deployment and control
strategies. Successful implementation of such controls can
permit either service improvements or cost reductions thus
producing increased operating efficiency. However,
realization of potential benefits is critically dependent
upon the willingness and the capacity of operating managers
to exploit fully the capabilities of an AVM system.

This study was conducted within the Transportation Systems
Center (TSC) in support of UMTA's evaluation of the
engineering and operational practicalities of AVM. As a
result, the benefit-cost analysis focuses strictly on AVM
and does not address potential payoffs of less sophisticated
and less expensive alternative fleet control systems.

The core of this analysis is a newly developed computerized
benefit-cost accounting model. The model calculates the
total life cycle costs of alternative AVM location systems,
then determines the dollar value of cost reduction benefits
made possible through use of AVM's real-time position
location information. The model calculates the costs and

benefits which would accrue to bus, police, and taxi
operators in any metropolitan area.

Many uncontrollable variables and uncertainties lie between
this study and the real-world impacts of a large scale AVM
system. Because of this uncertainty, the study presents two
sets of benefits, low and high, based respectively on
conservative and reasonably optimistic projections.

HIGH ⬛ AND LOW ▨ RANGE OF BENEFIT COST RATIOS
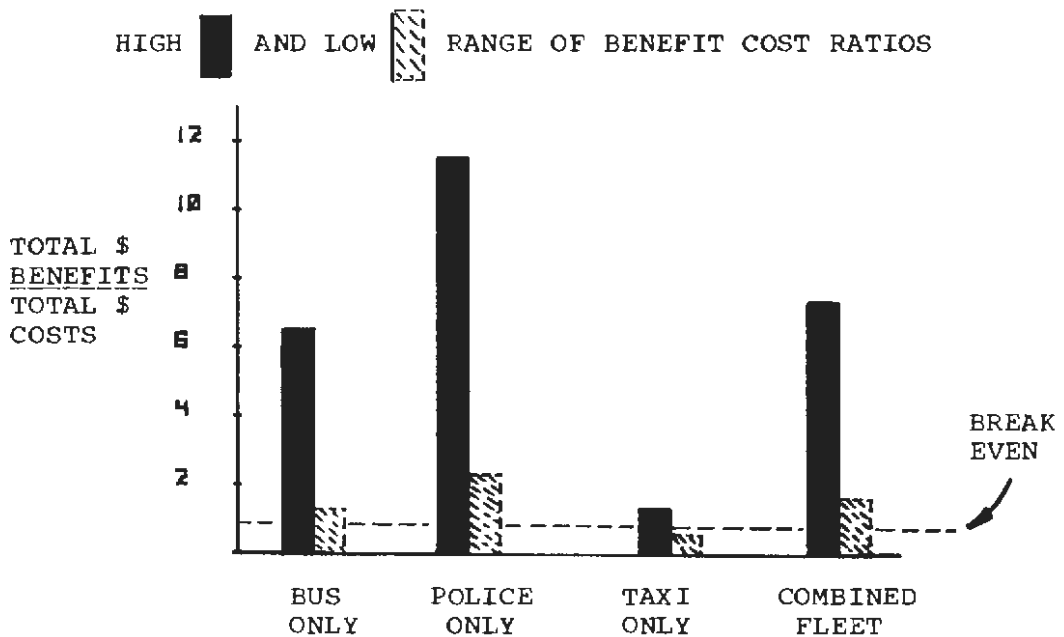
Both sets of benefits rest on a combination of hard data and
professional evaluation, and neither the high nor the low
benefits can be assigned greater liklihood than the other in
the absence of more extensive applications data. The range
of benefits gives a representative appraisal of uncertainty,

and does not risk masking uncertainty with questionable
precision in establishing "most likely" estimates.

The sensitivity of study results, conclusions to variations
in key assumptions, and system descriptions were examined
with the computer model.

All calculations and results are directly dependent upon
input system descriptions and particularly the cost
estimates of alternative location systems. This point
carries special significance in light of the study's
assumption that all competing location systems meet a
uniform performance standard.

The AVM benefit-cost analysis concludes that:

- AVM installations to date have not assigned
  importance to formalized cost-benefit related data
  gathering or analysis.

- Police cost savings are the most significant - Due
  primarily to the high cost of staffing patrol
  cars, even small reductions in required vehicles
  account for large payroll savings.

- Bus savings are considered positive - However,
  approximately half of the total savings are made
  possible by linking automatic passenger counters
  with AVM in order to replace manual schedule
  checkers. AVM bus savings vary widely between
  cities due to extreme differences in operating
  cost factors such as insurance, O&M, number of
  checkers and service operating characteristics of
  transit properties.

- Taxi operator savings do not exceed system costs -
  Limited payroll savings accompany vehicle
  reductions because drivers are paid strictly on a
  commission basis.

- Sharing costs among a mix of users does not
  provide significant savings - Only one quarter of
  AVM costs are eligible for sharing between users.
  In addition, different location systems are the
  most economical for fixed and random route fleets.
  The benefits of shared costs are diluted when
  participants compromise otherwise lower
  individualized technology costs.

- Costs and benefits are highly dependent upon site
  and fleet characteristics - Implementation
  planning must consider the changes in location
  system costs associated with changes in fleet
  size, mix or utilization, and operating areas.

- Security benefits of the silent alarm are
  important - No dollar value has been assigned to
  these benefits, but they appear to provide
  sufficient reason to proceed with an AVM
  implementation which might be marginal in terms of
  dollar benefits.

- Unusually careful planning and management are
  required to exploit AVM's potential benefits - The
  high and low assumptions used in this study
  illustrate that the extent of savings can vary
  greatly with slight changes in AVM utilization.

I. INTRODUCTION

AVM (Automatic Vehicle Monitoring) systems provide an information gathering and processing tool for the centralized management and control of urban vehicle fleets. Successful application and operational exploitation of AVM technology may yield significant improvements in fleet productivity, efficiency, and schedule reliability for bus systems, taxi companies, police forces, and other urban fleet operators. Because of this potential, UMTA and TSC are exploring the technical, operational, and economic feasibility of AVM.

This benefit-cost analysis is part of the overall UMTA/TSC evaluation of AVM. The study looks beyond field experimentation and focuses on the probable costs and achievable benefits of an AVM system fully deployed in a major metropolitan area. A comprehensive analysis of the literature and AVM-related experience in the U.S., Europe, and Canada have been integrated with additional research here at TSC to develop a computerized cost-benefit model. The model is a management tool which accounts for the total life cycle costs and benefits for any AVM system. Because of this, it is useful for a wide range of AVM sensitivity analyses; for studies of particular AVM programs; and with

minimal adjustment, for the analysis of other technical or management innovations which address transportation operating efficiencies.

The model approaches costs in terms of four generic AVM location systems. The cost factors for the generic systems have been developed by TSC's AVM Project Office, and the operational analysis and model building were accomplished within the Transportation Management Research Branch, under the Office of Systems Research and Analysis. Benefits are defined within the model as cost reductions made possible by increased operating efficiency; levels of service to the public are held constant. The study addresses AVM utilization by bus, police, and taxi operators, and by a cost sharing multiple user fleet sharing total costs. The impact on the study results of key assumptions and data inputs is explored by means of sensitivity analysis.

Chapter II of the study defines AVM, lists all the claimed benefits, and discusses previous research and actual field experience with AVM systems. Chapter III explains the concept, structure, and assumptions of the model; it explains the logic which in the end defines the results of the study. Chapter IV presents AVM deployment costs and reviews the sensitivity of location system cost rankings to

differences in fleet size and area. Chapters V and VI
discuss AVM payoffs and the sensitivity of those payoffs to
the dimensions of the model and the base case fleets.
Chapter VII concludes with a review of those benefits which
were not converted to dollar values.
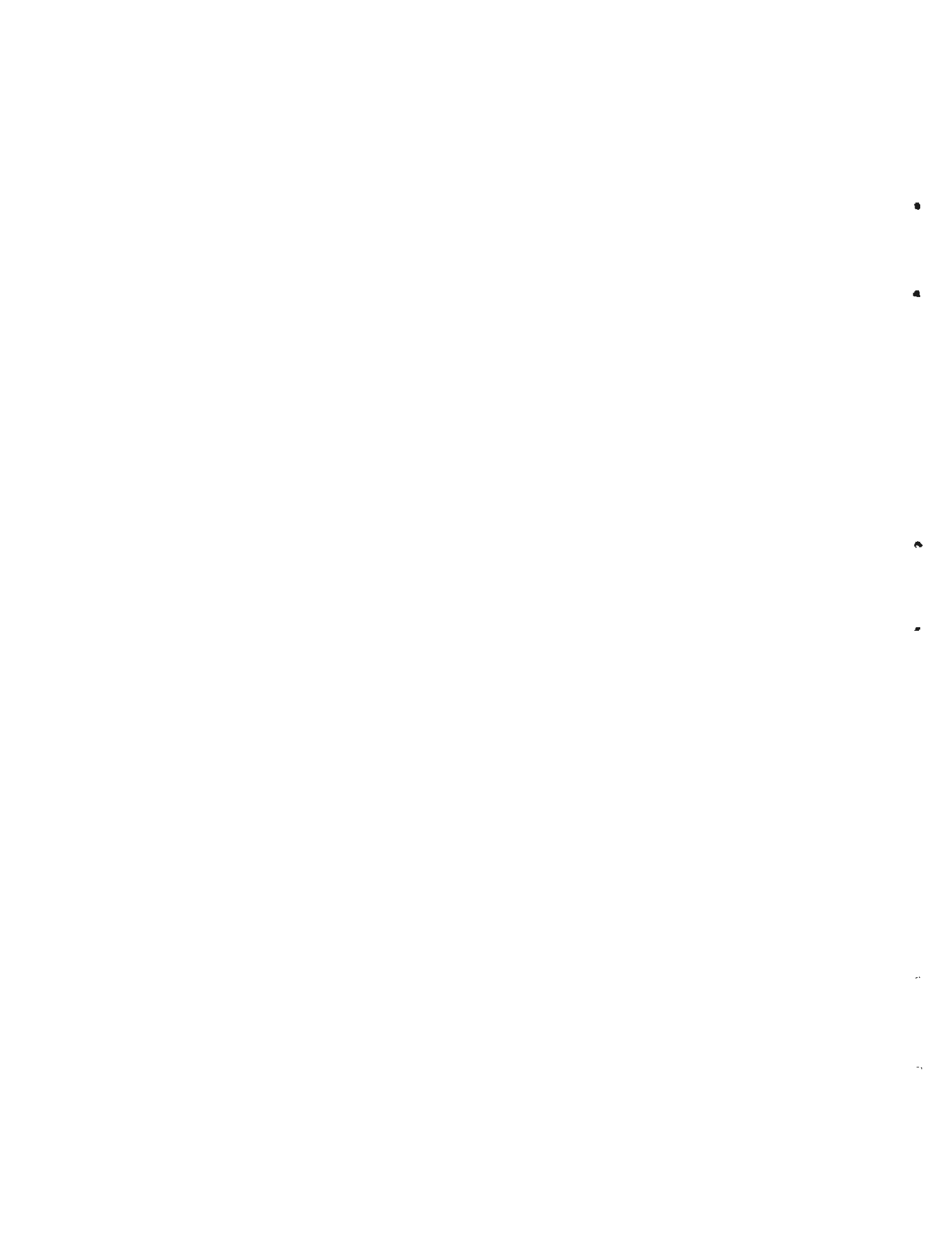
II.   AVM TECHNOLOGY, BENEFITS, AND EXPERIENCE

2.1   AVM Systems Description

An AVM system maintains a continuously updated file of all
vehicle locations in an equipped urban fleet. It consists
of a central computer facility to coordinate and manipulate
real-time data as it is collected; a two-way communication
system for digital and voice data; and a means of specifying
vehicle location. The data processing system offers the
opportunity to add on a computer-assisted dispatch system
and to report transit emergencies directly to police
headquarters. The communication system supplements
traditional voice communication with digital data which can
include vehicle status information, such as exact passenger
data; silent emergency alarms; and non-voice operating
commands from the dispatcher, such as skip-a-stop or pause-
at-the-next-stop. However, the most revolutionary element
of AVM is the vehicle location subsystem. Continuous
current knowledge of vehicle locations provides the
information necessary to control and adjust fleet operations
on a real-time basis. Put differently, the vehicle location
subsystem creates opportunities for more efficient and
productive utilization of equipment and personnel.

There are four generic kinds of location subsystems, each of which are defined to meet the basic design specifications of the UMTA/TSC AVM project. The differences between the location systems are summarized below and illustrated in Figure II-1.

Sharp Signpost: This type of system provides precise position location only at particular points. It operates around either a narrow beam optical scanner, a microwave transmitter or magnets imbedded in the road surface.

Broad Signpost: This group of systems provides area coverage within a range of 50 to 100 feet of a signpost. Coded radio signals are transmitted from these dispersed signposts to vehicles within their range.

Radio Frequency: These systems (including VLF, pulse trilateration, and AM phase lock) provide position location information at any point within the service area by means of computer-analyzed radio signal triangulation.

Dead Reckoning: Position information is provided at all points within the service area without reference to external signals. Location is determined through a combination of precision odometers and heading indicators.

FIGURE II-1

GENERIC CLASSES OF
LOCATION SUBSYSTEMS

RADIO FREQUENCY - POSITION DEFINED AT ALL POINTS

SIGNAL FROM MOBILE TO 3 RECEIVERS

3 TRANSMIT 3 SIGNALS TO VEHICLE

DEAD RECKONING - POSITION DEFINED AT ALL POINTS

INITIAL POSITION

TURN MEASURED

ODOMETER MEASURED

FINAL POSITION

STREET INTERSECTIONS

STREET INTERSECTIONS

NARROWBAND - POSITION DEFINED AT POINT X SEE FOR INSTL. INTERSECTION

SIGNPOST 40 FT

POSTS IN ROAD

PULSE READ FROM CODE RAIL

BROADBAND SIGNPOST - POSITION DEFINED WHERE SENSORS RANGE 1 S.P. PER INSTL. INTERSECTION

STREET INTERSECTIONS

SIGNPOST DETECTION RANGE

The number of manufacturers of these various technologies reflects an extensive comittment to the potential economics of AVM. Their installations and evaluations to date have led them to conclusions that even minor operational improvements justify serious investigations. Consistently positive dollar estimates related to anticipated AVM benefits are reflected in a series of proposals recently evaluated by the TSC AVM project office. Returns on investment (ROI) for even small fleets are estimated to reach payback in 3 to 4 years. The extent of supportive evidence or analyses for such ROI's is unfortunately slim and the paucity of sufficient data to draw statistically sound inferences is repeatedly recognized as justification for rigorous test and demonstrations.

2.2 The Potential Benefits of AVM

AVM systems offer a unique combination of capabilities which in theory offer the means for significant service, management, and economic benefits. This section surveys the range of potential AVM benefits and, in effect, outlines a protagonist's case for AVM. The cost-benefit study as a whole analyzes the probable achievability and value of these claims.

2.2.1 <u>Fixed</u> <u>Route</u> <u>Schedule</u> <u>Adherence</u>. AVM establishes a closed-loop information system which informs a dispatcher of the disposition of his vehicles and permits him to control their deployment according to several strategies. This could yield the following benefits in fixed route transit service:

- Increased on-time service, with buses never early and seldom late.

- More uniform headway adherence on short headway routes.

- More even distribution of passengers between vehicles.

- Reduced layover time due to reduced uncertainty of total travel time. Thus, fewer vehicles and drivers can maintain a given frequency of service on major routes.

- Fewer personnel required to check and control schedule adherence.

2.2.2 <u>Random</u> <u>Route</u> <u>Dispatch</u> <u>Improvements</u>. Closed-loop control capabilities are also available to random route vehicle dispatchers. Here they permit the dispatcher to insure that only the nearest vehicle is used in response to each demand on the system. As a result:

- Average response times to service and emergency calls can be reduced.

- Police can improve coverage with the same mobile cruiser force or can maintain coverage with a smaller force.

- Taxis can reduce the proportion of dead-head miles to revenue miles and thus meet demand with a smaller fleet.

2.2.3 Operating and Management Information. On-vehicle sensors and the communication subsystems permit the collection of complete route and vehicle data according to time and location. AVM system software can compile and analyze this data to provide the following potential benefits:

- Accurate passenger counts by stop and time of day to support optimal scheduling.

- Fewer personnel required to gather and analyze passenger demand and scheduling information.

- Improved management effectiveness and new operating strategies rooted in better historical data.

- Aid in planning and rapid evaluation of new routes.

2.2.4 Silent Alarm. Digital transmission of the vehicle code and exact location in case of emergency offers these benefits:

- Aid to police for quick apprehension of criminals.

- Deterrent effect on criminal activity.

- Improved security and peace-of-mind for passengers and drivers.

2.2.5 Improved Patronage and Farebox Revenue. Most of the
AVM benefits discussed above tend to improve the reliability
and attractiveness of public transit. Even if there is no
increase in frequency of service, the cumulative effect of
these benefits should improve ridership and revenue.

2.2.6 Expanded Benefits. AVM may be viewed as a series of
modular building blocks which can be varied to suit
particular situations. System capabilities can be expanded-
-at added cost-- to achieve the following kinds of benefits:

- Electronic interaction with traffic light
  controllers to gain signal priority for late
  buses.

- Real-time display of schedule status and expected
  vehicle arrival time for patrons at a major bus
  stops increasing public confidence in service
  reliability.

- Expanded on-board sensors to warn dispatchers and
  maintenance personnel of impending vehicle
  failures (such as falling oil pressure).

2.3 AVM Operating Experience

Various vehicle monitoring systems have been implemented in
Europe and in North America. Sites include Dublin, Hamburg,
London, Paris, and Zurich in Europe, and Chicago, Orlando,
and Dallas in the U.S., and Vancouver, B.C., and
Mississauga, Ont., in Canada.

As categorized in Table II-1 below, the European and
Canadian systems were intended primarily to improve the
level of transit service, while U.S. applications have been
used primarily to enhance public safety.

TABLE II-1.   PRIMARY USE AND LOCATION OF AVM SYSTEMS

Service Improvements	Public Safety
Dublin	St. Louis
Hamburg	Chicago
London	Orlando
Paris	Dallas
Zurich	
Mississauga	

It is also possible, as is done in this study, to view AVM
as a means of reducing operating costs without reducing
service levels.

Unfortunately, none of the systems implemented to date had
as a major objective, cost savings through improvement in
service operating efficiencies. Whether or not a link can
be demonstrated remains conjecture, for regardless of the
purpose of these AVM systems, very few have produced
consistent empirical data on their operational or financial
impacts.

During on-site visitation and through extensive
correspondence, transit operators throughout Europe
repeatedly stated that AVM was looked upon as a means of
improving service reliability. This approach means that
excesses in capacity are to be converted into service
expansions at no increase in operating costs. In Zurich,
when the usage of AVM resulted in a reduction of 12 buses,
they were retained for service expansion.

Each European AVM operation is characterized by estimating
vehicle location and transmitting location data to a central
control station. Hamburg, London, and Zurich employ
location data to exercise fleet control via two-way radio
communications. In Hamburg and Zurich all AVM equipped
buses have passenger counters.

The European AVM benefits perspective derives from their
views that bus transportation is an urban necessity, a
public utility, and an integral component of the services
provided by municipal governments. Even the integration of
a silent alarm capability with AVM is of lesser importance
as transit crime is virtually non-existent in Europe.
Utilizing AVM related information to revise schedules is not
considered either, as their schedules, while they may vary
by time of year, are generally not revised.

AVM does provide the means for better fleet control to keep
vehicles on schedule and thus provide better service. The
beneficial aspect of such control is increased ridership,
and while Hamburg and Zurich have reported systemwide
patronage increases, it is unknown whether these increases
were greater for AVM equipped than non-AVM equipped routes,
as no formal data gathering was planned.

The St. Louis Metropolitan Police Department conducted
extensive tests with a dead-reckoning AVM system in District
3, with 35 instrumented cars. The primary objective was to
demonstrate quicker response times, and, in 9 out of 11
months, travel time to respond to calls was significantly
shorter. Over the entire 11 months, travel time saved was
approximately 1/2 minute out of an average of 5 minutes.
Dispatch times were expected to increase due to a greater
work load, and while they initially did increase, they
ultimately were down 1.4% on the average following a short
learning period. The police department estimates total time
savings at 15%, and is proceeding with citywide
implementation on that justification.

Chicago Transit Authority (CTA) installed a broad signpost
system with a silent alarm for the prime purpose of
improving security on board transit vehicles. They have

recorded information on time-point passage, but make no attempt to apply headway control. The property management is quite satisfied with the crime reduction aspect of AVM and wishes to expand the coverage. Since control was not attempted in Chicago, there is no data on the value of improvements such as load factor or layover reduction...two of the bus benefits postulated in this study. However, AVM has enabled CTA to reduce the number of point-men, mobile supervisors and terminal telephone men, and save the cost of special telephones installed on the streets and at four terminal points for the use of these employees.

In Dublin, a system using two-way radio, manual polling, and voice response from the vehicle operator emulates an AVM system, though it is much more labor intensive. They have, however, gathered data on real-time schedule control, comparing a route using a dispatcher with radio control to a similar but uncontrolled route. Passenger wait time on the controlled route averaged 25% less (.93 minutes) than on the comparable uncontrolled route. This indicates the magnitude of efficiency improvement which can be expected with AVM.

The experience and information attainable from Dublin represent the nearest approach to a deliberate experiment intended to record data for analytical purposes.

While the costs of implementing AVM are well recognized and documented, further installation and investments for the purposes of attaining cost savings with AVM will not be convincingly justified without a well designed and controlled period of real-world experimentation.

III. THE STRUCTURE AND ASSUMPTIONS OF THE
BENEFIT-COST MODEL

The heart of this analysis is a TSC computer model which
converts technical, operational and financial information
into cost and benefit dollar totals for a specific AVM
deployment. The logic and assumptions of the model have a
significant impact on the study results; indeed, they define
those results. While the next three chapters examine in
detail the costs and benefits of AVM and the sensitivity of
the results to changes in specific data inputs, this chapter
presents an overview of the model, summarizing its key
methods and assumptions. Appendix A supplements this
chapter by listing and justifying all data entries and
parameters used in the base case calculations.

The TSC AVM model is a computational tool which runs in
sequential cost and benefit modules. As Figure III-1
illustrates, the cost module converts AVM cost elements,
such as terrain, area, and fleet characteristics into total
life cycle system costs. The benefit module, as shown in
Figure III-2, first factors AVM impacts against fleet
operational and financial data to compute cost avoidance
benefits, and then compares the benefits with system costs.
This model is not a monte carlo or gaming simulation which

COST FACTORS FOR
EACH AVM LOCATION
SYSTEM

-- on-vehicle costs
-- wayside costs
-- central costs

TERRAIN AND
AREA CHARACTERISTICS

FLEET CHARACTERISTICS

- by user type
- fleet size
- operating area
- number of 2-way
  radios installed
- need for passenger
  counters

COMPUTATION

OF

COSTS

TOTAL AVM
SYSTEM COSTS

- costs in present
  value and total $
- capital & maintenance $
- system cost by fleet
- select low cost
  system

- determines cost of
  shared multiple system
- assigns cost shares
- compares single user
  costs & shared cost
  of multiple system

TO BENEFIT
MODULE

FIGURE III -1

AN OVERVIEW OF THE COST MODEL

3-2

Cost Module
Outputs

Operational
Characteristics

-Run Times

-Headway Distributions
-Layover Percentages
-Annual Miles
-Operators Per Vehicle
etc.

Financial
Characteristics

-Vehicle Costs
-O&M Costs
-Salaries,
Overhead and
Benefits

AVM Impacts

-Layover
-Data Collection
-Avoided Deadhead
-Loadfactors

Computer
Calculates
Benefit

Fleet Savings

-Broken Out By
Vehicle and Personnel
-Broken Out By
Source (AVM Impact)
Subtotaled in $$$
and "Item B/C Ratios"

Total Benefits and
Cost for Each Fleet

-Overall B/C Ratios

FIGURE III-2

AN OVERVIEW OF THE BENEFIT MODULE

3-3

determines the operational effectiveness of AVM; it is sophisticated accounting device which requires specific AVM effectiveness estimates as inputs in order to produce meaningful results.

The model, designed for TSC's time sharing computer, is interactive and conversational. Many parameters must be set on every run and the remainder may be changed within the computer program (see Appendix B, Users Manual). The result is an extraordinarily flexible instrument which can accommodate any urban size area and a large number of vehicle fleet combinations. This makes this model useful beyond this particular study since it can analyze any specific AVM project or proposal. In fact, it can be used with minimal effort for benefit-cost analyses of almost any innovation designed to improve transportation efficiency.

3.1 The Base Case AVM System

The purpose of this study is to determine the benefit and cost tradeoffs for a fully deployed AVM system in a major metropolitan area. In order to accomplish this it was necessary to specify the parameters of such a system, which would become the base case or reference system. The base case is an abstraction similar to the geography, fleet sizes, and service characteristics of a large city such as

Los Angeles. Chapter VI examines the sensitivity of the study results to these parameters and offers insight into the application of the results to other urban areas.

3.1.1 Vehicle Fleets. The study results reflect operations of three different fleets: 2,400 buses which operate throughout the metropolitan area and 1330 police patrol cruisers plus 800 taxis which operate only in a central core area. Demand responsive Dial-A-Ride fleets were included in the early analysis but eliminated from the base case due to very poor returns on AVM investments. However, the TSC model contains both Dial-A-Ride and general subroutines which may be used for follow-on studies of Dial-A-Ride or other fleets such as ambulances, fire apparatus, cement trucks, commercial delivery fleets, etc.

3.1.2 Service and Operating Area. The overall service area, illustrated in Figure III-3, is 5,000 square miles bounded by an imaginary line connecting the tips of the radial bus routes. Within this service area is a central core of 475 square miles served by the police, taxi and bus -- that is, by both random and fixed route fleets. The buses operate over 3,825 route miles, of which 2,647 are outside the core area. Terrain in the entire area is classified as rugged due to canyons and defiles. This

5000 Square Mile
  Service Area

  -- Encompasses all
    3825 Route Miles

  -- 2647 Route Miles
    Outside Core

475 Square Mile
  Core Area

--Contains all Police
  and Taxi Vehicles

--Contains 1178 Bus
  Route Miles
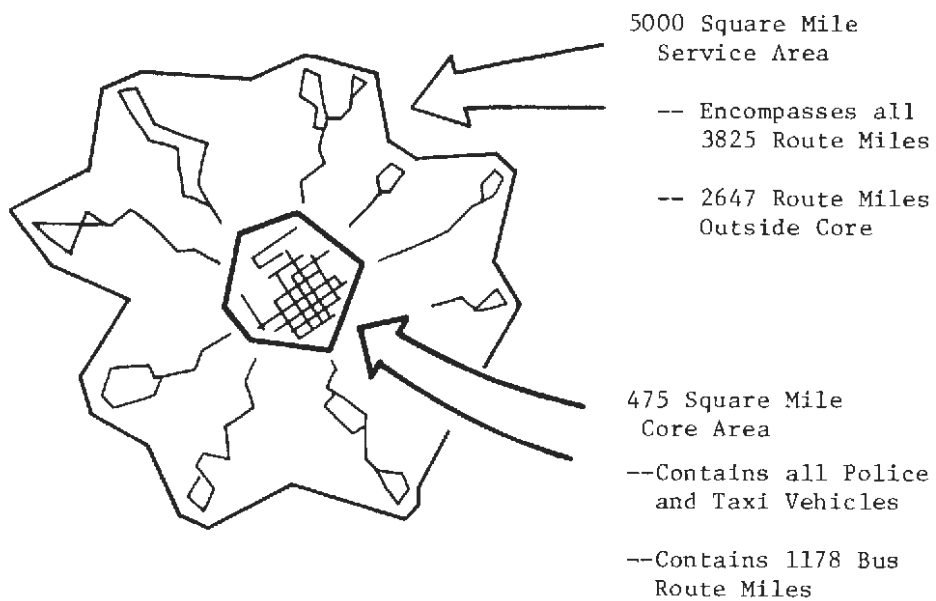
FIGURE III-3

THE BASE CASE OPERATING AREA

causes the model to augment certain categories of AVM
wayside equipment costs as would be required to insure high
quality communications.

3.1.3 Deployment Scenarios. Within the base case, costs
and benefits are developed for four different deployment
scenarios, that is, for four different user fleets. Three
scenarios represent the independent bus, police and taxi AVM
systems. The fourth scenario represents a utility-type
multiple-user AVM system with the bus, police and taxi
operators sharing common infrastructure costs. The model
calculates complete cost and benefit totals for each
scenario.

3.2 AVM Cost Calculation Approach
3.2.1 AVM Components. The study determines the system
costs and benefits for a core AVM system (location, computer
and digital/voice communication subsystems) plus silent
alarm and passenger counters. Neither costs nor benefits
are included for AVM "accessories" such as bus stop
passenger information displays, traffic light actuators, or
vehicle mechanical status indicators. Beyond this, the
model accumulates only costs and benefits greater than those
associated with comparable non-AVM equipped fleets. Put
differently, a radio-equipped non-AVM bus fleet establishes

the zero cost and zero benefits bases against which the AVM-equipped bus fleet is compared.

3.2.2 Passenger Counters. Bus managers may choose to equip all or a portion of their fleets with passenger counters. If all vehicles are equipped, the property will gain the capacity to measure and record all passenger service utilization by route, stop, and time of day, and may be able to use this information on a real-time basis to adjust service in response to unexpected surges of demand. However, considerable expense can be avoided if the managers choose to equip only a portion the fleet, collect samples of service utilization data, and adopt less sophisticated measures to accommodate unexpected demands. The base case bus fleet assumes that 120 passenger counters are purchased, enough to equip five percent of the fleet. This provides two counter-equipped buses for each of the current total of sixty manual checkers, and it enables bus managers to collect sample data which is at least as good as the present manually produced data.

3.2.3 Generic AVM System Costs. AVM deployment costs have been developed from proposals submitted to the Department of Transportation in October 1975 by four contractors seeking to install a multiple user AVM demonstration system in Los

Angeles. The proposals covered equipment, programming, installation, calibration, and maintenance for various fleet sizes. The data in the proposals have been analyzed by TSC's AVM Project Office, which established the four generic classes of location system (sharp signpost, broad signpost, radio frequency, and dead reckoning). This was done to describe and categorize the proposals, and then identify representative cost factors and their variations for each generic class of systems in terms of on-vehicle equipment, wayside equipment and central computer and communications equipment. Using these cost factors, as specified for 1,000 vehicle fleets,* the benefit-cost model sizes the AVM system for the base case: service area; number of route-miles; and number of vehicles. It then sums the capital costs, and computes the maintenance expense.

Benefit-cost ratios are, by definition, directly sensitive to cost totals, and the base case AVM costs are only as dependable as the data in the eight proposals. In the judgement of the TSC AVM Project Manager, the estimates in the proposals are realistic, the best available, and at this

_____

*Since most fleet combinations in the base case exceed 1,000 vehicles, use of the 1,000 vehicle criterion costs may under-state potential economies of scale associated with a nation-wide implementation of transit, police, and taxi fleets.

point in time they remain dependable within the following
limits shown in Table III-1 below.

TABLE III-1.   TOTAL SYSTEM COST VARIATIONS IN GENERIC AVM
               SYSTEMS

Sharp Signpost	$\pm$ 20%
Broad Signpost	$\pm$ 5%
Radio Frequency	$\pm$ 18%
Dead Reckoning	$\pm$6.5%

The impact of changing system costs will be addressed when
AVM benefits are compared to the different location system
costs in Chapter V.

3.2.4 AVM Labor Costs.   The AVM cost estimates described in
the preceding section include all labor for programming,
installation, calibration and maintenance. Computer support
will be provided by a closed loop minicomputer which will
not require a dedicated operator. Off-line analyses of
management information and related computer operations are
assumed to be an extension of present data processing
programs rather than unique costs attributable to AVM.
Vehicle dispatch consoles are designed to support up to 250
vehicles, similar to the workload of present base case
dispatchers. Vehicle operators will perform at the same
skill and pay levels with or without AVM.

There are two potential labor expenses which may not be
accounted for in these assumptions. The first is the non-
productive time devoted to AVM start-up training, which may
require up to four hours for each vehicle operator (this
would be a one-time expense since refresher and new
personnel training would be included in regular training
programs). The second potential expense is in increased
skill and consequent salary levels for dispatchers. For
example, the St. Louis Police Department is installing a
city-wide AVM system and replacing police cadet dispatchers
with lieutenants. Neither of these expenses are reflected
in the base case data. The first is omitted, because the
training expenses are considered speculative, and the second
is omitted because the use of senior personnel as
dispatchers may reflect a unique policy choice by one type
of fleet in one city. However, the model has the capability
to add additional labor, equipment and installation costs.
Test runs indicate that costs covering the four hour startup
training have a negligible impact on the bus results, though
a shift to lieutenant dispatchers would have a discernible
impact on the police results. (Specifically, the inclusion
of these factors would increase system costs and decrease
benefit-cost ratios by 2.5% for the bus and by 10% for the
police.) Future cost projections and field tests must
address these topics more clearly and, in the meantime,

police planners in particular should be sensitive to the area of dispatcher requirements.

3.2.5 Multiple User Cost Sharing. Shared AVM systems have been expected to lower costs for participating users and, as indicated above, the TSC model provides a mechanism for testing this hypothesis. In order to do this, a standard or rule to apportion common costs among users was adopted. This standard prorates basic data processing and communications costs according to the number of vehicles and then distributes wayside equipment costs according to both the number of vehicles and the square miles (or route miles, if appropriate) in individual service areas. Within any given area, wayside costs are divided in direct proportion to the size of each fleet which serves that area. When a fleet operates in two or more areas -- as the bus fleet does in the base case --its vehicles are assumed to be uniformly distributed and directly proportioned to the two areas served. (The model can alternately calculate proportionate costs on the basis of route miles instead of areas.) When an operator deploys the only instrumented vehicles in any area -- as the bus does outside the core in the base case -- he bears all of the wayside costs attributable to that area. As a result, all vehicles and all operators are treated

equally; there is no allowance for differences in benefits, ability to pay, or any other such criteria.

All participants in a shared AVM system must install and use the same type of location system. It is possible that the location system which was the lowest cost choice for an independent AVM user would not be the lowest cost choice for the total combined fleet. When this happens the share of multiple user costs may be little less than the price of an independent dedicated system. It is also conceivable that one user could require much greater accuracy and thus more expensive equipment than the other users; such a situation would probably preclude participation in a shared system.

3.2.6 Limitations of the Cost Results. The method of assigning and apportioning costs used in this study is adequate for comparing urban areas of varying sizes and making an estimate of the benefit/cost ratio for a go/no go decision, but it is insufficient to determine the exact cost of any unique application. Any decision on actual AVM implementations must give detailed consideration to factors omitted in the model, such as the exact shape of the service area and possible overlap of route miles, and must insure that assumptions and cost factors of the model have been tailored to the specific features of the system at hand.

3.3 AVM Benefit Evaluation

3.3.1 Location System Performance. The UMTA/TSC AVM system specification requires location accuracy of closer than 300 feet and time accuracy of better than 15 seconds. All contractors claim to have achieved these standards. Since there has been no competitive evaluation of location system performance, the benefit-cost analysis assumes that each class of location system meets these requirements and thus can provide equivalent benefits. As a result, only one benefit total is calculated for each deployment scneario. A comparison is then made between this benefit total and the total cost of the least expensive location system for that deployment. Since the assumption of equal performance accuracy may be questioned, the model has the option to compare benefits against any location system cost total. Chapter V presents the full range of cost and benefit combinations for each deployment scenario.

3.3.2 Derivation and Meaning of Benefit/Cost Ratios. All costs and dollar benefits are expressed in constant 1975 dollars in order to eliminate the impact of inflation. These constant dollars are then converted to present value dollars by discounting at ten percent annually over the ten year life of the AVM system. This is done for all comparisons and evaluations since the present value

technique yields a unit of measure which reflects both the dollar magnitude and the time value of money by giving greater emphasis (at ten percent per year) to cost and benefits realized early in the project than to those realized at later times.

Final results are presented as benefit-cost ratios (B/C), which are present value benefits divided by present value costs. A benefit-cost ratio greater than 1.0 indicates that an alternative is a productive investment, returning dollar benefits which exceed system costs. A benefit-cost ratio of less than 1.0 indicates that system costs exceed dollar-benefits -- that is, that the alternative under consideration does not pay its way in terms of dollar benefits.

3.3.3 Service and Management Improvements. Benefit-cost ratios reflect only those factors which have been expressed in monetary terms. One significant AVM benefit--the set of security benefits--has not been monetized because two factors combine to produce highly speculative savings figures. These factors are low confidence in the dollar values which may be assigned to a particular benefit and unusual difficulty in demonstrating a causal connection

between the benefit and AVM. Security benefits are discussed in Chapter VII.

It is important to note that a decision against monetizing a benefit does not imply insignificance. On the contrary, important benefits are discussed in Chapter VII -- benefits which decision-makers may conclude are sufficient to justify proceeding with an investment which, in dollar terms alone, appears to be marginal or non-productive.

3.3.4 Capture of Dollar Benefits. Most AVM benefits appear in the area of fleet efficiency and productivity. Efficiency and productivity improvements, whether from AVM or any other source, require managers and policy makers to choose a strategy to exploit those improvements. This choice may be made explicitly or implicitly, but it cannot be avoided. The almost infinite range of exploitation possibilities can be summarized best as a continuum (illustrated below) between two polar strategies: either plow back the added productivity to increase the level of service produced by the present number of vehicles and personnel; or capture the added productivity by reducing the fleet and staff size to the minimum required to maintain the current level of service.

INCREASED EFFICIENCY. . .

REQUIRES A CHOICE BY
LOCAL POLICY-MAKERS. . .
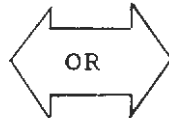
IMPROVED SERVICE   CONSTANT SERVICE
    YIELDING   ⟨ OR ⟩   YIELDING
PUBLIC BENEFITS   OPERATING ECONOMIES

Attention to the choice and design of management's
exploitation strategy is crucial for analysts since it
defines the benefits which must be measured. In this study,
a pure strategy of capturing benefits by cost reduction is
assumed. This represents a valid goal for transit and
public safety managers; it defines clearly the resources
freed by AVM technology; it minimizes the danger of double-
counting benefits; and it avoids speculative benefit
methodology, such as valuations of patron wait and travel
time. And in the end, this choice of strategy remains an
analytic artifice, one which leaves to each individual
community the real philosophical and managerial questions of
using AVM improvements to reduce budgets or to increase
public service.

3.3.5 Estimating the Range of Dollar Benefits. The ideal
estimate of AVM benefits would be succinct and confident--a
single figure summarizing a mass of data. Unfortunately,

the trade-off between precision and confidence in the
projection of AVM impacts is such that the study does not
present single "most likely" benefit estimates. It became
clear in our analysis that many uncontrollable variables and
considerable uncertainty lie between this study and the
real-world impacts of a large scale AVM system. These
obscuring elements range from economic, social, and
political trends, to issues of management choices and
effectiveness. In order to reflect these uncertainties and
to highlight the sensitivity of AVM payoffs to them, the
study presents sets of high and low benefit estimates which
are rooted as much as possible in empirical data. In the
low cases the estimates represent conservative applications
of AVM experience, often understating demonstrated
achievements. In the high cases the estimates are
optimistic yet reasonable projections based mostly on
accomplishments. Although the low estimates entail less
risk, they are no more "probable" than the high estimates.
Since significant uncertainty exists, it is more useful to
mark the high and low limits of that uncertainty -- even if
the gap is uncomfortably large -- rather than cover up the
uncertainty with the spurious precision implied by a single
best estimate.

3.3.6 <u>Sensitivities</u>. The TSC benefit-cost study of AVM is
a complex interplay of many assumptions, and it highlights
the impact of key assumptions by means of sensitivity
analysis. This demonstrates the magnitude of change in the
study results given specific changes in inputs and
facilitates a <u>generalized</u> application of the results to
other urban areas or AVM deployments. Since AVM location
system costs vary in relation to type of fleet, fleet size,
and operating area, the model is used to search for changes
in the low cost location system; this is discussed in
Chapter IV. Resulting benefit-cost ratios are also examined
for the different fleets in relation to density, urban size,
operational characteristics, and AVM impacts. Density is
varied by adjusting fleet size and operating area as single
factors. Urban size reflects the total mix of area, fleet
size, and operating characteristics. Key operating
characteristics include the proportion of a bus fleet
operating on short headways, the amount of layover in the
system, the extent of the manual data collection effort, the
percentage of non-revenue mileage in a taxi fleet, and the
percentage of preventive patroling performed by police
cruisers. AVM impacts focus on operating efficiencies --
that is, changes in the key operating characteristics. This
information is presented in Chapter VI.

IV. AVM SYSTEM COSTS

Chapter IV is a discussion of AVM life cycle system costs.
It begins with a brief description of the cost calculation
method, then presents the costs of the four base case
deployment scenarios for bus, police and taxis operating
independent AVM systems, and for all three sharing a
multiple user AVM system. After a breakdown of the cost
shares for the multiple user system, the chapter concludes
by reviewing the impacts of fleet size, fleet type and
operating area on the location system cost rankings.

4.1 Development of System Costs

As indicated in Chapter III, the AVM costs displayed in this
study are an extrapolation of cost factors distilled from
eight contract proposals. Some cost factors are fixed and
others vary according to fleet size, route miles, or square
miles. The factors reflect the on-vehicle, wayside and
central equipment costs appropriate to each of the four
generic location systems. On-vehicle costs vary only with
the size of the fleet, and wayside costs vary only with the
dimensions and structure of the operating area. Central
equipment costs have fixed minimum computer and
communication costs tied to each type of location system,
regardless of system size, plus variable computer and

communication costs which grow along with the size of the service area and/or the number of vehicles.

The sum of the on-vehicle, wayside and central equipment costs is the total capital cost of the system. With minor exceptions, annual maintenance costs are estimated at ten percent of the capital cost of each type of equipment. These annual costs, which are expressed in constant 1975 dollars, are converted to a single present value amount for maintenance and this figure is added to the capital costs, producing a total life cycle cost expressed in present value dollars. This is illustrated in Figure IV-1. A more detailed review of the cost calculations (cost uncertainties were explained on page 3-10) is in Appendix B and the location system cost factors may be found in Appendix A.

4.2 AVM Costs for the Bus Alone

The base case bus fleet consists of 2,400 vehicles serving 3,825 route miles within a service area of 5,000 square miles. Since neither police nor taxis will be sharing the AVM system in this deployment, the 475 square mile core area in which they operate requires no special attention.

Table IV-1 presents the life cycle AVM system costs for the base case bus fleet operating alone. Notice that the sharp

AVM LIFE CYCLE IN YEARS
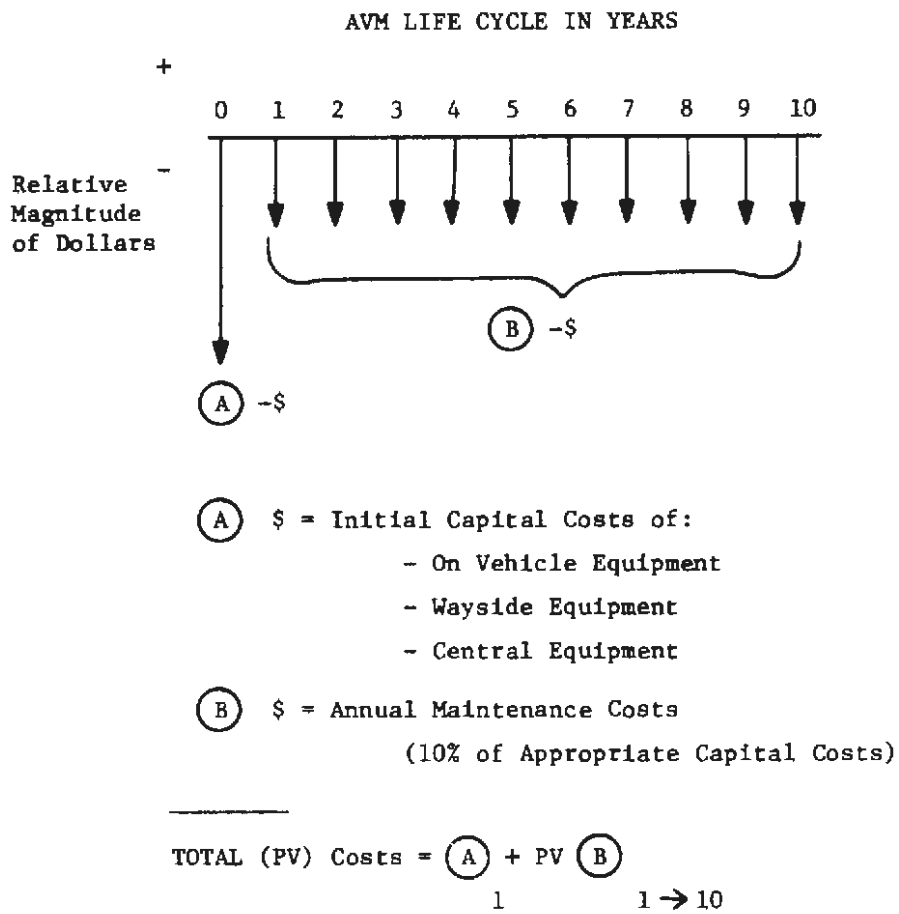
FIGURE IV-1

AVM LIFE CYCLE COSTS

TABLE IV-1

AVM LIFE CYCLF SYSTEM COSTS
FOR A SINGLF-USFR BUS FLFFT
(Present Value, $000) [1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	7,146	2,826	3,906	9,762
Wayside Equipment	1,318	475	1,193	2,396
Central Equipment	838	575	302	1,425
Total Capital Costs	9,302	3,876	5,401	13,584
Cost Uncertainty	+20%	+5%	+18%	+6.5%
Total Maintenance Costs	5,716	2,511	3,448	8,053
Total System Costs	15,018	6,387	8,849	21,637

[1]Present value calculated at ten percent discount rate.

signpost and dead reckoning location systems are two to
three times more expensive than the broad signpost and radio
frequency techniques. Both of the highest cost systems
possess sophisticated and expensive on-vehicle components,
which explains much of their total cost disadvantage.

Displaying the least expensive central computer and
communication costs, the radio frequency technique is much
more economical than the preceding location systems, yet it
still suffers a 28% disadvantage when compared to the broad
signpost. The low cost of the latter is explained by
relatively inexpensive on-vehicle equipment and the ability
to place wayside instruments only along the bus routes.

A central assumption of this analysis is that all location
systems meet the same performance standards. If this
assumption is abandoned, as is possible after field tests
are completed, sharp signpost and dead reckoning -- and even
radio frequency -- would have to exhibit substantial fixed
route performance advantages to be preferable to broad
signpost at current price estimates.

4.3 AVM Costs for the Police Alone
The base case police fleet consists of 1,330 cruisers
providing service in a 475 square mile area. The AVM system

4-5

must cover this entire operating area, not just a lattice
work of routes on major thoroughfares as in the bus alone
scenario. The impact of the total area requirement is clear
in Table IV-2, which presents the single user police costs.
Both signpost systems are at a disadvantage due to the need
for extensive wayside equipment deployments. Dead
reckoning, which had been the highest cost option for the
bus alone, is now some two million dollars below sharp
signpost for this random user application. Radio frequency
is now less expensive by over one million dollars compared
to the broad signpost system. Despite the impact of area
coverage, broad signpost remains substantially less
expensive than dead reckoning. Radio frequency is the least
expensive police only system by a margin of 21%.

4.4 AVM Costs for the Taxi Alone
The base case assumes that 800 taxis operate in a 475 square
mile area and are supported by a single dispatch system.
The AVM coverage requirements for this area are identical to
the police, and the location system costs exhibit the same
rank order for both operators. However, the smaller size of
the taxi fleet heightens the difference already noted
between the bus and the police. Radio frequency reflects a
34% cost advantage over broad signpost because the smaller
taxi fleet deemphasizes radio frequency's higher on-vehicle

TABLE IV-2

AVM LIFE CYCLE SYSTEM COSTS
FOR A SINGLE USER POLICE FLEET
(Present Value, $000)[1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	4,323	1,530	2,128	5,320
Wayside Equipment	2,852	1,325	238	254
Central Equipment	586	415	214	978
Total Capital Costs	7,760	3,269	2,580	6,552
Cost Uncertainty	$\pm 20\%$	$\pm 5\%$	$\pm 18\%$	$\pm 6.5\%$
Total Maintenance Costs	4,794	2,037	1,614	4,002
Total System Costs	12,555	5,306	4,193	10,553

[1] Present value calculated at ten percent discount rate.

costs. And further, due to the total number of signposts needed to meet random user areawide coverage requirements, there are no compensating reductions in broad signpost's higher wayside costs. A similar relationship between dead reckoning and sharp signpost results in four relatively evenly spaced costs. This is in sharp contrast to the bus and police deployments, which produced marked gaps between the two highest and two lowest cost location systems. Taxi cost data is presented in Table IV-3.

TABLE IV-3

AVM LIFE CYCLE SYSTEM COSTS
FOR A SINGLE USER TAXI FLEET
(Present Value, $000)[1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	2,600	920	1,280	3,200
Wayside Equipment	2,846	1,325	237	253
Central Equipment	460	335	186	720
Total Capital Costs	5,906	2,580	1,703	4,173
Cost Uncertainty	+20%	+5%	+18%	+6.5%
Total Maintenance Costs	3,655	1,608	1,069	2,535
Total System Costs	9,561	4,187	2,772	6,708

[1]Present value calculated at ten percent discount rate.

4.5 AVM Costs for the Multiple User Fleet

The fourth deployment scenario assumes that the bus, police
and taxi fleets are served jointly by a single AVM system.
The operating area for this mixed fleet, pictured earlier in
Figure III-3, consists of two concentric areas. The 475
square mile inner core area is served by police, taxi and
bus, while the remaining 4,525 square miles in the outer
ring is served only by the bus. The 3,825 total bus route
miles are divided with 2,647 route miles (69%) in the outer
ring and 1,178 route miles (31%) in the inner core. (In the
absence of more appealing logic this assumption was based on
the proportionate relationship between the radii of the two
areas.)

The structure of the service area requires that the AVM
system combine total area coverage within the 475 square
mile core area with a skeletal route structure outside the
core. Since it is assumed that the same location system
must be used throughout the service area, the cost ranking
becomes a contest between the advantages which broad
signpost displayed in the bus-only system and those that
radio frequency displayed in the two random route systems.
As Table IV-4 illustrates, broad signpost enjoys a 10% cost
advantage over radio frequency. Lower unit costs for on-
vehicle equipment enable broad signpost to overcome

disadvantages in wayside and central equipment. Notice, too that a large gap has reappeared between the two lowest cost and the two highest cost location systems.

TABLE IV-4

AVM LIFE CYCLE SYSTEM COSTS
FOR A MULTIPLE-USER SYSTEM
(Present Value, $000)[1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	14,069	5,276	7,314	18,282
Wayside Equipment	3,847	1,689	1,096	2,270
Central Equipment	1,468	975	410	2,627
Total Capital Costs	19,384	7,940	8,820	23,179
Cost Uncertainty	±20%	±5%	±18%	±6.5%
Total Maintenance Costs	12,205	5,099	5,623	14,408
Total System Costs	31,589	13,039	14,443	37,587

[1]Present value calculated at ten percent discount rate.

4.6 Cost Shares for the Multiple User System

Two cost elements are shared in a multiple user system. The first, fixed central computer and communication costs, are basic charges which are not considered sensitive to differences in service areas. Because of this, these costs are divided among users in direct proportion to the total number of vehicles in each participating fleet. The second element, wayside equipment costs, is more complicated because it is directly related to operating areas.

As indicated in Chapter III, common user wayside costs are apportioned in relation to the number of vehicles in areas used by two or more instrumented fleets. Thus the bus bears all costs associated with the outer ring, where it operates alone, but shares costs associated with the core. In order to determine the shares within the core it is necessary to apportion the bus fleet between the outer ring and the core. This is done in direct relation to the number of square miles in both areas, 90% in the outer ring and 10% in the core; the result, illustrated in Figure IV-2, attributes 240 buses to the core.

(1) First, Distribute Buses Between Areas:

90% of Buses   10 % of Buses

Outside Core   Inside Core
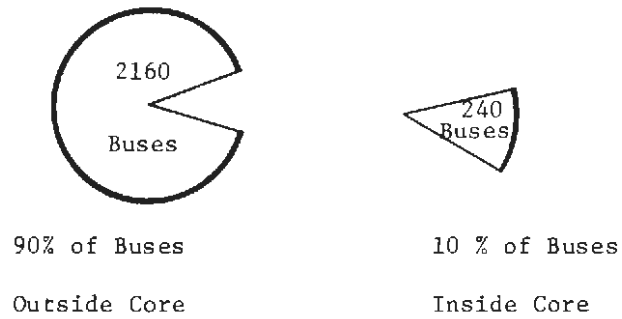
(2) Then Distribute Core Costs Among 2370 Users:
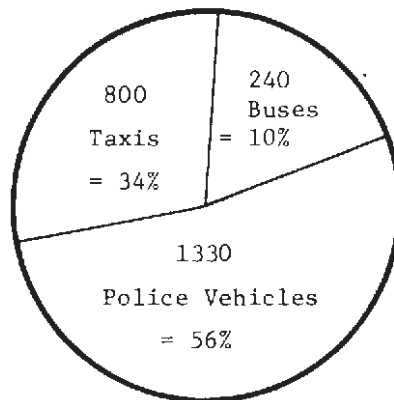
FIGURE IV-2

CALCULATION OF MULTIPLE USER COST SHARES

Core wayside costs are divided in proportion to fleet size, with 56% to the police (1330 vehicles), 34% to the taxi (800 vehicles), and 10% to the bus (240 vehicles). Each user's total share of the lowest cost multiple user system is shown on Table IV-5.

TABLE IV-5

COST SHARES FOR THE LOW-COST MULTIPLE USER SYSTEM, BROAD SIGNPOST LOCATION SYSTEM

(Present Value, $000)[1]

	Bus	Police	Taxi	Total System
Capital Costs				
On-Vehicle Equipment	2,826	1,530	920	5,276
Wayside Equipment	496	745	448	1,689
Central Equipment	493	291	191	975
Total Capital Costs	3,815	2,566	1,559	7,940
Total Maintenance Costs	2,546	1,588	965	5,099
Total System Cost	6,361	4,154	2,524	13,039
Percentage Shares	49%	32%	19%	100%

[1]Present value calculated at ten percent discount rate.

Table IV-6 compares cost shares in the low cost multiple

user system with low cost individual AVM systems. Although

one would expect shared infrastructure costs to produce

meaningful savings, this is not the case. Total AVM

multiple user costs savings -- 0.5% for the bus, 1% for the

police, and 9.1% for the taxi--do not appear to justify the

additional management time and coordination which a shared

system would demand.

The surprisingly small advantage of a shared system is due

to two factors. First, the shared system elements represent

a relatively small part of the total costs. In the shared

broad signpost system only 24% of total costs are associated

with the purchase and maintenance of shared infrastructure

costs. Second, the decision to participate in a shared

system--that is, the desire to parcel out part of the common

costs--addresses the lowest cost system which, in this case,

differs from each participant's optimum individual system,

and thus dilutes their associated cost savings.

Specifically, the bus fleet must absorb part of the costs

for instrumenting the entire 475 square mile core instead of

just fixed route miles; and the police and taxi fleets must

buy into a location system which is not their optimum low

cost choice. Table IV-6 shows clearly that the benefit of

TABLE IV-6

COMPARISON OF SINGLE AND MULTIPLE USER COSTS
FOR THE LOW COST LOCATION SYSTEM
(Present Value, $000,000)[1]

	Low Cost Individual AVM	Share of Low Cost Multiple User AVM	Multiple User Savings
Bus	6.39*	6.36*	0.5%
Police	4.19**	4.15*	1.0%
Taxi	2.77**	2.52*	9.1%
TOTAL COST	13.35	13.03*	2.4%

*Broad Signpost

**Radio Frequency

[1]Present value calculated at ten percent discount rate.

sharing 24% of system costs barely outweighs the negative
impact inherent in suboptimal technology choices.

There are, however, deployment scenarios which would extract
more advantage from a multiple user AVM. The fleet
structure which would draw the greatest advantage appears to
be a shared random route or blanket coverage system with
minimal variation in service area boundaries. This
structure increases the likelihood that the same location
system would be low cost in all possible combinations of
users, and it increases the proportion of wayside costs
eligible for sharing. A test run of a multiple user system
serving only police and taxi (base case fleets) resulted in
multiple user cost reductions of 6% for the police and 14%
for the taxi.

4.7 Sensitivity of Location System Cost Rankings
The preceding section partially illuminated the interaction
between fleet sizes, operating areas, and potential
advantages of multiple user cost sharing. That interaction
is rooted in the impact of fleet size and operating area on
system costs, and this section examines more closely the

relationship between those variables and the cost rankings of the four generic location systems. As a reference, Table IV-7 summarizes the total costs of all base case fleet and location system combinations.

TABLE IV-7

TOTAL SYSTEM COST ESIMATES
(Present Value, $000,000)[1]

| | Deployment Scenario | | | |
	Bus Only	Police Only	Taxi Only	Multiple User
Sharp Signpost	15.0	12.6	9.6	31.6
Broad Signpost	6.4*	5.3	4.2	13.0*
Radio Frequency	8.8	4.2*	2.8*	14.4
Dead Reckoning	21.6	10.6	6.7	37.6

*Lowest cost system for each deployment scenario.

[1] Present value calculated at ten percent discount rate.

Cost sensitivity analysis begins with the benefit-cost model. A minimum of four variations were run for each set of parameters which are addressed below. The data from the model were analyzed with regression techniques and extended on charts for visual interpretation. The resulting cost curves have the appearance of straight lines primarily because all costs are based on estimates for a 1,000 vehicle purchase; they do not reflect economies of scale beyond that point. In addition, several cost elements are constant in each sensitivity case as they are unaffected by the test variable, just as wayside costs are unaffected by changing the fleet size.

Location system relative costs appear to be insensitive to fixed route fleet size. As Figure IV-3 illustrates, varying bus fleet size within the constraints of the base case produced no change in the relative rank of location system costs. Broad signpost holds a clear cost advantage which increases monotonically with fleet size.

Location system cost rankings do change in response to random route fleet size, but only when the fleet is extended to very small or very large numbers of vehicles relative to the operating area. Figure IV-4 shows the relatively high initial wayside costs imposed on both signpost systems by
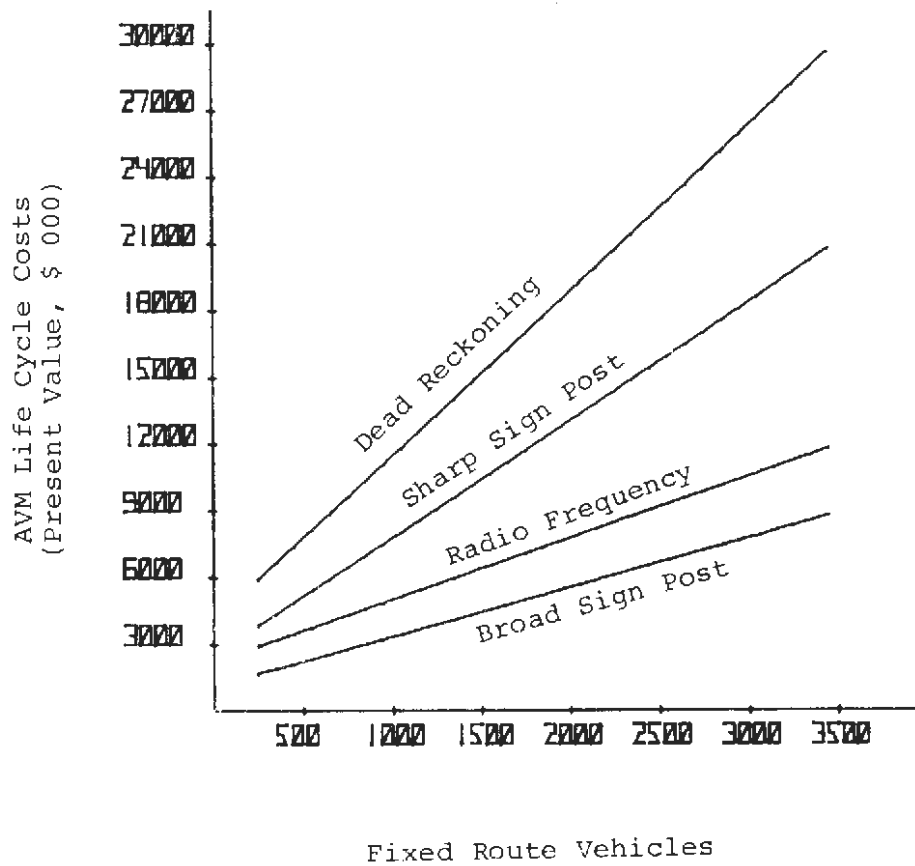
FIGURE IV-3   LOCATION SYSTEM COST AS A FUNCTION
                OF FIXED ROUTE FLEET SIZE*

                *Within Constraints of
                 Base Case Except for
                      Fleet Size
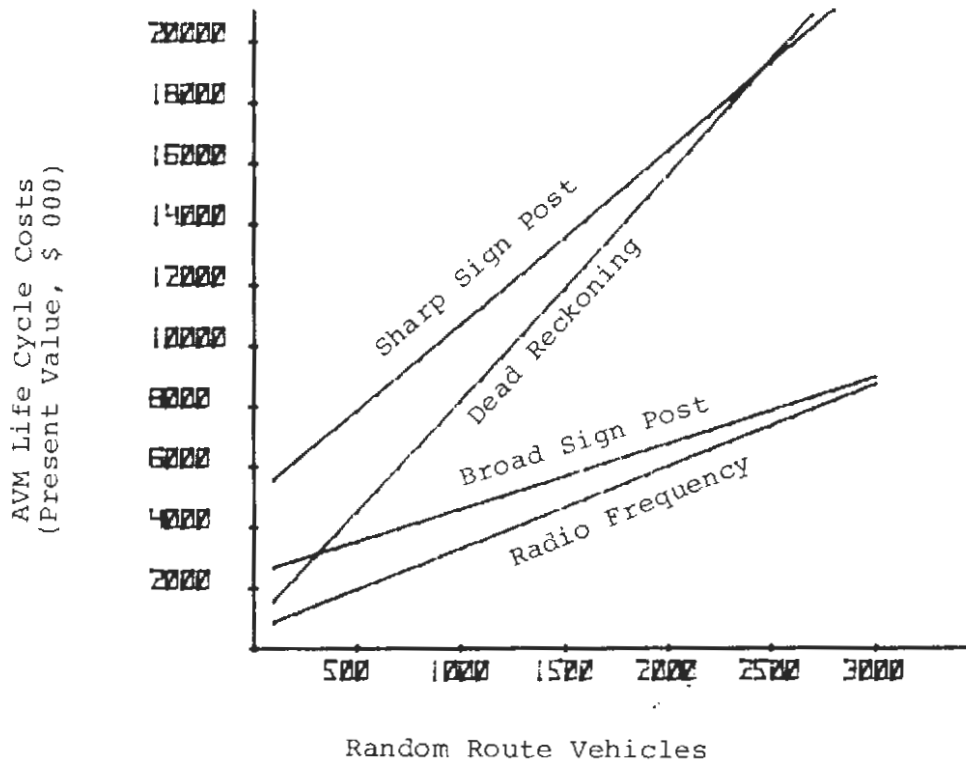
FIGURE IV-4

LOCATION SYSTEM COST AS A FUNCTION
OF RANDOM ROUTE FLEET SIZE*

*Within Constraints of
Base Case Except for
Fleet Size.

4-20

the dimensions of the area even when there are no vehicles. The slope of the cost lines show the variation in per-vehicle costs of each system. Broad signpost becomes competitive with radio frequency at the point where the higher per-vehicle costs of radio frequency outweigh the higher wayside costs of broad signpost--at about 3,000 vehicles in a 475 square mile area.

Higher per unit costs and coverage requirements of dead-reckoning wayside equipment changes the competitive relationship between dead reckoning and sharp signpost systems at about 2,500 vehicles.

Sensitivity of location system cost rankings for multiple user fleets was tested by varying the total number of random route vehicles which were added to the base case fleet. These random route vehicles were restricted to the 475 square mile core area while the 2,400 buses operated throughout the 5,000 square mile service area. Figure IV-5 presents the total system costs (it does not address cost shares between users). The resulting curves are similar to those of the fixed route fleet in that location systems are continuously in the same rank order. However, in this case there is a marked gap between the two highest and two lowest

Number of Random Route Vehicles
Added to a Base of 2400 Buses.
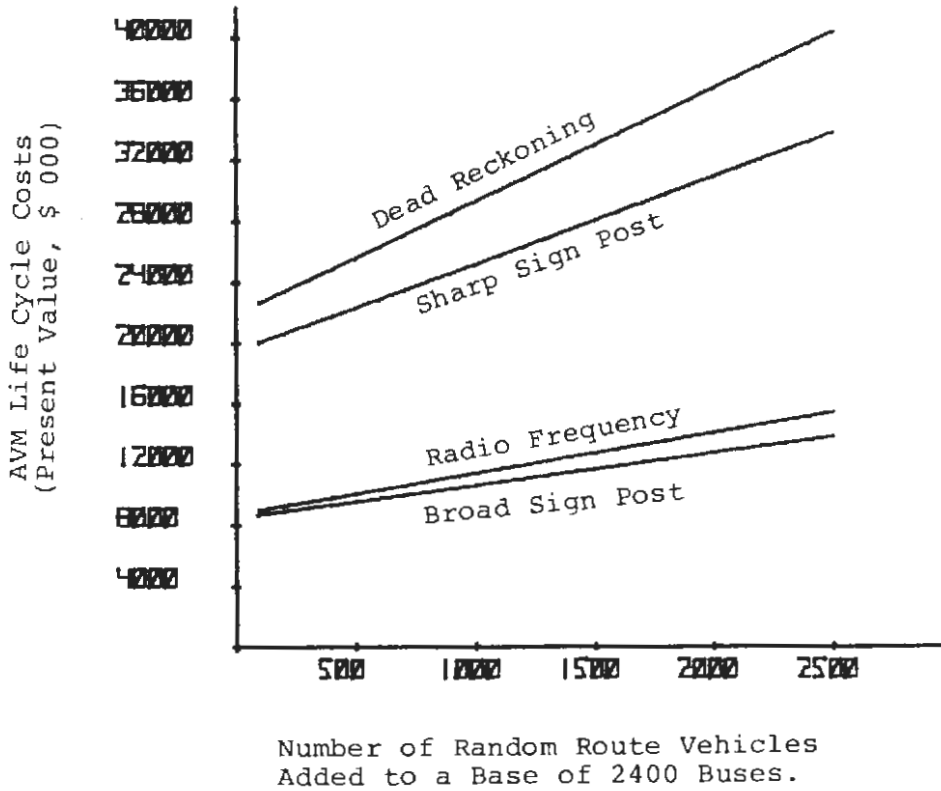
FIGURE IV-5

LOCATION SYSTEM COST AS A FUNCTION
OF MULTIPLE USER FLEET SIZE*

*Within Constraints of
Base Case Except for
Fleet Size.

cost location systems and a very small difference between broad signpost and radio frequency costs.

The final cost sensitivity test looks at the impact of operating area on random route cost rankings. For a fleet of 1,000 vehicles we see in Figure IV-6 that radio frequency has an increasing cost advantage over broad signpost as the operating area increases beyond about 125 square miles. The crossover between broad signpost and radio frequency at 125 square miles is analagous to their crossover beyond 3,000 vehicles in Figure IV-4, which varied random route fleet size in a fixed area. In general terms, broad signpost costs improve relative to radio frequency costs as the vehicle density increases.
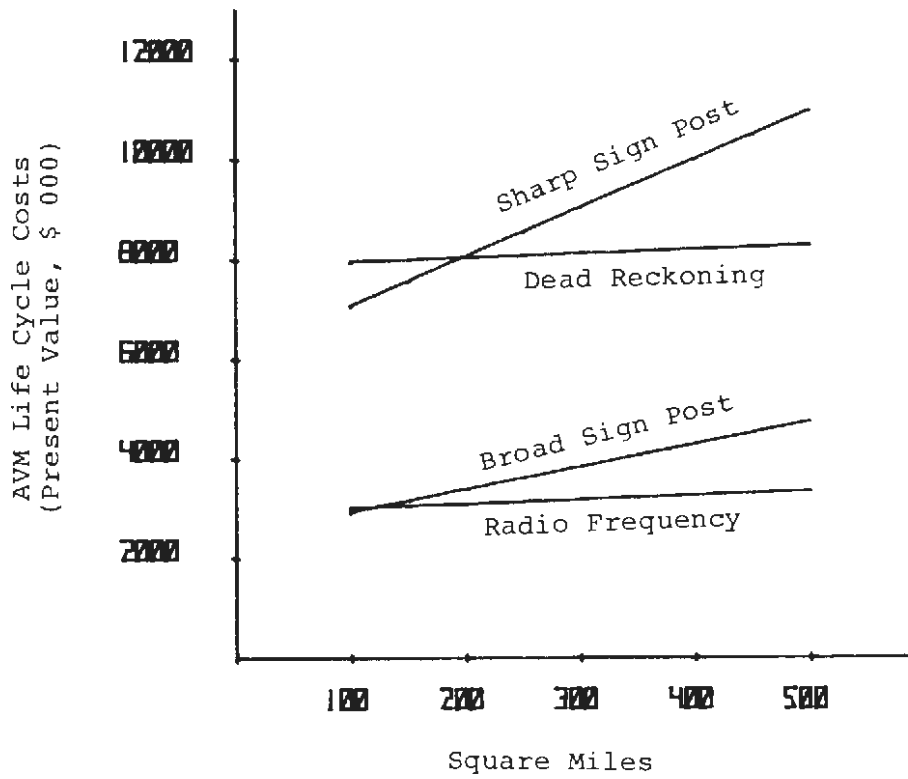
FIGURE IV-6

LOCATION SYSTEM COST AS A FUNCTION
OF OPERATING AREA*

*For 1,000 Random Route Vehicles
Within Constraints of
Base Case.

V. AVM SYSTEM BENEFITS

This chapter discusses the impact of AVM on bus, police, and taxi operations; the dollar value of those impacts; and the relationship between system costs and benefits. Section 5.1 explains the methods used to sum dollar savings for all users. The next three sections focus on the bus, police, and taxi fleets, and the final sections review the results for the combined multiple user fleet. Data values used in the benefit calculations are listed in Appendix A.

5.1 The Measurement of Benefits

Most AVM benefits center around fleet productivity and result in an estimate of the number of vehicles which may be saved without affecting service. In these cases the unneeded vehicles are the catalysts which produce capital, operating, and payroll savings. All savings quantified in this study, regardless of source, fall into one of these three categories: vehicle capital costs, vehicle operating and maintenance (O&M) costs, and personnel costs.

5.1.1 <u>Vehicle</u> <u>Capital</u> <u>Costs</u>. Vehicle capital savings begin with a projection of the impact of AVM on fleet size and yield an estimate of the number of vehicles to be saved. These savings begin to be realized at the end of the first

year of AVM operation. Savings are realized by avoiding normal replacement purchases, not by selling excess vehicles, which means savings may not be realized any faster than the fleet deterioration or attrition rate.

Fleet attrition is determined by dividing the average vehicle life into the fleet size. Thus a bus fleet with 1,500 vehicles and a ten year average vehicle life would replace 150 buses each year. If AVM saved 100 vehicles the fleet would purchase only 50 buses at the end of the first year, realizing cost savings of the present value of the net cost of 100 buses, one year in the future. Example 1 in Figure V-1 illustrates this process.

Police cruisers and taxis have relatively short lifespans, requiring each vehicle in the fleet to be replaced several times during the AVM system life of ten years. A fleet of 1,500 police cruisers with an average life of three years would replace 500 cars each year. If AVM saved 100 vehicles in this fleet, the police would purchase only 400 vehicles at the end of year one, saving the cost of 100 cruisers at that point. In addition, they would save the cost of those cruisers again at the end of the fourth and seventh years of the AVM life cycle -- the points at which on average they would have had to replace the cruisers again had it not been

for AVM. The total capital saving is the present value of the savings at years one, four, and seven. Example 2 in Figure V-1 depicts this process.

Example 1   1500 Bus Fleet

                           10 Years Bus Life

                           100 Buses Can be Saved

One Time Savings From
100 Buses Not Purchased

0 1 2 3 4 5 6 7 8 9 10

SYSTEM LIFE TIME

Example 2   1500 Police Fleet

                           3 Year Car Life

                           100 Vehicles Can be Saved

100 Vehicles not Purchased

0 1 2 3 4 5 6 7 8 9 10

SYSTEM LIFE TIME
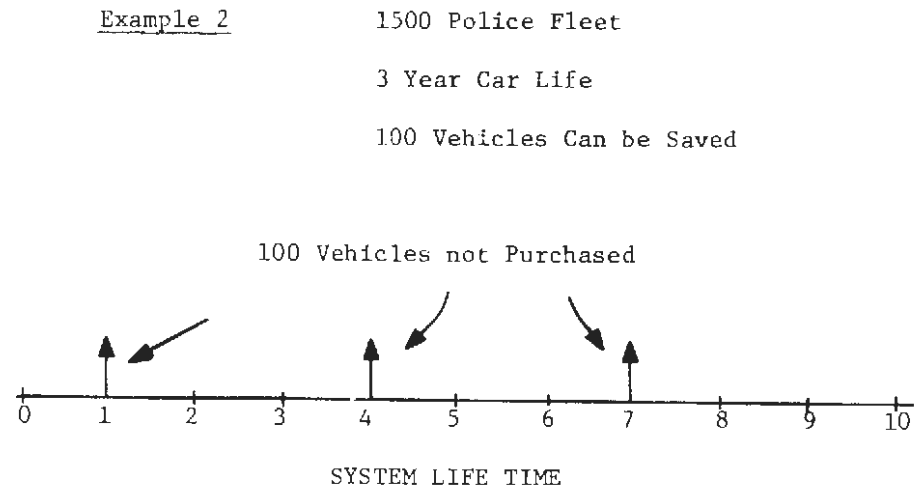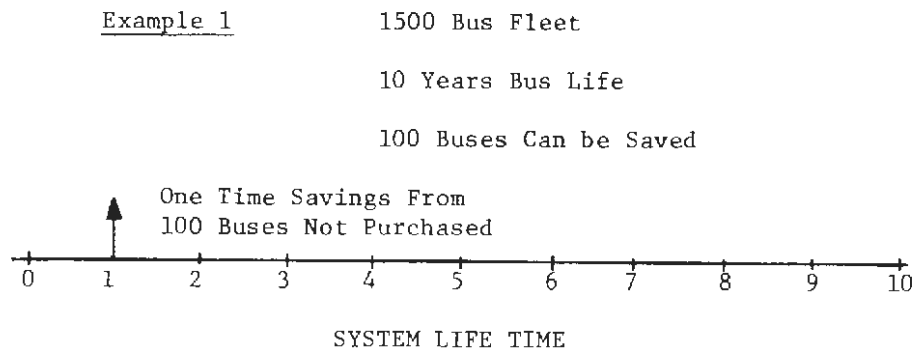
FIGURE V-1

CALCULATION OF VEHICLE CAPITAL SAVINGS

5-3

5.1.2 <u>Vehicle</u> <u>O&M</u> <u>Costs</u>. Reductions in fleet size are generally associated with reductions in vehicle operating costs. A substantial portion of operating costs are tied directly to vehicle mileage, but there are also cost elements inherent in the ownership of a vehicle which do not vary with mileage. The first category includes costs such as fuel, tires, and most periodic maintenance; the second category includes insurance and periodic maintenance performed according to the calendar. While one category of AVM bus savings is limited to fixed O&M reductions, the remainder of the bus savings and all police and taxi savings reflect both fixed and variable O&M.

First, the annual dollar amount of O&M per vehicle which is incurred by the set of vehicles being saved must be determined. This will be the 1975 dollar equivalent of either the fixed O&M alone or the total O&M. When multiplied by the number of vehicles which are saved, this produces a total recurring annual benefit. The total O&M savings for each set of vehicles is the present value of the repeated annual savings, as illustrated in Figure V-2.

Repeated Annual O&M Savings

dollar
magnitude

$$0 \quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10$$

SYSTEM LIFE TIME

Total Present Value of Annual O&M Savings...

$$= \sum_{1}^{10} \text{PV of Each Annual Saving}$$
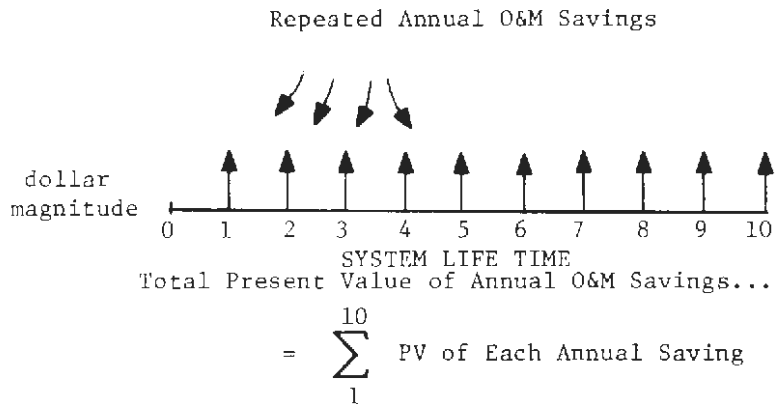
FIGURE V-2

CALCULATION OF OPERATING AND MAINTENANCE SAVINGS

5.1.3 Personnel Costs. Staff reductions produce savings in salary, benefits, and overhead. Salaries vary in terms of skill levels, seniority, overtime, and industry practice; some jobs are paid almost exclusively by commission. Benefits include employer contributions to insurance and pension programs, social security, and workmen's compensation. Overhead consists of administrative and supervisory support costs. Since each job category addressed in this study has a unique mix of cost elements, the model calculates the average 1975 dollar value of individual compensation which fits every category.

The number of positions which can be saved due to AVM reflects the characteristics of each particular efficiency improvement. In some cases the saving is tied directly to the number of vehicles saved. In other cases it is usually determined according to changes in operating hours.

Since a variety of legal, labor, and community practices limit management's freedom of action in realizing staff reductions, it is likely that staff savings made possible by AVM would not be achieved immediately. Such savings usually are realized over a period of years through attrition, and it is possible that the total reduction target may not be reached by the end of the AVM's ten year life cycle.

The model applies the best available attrition rate to the work force in question and determines the number of positions which will be vacated in the first year. Next, it calculates the 1975 dollar value of the first year's attrition, and then, since avoided salaries are a recurring benefit, the model determines the present value of this savings over the AVM life cycle. This value is stored, the staff size is reduced, and the model moves to year two where it applies the attrition rate to the reduced staff and calculates the present value of that year's attrition. This is repeated until the staff reduction goal is achieved or

the ten year AVM life cycle is exhausted. Figure V-3 is a

simplified illustration of this calculation.

GOAL
ATTAINED
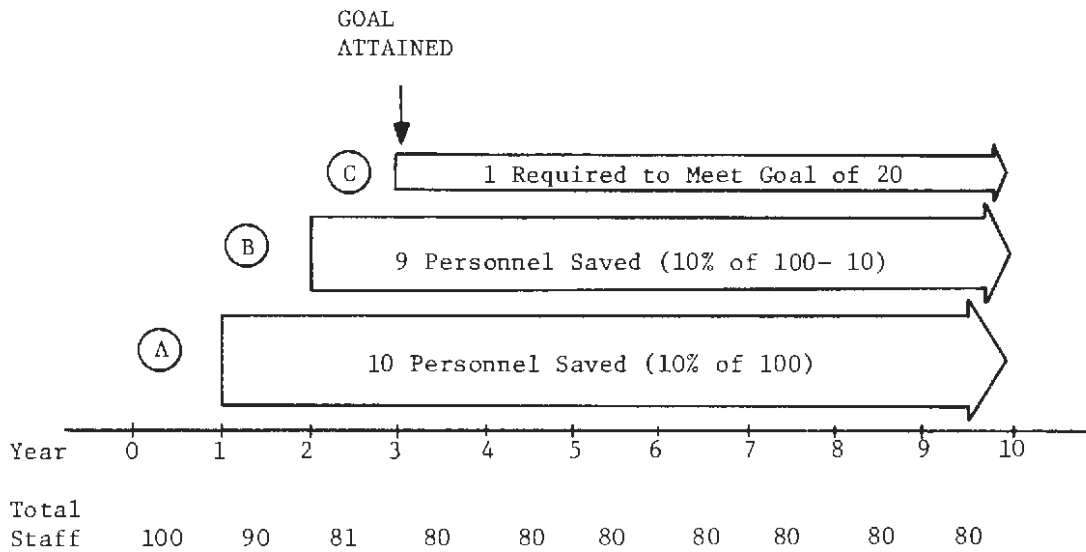
INITIAL STAFF = 100

TARGET REDUCTION OF 20

ATTRITION RATE = 10%

(A) = 9 years of savings of annual payroll for 10 people

(B) = 8 years of savings of annual payroll for 9 people

(C) = 7 years of savings of annual payroll for 1 person

FIGURE V-3

ILLUSTRATION OF PERSONNEL SAVINGS
THROUGH ATTRITION

5.2 AVM Benefits for the Bus

AVM can reduce bus operating costs in three significant ways. First, it can reduce the requirement for manual data collection by providing an interface for transmitting optional passenger counter data. Second, AVM can reduce non-productive bus layover time when exact position location information is used to improve schedule adherence. Finally, AVM can free buses on some routes by enabling schedulers to lengthen headways without increasing the average wait time perceived by passengers. This section discusses each of these impacts, then presents the overall bus benefits and conclusions.

5.2.1 Data Collection Benefits. Bus managers need data on actual run times and on passenger utilization of their service, stop by stop, in order to insure that schedules are realistic and meet the needs of the community. Accurate run times in schedules encourage improved public acceptance and good labor relations. Good measures of passenger demand insure that some routes are not over-served nor others inadequately served. In addition, some metropolitan areas use measures of demand to apportion community support of operating deficits.

Many properties employ checkers to collect this kind of information. Checkers, who earn an average $15,800 in the base case, ride buses and record times and numbers of passengers by stop. The location reporting capability of AVM provides the time and place aspects of this manually gathered information, and the addition of a mechanical passenger counter (costing $550) to a bus's AVM digital data link makes it possible to eliminate the manual efforts of counting passengers. (Data reduction and manipulation is assumed to be roughly equivalent in both techniques.)

The base case bus fleet employs 60 checkers. When AVM is implemented, 120 of 2400 buses are equipped with passenger counters. These buses can be shifted from route to route to gather data, just as are the checkers. As a result of this capability, it is assumed that the base case fleet can reduce its requirement for manual checkers by two-thirds without reducing the quality of data which it collects. This may be conservative since; (a) there are two counter-equipped buses for each initial checker; (b) the buses do not have shift and overtime restrictions; and (c) a staff of twenty people is still maintained to supplement the automated capability. However, this allows a cushion for any mechanical difficulty that may arise with the counters and permits the operator to retain flexibility.

AVM permits the base case to save 40 checker positions, and the incumbents may be released or given other duties within the property. In the first case, 40 personnel must be reduced through attrition, since it is assumed that layoffs are not acceptable. This situation constitutes the low estimate of the data collection benefits, and the forty positions are vacated at an attrition rate of ten percent applied initially to the total force of 60 checkers and annually thereafter to the subsequently reduced staff. As a result, it takes ten years to reach the goal of forty position savings. When the checkers are given other duties they can be absorbed much more quickly and, in the high estimate of the data collection benefit, the forty positions are vacated by applying the ten percent attrition rate to the total transit property administrative work force. This reduces the checker force to the desired strength of 20 people within a year.

The low case data collection benefit yields present value savings of $3,795,600, which covers 59% of the present value costs of implementing a broad signpost AVM system. That is, the "item benefit-cost ratio" for this savings divided by the total broad signpost cost is 0.594. The high case data collection benefit yields present value savings of $7,331,600 with an item B/C of 1.148 for checkers alone.

The data collection savings are the most confident of the three types of bus savings.

5.2.2. Layover Benefits. The time a bus spends outside of the garage is called platform time. Total bus platform time is made up of deadhead (which is non-revenue travel time), revenue running time on routes, and layover. Layover is the time allowed in the schedule at the end of revenue runs. Part of this time is for driver rest breaks and the rest is a cushion to absorb late arrivals at the end of one run and still permit the next run to begin on time. This portion of layover, sometimes called slop, is a form of insurance against spiraling and self-perpetuating increases in late buses. However, excess layover is expensive insurance, paid for with an idle bus and driver.

Excess layover is a logical target for AVM. Exact vehicle location information for an entire route or set of routes enables a central dispatcher to implement operational strategies and control methods designed to minimize disruptions in service and to maximize schdedule adherence. If these controls are successful, the variation in running time can be reduced, thus cutting the need for slop. Reducing average layover for a property immediately increases the productivity of vehicles and drivers. If

overall productivity can be increased, the property can
continue to offer the same service and headways with fewer
vehicles.

The best available evaluation of AVM-type bus control
strategies comes from Dublin, where a manual radio control
system was used to provide near real-time position location
information for use in controlling fleet movements. The
Dublin data reports a reduction of .93 minutes (25%) in
average passenger wait time following route instrumentation
and control. Since the reduction in wait time was due to
better schedule adherence, we use this data as the key to
AVM's impact on layover in the base case. For the low
benefit, we credit AVM with reducing layover by the absolute
value of .93 minutes, and in the high case we credit AVM
with a 25% reduction.

The base case factors are considered fair though
conservative. The Dublin data represent the average
reduction in wait time along the entire route; deviations
from schedule may be aggravated and cumulative over distance
and should be much greater at and near the end of a route
than they are at or near the start of that route. Thus a
reduction of .93 minutes in mean wait time understates the
reduction at the end of the route, which is where the

aggregate of all delays must be absorbed with layover. The
test route in Dublin had a one way run time of 25 minutes.
The average route in the base case fleet has an average one
way run time of 68.2 minutes. This longer run time permits
greater fluctuations from schedule, so that if the base case
fleet equals Dublin's degree of control effectiveness, one
can argue that the results are likely to be greater. The
control techniques in Dublin were neither automated nor
continuous. One may expect that a well-designed and managed
AVM system should at least equal Dublin's radio control
system in effectiveness. Finally, no data have been found
to contradict the Dublin results.

Our base case fleet has an average layover of 13.67 minutes,
which is 16.7% of total platform time and 20% of average one
way run time. Applying the Dublin factors to the base case
reduces layover by .93 minutes to 12.74 minutes (19% of run
time) for the low benefit and by 25% to 10.25 minutes (15%
of run time) for the high benefit.

The model converts layover reductions into vehicle savings
only after shrinking the target vehicle population by
factoring out the maintenance float and those vehicles on
routes with headways of over ten minutes. (On long headway
routes, layover is dictated by the decision to provide less

frequent service and long layover on these routes is not a sign of slop). The final relationship between percentage reductions in layover (which are entered into the model) and percentage reductions in the total bus fleet (which are determined by the model) is on the order of twenty five to one (25:1). That is, a 25% reduction in layover yields approximately a 1% reduction in the total fleet.

AVM produces layover savings of seven buses in the low case and 22 buses in the high case. Only limited O&M savings accompany these reductions because the savings were achieved out of idle layover time, not running time. Twelve drivers or the equivalent in payroll hours may be released through attrition in the low case, while 38 may be released in the high case. The present value of the capital, O&M, and personnel savings is $1,714,000 in the low case, with an item B/C of 0.269; and $5,977,000 in the high case, with an item B/C of 0.936. These are confident estimates as long as AVM is applied and exploited effectively by operating managers.

5.2.3 Load Factor Improvements. Regular users of bus service adapt their behavior to the quality of that service. They learn the schedule and establish a level of confidence in the service. If the schedules are dependable, passengers

are more inclined to arrive at the bus stop shortly before the bus is due since they are confident that the bus will be on time. If the arrival times are less predictable, with buses frequently early or late, passengers tend to arrive earlier to reduce the risk of missing an early bus, thus extending their average waiting time.

The AVM Project Office at TSC has developed a managerial strategy, presented at Appendix D, which exploits this apparent behavioral tendency to vary passenger arrival time based on the variability of service. If AVM enables transit managers to improve schedule adherence or reliability, they can capture benefits by lengthening the headway between buses without changing the perceived passenger waiting times. The extended headway reduces the vehicle and driver assets invested in the route and increases the average load factor on the remaining buses. These increased loads can be spread more evenly as "bunching" of the buses can be eliminated with AVM. Potential changes in load factors, of course, will vary in relation to the quality of schedule adherence prior to implementation of any controls. A route with good headway adherence and little bunching will achieve minor load factor increases and vehicle savings, but a route with poor headway adherence and significant bunching may

garner important benefits if all vehicles are not already loaded to capacity.

Load factor improvements are separate and distinct from layover reductions. Load factors focus on operating efficiencies during the revenue run and attempt to reduce the number of revenue runs, while layover savings arise from reducing unnecessary idle time at the ends of revenue runs.

Average load factor improvements of one and ten percent have been adopted as the low and high base case benefits. Both factors represent relatively good initial schedule adherence and modest improvements in layover. Calculations were performed only after the base fleet had been reduced by the layover savings in order to avoid double counting. The target fleet population was further restricted to vehicles operating during peak hours only on headways of ten minutes or less.

Load factor improvements save ten vehicles for the low benefit input, and 91 vehicles for the high benefit input. Payroll dollars equivalent to seventeen drivers can be freed in the low case and 157 in the high case (out of an initial base case force of 4,900 drivers). The present value of the low benefit is $3,197,000, for an item B/C of 0.50; the

present value of the high benefit is $28,181,000, for an item B/C of 4.412. In the absence of supporting experimental data, the load factor benefits must be regarded as the most speculative of the bus benefits.

5.2.4 Composite Bus Results. Table V-1 is the bus benefit output from the computer model. It shows each source of savings individually, including all of the elements which were summarized in the preceding sections. All dollar costs and savings are expressed in present values discounted at ten percent. The lower part of Table V-1 shows the total savings, which are $8,707,400 in the low case and $41,,490,700 in the high case. These benefits are compared with the low cost individual AVM and with the bus's share of the low cost multiple user AVM. (Both are broad signpost location systems.) The single user, total benefit cost ratio is 1.363 in the low case and 6.496 in the high case. Participation in the base case multiple user system has a negligible impact on these results.

TABLE V-1

Cost Benefit Summary for: Bus
(Dollar Values in Thousands)

Savings Source:		Layover Reduction		Load Factor Improvement	
		Low	High	Low	High
% Change		6.8	25.0	1.0	10.0
Vehicles Saved		7.	22.	10.	91.
Capital	$	375.5	1294.4	558.6	5302.8
O&M		70.5	562.7	751.4	5996.4
Sub Total	$	446.0	1857.1	1309.1	11299.1
Item Benefit/Costs					
Single User		0.070	0.291	0.205	1.769
Multi-User		0.070	0.292	0.206	1.776
Drivers Saved		12.	38.	17.	157.
Salary	$	1034.8	3361.1	1539.2	13769.9
Overhead+Ben		233.9	759.7	347.9	3112.2
Sub Total	$	1268.7	4120.8	1887.1	16882.1
Item Benefit/Cost:					
Single User		0.199	0.645	0.295	2.643
Multi-User		0.199	0.648	0.297	2.654

		Data Collection	
		Low	High
Personnel Saved		40.	40.
Salary	$	1897.8	3665.8
Overhead+Ben		1897.8	3665.8
	$	3795.6	7331.6
Item Benefit/Cost:			
Single User		0.594	1.148
Multi-User		0.597	1.153
Total Savings	$	8707.4	41490.7
System Costs:			
Single User		6386.7	6386.7
Multi-User		6360.7	6360.7
Benefit/Cost Ratio			
Single User		1.363	6.496
Multi-User		1.369	6.523

Changing the location system has a major impact on the
results since the higher costs translate into direct
reductions of the B/C. Table V-5 at the rear of this
chapter summarizes the full range of B/C ratios for all
fleets and all location systems, but Figure V-4, shown on
the next page, is a graphic display of the impact of the
four single user bus location system costs on the low and
high B/C ratios. The horizontal lines connect the high and
low B/Cs for each location system. Higher lines represent
higher cost technologies and the dashed perimeters
surrounding these cost lines represent the effect on the B/C
ratio resulting from variations in system cost estimates
(see paragraph 3.2.3) of: ±6.5% for dead reckoning; ±20%
for sharp signpost; ±18% for radio frequency; and ±5% for
broad signposts. As can be seen, cost variations or
selection of higher cost location systems can significantly
erode potential payoffs in terms of the B/C ratio.
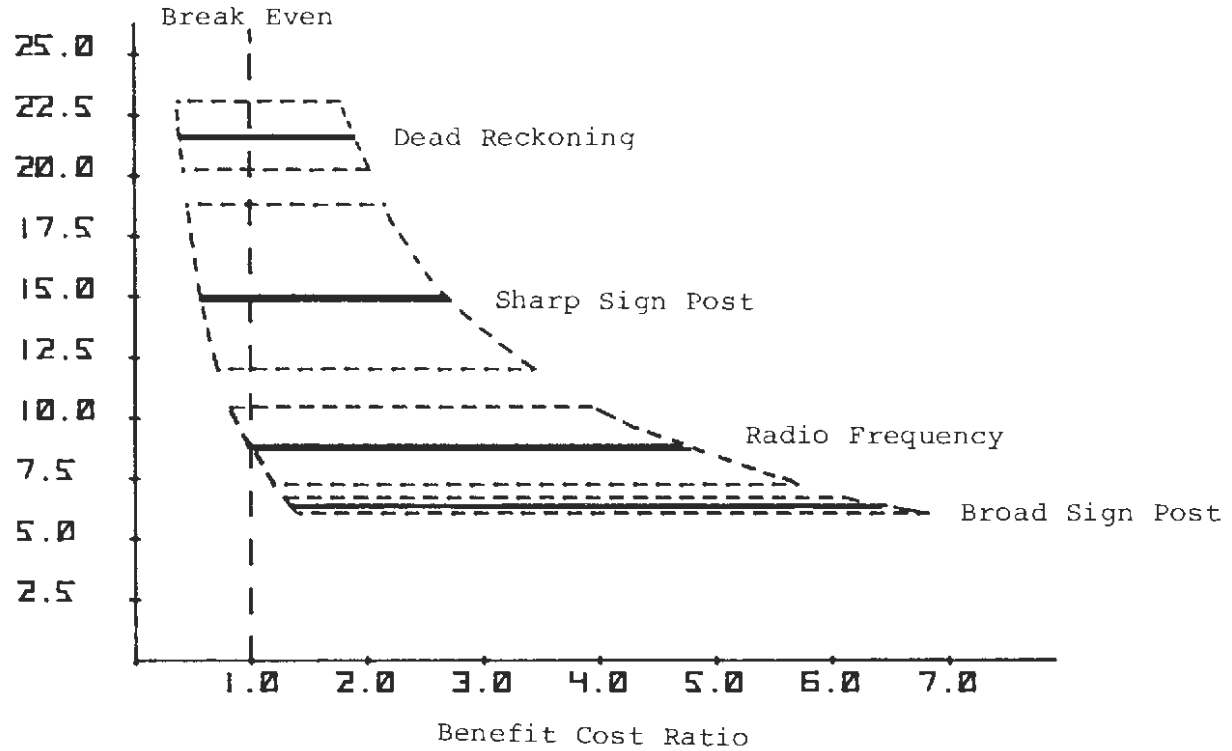
FIGURE V-4

TECHNOLOGY COSTS AND BENEFIT/COST
RATIOS FOR BUS

5.2.5 Bus Conclusions. The low case B/C is the natural
place to turn for a single indicator about the viability of
AVM as an investment. Before assuming the attainability of
a B/C of 1.363, one must consider the three sources of the
benefits:

Benefit Source	Item B/C	% of Total B/C
Data Collection	0.594	44%
Layover	0.269	20%
Loadfactor	0.500	37%
Total Bus Benefit	1.363	101%
		(rounded)

Data collection is the largest portion of the total B/C.
While the benefit has been calculated conservatively, its
source is strictly the reduction in manual checkers. This
makes the payoff heavily dependent on the number of checkers
employed by a particular property.

Layover reductions are a traditional benefit connected with
AVM fleet control, yet it produces only a small item B/C.
Its application in this analysis is a conservative extension
of the Dublin data, which is the only quantitative evidence
supporting such improvements.

Over a third of the total payoff comes from the load factor improvements, which are considered speculative, and will require an extensive measurement of actual performance improvements to be validated. If this item B/C is omitted, the total payoff drops to .863, which is marginal even considering the conservative nature of the two remaining elements.

5.3 AVM Benefits for the Police

5.3.1 AVM Impact on Police Operations. Police cruisers are assigned to beats and districts to conduct preventive patrols and respond to emergency and routine service calls. AVM is attractive to law enforcement officials because the ability to dispatch the closest patrol car to an emergency offers the opportunity to shave seconds and perhaps minutes from average response times, thus increasing the likelihood of apprehensions and improving protection of people and property. Police response time savings are of interest from a transportation perspective because they translate into mileage reductions and operating efficiencies.

The St. Louis experiment with a dead reckoning AVM achieved response travel time saving of 10%, and analysis indicates that this equates to a similar or slightly smaller reduction in mileage travelled (Larson, Roos). Based on this,

percentage reductions in police response miles of 2% and 10% were adopted as the base case low and high benefits.

Mileage devoted to preventive patrol is not eligible for saving. Fifty percent of base case mileage is eliminated on this basis and AVM savings are applied only to the remainder. The total miles which can be saved are equivalent to 11 cruisers in the low case and 53 in the high case (from a fleet of 1330). Full O&M and personnel savings are associated with each cruiser. O&M includes costs of mileage and ownership. Personnel includes the average $21,800 salary and equivalent benefits for each of the 3.3 patrolmen who staff a cruiser. Personnel savings total 35 in the low case and 176 in the high case. Both targets are assumed to be achieved by attrition at a rate of 10% applied to the initial patrol force of 4,389.

The TSC estimate of vehicle savings was tested against the parameters of the Jet Propulsion Laboratory's (JPL) police AVM model, which derives efficiency improvements from location system accuracy relative to fleet and area dimensions. TSC vehicle savings were well within the targets that the JPL model established for UMTA specified AVM location system accuracies equivalent to those in the

UMTA specification and applied within the base case dimensions.

5.3.2 Police Results. Table V-2 displays the detailed benefit and payoff data for the police. The low benefits produce present value savings of $10,006,500, 96% of which flow from personnel savings. The remaining 4% are a combination of vehicle capital and O&M savings. These savings produce a single user B/C of 2.386 for the low cost radio frequency location system. This is the largest value for a low benefit B/C for any single user of AVM in the study. Present value savings and B/C in the high case are nearly five times greater than the low case, reflecting the difference in AVM impacts. Improvements in B/C due to multiple user cost sharing are on the order of 1%.

The large personnel costs associated with each police cruiser provide leverage which increases the dollar benefits of AVM impacts. These substantial benefits enable the police to absorb a greater range of increased system costs before dropping below the breakeven point. Figure V-5 shows that for low benefits only the two highest cost location systems dip below breakeven conditions.

TABLE V-2

Cost-Benefit Summary for: Police
(Dollar Values in Thousands)

Savings Source:		Response Time Reduction	
		Low	High
% Change		2.0	10.0
Vehicles Saved		11.	53.0
Capital	$	109.6	580.9
O&M		323.0	1615.2
Subtotal	$	432.6	2196.0
Item Benefit/Cost:			
Single User		0.103	0.524
Multi-User		0.104	0.529
Patrolmen Saved		35.	176.
Salary	$	4786.9	23332.8
Overhead+Ben		4786.9	23332.8
Sub Total	$	9573.9	46665.7
Item Benefit/Cost:			
Single User		2.283	11.129
Multi-User		2.305	11.235
Total Savings	$	10006.5	48861.7
System Costs:			
Single User		4193.1	4193.1
Multi-User		4153.7	4153.7
Benefit/Cost Ratio:			
Single User		2.386	11.653
Multi-User		2.409	11.763

Break Even

Present
Value
of
Life Cycle
System Costs
1975 $ 10^6

(Discounted @ 10%)

15.0
13.5
12.0 ────────────── Sharp Sign Post
10.5 ────────────── Dead Reckoning
9.0
7.5
6.0
4.5
3.0
1.5

⎫
⎬(Cost variations overlap)
⎭

──── Broad Sign Post
──── Radio Frequency

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Benefit Cost Ratio

FIGURE V-5

TECHNOLOGY COSTS AND BENEFIT/COST
RATIOS FOR POLICE

The results of this study, Doering's work in Orlando, the expansion of the FLAIR AVM in St. Louis, and the JPL analysis all reinforce the conclusion that AVM offers significant benefits to police and public safety managers.

5.4 AVM Benefits for the Taxi

5.4.1 Impact of AVM on Taxi Operators. Radio controlled taxi operations are analagous to police operations in that dispersed vehicles are assigned to random service calls. Knowledge of vehicle location permits assigning the closest car to each ride request with the goal, in this case, being a reduction of non-revenue miles.

The base case fleet accumulates 50% of total miles in non-revenue operations. Part of this non-revenue movement (deadhead) is unavoidable because passenger destination and subsequent pick up points do not coincide. Simulation conducted at TSC indicates that this unavoidable deadhead amounts to 18% of total miles, leaving 32% of total miles as avoidable deadhead. Avoidable deadhead is cruising in search of fares and returning from passenger drops to central pick up or dispatch points. AVM can help reduce this portion of deadhead.

Analysis and extrapolation of St. Louis police data and consultation with taxi operators resulted in base case low and high benefits for reductions in avoidable deadhead mileage being set at 10% and 20%. This translates into vehicle savings of 33 in the low case and 66 in the high case (out of a fleet of 800). Capital and total O&M savings are associated with these savings as are 69 drivers in the low case and 138 drivers in the high case. Since these jobs are paid on a commission basis, the sole value to the operator is the reduction of fringe benefits worth $1,350 annually per driver.

5.4.2. Taxi Results. Table V-3 displays the model benefit output for the base case taxi fleet. Reduction of deadhead miles yields total present value savings of $2,059,000 in the low case and $4,110,100 in the high case. The respective B/C's are 0.743 and 1.482 for the taxi alone scenario. Participation in a multiple user system improves the taxi B/C's by nine percent, but the taxi remains well below the breakeven B/C point for low benefits. Figure V-6 shows that taxi B/C's exceeded 1.0 only for the high benefits when combined with the two lowest cost systems.

The taxi benefits are in marked contrast with the police. Taxis achieve a larger fleet reduction of 4% in the low case

TABLE V-3

Cost-Benefit Summary for: Taxi
(Dollar Values in Thousands)

Source of Savings:	"High-Flagging" Reduction	
	Low	High
% Change	0.0	0.0
	Reduce Dead-Head Miles	
% Change	4.1	8.2
Vehicles Saved	33.	66.
Capital	$ 239.1	485.7
O&M	1238.5	2476.9
Sub Total	$1477.6	2962.7
Item Benefit/Cost:		
Single User	0.533	1.068
Multi-User	0.585	1.174
Drivers Saved	69.	138.
Salary	$ 0.0	0.0
Overhead+Ben	581.5	1147.5
Sub Total	581.5	1147.5
Item Benefit/Cost:		
Single User	0.210	0.414
Multi-User	0.230	0.455
Total Savings	$ 2059.1	4110.1
System Costs:		
Single User	2773.1	2773.1
Multi-User	2523.7	2523.7
Benefit/Cost Ratio:		
Single User	0.743	1.482
Multi-User	0.816	1.629

FIGURE V-6

TECHNOLOGY COSTS AND BENEFIT/COST
RATIOS FOR TAXI

while the police fleet reduction was only 0.8%. Despite
this, the taxi low case single user B/C is 0.743 while the
comparable police B/C is 2.386. The great difference is
explained by personnel costs. This category, which
accounted for 96% of police savings, comprises only 28% of
the taxi savings. A saved taxicab has a small total of
avoided employee benefits compared to a saved patrol car
which has over three salary and overhead units associated
with it.

Taxi fleets achieve the greatest benefits from AVM in terms
of fleet reduction and vehicle productivity. Ironically,
taxi operators may not be able to afford these improvements
at current AVM cost estimates because the salary structure
of the industry precludes capture of labor savings.

5.5 Total Multiple User AVM Benefits

AVM benefits for the multiple user fleet are a summation of
individual fleet savings; there are no operational impacts
and benefits of AVM attributed to the shared system. Table
V-4 presents the total results of all fleets for comparison
purposes. Figure V-7 does the same for the multiple user
payoff envelope.

TABLE V-4

Cost-Benefit Summary for: Multi-User
(Dollar Values in Thousands)

Savings Source:	Low	High
Bus	$ 8707.4	41490.7
Police	10006.5	418861.7
Taxi	2059.1	4110.1
Capital Savings	$ 1285.8	7663.7
O&M Savings	2383.4	10651.2
Personnel Savings	17106.8	76147.7
Loss Adjustments	0.0	0.0
Total Savings	$20773.0	94462.6
System Costs:		
Multi-User (broad sign post)	$13038.2	13038.2
Benefit/Cost Ratio:		
Multi-User	1.593	7.245

Break Even

40.0

35.0

Present
Value
of
Life Cycle
System Costs
1975 $ x 10^6

(Discounted @ 10%)

30.0

25.0

20.0

15.0

10.0

5.0

Dead Reckoning

} (cost variations overlap)

Sharp Sign Post

Radio Frequency

Broad Sign Post

(cost variations overlap)

1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
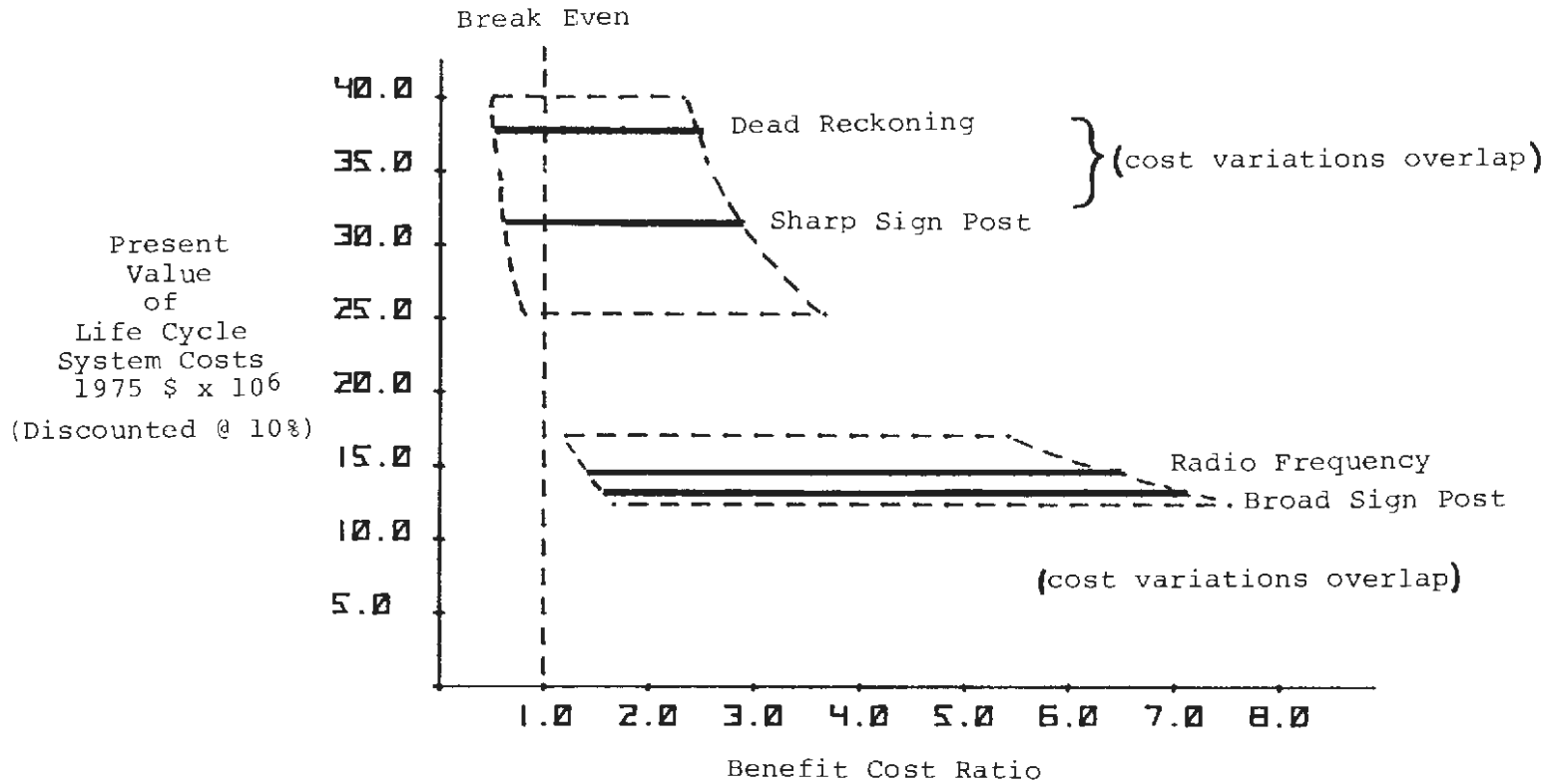
Benefit Cost Ratio

FIGURE V-7

TECHNOLOGY COSTS AND BENEFIT/COST
RATIOS FOR MULTIPLE USER FLEET

As a final summary, Table V-5 summarizes B/C's for all fleets and location systems.

TABLE V-5

AVM INVESTMENTS PAYOFFS
(Benefit/Cost Ratios)

Benefit Estimate:	Broad Signpost		Radio Frequency		Sharp Signpost		Dead Reckoning	
	Low	High	Low	High	Low	High	Low	High
Bus Alone	1.36	6.50	0.98	4.69	0.58	2.76	0.40	1.92
Bus Shared	1.37	6.52	*	*	*	*	*	*
Police Alone	1.89	9.21	2.39	11.65	0.80	3.89	0.95	4.63
Police Shared	2.41	11.76	*	*	*	*	*	*
Taxi Alone	0.49	0.98	0.74	1.48	0.22	0.43	0.31	0.61
Taxi Shared	0.82	1.63	*	*	*	*	*	*
TOTAL MULTIPLE	1.59	7.25	1.44	6.54	0.65	2.99	0.55	2.51

*Not available.

VI   SENSITIVITY ANALYSIS

6.1   Introduction

An analysis was conducted to examine the impact of
variations in the key assumptions used in the calculation of
AVM related benefits. In some cases, the range of variation
was expanded to extremes to illuminate any possible
discontinuities and limitations of the model or of AVM
applications.

The sensitivity results should be used to develop only the
broadest generalities regarding AVM utility. Though the
model utilized to obtain the information is extremely
flexible the precise makeup of user fleets and their
distribution will, in the real world, vary in a
discontinuous fashion. Thus, large excursions from the base
case should be described individually using actual
configurations and information about the site in question.
For purposes of the urban size analysis, the assumptions
used are considered as gross approximations of the changing
service characteristics that exist in different urban
environments.

6.2. Approach

The model used to generate the results of this study was developed to be an extremely flexible tool, readily adaptable to support sensitivity analysis of this type. However, once a number of data points for each case had been computed a regression analysis was then used to develop the complete data set. While most of the relationships appear to be linear, a least squares parabolic solution gives the most consistent fit.

Analyses were conducted for the low range of individual user costs and benefits by varying fleet sizes, areas, and percentage improvements. In addition to individual cases, estimates of the trends of benefits and costs in different urban size locations were also made. These estimates reflect an assumed exponential relationship between reduced fleet sizes and operational descriptors such as run times.

6.3 Single User Sensitivities

6.3.1 Bus. All of the following figures are presented as variations around the base fleet of 2400 vehicles operating on 3825 route miles. Cost estimates are for a broad signpost system utilized only by the bus fleet. Only the low estimates of benefits are analyzed.

6.3.1.1 Sensitivity to Fleet Size. Variation in expected
total costs and total benefits (low range only) are shown in
Figure VI-1.

Note that the benefits shown, yield a value even when there
are only a few vehicles in the fleet. This situation
reflects the present value of benefits of decreasing the
fixed "field checker" work force by some 40 people.
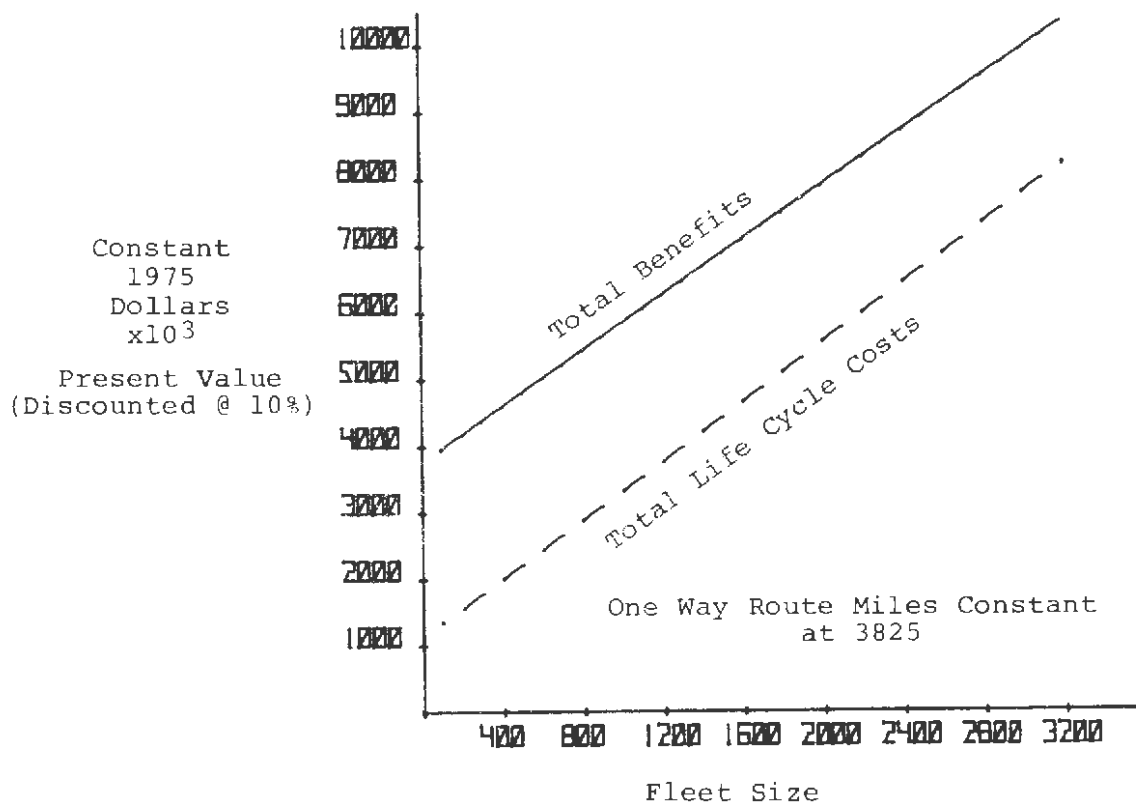
FIGURE VI-1

TOTAL COSTS AND BENEFITS FOR BUS
ONLY OPERATIONS

As the fleet size increases so do the costs and benefits though the benefits grow at a slower rate than costs. Thus the benefit cost ratio reaches a limiting point at about 2000 vehicles. This is shown in Figure VI-2A. Figure VI-2B illustrates the constancy of benefits attributable to each bus and the decaying nature of the costs per bus, reaching a lowest figure of about $2600.

The benefits shown, however, are not considered realistic at fleet levels much below 1200 vehicles, as the route miles and area were held constant in this analysis of fleet size variations. The implicit effect of shrinking the total fleet without changing area, or route miles, would be to produce a bus system that has one way run times of over two hours which would more nearly represent a commuter operation than that of a typical fixed route transit system. Additionally, the benefits derived for the base case from the attrition of field checkers is not directly dependent upon either fleet size or the installation of AVM but rather on automatic passenger counters which coincidentally, but perhaps unnecessarily, transmit their information in real-time by means of AVM. The effect of varying the number of checkers for different attrition bases is shown in Figure VI-3.

TOTAL BENEFIT-COST RATIO
FOR VARYING FLEET SIZES

FIGURE VI-2a

Benefit
Cost
Ratio

Bus Fleet Size

TOTAL BENEFITS & COSTS
PER BUS FOR VARYING FLEET SIZES

FIGURE VI-2b

Present
Value
1975 $ x 10^3
(Discount = 10%)

Total Benefits Per Bus

Total Costs Per Bus

Bus Fleet Size
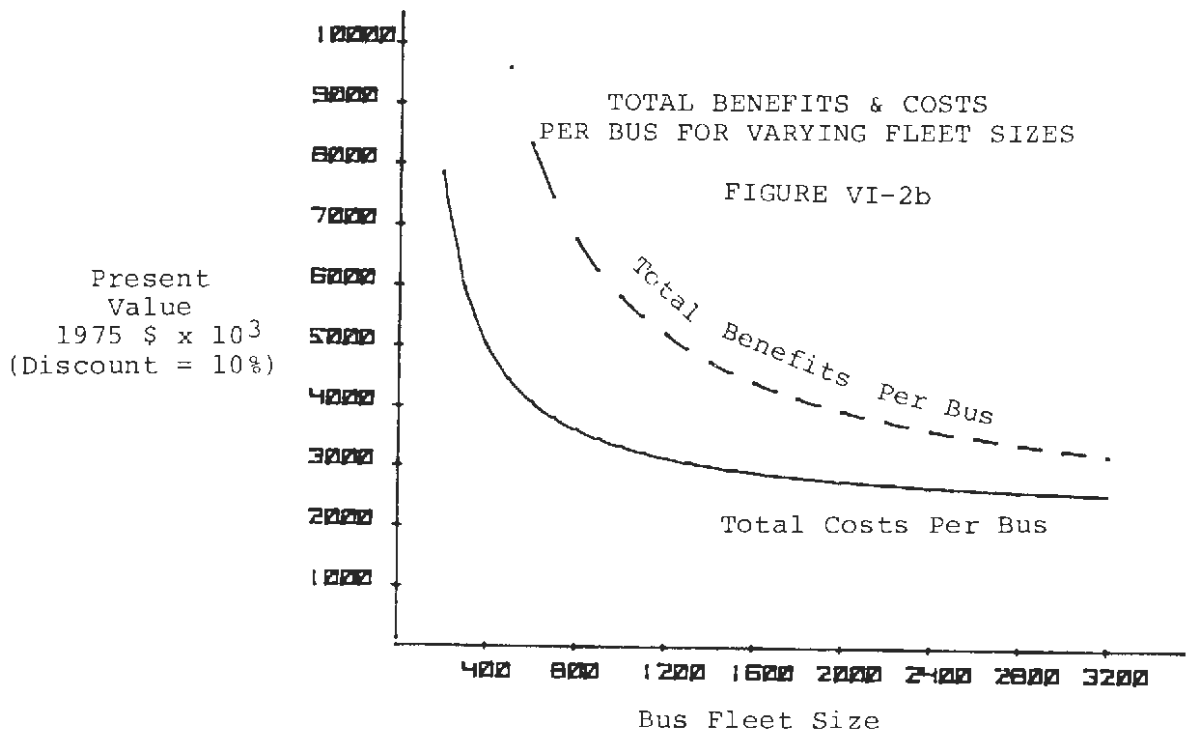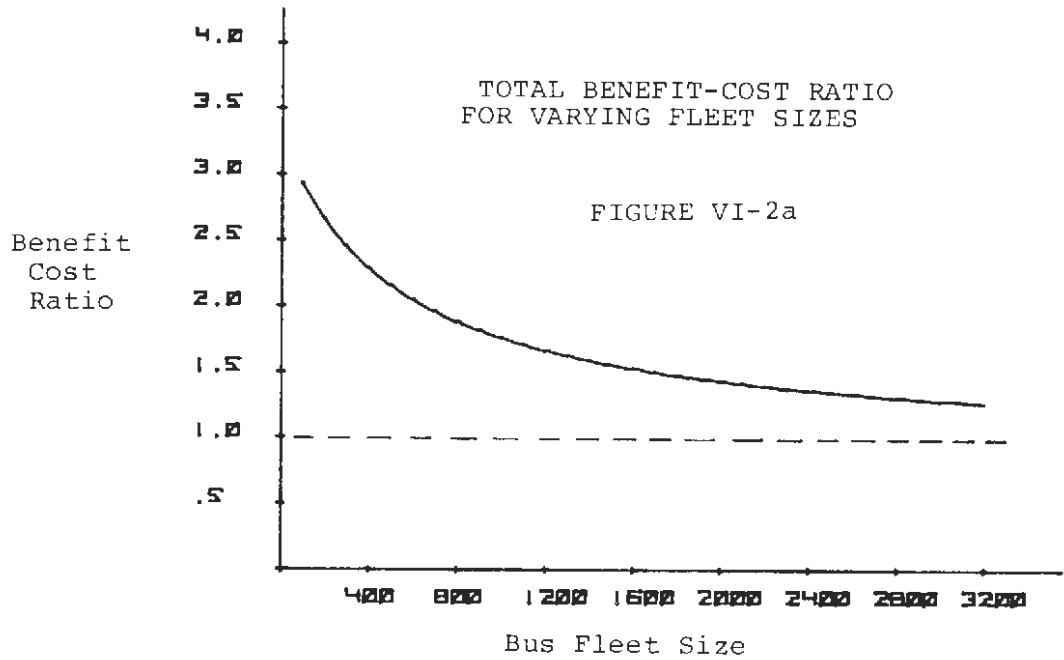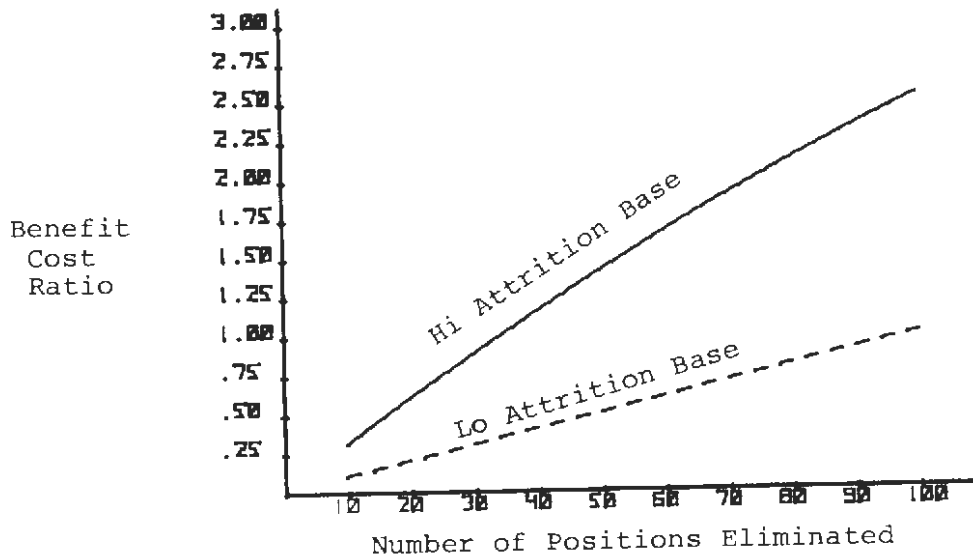
EFFECT ON BENEFIT COST RATIO OF
REPLACING CHECKERS WITH AUTOMATIC
PASSENGER COUNTERS

FIGURE VI-3

Some properties employ as few as 1 checker for every 300
buses as opposed to 1 for every 40 buses as used in the base
case. Thus, it is important to isolate these savings from
"operational benefits" that derive from more consistently
applicable control strategies that are directly dependent
upon postion location information.

These operational benefits result from vehicle and driver
payroll savings made possible through reductions in layover
time and increases in load factors. The information on
costs and operational benefits, both totally and on a per
bus basis, are shown in Figures VI-4A and VI-4B.

6-6

TOTAL SYSTEM COSTS & OPERATIONAL
BENEFITS FOR VARYING BUS FLEET SIZES

FIGURE VI-4a

Present
Value
in 1975 $ x 10^3
(Discount = 10%)

Fleet Size

TOTAL SYSTEM COSTS & OPERATIONAL
BENEFITS ON A PER BUS BASIS
FOR VARYING FLEET SIZES

FIGURE VI-4b

Present
Value in
1975 $ x10^3

(Discounted @ 10%)

Costs Per Bus

Operational Benefits Per Bus

Fleet Size

6-7
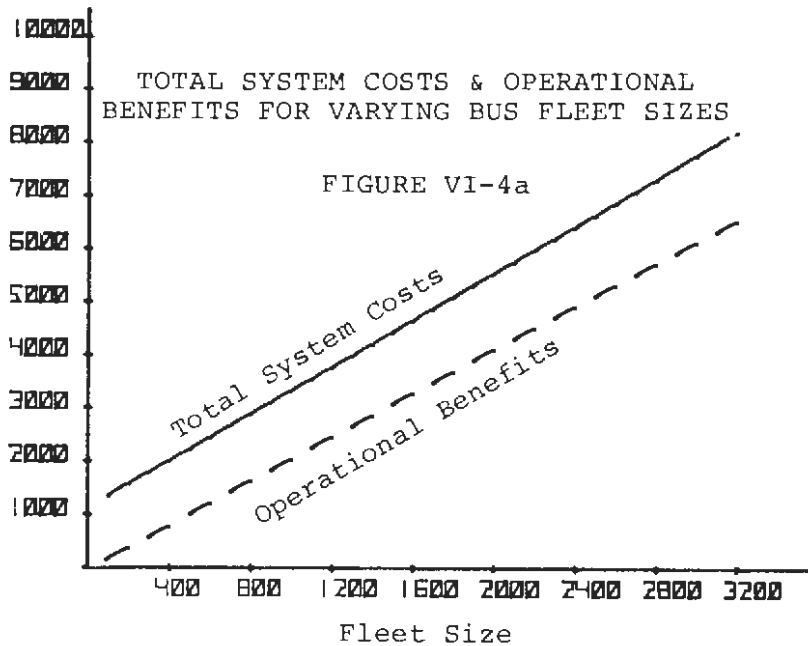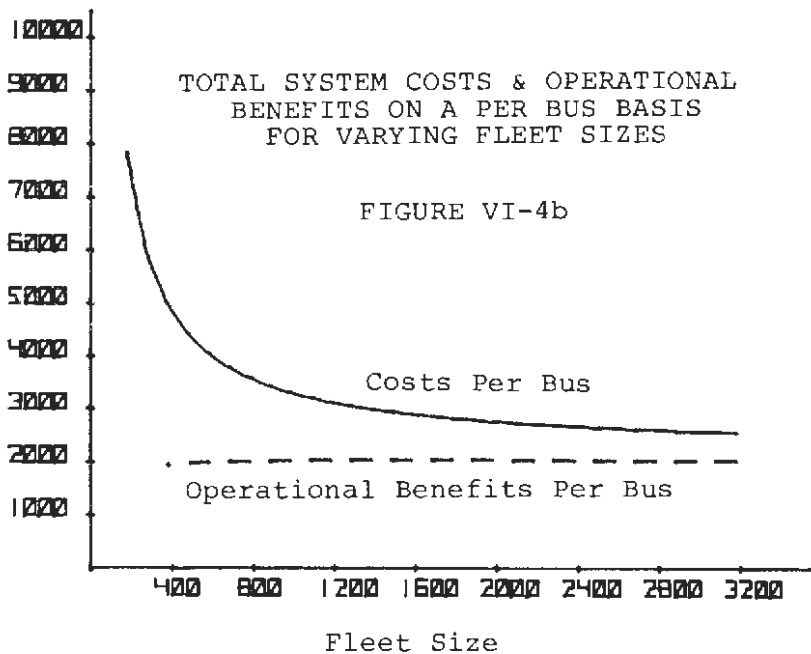
The extent of improvements in these two factors is
conservatively assumed to be limited to only those buses out
of the total fleet that are operating during peak hours on
routes with headways of 10 minutes or less. Figure VI-5
illustrates the resulting operational B/C ratio.
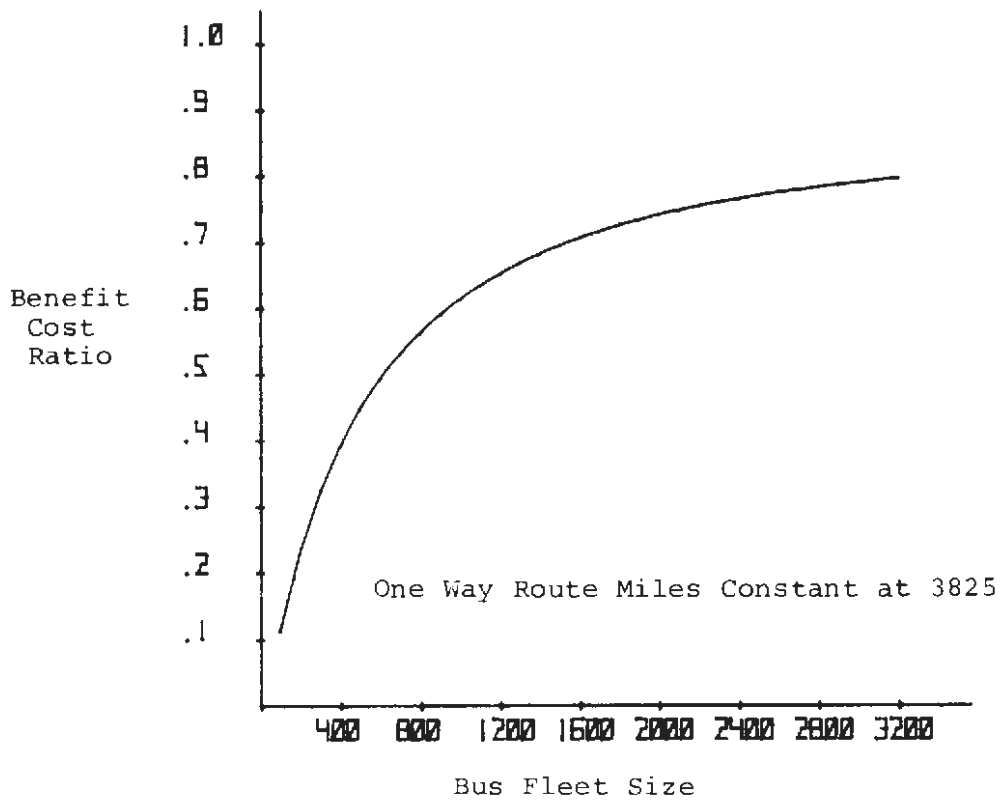
EFFECT ON BENEFIT COST
RATIO DUE TO OPERATIONAL
SAVINGS AS A FUNCTION OF FLEET SIZE

FIGURE VI-5

6.3.1.2 Sensitivities to Layover Reductions. Because
different bus sytems exhibit different layover times when
compared against average one way run times, various layover
times were analyzed as a function of the degree of
improvement or reduction thought possible with AVM. Figure
VI-6 illustrates the resultant effect upon the base case
benefit cost ratio.
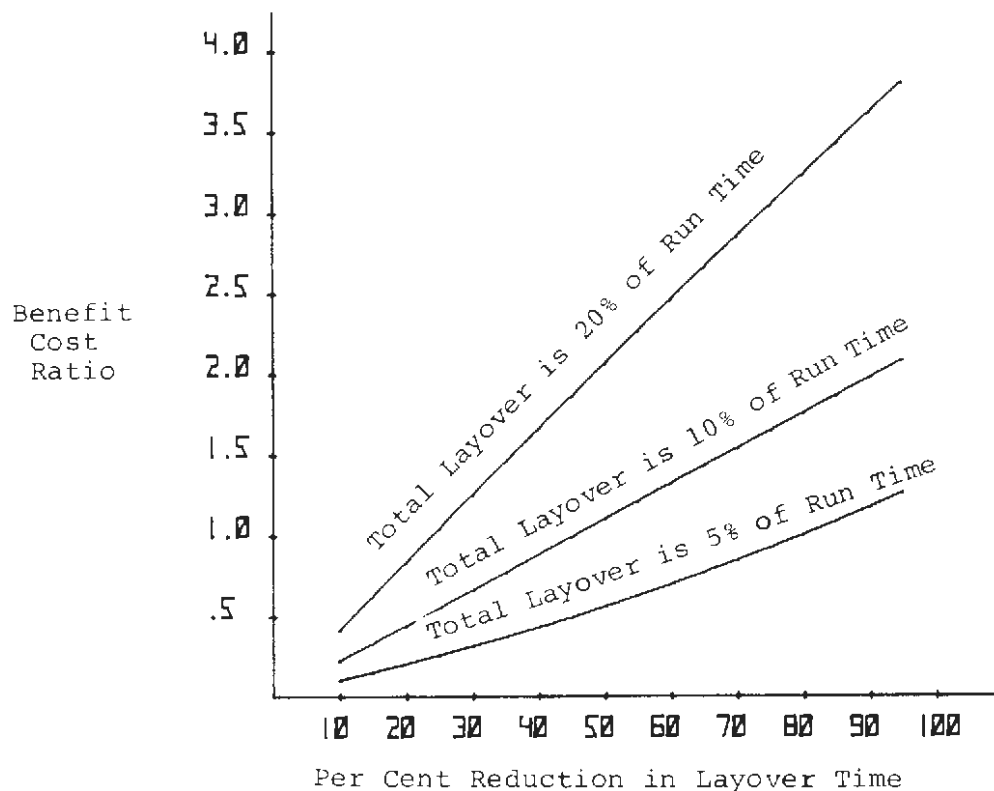
EFFECT ON BENEFIT/COST RATIO
OF DECREASING LAYOVER TIME

FIGURE VI-6

As shown in a case where only layover reductions are made, a 10 percent reduction in layover time, for the base case system operating with layovers equal to 20% of run time, will result in a contribution to the overall benefit cost ratio of approximately 0.4-0.5. This saving is derived not only from the avoided capital and O&M costs associated with the seven buses saved, but reductions in payroll are also present which accounts for over 70% of the total layover savings. Recall that this information is based upon a base case operation where 50% of the buses operate, during rush hour peaks, on headways of 10 minutes or less. As expected, as this percentage increases so do the corresponding savings from layover reductions which now affect a larger percentage of the fleet. The effect is essentially one to one, that is, as the percent of buses on short headways nears 100%, only half of the improvement thought possible for 50% on short headways is needed to return the same benefit. This situation is shown in Figure VI-7.

6.3.1.3 Sensitivity to Load Factor Increases. Savings similar to those from layover reductions occur when load factors are increased by using longer headways and tightly controlling schedule adherence. By closely maintaining published schedules, average passenger wait time remains constant and the same volume of service is possible with the

Benefit
Cost
Ratio

Payroll Savings

Vehicle Cost Savings

(Layover = 20% of Run Time)

Per Cent of Peak Fleet on Headways
of $\leq$ 10 Minutes
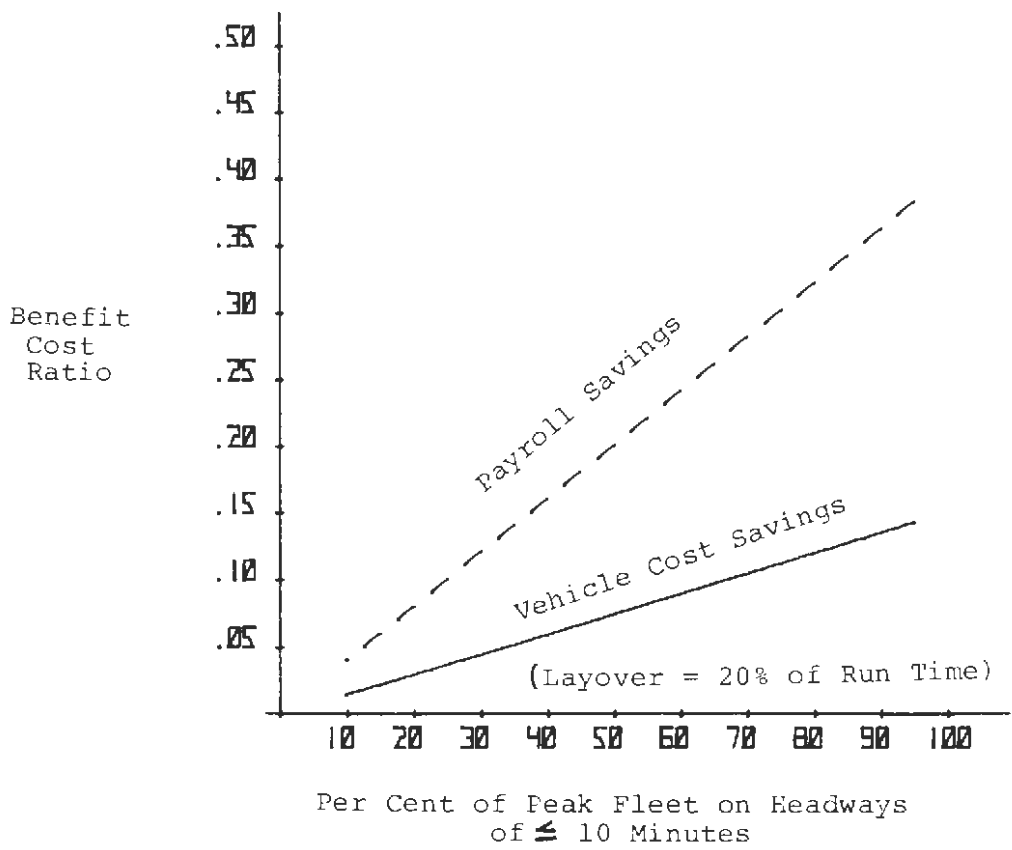
EFFECT ON BENEFIT COST RATIO DUE
TO LAYOVER REDUCTIONS

FIGURE VI-7

deployment of fewer vehicles which operate at higher but
more evenly distributed factors. A percentage improvement
in this factor has a more pronounced affect than a
corresponding reduction in layover time, as can be seen in
Figure VI-8.

Benefit
Cost
Ratio

(50% of Fleet on Short Headways)

Per Cent Increase in Load Factor
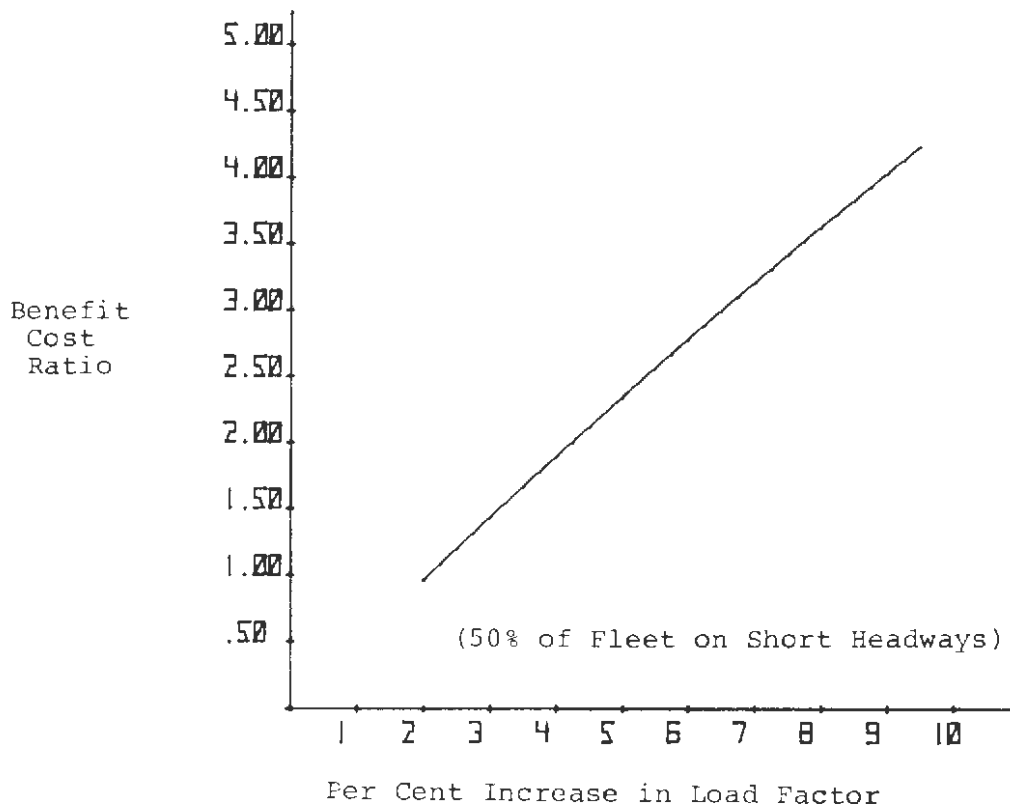
EFFECT ON BENEFIT COST RATIO
OF VARYING LOAD FACTOR

FIGURE VI-8

Again, as in the case with layover savings, the more buses operating during peak hour the greater the savings that can be expected for a given percentage improvement in load factor. This situation is shown in Figure VI-9, where the contribution to the overall benefit cost ratio is shown for vehicles and payroll savings arising from a 1% load factor increase.
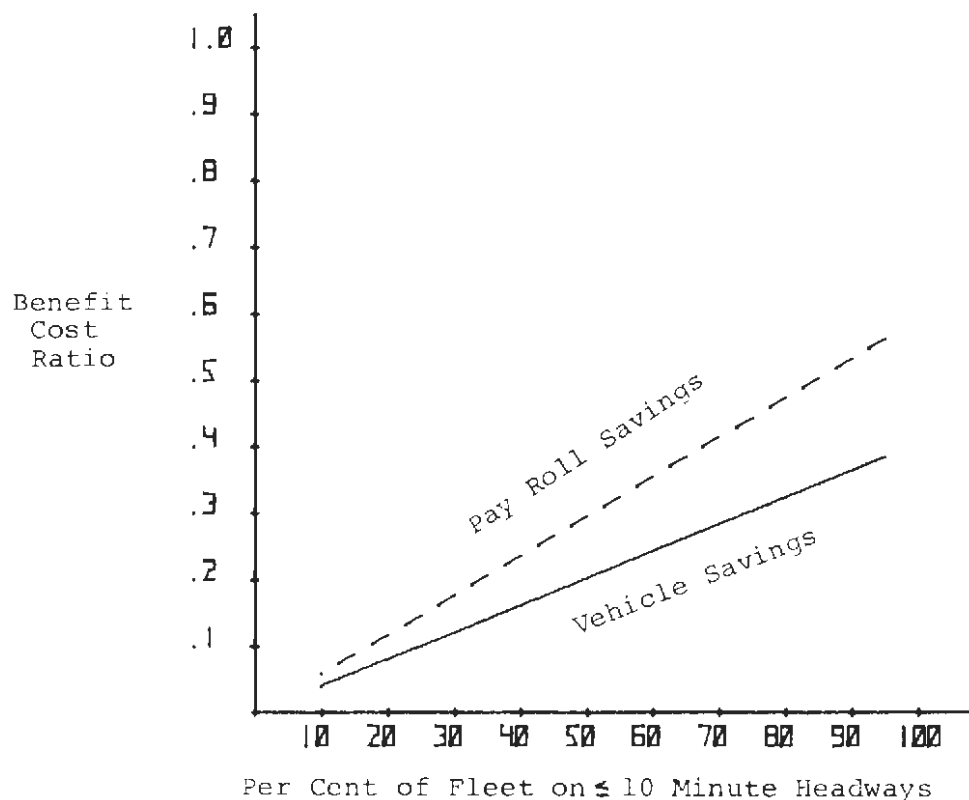
EFFECT ON BENEFIT COST RATIO DUE TO
A 1% LOAD FACTOR INCREASE IN BUS
LOAD FACTOR

FIGURE VI-9

6.3.1.4 Sensitivity to Route Miles. Strictly speaking, a reduction in the number of route miles in a transit system, if nothing else changes, will not return any real benefits per se, but would act only to reduce the AVM system deployment costs. However, if only route miles are reduced, yet the same number of buses generate the same annual mileage, implicitly then, the average number of buses per route must increase. The net effect would be to produce an increase in the percentage of buses operating on short headways.

6.4.2 Police. The following figures are based on variations around the base fleet of 1330 police vehicles operating over 475 square miles. Cost estimates are for a radio frequency system utilized only by the police force. Only the low estimates of benefits are analyzed.

6.4.2.1 Sensivity to Fleet Size. Because of the high cost of operating a police patrol car, attributable in large part to the salaries of the round-the-clock work force manning each car, single vehicle savings yield relatively higher benefits than in a corresponding case of a single bus saved. Thus, as shown in Figures VI-10A and VI-10B the total benefits are returned more quickly than total costs accrue. Costs and benefits on a per car basis show a rapid decrease

TOTAL BENEFITS & COSTS
FOR VARYING SIZES OF
POLICE FLEETS

FIGURE VI-10a

Present
Value
in
1975 Dollars x 10^3
(Discounted @ 10%)

Total Benefits

Total Costs

Police Fleet Size

BENEFITS & COSTS PER CAR FOR VARYING
SIZES OF POLICE FLEETS

FIGURE VI-10b

Benefits Per Car

Present
Value
in
1975 Dollars
(Discounted @ 10%)
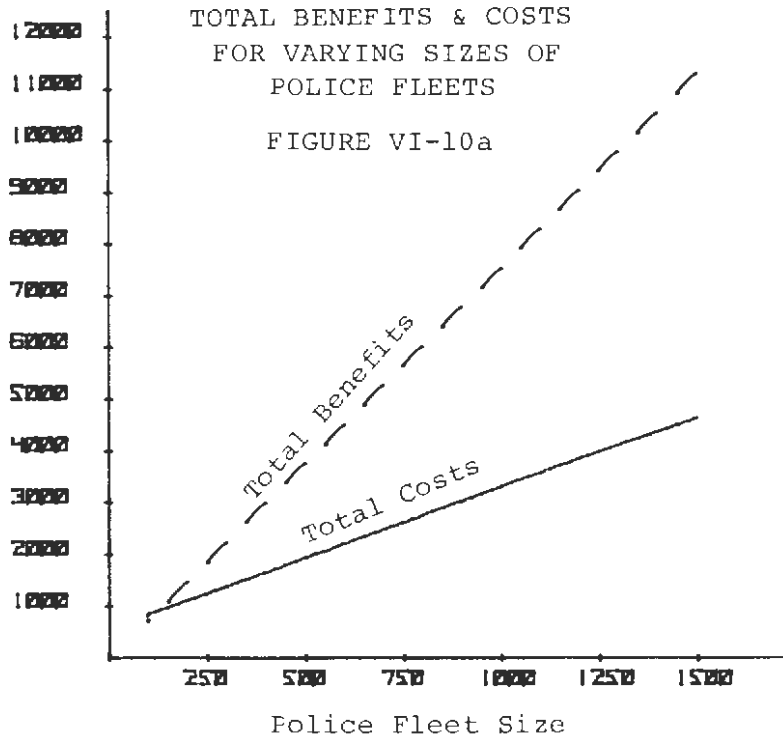
Costs Per Car
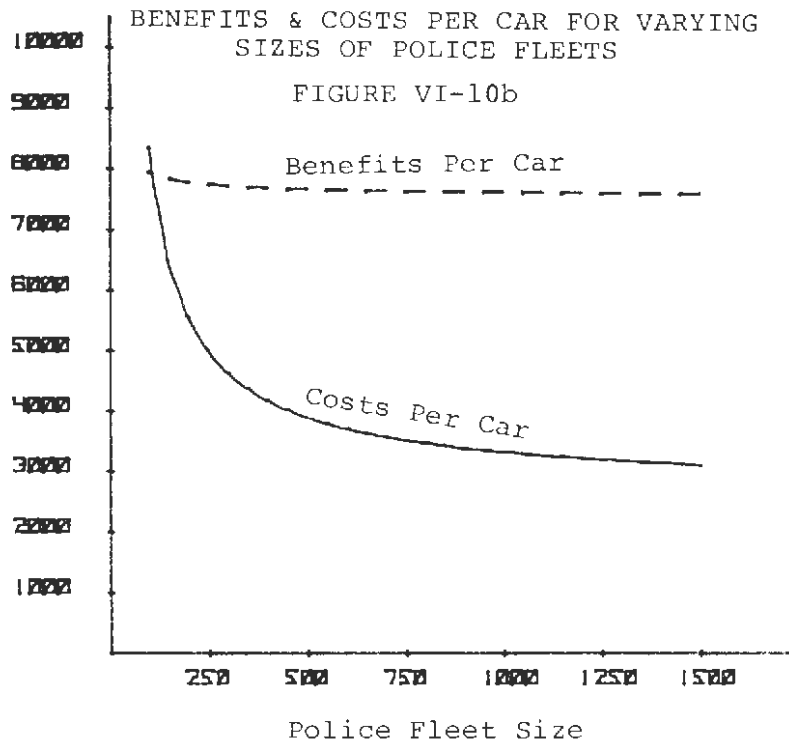
Police Fleet Size

in expenditures per car against a constant benefit per car.
The effect on the resultant benefit cost ratio is shown in
Figure VI-11.
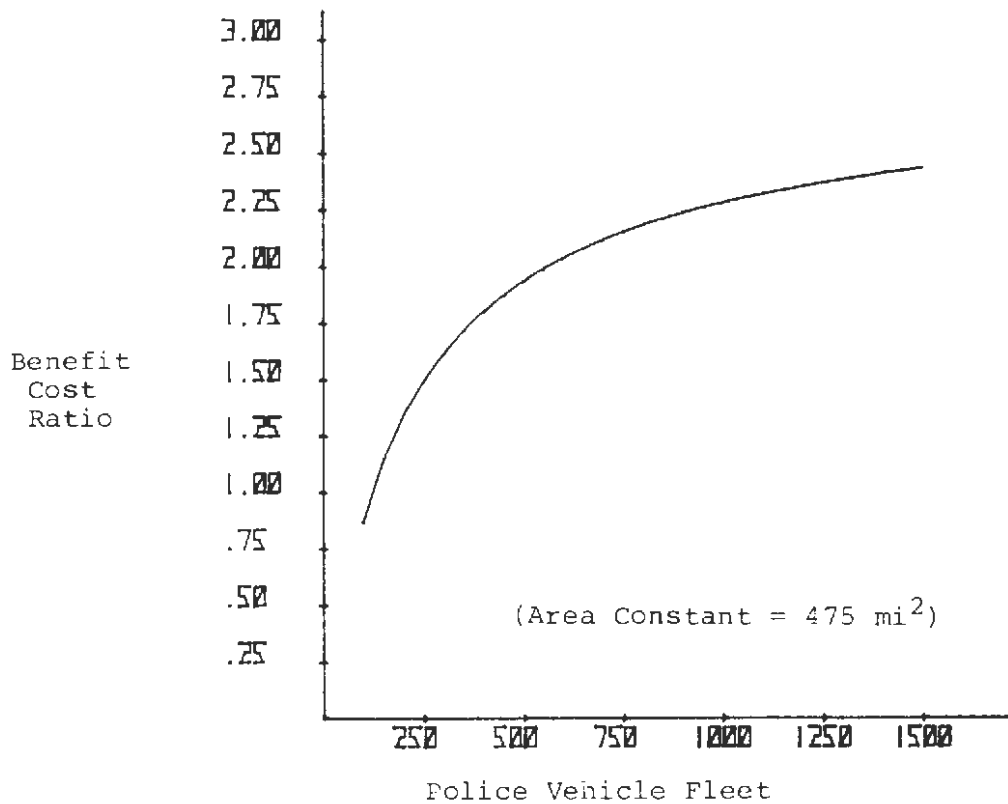
EFFECT ON BENEFIT COST RATIO FOR
VARYING SIZES OF POLICE FLEET

FIGURE VI-11

Recall however, that these effects are derived for a
constant area with a constant percentage reduction in time
and miles due to AVM.

Within practical limits, this assumption yields realistic
results that would be expected with an increasing density of
cars within a given area.

6.4.2.2 Sensitivity to Area. Figure VI-12 illustrates the
effect of decreasing the fleet density by increasing the
area over which a fixed fleet is dispersed.
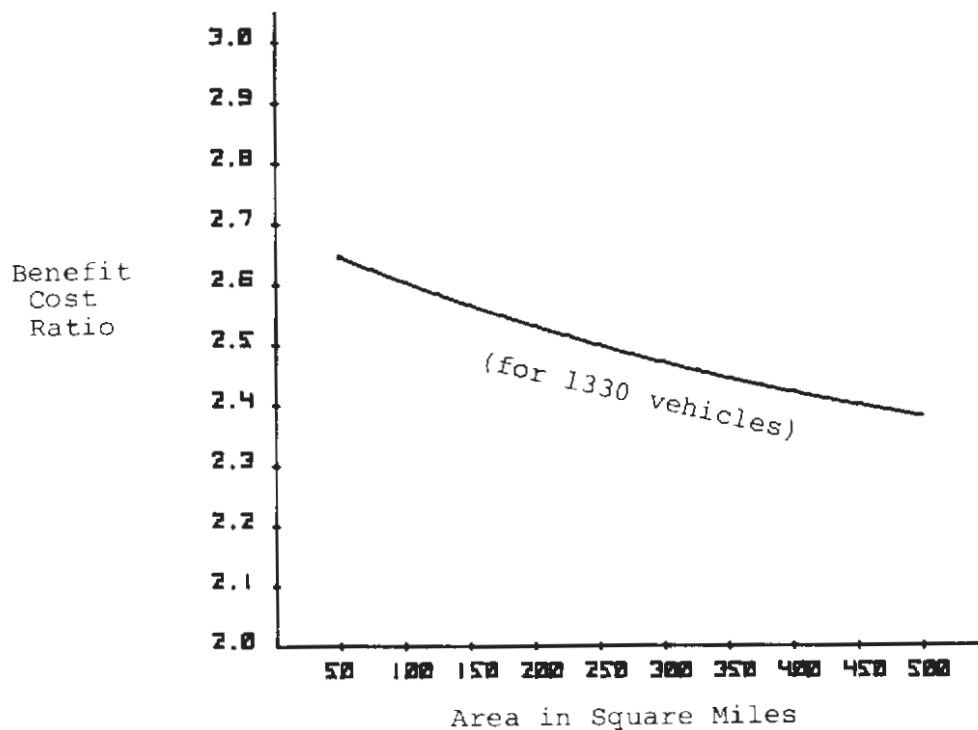
BENEFIT/COST RATIO FOR POLICE
AS A FUNCTION OF COVERAGE AREA

FIGURE VI-12

As can be seen the benefit cost ratio decreased as wayside
equipment deployment costs increase. These results can lead
to erroneous conclusions, since there are practical limits
to the number of patrol cars per square mile, and no
adjustment was incorporated to reflect the possibility of
greater savings available in a low density operation. If
this fact was taken into account, shrinkage of area around
the base case would show decreasing benefits.

6.4.2.3 Sensitivity to Percent of Annual Miles Spent on
Preventive Patrol. As the patrol area shrinks, it is
realistic to believe that the fleet size would also decrease
unless, of course, the number of vehicles involved in
strictly preventive patrol went up. As this happens, the
benefits that could be expected, in terms of miles saved
would also be expected to decrease as shown in Figure VI-13.

Again, care must be taken in drawing conclusions from this
information. In an extreme case where none of the annual
mileage was spent on preventive patrol, the assumptions made
in the model do not account for the fact that the position
of each vehicle would then be known continuously by the
dispatcher. AVM would furnish no additional position
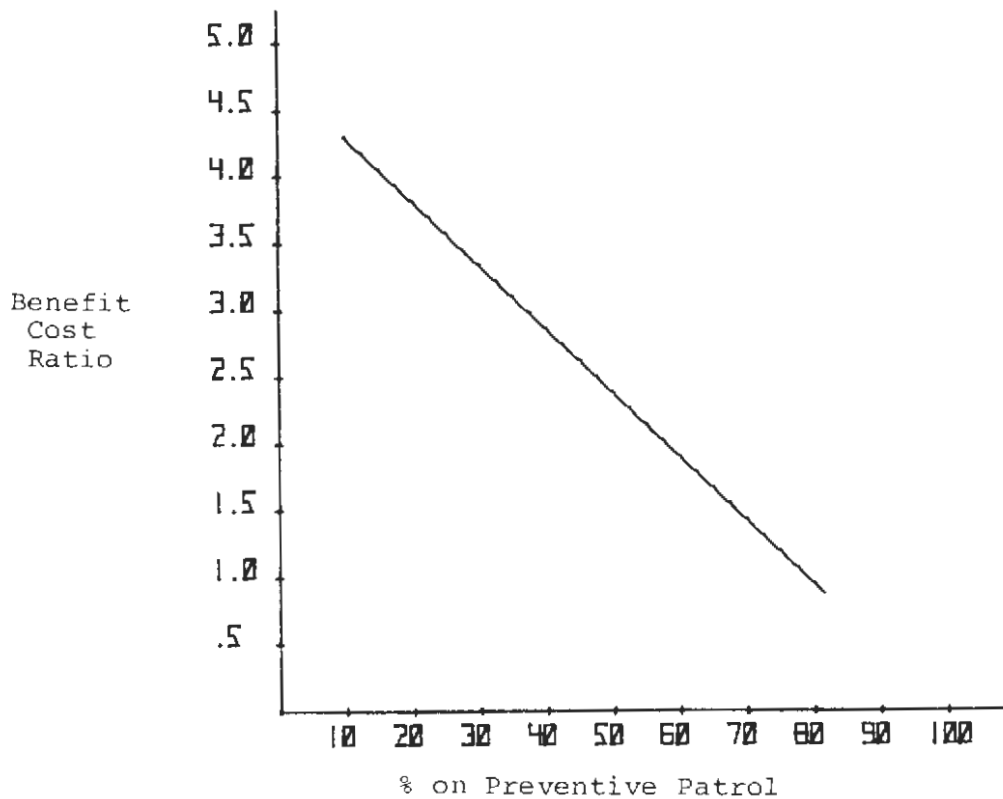
EFFECT ON BENEFIT COST RATIO FOR POLICE
AS A FUNCTION OF PERCENTAGE OF TIME
SPENT ON PREVENTIVE PATROL

FIGURE VI-13

information, and the benefit in this case would be expected
to disappear. Significant curtailment of available benefits
occurs as this saturation point is approached.

6.4.2.4 Sensitivity to Expected Decrease in Response Time
and Mileage. As the assumed savings thought possible
through dispatching the single nearest vehicle to an

emergency are increased, the effect on the overall benefit
cost ratio is dramatically positive.   Figure VI-14
illustrates this situation.

As was just pointed out however, for a lesser percent of the
fleet involved in preventive patrol, the resultant savings
would be expected to increase up to a limiting value and
drop off rapidly.   A much more extensive analysis of this
situation is suggested in order to determine the particular
mix of police operations that would show the largest benefit
for a given savings in time and mileage.

% of Response Miles Saved with AVM
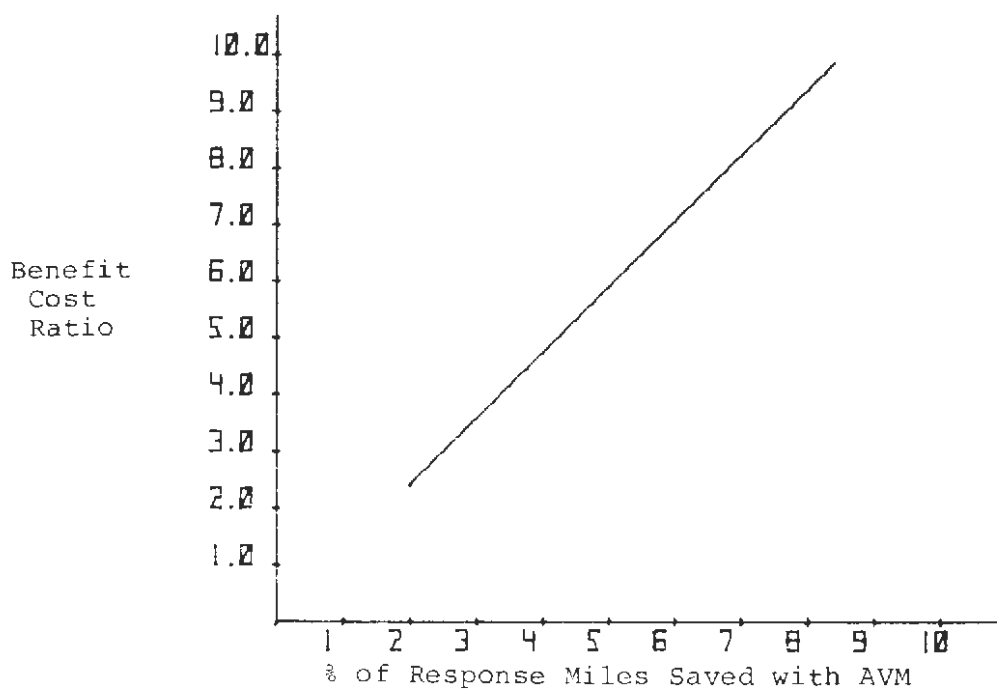
EFFECT ON BENEFIT/COST RATIO OF VARYING
RESPONSE MILEAGE SAVINGS

FIGURE VI-14

6.4.3 <u>Taxi</u>. The following figures are based on variations
around the base fleet of 800 taxis operating within a 475
square mile area, with cost estimates for a radio frequency
system utilized only by the taxi fleet. <u>Only the low
estimates of benefits are analyzed</u>.

6.4.3.1 Sensitivity to Variations in Fleet Size. Though
the taxi is a random route operation as is that of police,
only the costs of the AVM system are comparable. Because
the pay of drivers in a taxi system is based on commissions,
any reduction in the number of drivers does not result in
any significant payroll savings. Rather, the same
percentage commission is merely divided by fewer drivers.
Fixed vehicular operating costs and driver benefits are
saved however. Thus, as is shown in Figure VI-15A, the
benefits and costs assumed for the low case do not
intersect. Accordingly, neither do the benefits and costs
per car, as illustrated in Figure VI-15B. Thus, the overall
benefit cost ratio shown in Figure VI-16, does not reach a
breakeven point in the low case for a taxi operation.

TAXI COSTS & BENEFITS
AS A FUNCTION OF FLEET SIZE

FIGURE VI-15a

Present Value
in 1975
Dollars
$ x 10^3
(Discounted @ 10%)

Costs

Benefits

Area Constant at 475 Mi^2

Fleet Size

TAXI COSTS & BENEFITS
ON A PER CAR BASIS FOR
VARYING FLEET SIZE

FIGURE VI-15b

Present
Value
in
1975 Dollars
(Discounted @ 10%)

Costs Per Car

Benefits Per Car
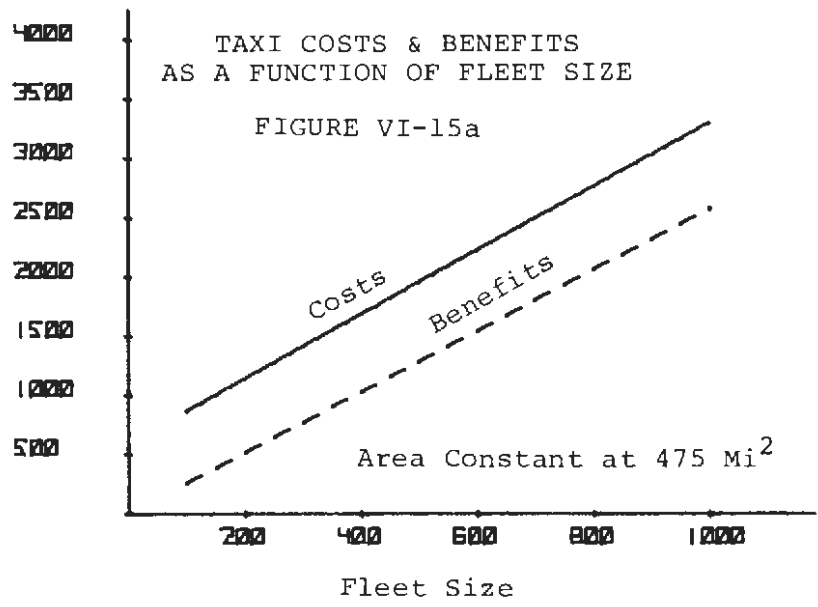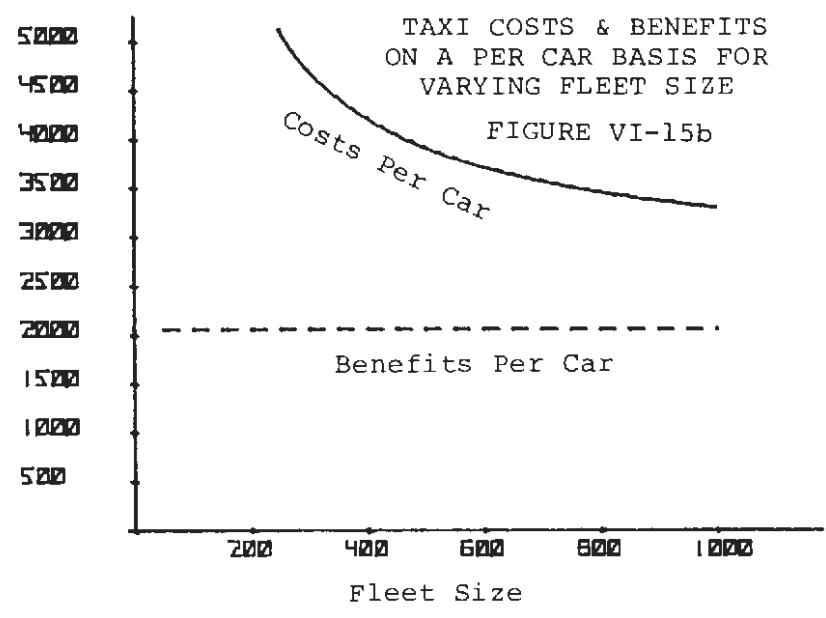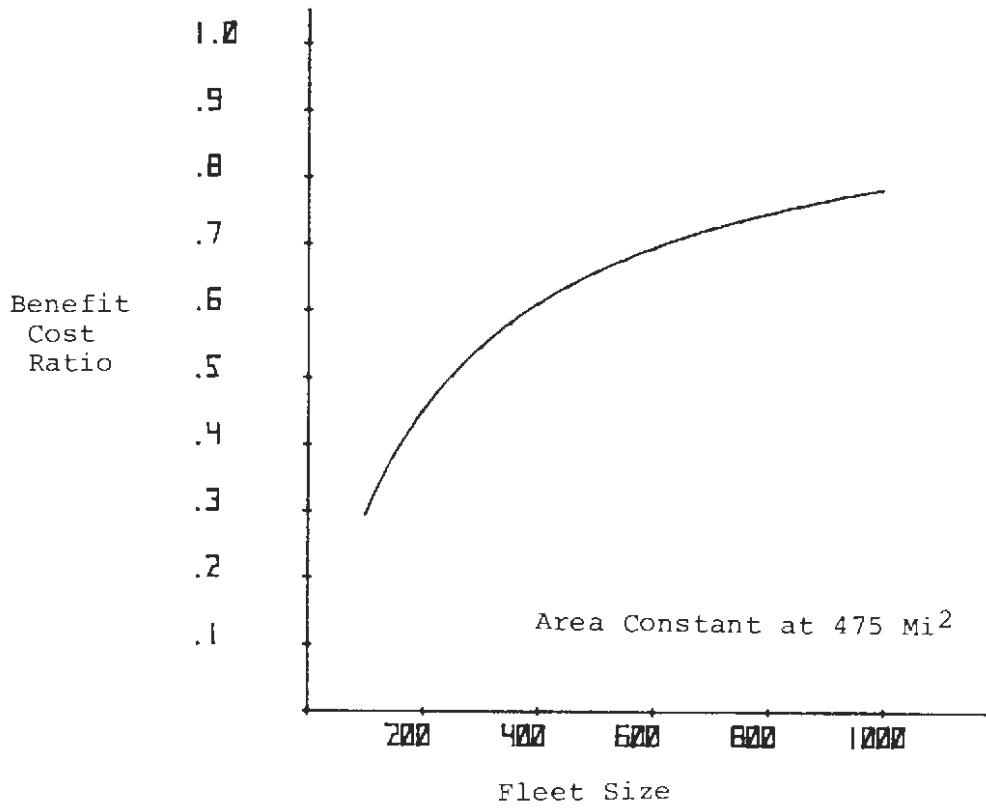
Fleet Size

EFFECT ON TAXI BENEFIT-COST
RATIO FOR VARYING FLEET SIZES

FIGURE VI-16

6.4.3.2 Sensitivity to Variations in Area. For identical

reasons as those given for the police case above, the

benefit/cost ratio shows a decreasing relationship to

increases in the size of the area covered. This relation

does not decay as rapidly as for police as the unit benefits

to be realized are less. However, it is also reasonable to

expect that as the area of coverage decreases, fewer taxis

would be deployed as the total demand for service would be
expected to shrink with area as well. Thus, Figure VI-17
should only be interpreted over a small range around the
base case, to avoid the narrow conclusion that a fixed sized
taxi fleet operation uniformly benefits when the service
area is decreased.
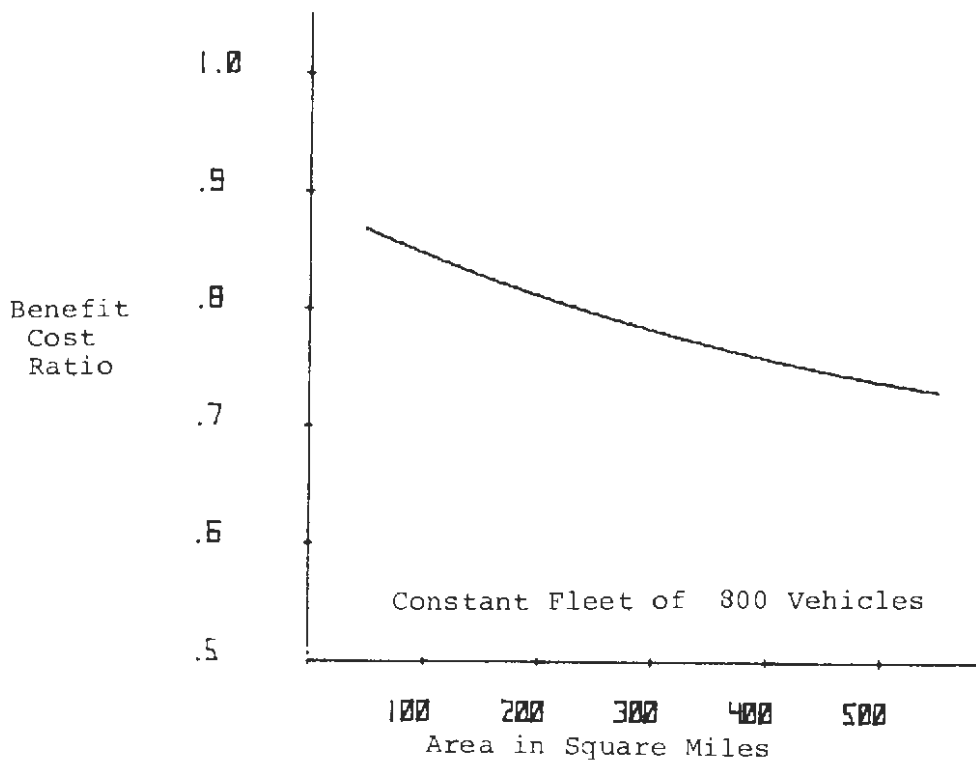
TAXI BENEFIT COST RATIO
SENSITIVITY TO
AREA OF COVERAGE

FIGURE VI-17

6.4.3.3 Sensitivity to Non-Productive Annual Mileage.
Almost analogous to the police operation, wherein a portion

of the annual operating mileage is spent cruising on
preventive patrol, a taxi accumulates non-revenue miles not
only in cruising but in traveling to and from a fare, This
non-revenue mileage is that which can be reduced through
more effective dispatching. Thus expected savings from any
percentage improvement are directly tied to the amount of
non-revenue mileage generated. The relationship between
this factor, assuming a 10% saving in such mileage, is shown
in Figure VI-18. The expected savings reach a finite value
at a point of 82%. This is because the base case assumes
that 18% of the total mileage will be unavoidable as the
next pickup point will seldom coincide with the previous
drop off point.

6.4.3.4 Sensitivity to Expected Mileage Savings. Of
course, as the assumption of the extent of savings
achievable through nearest vehicle dispatching is changed,
the benefits vary accordingly. The effect of varying this
assumption from the base case value of 10% is shown in
Figure VI-19.

Benefit
Cost
Ratio

Non-Revenue Mileage as a Percent
of Annual Miles
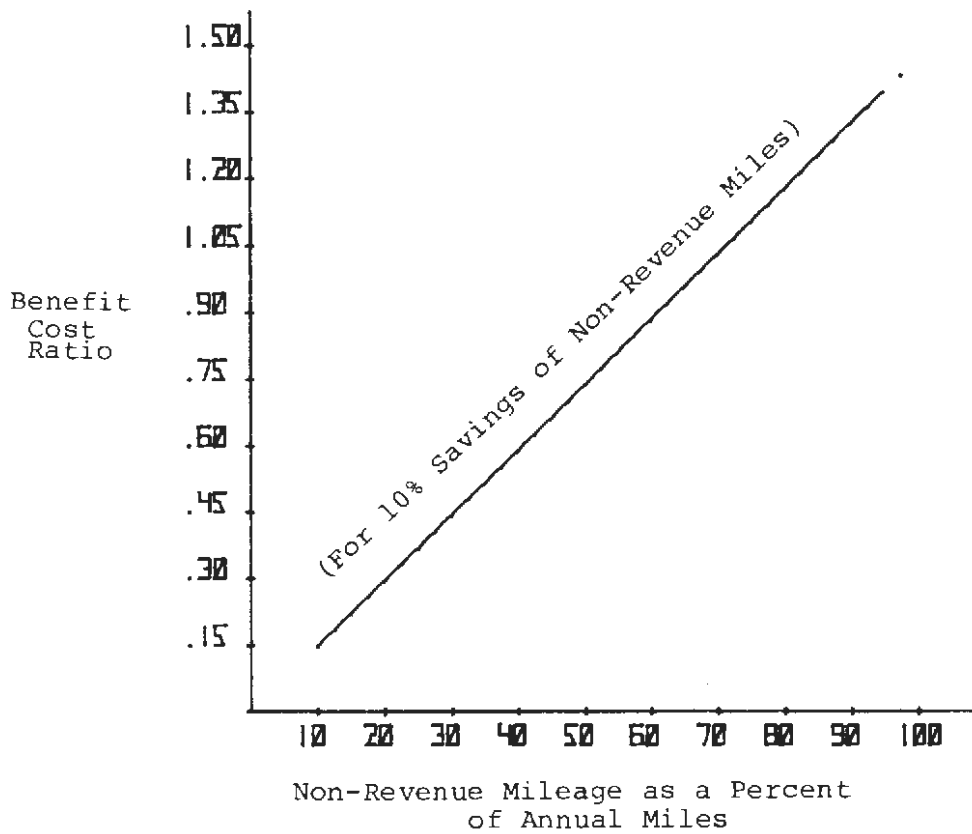
SENSITIVITY OF BENEFIT/COST RATIO
TO TAXI NON-REVENUE MILEAGE

FIGURE VI-18

Benefit
Cost
Ratio

(For Non Revenue Mileage=50% of Total)

Per Cent Mileage Saved
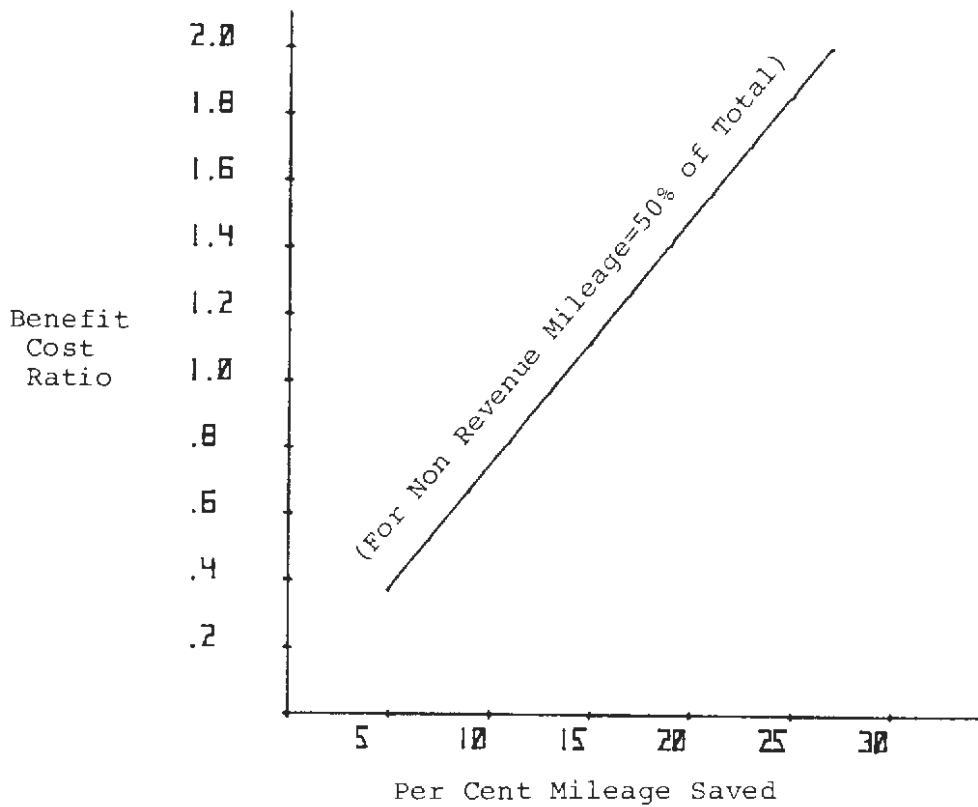
EFFECT OF TAXI MILEAGE
SAVINGS ON BENEFIT/COST RATIO

FIGURE VI-19

6.5 Multiple User Case Sensitivities

Variations in individual descriptors that forcibly hold
interrelated variables constant tend to distort the true

picture of what might be expected if a different site were chosen for AVM deployment.

As service areas expand or decrease, a matching of such changes to another representative urban area would undoubtedly show corresponding reductions in fleet sizes and operational characteristics. Even so, the highly individualized nature of todays urban areas would obviate all but the most vague of relationships.

This factor notwithstanding, it was felt necessary to develop a view of the possible effects of applying AVM in other urban areas. The following changes to the base case were used to describe other urban areas:

- The same percentage decrease in area would be applied to the total bus route miles, central core area and all operating fleet sizes.

- The number of field checkers would be decreased proportionate to changes in fleet size.

- The run times and layover times assumed for buses would be reduced exponentially.

- All other operating characteristics and cost factors as well as percentages used in all assumptions dealing with savings would be held constant.

Shown in Figure VI-20 is the expected trend in the low benefit cost ratio for varying sized urban cities subject to the assumptions mentioned above.

Benefit
Cost
Ratio

2.50

2.25

2.00

1.75

1.50

1.25

1.00

.75

.50

.25

Police Only — 2.39 - 2.41

Multiple User Total — 1.59

Bus Only — 1.36 - 1.37

Taxi Only — .74 - .82

10 20 30 40 50 60 70 80 90 100

Urban Size as a Per Cent
of Base Case City
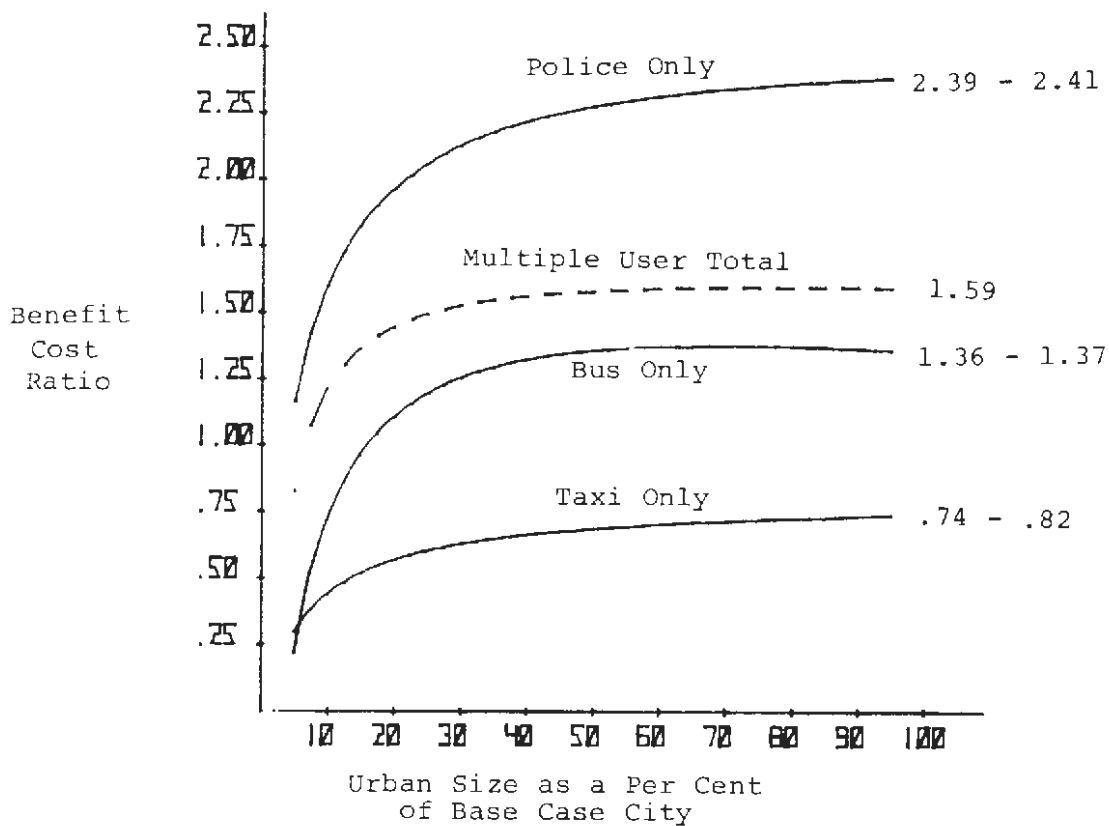
INDIVIDUAL AND
MULTIPLE USER BENEFIT COST
RATIOS AS A FUNCTION OF
URBAN SIZE

FIGURE VI-20

Individual user B/C ratios (low) are shown as solid lines
and the B/C ratio that would be expected in a multiple user,
cost sharing situation is shown as a dotted line.

The range of numbers shown at the terminus of each curve
represents the maximum B/C value for individual operations
and that expected by that user in a multi-user scenario.

Taxi operations were not analyzed in depth for this scenario as their financial operating structure is such that the low estimate of mileage-related savings apparently cannot exceed system implementation costs. Admittedly, while such limitations are readily subject to question, the extent of the implied analysis is beyond the scope of this current study. Additional emphasis was placed upon bus operations as it was felt that the possible impact would be of primary interest on fixed route operations.

Because the size of the field checker force was diminished with fleet size, the benefits within smaller bus operations are accounted for in a more realistic fashion. Thus, while benefits do exceed costs for most cases, urban sizes under 15-20% of the base case encountered costs which outweighed benefits as shown in Figure VI-21. Indications of the physical properties of the urban environment suggested by each percentage can be estimated from other characteristics of the base case city.

The total bus fleet of 2,400 vehicles operated over a system that provided 3,825 route miles of service. Thus a 50% urban situation would be represented by a system having 1,200 vehicles and operating 1,912 one way route miles.

Present
Value
in
1975
Dollars
$ x 10^3

Benefits

Costs

Urban Size as a % of Base Case
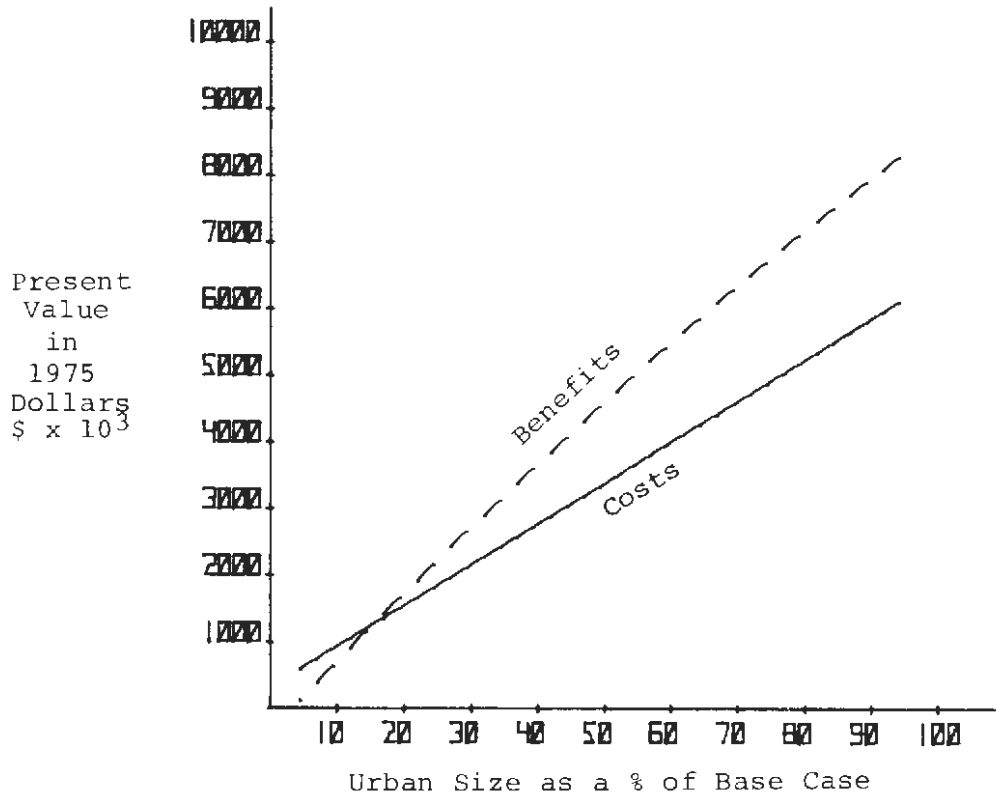
SYSTEM COSTS & TOTAL BENEFITS FOR
BUS OPERATIONS IN VARYING
URBAN SIZED AREAS

FIGURE VI-21

Hard conclusions as to the relationship of benefit/cost to
city size should not be drawn from before such factors as
the efficiency of operation and the extent of transit
dependence by the population (unique for each service area)
are considered.

As can be seen in Figure VI-22, the costs per bus approach
the $2,600 figure shown earlier for bus only operations.
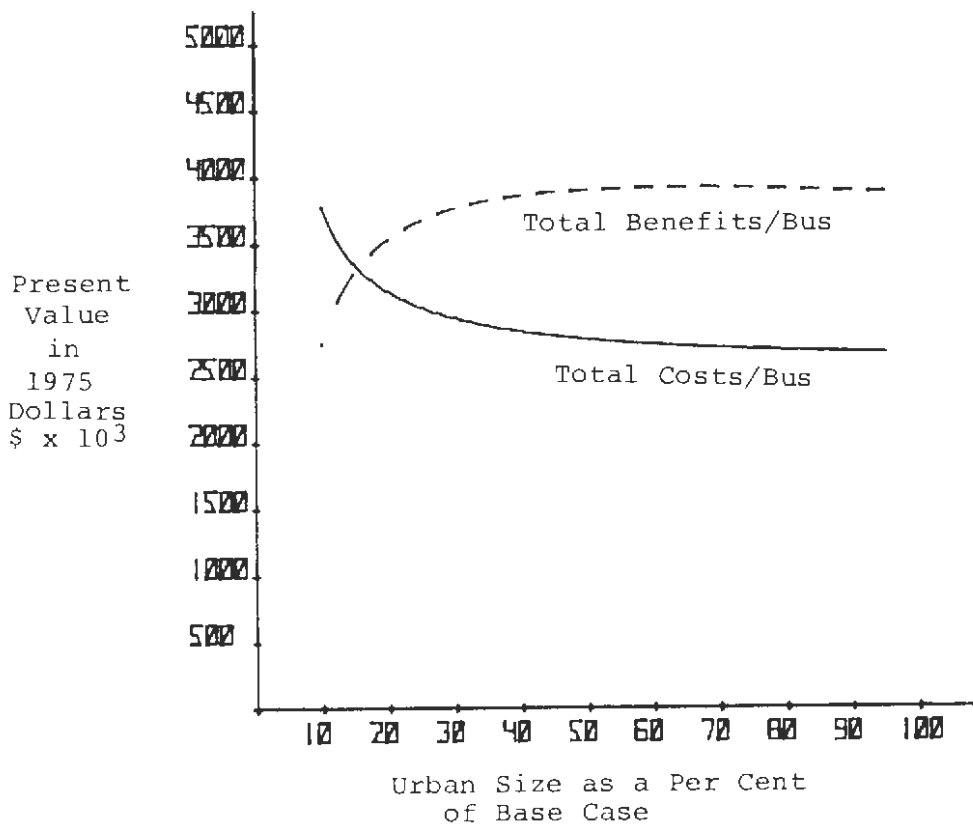
TOTAL COSTS & BENEFITS PER BUS

FIGURE VI-22

Note, however, that the total benefits still include savings from checkers and operations. Separating these results as shown in Figure VI-23, shows that operational benefits on a per bus basis never exceed the $2,600 value and result in the B/C ratios illustrated in Figure VI-24 which compares both total and operational benefits.
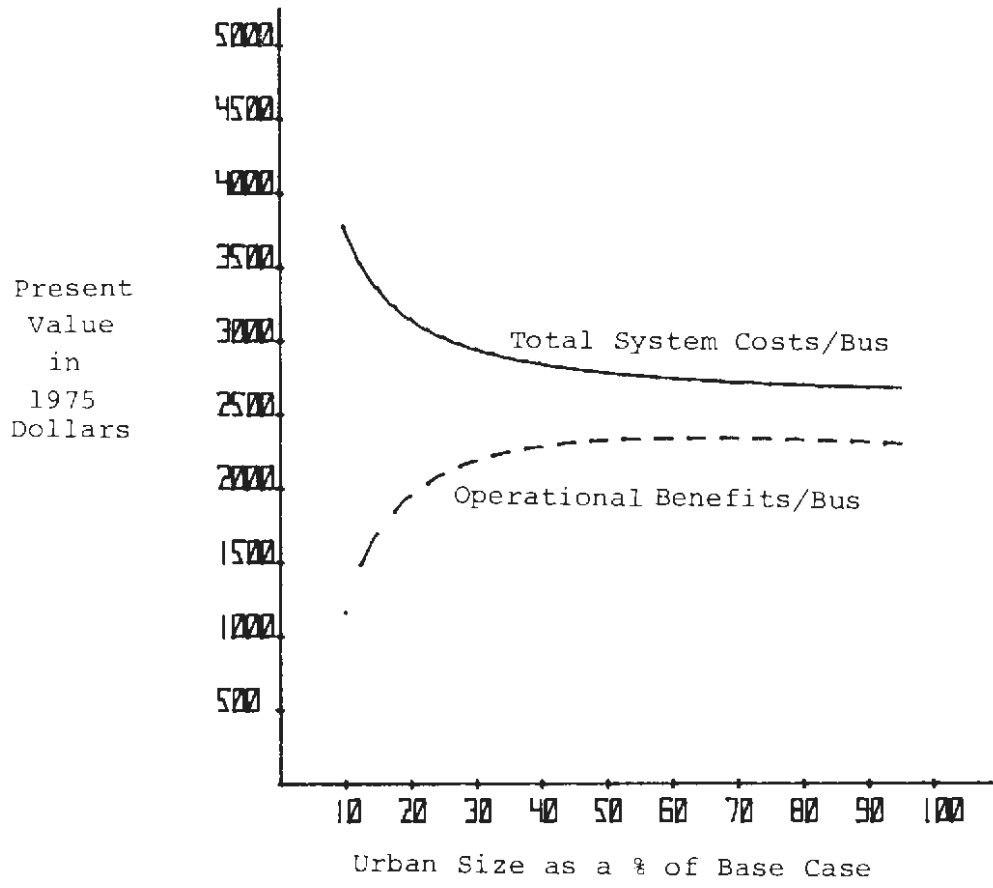
SYSTEM COSTS & OPERATIONAL BENEFITS
FOR VARYING URBAN SIZE AREAS

FIGURE VI-23
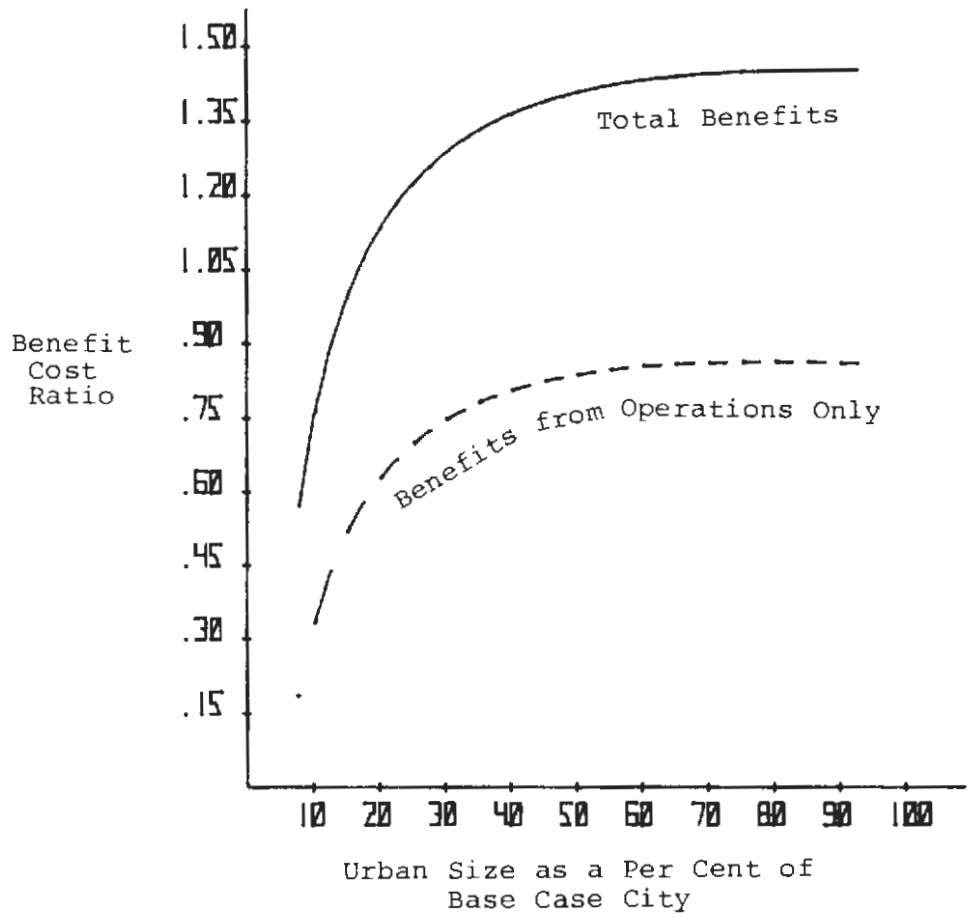
TOTAL & OPERATIONAL BENEFITS FOR
BUSES AS A FUNCTION OF URBAN SIZE

FIGURE VI-24

VII. SERVICE AND MANAGEMENT BENEFITS

7.1 Cost Reduction vs. Service Improvement

The prinicipal benefit of AVM is improved operating efficiency, which flows from continuous vehicle location information. The benefit-cost model captures efficiency improvements by holding the level of service constant while reducing fleet size and personnel strength. This approach yields a straightforward and confident estimate of the cost savings which can be achieved at a given level of effectiveness.

As indicated in Chapter III, cost reduction is only one of a wide range of strategies open to management for exploiting improved operating efficiency. The range of choice has been described as a continuum between two polar positions and illustrated as follows:

INCREASED EFFICIENCY. . .

REQUIRES A CHOICE BY
LOCAL POLICY-MAKERS. . .

IMPROVED SERVICE   CONSTANT SERVICE
YIELDING   OR   YIELDING
PUBLIC BENEFITS   OPERATING ECONOMIES
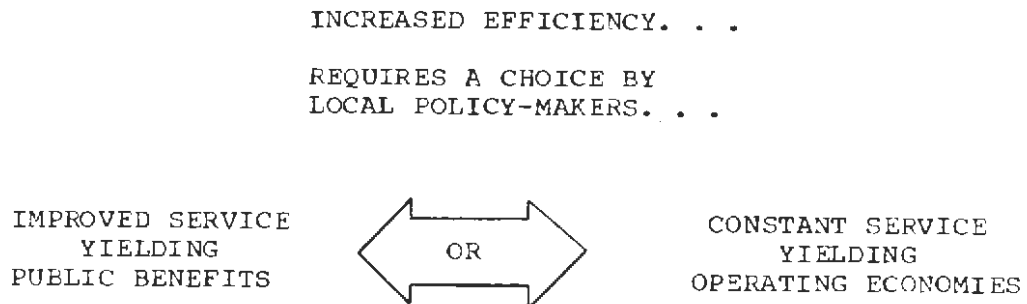
If managers elect to pursue a variation of the first goal, as have many in western Europe, analysts will be challenged to measure the benefits of improved service.

Improved service through AVM may mean reduced passenger wait times, more confident schedules, and shorter total trip time; operating efficiencies may be converted into more frequent trips and wider service provided by the same force of drivers and vehicles. Assigning dollar values to these benefits requires that ridership changes be projected from the service improvements. This cannot be done confidently because there is no generally accepted patron demand function or valuation of passenger wait and travel time. (For example, available estimates of the value of passenger wait and travel time vary by a multiple of four.) Faced with this difficulty, an analyst might choose to estimate the value of public benefits in terms of the avoidable cost of producing those benefits--that is, by measuring AVM cost savings, as has been done in this study.

7.2 Schedule Improvement

AVM, coupled with a reliable passenger counter, will produce a continuous record of bus demand data which can be grouped by route, stop, and time of day. As discussed in Chapter III, this data may be sampled or it may be measured in

totality. In either case, it is the raw material for developing and optimizing the total schedule, for readjusting routes and vehicle assignments to respond most effectively to overall demand, and thus to improve service. This benefit goes beyond the ability of AVM to help keep buses on schedule, beyond the layover and loadfactor improvements which grow out of that ability. It also goes beyond data collection savings which are achieved by automating the checker function. The schedule improvement benefit is defined as the long-term value of having good demand data in hand and using it regularly to adjust service to changing patterns of community needs and demands. The potential dollar value of this benefit depends upon the pre-AVM quality of each property's data collection, demand estimation, and schedule-making. This is difficult to specify in advance of AVM implementation and will vary greatly between properties, but it is clear that it is an important potential benefit. The schedule improvement benefit is not a factor in the base case due to the assumption that equipping 120 buses with passenger counters produces data comparable in value to the product of the current force of 60 manual checkers.

7.3 Security and the Silent Alarm

Exact location data from AVM offers important benefits when coupled with a silent alarm which permits the vehicle operator to transmit a digital code requesting emergency assistance without voice contact. This permits help to be directed to the exact point of need in the shortest time.

Insufficient data is available to make a confident dollar estimate of the value of the silent alarm. It is difficult to establish a causal connection between decreases in crime and a specific deterrent (such as AVM and the silent alarm) because criminal behavior is deeply rooted in a complex social environment. Even if this is accomplished, it remains difficult to find a widely accepted valuation of crimes against people, and even harder to project the ridership impact and general social value of increased feelings of personal security.

Despite these problems, the silent alarm appears to offer substantial benefits. For example, the Chicago Transit Authority found in a small sample that police response time to silent alarms was 38% faster for buses equipped with AVM than for buses equipped only with an alarm and no location indicator. It seems reasonable to agree with a modified

version of the argument for AVM and the silent alarm which
was presented in Chapter II:

- AVM and a silent alarm should bring an increase in
  apprehension of taxi and transit criminals and
  vandals.

- Apprehensions plus publicity should lower transit
  crime and vandalism through deterrence. (However,
  transit crime and vandalism may be displaced to
  other targets.)

- Vehicle operator and police morale seem likely to
  increase so long as they have confidence in an AVM
  with silent alarm and "officer needs assistance"
  codes. This may reduce turnover and lost time and
  increase productivity.

- Public perceptions of greater safety may increase
  transit and taxi ridership, especially during
  night hours and in high crime neighborhoods.

These potential security benefits may be sufficient reason

for decision-makers to proceed with an AVM implementation

which appears marginal in terms of strict dollar benefits.

VIII. BIBLIOGRAPHY

GENERAL REFERENCES AND BUS OPERATIONS

"Automatic Passenger Counters," The MITRE Corporation, (M74-95), Presented at American Transportation Association Conference, New York, October 13-17, 1974.

Automatic Vehicle Monitoring Systems Study - Report of Phase 0, Vol. 2: Problem Definition and Derivation of AVM System Selection Techniques. Prepared by Jet Propulsion Laboratory, Pasadena, California, for the National Science Foundation, Washington, D.C.

Blood, Bernard E., "Advance Multi-User AVM System," Acquisition Paper, Department of Transportation, Transportation Systems Center (DOT/TSC), August 16, 1974.

Blood, Bernard E., "Automatic Vehicle Monitoring Deployment Costs," Unpublished Project Document, DOT/TSC, March 2, 1976.

Blood, Bernard E., "Additional Information - AVM System Deployment Costs," Internal Memo, DOT/TSC, January 3, 1977.

Bruce, P. and Scales, W., AVM Test and Evaluation Site Selection Criteria and Evaluations, -6631, March 18, 1974.

Bruce, Paul, Multi-User AVM Test and Evaluation in Los Angeles Transit Property AVM Requirements, The MITRE Corporation, MTR-6729, July 1974.

Bruce, Paul; Scales, W.C.; and Stewart, C., Los Angeles Multi-User AVM Test System Technical Input to Statement of Work, The MITRE Corporation, MTR-6781, October 1974.

Benefits and Costs of an Automatic Vehicle Monitoring System, The MITRE Corporation, September 1971.

"Crime and Vandalism in Public Transportation," Transportation Research Record, Transportation Research Board, National Research Council, 1974.

Finnamore, Alan J. and Bly, Philip, H., Bus Control Systems: Some Evidence on Their Effectiveness, Traffic Control and Transportation Systems, 1974.

French, Robert L. and Lang, Guy M., "Automatic Route Control System: IEE Transactions on Vehicular Technology," Vol. VT-22, No. 2, May 1973.

Gertler, Judy and Heaton, Carla, "Preliminary Evaluation Plan for Automatic Vehicle Monitoring Test and Evaluation Project," WP-230-C.3-68, DOT/TSC, March 26, 1975.

Heaton, Carla; Lee, Chester; and Lundquist, Pamela, "Selection of Routes for the Automatic Vehicle Monitoring Test and Evaluation Project," Unpublished Working Paper, WP-230-U.3-57, DOT/TSC, December 11, 1976.

Harrison, J.H., "A Prototype Transit Vehicle Monitoring System," B.C. Hydro and Power Authority, March 1975.

I.I.T. Research Institute, "Frequency Management for Vehicle Command and Control: Final Report," U.S. Urban Mass Transport Administration, PB 202 366, April 1971. (Automatic vehicle location system for public vehicles operating in metropolitan areas.)

Jolliffe, J.K., and Hutchinson, T.P., "A Behavioral Explanation of the Association Between Bus and Passenger Arrivals at a Bus Stop," Transportation Service, Operating Research Society of America, Vol. 9, No. 3, Baltimore, Maryland, August 1975.

Lukes, Martin and Shea, Raymond, Monitor CTA - Final Report, Sponsored by DOT/UMTA, Contract No. DOT-IL-06-0010, May 1973.

Miller, Harold, G. and Basham, William M., Evaluation of the Monitor-CTA Automatic Vehicle Monitoring System, Report No. UMTA-MA-06-0024-74-1, DOT/TSC, March 1974.

Oliver, B.W. and Pickard, J., "Vehicle Locating Monitoring Systems for Fleet Operators," J. Sci and Technology 38(3): 94-101, 1971.

Pavlenko, Gregory P.; Polovinkoff, Victor S.; and Raskin, Eugene M., Automatic Dispatching System Concepts Applied to Urban Passenger Transport, Traffic Control and Transportation Systems, 1974.

Roth, S.H., "Automatic Vehicle Monitoring Technology Review," PB 207 849, The MITRE Corporation, Urban Mass Transport Administration, August 1971.

Scales, W.C., "AVM Cost Estimates," MITRE WP 7898, DOT-UT-00007, August 5, 1971.

Scales, W.C., Automatic Vehicle Monitoring: Innovative Technologies and Alternative Directions for Continuing Analysis and Development, The MITRE Corporation, September 26, 1973.

Scales, W.C., _Automatic Vehicle Monitoring Systems_, MITRE M-75-9, October 1974.

Scales, W.C., _Urban Field Tests of Four Vehicle Location Techniques_, Report No. UMTA-VA-06-0012-73-1, MITRE, April 1973.

Scales, W.C. and Murray, William S., _Overview of Automatic Vehicle Monitoring Systems_, MITRE, MTP-386, August 1973.

Shellow, Robert; Romauldi, James P.; and Bartel, Eugene W., "Crime in Rapid Transit Systems: An Analysis and a Recommended Security and Surveillance System," Carnegie-Mellon University, Urban Systems Institute.

Sinha, Kumares and Roemer, Forrest P., "Personal Security in Buses and Its Effect on Ridership in Milwaukee," _Transportation Research Record_, Transportation Research Board, No. 487, 1974.

Swetnam, G.F., _Utility of Combined Bus Priority and Automatic Vehicle Monitoring Systems_, The MITRE Corporation, June 4, 1974.

Thrasher, Edward J. and Schnell, John B., "Studies of Public Attitudes Towards Transit Crime and Vandalism," _Transportation Research Record_, Transportation Research Board, No. 487, 1974.

Urban Vehicle Monitoring: Technology, Economics, and Public Policy, Vol. I, Institute of Public Administration, Sponsored by the Assistant Secretary for Research and Development, HUD, Contract No. H-1030, DATE?.

Wachs, Martin, "Attitudes Toward Transit Service: An Interpretive Review," _Journal of the American Institute of Planners_, Vol. 42, January 1976.

Police Vehicle Operations

Bales, Robert A., "A Police Car Simulation Model: Conventional Versus AVM Dispatching," Transportation Systems Planning Department, The MITRE Corporation, February 1970.

Bales, Robert A., "A Simulation Model for Comparing AVM Versus Conventional Dispatching of Police Cars," The MITRE Corporation, February 15, 1970.

Doering, Robert D., _Vehicle Locator Feasibility Study_, City of Orlando Police Department, Orlando, Florida, March 1974.

Larson, R.C., Models for the Allocation of Urban Police Patrol Forces, Operations Research Center, Massachusetts Institute of Technology, November 1969.

Roos, Mary, "Trip Report - Visit to the St. Louis MPD to Discuss Performance of AVM Equipment Form Management Viewpoint," Unpublished Paper, DOT/TSC, September 1, 1976.

Taxicab Operations

"Application for a Research and Demonstration Grant, Taxicab Monitoring and Dispatching System," Southern California Association of Government, April 11, 1973.

"Automatic Vehicle Monitoring Benefits to the Taxi Operator," Information Identification Incorporation, February 1974.

Heathington, Kenneth W. et al, An Analysis of Two Privately Owned Shared Ride Taxi Systems, Transportation Center, Tennessee University, Knoxville, Tennessee, April 1975.

Strauss, William A., "The City of Boston and Its Taxicabs," The 1970 "Spring Exercise" Public Policy Program, John F. Kennedy School of Government, Harvard University, Cambridge, Massachusetts, 1970.

EUROPEAN TRANSIT OPERATIONS

Conde, Cabeza M., "The Use of Electronic Systems with a View Toward Improving the Operation of Surface Public Transport," International Union Public Transport, 40th International Congress, pt. 1, 24 p., 1973.

Cohen, Norman V. and Shields, L.R., "Use of a Radio Location System on a London Bus Route," London Transport Executive, Economic and Operational Research Office, Department of the Chief Commerical and Planning Offices, DATE?.

Fitzgerald, B.J., "Radio Telephone Control System of Dublin City Bus Services," Dublin City Bus Services, Dublin, Ireland, August 1972.

Giraud, Alain and Henry, Jean-Jacques, "On-Line Control of a Bus Route: Studies and Experiments in Toulouse," Presented to the Third International Symposium on Control in Transportation Systems, Columbus, Ohio, August 9-13, 1976.

Herman, F. and Zimmerman, W., "The Radio Control System of the City of Zurich Transport Authority," Brown Boveri Review, 6, 1974.

Kleim, B.W., "Observation of Bus Monitoring Systems in Paris, France; Zurich, Switzerland; Hamburg, Germany; London, England," TSC AVM Document No. 4.1.5, August 1976.

Lewis, R.L. et al, "Computer Scheduling and Dispatching: A Scientific Approach to Improving the Efficiency of Bus Operation in OECD," Consultants Group on Transport Research Improvements and Innovations in Urban Bus Systems, p. 169-96, Paris, France, October 1969.

Linder, Jurgen, "Transit Vehicle Automation, Guidance, Information, Vehicle Positioning and Safety," Verkerh und Technik, p. 42-48, February 1973 (in German).

"London Transport: Eus Control Centre at Mansion House," London Transport Executive, Department of Operational Research, April 1973.

Perrin, Jean-Paul, "Automation of Bus Operation in Paris," Control in Transportation Systems, Proceedings of the IFAC/IFIP/IFORS, Third International Symposium on Control in Transportation Systems, Columbus, Ohio, August 9-13, 1975.

Richbell, L.E., "Bus Priorities Using Selective Vehicle Detection," Construction, p. 21-23, March 1974.

Sniter, Alain and Cassy, Marc, "Systeme Experimentale de Controle Automatique du Mouvement des Autobus: SECAMA," Extrait due Bulletin, Documentation Information, Janvir-Fevrier-Mars, 1974. (An Experimental System for the Automatic Control of Bus Movement: SECAMA.)

Sniter, Alain; Cassy, Marc; and Adam, Michael, "Systems de Controle Automatique du Mouvement des Autobus de La RATP," Automatisme, No. 819, Aout-Septembre 1973. (An Automatic Control System for the Movement of Buses from RATP.)

Stone, D., "Systems for the Automatic Control and Monitoring of Bus Service," Traffic Engineering and Control, 12:410 plus, December 1970.

Tappert, H., "Automatic Control of Vehicles and Passenger Counts," International Union Public Transport, 37th International Congres, Barcelona, Spain, pt. 4, 1967.

Tappert, Dr. Hans and Mies, Arnold, "Das Hamburger Bus - Uberwachungsystem," Verkehr Und Technik, 1973. (The Hamburg Bus - Monitoring System, Traffic and Technical Information.)

Tappert, Dr. Hans (Technical Director HHA), "Real Time Bus Control: Improving the Reliability of Bus Transportation," Presented at Technology Assessment Review: Improvements and Innovations in Urban Bus Systems, OECD, Paris, France, February 24-25, 1969.

APPENDIX A
BASE CASE DATA INPUTS

This appendix presents the operational and financial data used to calculate the base case benefits. Each entry lists the parameter, the base case value, and the source.

BUS

- Fleet Size

    2,400 vehicles. Southern California Rapid Transit District (SCRTD).

- Capital Cost Per Vehicle

    $64,000. TSC estimate.

- Vehicle Lifetime

    12 years. TSC estimate based on SCRTD data.

- Portion of Fleet Down for Maintenance

    16.53%. TSC analysis of SCRTD data.

- Portion of Fleet to be Equipped with Passenger Counters

    5%. TSC estimate.

- Area Coverage

    5,000 square miles. TSC analysis of SCRTD data.

- Number of Route Miles

    3,825. SCRTD estimate.

- Load Factor Improvement Due to AVM

    1% in the low case; 10% in the high case. TSC estimate.

- Portion of Buses on Short Headway Routes During Peak Hours

    50.07%. TSC analysis of SCRTD data.

- Platform Time

    81.8 minutes. TSC analysis of SCRTD data.

- Average One-Way Running Time

    68.2 minutes. TSC estimate based on SCRTD data.

- Average Layover Time

    13.67 minutes. TSC analysis of SCRTD data.

- Layover Improvement Due to AVM

    .93 minutes in the low case; 3.42 minutes in the high case.

    TSC estimate.

- Annual Insurance Cost per Vehicle

    $3,200. TSC estimate based on data provided by the
    American Public Transit Association (APTA).

- Annual Operation and Maintenance Cost per Vehicle

    $17,120. TSC estimate based on APTA data.

- Initial Checker Force

    60. SCRTD.

- Checkers to Remain with AVM

    20. TSC estimate.

- Portion of Periodic Maintenance Done According to the
  Calendar

    7.5%. TSC estimate.

- Attrition Rate

    10%. SCRTD estimate.

- Average Checker Salary

    $15,800. SCRTD estimate.

- Average Benefits and Overhead for Checker

    $15,800. TSC estimate.

- Initial Driver Force

    4,900. SCRTD estimate.

- Portion of Driver Payroll that is Overtime

    4.88%. TSC analysis of SCRTD data.

- Average Driver Salary

    $13,800. SCRTD estimate.

- Benefits and Overhead for Driver

    $3,100. TSC analysis of SCRTD data.

- Driver Pay Hours per Year

    2,284. TSC analysis of SCRTD data.

POLICE

- Fleet Size

    1,330 Patrol Cars. Los Angeles Police Department (LAPD).

- Vehicle Capital Cost

    $4,400. LAPD.

- Vehicle Lifetime

    3 years. LAPD estimate.

- Portion of Fleet Down for Maintenance

    20%. LAPD estimate.

- Area Coverage

    475 square miles. TSC estimate based on Los Angeles data.

- Annual Miles per Car

    27,000. LAPD estimate.

- Portion of Miles Spent in Preventive Patrol

    50%. TSC estimate.

- Reduction in Response-to-Call Mileage Due to AVM

    2% in low case; 10% in high case. TSC estimate.

- Operation and Maintenance Cost per Mile

    $.183. LAPD estimate.

- Annual Insurance Cost per Car

    $0. LAPD.

- Patrolmen per Vehicle

    3.3. LAPD estimate.

- Average Patrolman's Salary

    $21,800. LAPD estimate.

- Average Annual Benefits and Overhead for Patrolmen

    $21,800. TSC estimate.

- Attrition Rate

    10%. TSC estimate.

TAXI

- Fleet Size

    800 cabs. Yellow Cab Company of Los Angeles.

- Vehicle Capital Cost

    $3,000. Estimate.

- Vehicle Lifetime

    3 years. Estimate.

- Area Coverage

    475 square miles. TSC estimate based on Los Angeles data.

- Average Annual Mileage per Cab

    50,000. Estimate.

- Portion of Mileage that is Non-Revenue

    50%. TSC estimate.

- Portion of Mileage that is Unavoidable Non-Revenue

    18%. TSC estimate.

- Portion of Avoidable Deadheading Saved Due to AVM

    10% in the low case; 20% in the high case. TSC estimate.

- Operation and Maintenance Cost per Mile

    $.093. TSC analysis of data in Paratransit, by

    R.F. Kirby, et al.

- Annual Insurance Cost per Vehicle

    $1475. TSC analysis of data in Paratransit.

- Drivers per Vehicle

     2.1. TSC estimate.

- Drivers on Salary

     0.

- Annual Non-Salary Benefits per Driver

     $1,350. TSC estimate based on YLCA data.

- Attrition Rate of Taxi Drivers

     33%. TSC estimate.

AVM COST FACTORS

Costs for AVM equipment are drawn from "Automatic Vehicle
Monitoring System Deployment Costs," by Bernard E. Blood,
TSC AVM Document 5.1.3. and memo from TSC AVM Project Office
entitled, "Additional Information - AVM System Deployment
Costs," listing percentage cost variations for generic
systems.

SHARP SIGNPOST

- On-Vehicle Equipment

    Location Subsystem

        Fixed Route $ 2,950 per vehicle

        Random Route $ 3,250 per vehicle

        Passenger Counter $ 550 each

- Wayside Equipment

    Signposts

        (6 per route mile, 148 per

        square mile) $ 40 each

    Remote Receivers

        (1 per 127 route miles, 1 per

        127 square miles) $ 10,000 each

- Central Equipment

    Basic Communication $ 20,000

    Variable Communication $ 1,000 per 250 vehicles

    Basic Data Processing $188,000

    Variable Data Processing $ 62,000 per 250 vehicles

- Total Cost Variation   ±20%

BROAD SIGNPOST

- On-Vehicle Equipment

  Location Subsystem $ 1,150 per vehicle

  Passenger Counter $ 550 per vehicle

- Wayside Equipment

  Signposts

    (1 per mile, 37 per square

    mile) $ 74 each

  Remote Receivers

    (1 per 210 route miles or

    square miles) $ 8,000 each

- Central Equipment

  Basic Communication $ 15,000

  Variable Communication $ 1,000 per 250 vehicles

  Basic Data Processing $160,000

  Variable Data Processing

    Fixed Route $ 39,000 per 250 vehicles

    Random Route $ 23,000 per 250 vehicles

- Total Cost Variation   ±5%

RADIO FREQUENCY

- On-Vehicle Equipment

    Location Subsystem $ 1,600 per vehicle

    Passenger Counter $ 550 each

- Wayside Equipment

    Signposts (Signal Boosters)

        (1.25 per mile, 2.16 per

        square mile) $ 216 each

    Remote Receivers

        (1 per 260 miles or

        square miles) $ 8,000 each

- Central Equipment

    Basic Communication $ 10,000

    Variable Communication $ 1,000 per 250 vehicles

    Basic Data Processing

        Fixed Route   . $152,000

        Random Route $120,000

    Variable Data Processing $ 13,000 per 250 vehicles

- Total Cost Variation   ±18%

DEAD-RECKONING

- On-Vehicle Equipment

    Location Subsystem

        Fixed Route $ 4,040 per vehicle

        Random Route $ 4,000 per vehicle

    Passenger Counter $ 550 each

- Wayside Equipment

    Mapping Cost

        (1 per mile or square mile) $ 180

    Remote Receivers

        (1 per 41 miles or square miles) $ 14,000

- Central Equipment

  Basic Communication

      Fixed Route $ 29,000

      Random Route   0

  Variable Communication

      Fixed Route $ 8,500 per 500 vehicles

      Random Route $ 40,000 per 500 vehicles

  Basic Data Processing

      Fixed Route $264,000

      Random Route $204,000

  Variable Data Processing

      Fixed Route $109,000 per 250 vehicles

      Random Route $159,000 per 250 vehicles

- Total Cost Variation $\pm$6-1/2%
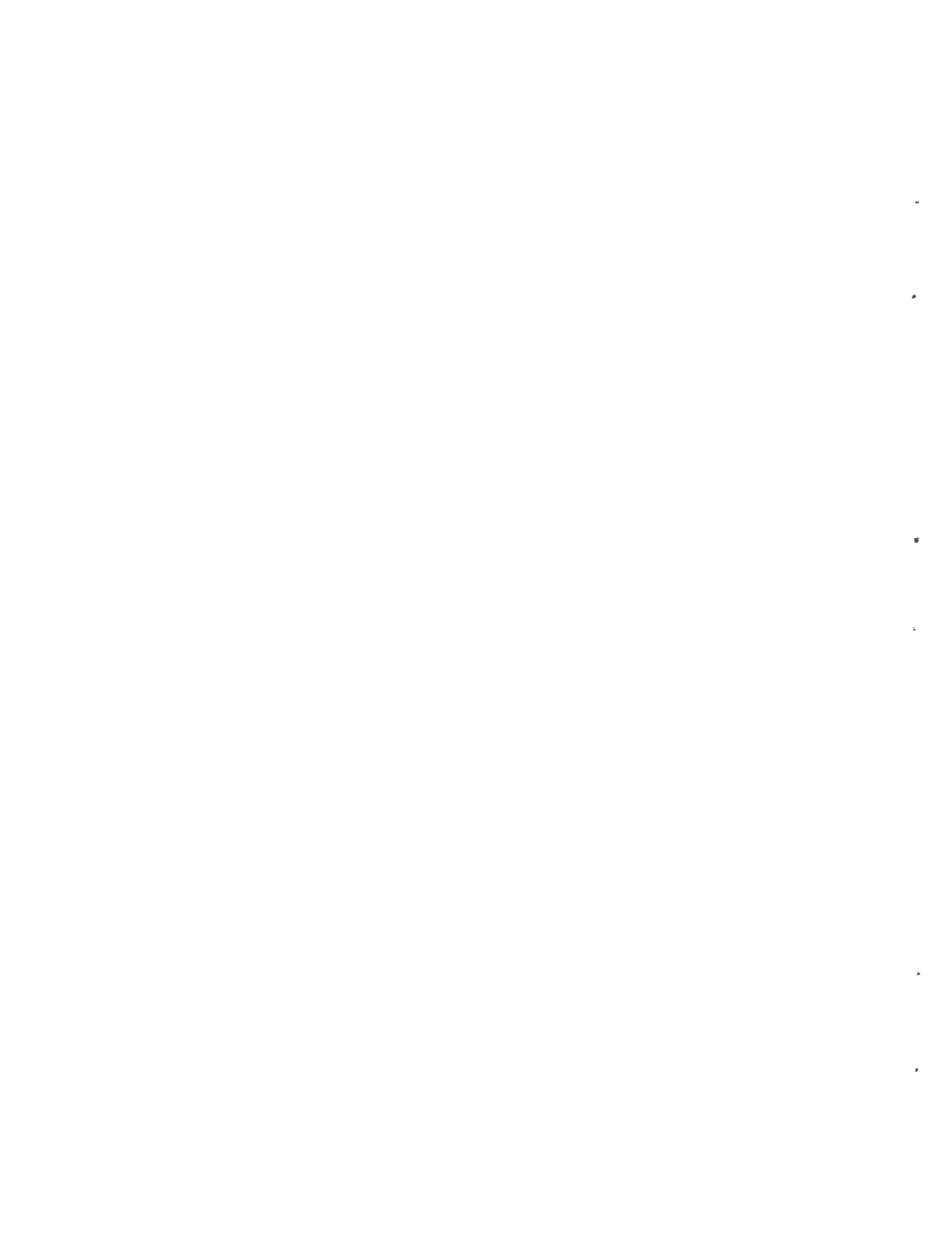
APPENDIX B
USER'S MANUAL FOR
BENEFIT COST MODEL

This appendix describes the inputs to be used during a run of the Benefit-Cost computer program, and is intended to bridge the gap between the descriptive material in the main text, and the detail program flow diagrams of the model that follows. It should be read before preparing input data.

A simplified format is used that lists data items (in their internal neumonics) to be input in the left hand column, with a description of procedures (and capitalized data titles) to the right of those variables. In this way, a quick perusal for a given fleet will give the order of entry of data items.

The program, written in Fortran IV, has two main programs, AVMPR and BENFT. The sub-programs called by each are:

Name	Blocks	Name	Blocks
AVMPR:	29	BENFT:	29
TELCO	1	BUSBN	21
DSUM	1	POLBN	9
		TAXBN	16
		DIABN	11
		VRAT	1
		CAPSV	2
		PATRT	4
		LOSS	9
TOTAL	$\overline{31}$		$\overline{102}$

The object programs are stored on disk at TSC and run on a PDP-KL-10. A block is defined as 600 characters. When compiled, the executable code for the cost program occupies 29 blocks and the benefit program 72.

The following functions are used to translate actual dollar values into 1975 dollars:

1. The Present Value Function

    $$PV(C) = [C(1-(1+rate)^{NYR}]/rate$$

2. Present Value of a Future Annuity Function

    $$PVFA(Y) = Y[1-(1+rate)^{NPER-n+1}]/(1+rate)$$

3. Present Value of a Future Sum

    $$PVFS(Y) = {}^{Y}/(1-rate)^{-N}$$

where:

RATE is the DISCOUNT RATE

NYR is the AVM SYSTEM LIFE

NPER is the NUMBER OF PERIODS

N is the NUMBER OF YEARS

COST CALCULATIONS

Each execution of the COST PROGRAM passes through the computational steps of the model four times, to provide Implementation cost figures for each of the generic AVM system technologies embodied in the Program. Representative cost factors for on-vehicle equipment, wayside equipment, and central equipment for each system are assessed for each fleet entered.

The model is designed for fleets that either travel on routes, or those in random service areas, and will also assess costs for an AVM system shared by up to six users. In beginning the Cost run, the first two input variables determine wayside equipment costs for the total area shared by all users. AREA consists of the combined areas, expressed in square miles, to be served by participating fleets, including the entire area served by buses, which is bounded by an imaginary line connecting the ends of bus routes extending outward from the core service area. TERRAIN DESCRIPTION adjusts that number of remote receivers required, to compensate for irregular obstructions that may interfere with signal transmission.

AREA

PXLMT

USER   The variables that follow regard individual fleets. Care must be taken in inputting TYPE OF FLEET, to type the word naming the fleet (e.g., BUS, TAXI, POLICE, DIAL-A-RIDE, EMERGENCY, etc.) first, with no blanks to the left (left adjusted). In the Benefit Program, separate subroutines have been written for BUS, POLICE, TAXI, and DIAL-A-RIDE fleets, and fleets so named must be left adjusted in the same manner, or they will be recognized

as a generalized fleet by the computer, thus by-passing specific fleet-
related COST and BENEFIT items. The NUMBER OF VEHICLES is next input.
For bus fleets, this will be followed by the PERCENT OF FLEET TO BE EQUIPPED
WITH PASSENGER COUNTERS. Inputs concerning the number of SQUARE MILES or
ROUTE MILES involve only those used by the fleet being costed. (Normally,
bus fleets would travel on fixed-routes only with no "square mile" cover-
age, and random route fleets would require square mile coverage only, with
no "fixed-route" coverage.)

NVEH (left column, aligned with "related COST and BENEFIT items..." line)
KCTR
SQ. MILES
RTE. MILES

After data for all fleets are entered, costs for a multiple user, shared
AVM system are calculated by typing TOTAL (left adjusted) in response to
TYPE OF FLEET, and then inputting the number of SQUARE MILES, covered by
random route users shared or non-shared, and any ROUTE MILES that are not
included within the "square miles" used by fixed-route users. Running
totals of unshared on-vehicle and unshared incremental central equipment
costs are maintained, and new costs for shared wayside and shared basic
central equipment are calculated, based on the total shared service area
data.

TOTAL
SQ. MILES
RTE. MILES

COST SHARES

All inputs for the cost sharing portion of the conversation are either
YES or NO or a number. All equipment that is not on a per-vehicle basis,
i.e., wayside and basic central equipment, is assumed shared if there is

more than one AVM user in an area. Central Communication and Data
Processing Cost shares are calculated according to the number of vehicles
in one fleet, in relation to the number of vehicles in all fleets.
Wayside cost shares for fleets in more than one area can be apportioned
MTHD   in one of two ways, based on conversation concerning METHOD OF APPOR-
TIONMENT. Inputting the number 1 will apportion vehicles according to
the number of route miles in that area in proportion to total route miles
traveled by that fleet.

(query)   To complete the inputs for the cost sharing program, it is necessary to
confirm the number of users that share a particular service area, the
size of the shared area, and the particular fleets involved. Conversation
will continue until all area input during the TOTAL multiple-user is
accounted for. The output will compare single user costs against cost-
shares for each fleet.

BENEFIT CALCULATIONS

The Benefit Program is entered upon command, with computer conversation based on the previously-run Cost Program. Separate subroutines are called for BUS, POLICE, TAXI, and DIAL-A-RIDE fleets, all others entering a general procedure. Default Values, reflecting data collected for the base case, are used when no specific value is stated for variable inputs that have been incorporated in the individual algorithms (see Appendix A). If a default has been stated, but a value of 0 is preferred, the operator must use a small, but finite, number (i.e., 0.00001) instead of 0 or carriage return to avoid the default value from being used.

In all cases, Capital and Operations and Maintenance Savings are calculated based on vehicles saved. The subroutine CAPSV returns the present value of capital costs avoided based on the vehicle life and costs. Personnel reductions consist of drivers saved and other administrative personnel. Driver Savings are calculated in relation to vehicles saved. The Bus Case additionally considers the administrative cost of data gathering personnel. The General Case allows for either proportional personnel reduction, or an input number to be attrited.

The mode-specific subprograms allow unique benefits to be calculated for fleets. The Taxi algorithm contains an option for savings due to high-flag reduction. As most bus operations employ a staff of checkers used for evaluation of passenger loadings and subsequent schedule revision, benefits that accrue from a reduction in this force are calculated.

Any additional costs for training and increased salaries, and additional personnel are calculated for each fleet, based on conversation at the end of the subroutine. The additional expenses are added to the total single and multiple user costs, before the benefit-cost ratios are calculated.

BENEFIT INPUTS

Vehicle Savings

BUS	POL	TAXI	DIA	GEN	Capital

Each subroutine requires estimates of savings due to
AVM economies. The BUS fleet derives its savings from
LOAD FACTOR IMPROVEMENT, input as LOW and HIGH percentage

PCNT
(LO)
(HI)

estimates, and layover reductions where average one-way

RTIME

RUN TIME and the percentage estimate of the BUS FLEET

FHDWY

EMPLOYED ON ROUTES WITH HEADWAYS OF LESS THAN 10 MINUTES

ALAY
RLAY
(LO)
(HI)

is input, followed by CURRENT LAYOVER in minutes, and
and future LAYOVER GOALS, (LOW and HIGH). Vehicle savings
for POLICE fleets result from a reduction in response

PPP

time mileage. A percentage relating MILEAGE SPENT IN
PREVENTIVE PATROL to total miles traveled is first input,

RPS
(LO)
(HI)

followed by LOW and HIGH percentage estimates of RESPONSE
MILEAGE SAVINGS.

TAXI vehicle savings derive from reductions in mileage
spent traveling in response to calls for service. Inputs

PPP

in this area include the PERCENTAGE OF TOTAL MILEAGE THAT

UDHP

IS UNPRODUCTIVE, the PERCENTAGE THAT IS UNAVOIDABLE

PVM

DEADHEAD, and an estimate of ANNUAL MILEAGE TRAVELED PER

RPS
(LO)
(HI)

VEHICLE. Low and High estimates of the REDUCTION IN
AVOIDABLE DEADHEAD MILEAGE are then input.

BUS   POL   TAXI   DIA   GEN

HFP
(LO)
(HI)

The subroutine will enter a loop (upon request) to esti-
mate costs and savings for equipment to prevent high-
flagging. The first input after the "YES" response to
the high-flag interrogation is the expected % REVENUE
INCREASE due to the anti-high-flag equipment. If the
net value of the additional equipment is negative in
both the high and low cases, confirmation will be required
to include these additional equipment costs and benefits
in the analysis.

DIAL-A-RIDE savings derive from increasing the efficiency
of vehicles, by allowing for notification (cost of pro-
viding this notification is described later) of vehicle
arrival and thereby reducing the amount of dwell time
vehicles encounter waiting for passengers to board.

PAX   PASSENGERS SERVED PER HOUR is first input, followed by
XMIN   current DWELL TIME PER STOP, and HIGH and LOW GOALS FOR
PAUS   REDUCTION IN DWELL TIME (in minutes).

For the GENERAL procedure, an estimate must be provided
PVS   for LOW and HIGH VEHICLE SAVINGS due to AVM. COST OF A
(LO)   NEW VEHICLE less salvage value, followed by EXPECTED
(HI)
XCC   VEHICLE LIFE is then entered.
XLF

					Vehicle Savings
BUS	POL	TAXI	DIA	GEN	Operation & Maintenance
					O&M and Insurance Savings are calculated next, based on
VIC	VIC	VIC	VIC	VIC	inputs. ANNUAL INSURANCE COSTS are entered, followed by
VOM	VOM	VOM	VOM	VOM	ANNUAL OPERATION AND MAINTENANCE COSTS. The BUS subrou-

PRMNT — tine calls for an estimate (in dollars, if the default is not used) of the PORTION OF MAINTENANCE COSTS USED FOR PERIODICS, (i.e., maintenance performed according to the calendar for each vehicle).

In order to provide notification of vehicle arrival to passengers, a staff of telephone operators must be added to place phone calls to alert passengers to the imminent arrival of the vehicle. Inputs to calculate the additional

CALLS
CSAL
CBEN

costs include CALLS PER CALLER PER HOUR, ANNUAL SALARY PER CALLER, and ANNUAL BENEFITS AND OVERHEAD PER CALLER.

FORCE
REM

Further savings for BUS fleets will result from a reduction in the number of checkers in the labor force. The CURRENT CHECKER FORCE and the NUMBER OF CHECKERS TO REMAIN IN THE DEPARTMENT (after AVM implementation) are then entered,

SAL
BEN
ARATE

followed by SALARY PER CHECKER, BENEFITS PER CHECKER, and the checker ATTRITION RATE.

BUS	POL	TAXI	DIA	GEN	Personnel Savings

Personnel savings for each fleet are calculated in direct proportion to vehicles saved (slight variation for bus described below). Variables input to perform this calcu-

PPV	PPV	PPV	PPV	
FORCE	FORCE	FORCE	FORCE	
SAL	SAL	SAL	SAL	
BEN	BEN	BEN	BEN	
ARATE	ARATE	ARATE	ARATE	

lation are PERSONS PER VEHICLE, TOTAL FORCE, ANNUAL SALARY and BENEFITS, and the DRIVER ATTRITION RATE. In the GENERAL Procedure, an option is available to calculate personnel savings by directly inputting the number of

PERS (LO) (HI)

people saved, rather than a number proportionate to vehicle savings.

OTIME
AHRS

Personnel Savings in the BUS algorithm derive first from a reduction in OVERTIME HOURS, input as a portion of TOTAL DRIVER HOURS PAID, the next input.

Each subroutine enters the subroutine LOSS to add start-up costs for an AVM system. After responding "YES" to con-versation concerning any additional implementation costs,

S	S	S	S	S
F	F	F	F	F

the first input concerns INSTALLATION COSTS PER VEHICLE, followed by any FIXED COST for central equipment (i.e., general purpose computer, switchboards) not included in

E	E	E	E	E

the COST PROGRAM. Costs of any AUXILIARY EQUIPMENT required to obtain the benefits claimed are then entered, and are calculated; a 10% maintenance cost is added.

BUS	POL	TAXI	DIA	GEN	
APERS	APERS	APERS	APERS	APERS	The number of any ADDITIONAL PERSONNEL TO BE ADDED (i.e., dispatchers, callers) are entered next, followed by esti-
ASAL	ASAL	ASAL	ASAL	ASAL	mates of ANNUAL SALARY AND BENEFITS PER PERSON ADDED.
ABEN	ABEN	ABEN	ABEN	ABEN	

Additional costs for salaries of personnel whose position might be upgraded to operate AVM are calculated for the

UPERS	UPERS	UPERS	UPERS	UPERS	10-year expected system life upon input of the NUMBER OF
USAL	USAL	USAL	USAL	USAL	PERSONNEL AFFECTED, and the AVERAGE ADDITIONAL SALARY

PER YEAR.

PT	PT	PT	PT	PT	Inputs concerning training costs follow. The NUMBER TO BE TRAINED is entered first, followed by the NUMBER OF
H	H	H	H	H	HOURS OF TRAINING PER PERSON required, and the COST
XI	XI	XI	XI	XI	PER PERSON. Any ADDITIONAL TRAINING COSTS (i.e., for

materials of instructors) is then input.

COST PROGRAM VARIABLES

HARDWARE COST VARIABLES

CLS: Per-Vehicle Location Subsystem Cost for Fixed-Route Fleet

CLS2: Per-Vehicle Location Subsystem Cost for Random-Route Fleet

CSP: Unit Cost for Site Preparations

YSP1: Spacing of Site Preparations on a Fixed-Route

YSP2: Spacing of Site Preparations in Area Coverage

CRR: Cost per Remote Receiver

PX: Placement of Remote Receivers

BCOM: Basic Communications Cost

ECOM: Variable Communication Cost

CDP1: Basic Data Processing Cost for Fixed-Route Fleets

CDP2: Basic Data Processing Cost for Random-Route Fleets

CEDP1: Variable Data Processing Costs for Fixed-Route Fleets

CEDP2: Variable Data Processing Costs for Random-Route Fleets

RATE: Annual Discount Rate

NYR: AVM System Life

NRR: Number of Remote Receivers Required

NSP: Number of Signposts Required
  Technology (I):
  1. Sharp Signpost
  2. Broad Signpost
  3. Radio Frequency
  4. Dead Reckoning

DEPLOYMENT VARIABLES

AREA: Total Service Area

PXMLT: Adjustment of Remote Receiver Placement According to Terrain

NVEH: Number of Vehicles in Fleet

KCTR: Portion of Bus Fleet to be Equipped with Passenger Counters

KRAD: Adjustment for Additional Voice-Radio Costs

NSR: Number of Fleets Sharing Service Area

DIST: Number of Miles or Square Miles Shared

INTERMEDIATE VARIABLES

  BAL: Running Total of Remaining Shared Area

FACTOR: Multiplier Dependent on Area Shared

XDENOM: Variable Denominator Used in Assessing Cost Shares
     for Wayside Equipment

 DENOM: Variable Denominator Used in Assessing Cost Shares
     for Central Equipment

  CRSP: Share of Signposts on Routes

  CASP: Share of Signposts in Mutual Random Service Area

PRINT:

FOR (USER)

Capital Costs	
On-Vehicle Equipment	TLS(I)
Signposts	TSP(I)
Remote Receivers	TRR(I)
Communications	
Basic	BCOM(I)
Variable	ECOM(I)
Data Processing	
Basic	BDP(I)
Variable	EDP(I)
Fleet Total	
Annual Maintenance Costs	
On-Vehicle Equipment	TLSM(I)
Signposts	TSPM(I)
Remote Receivers	TRRM(I)
Communications	
Basic	BCMM(I)
Variable	ECMM(I)
Data Processing	
Basic	BDPM(I)
Variable	EDPM(I)
Total Annual Maintenance	TOTM(I)
PV Annual Maintenance	PVTM(I)
PV Total Cost	PVCOST(I)

PRINT:

COMPARISON OF COSTS

FOR (USER)

	Alone (Tech)	Share of Multi-User (Tech)
Capital Costs		
On-Vehicle Equipment	TLS(LOW)	TLS(LOW, SHARED TECHNOLOGY)
Signposts	TSP(LOW)	SHRSP
Remote Receivers	TRR(LOW)	SHRRR
Communications		
Basic	BCOM(LOW)	SHRBC
Variable	ECOM(LOW)	ECOM(SHARED)
Data Processing		
Basic	BDP(LOW)	SHRDP
Variable	EDP(LOW)	EDP(SHARED)
Fleet Total	TOT(LOW)	TOT(SHARED)
Annual Maintenance Costs		
On-Vehicle Equipment	TLSM(LOW)	TLSM(SHARED)
Signposts	TSPM(LOW)	SHRSPM
Remote Receivers	TRRM(LOW)	SHRRRM
Communications		
Basic	BCMM(LOW)	SHRBCM
Variable	ECMM(LOW)	ECMM(SHARED)
Data Processing		
Basic	BDPM(LOW)	SHRDPM
Variable	EDPM(LOW)	EDPM(SHARED)
Total Annual Maintenance	TOTM(LOW)	TOTM(SHARED)
Project Value Total Maintenance	PVTM(LOW)	PVTM(SHARED)
Present Value Total Cost	PVCOST(LOW)	PVSHR

PRINT:

FOR MULTI-USER

Capital Costs	
On-Vehicle Equipment	GTLS(I)
Signposts	GTSP(I)
Remote Receivers	GTRR(I)
Communications	
Basic	GTBCOM(I)
Variable	GTECOM(I)
Data Processing	
Basic	GTBDP(I)
Variable	GTEDP(I)
Grand Total	TOT(I)
Annual Maintenance Costs	
On-Vehicle Equipment	GTLSM(I)
Signposts	GTSPM(I)
Remote Receivers	GTRRM(I)
Communications	
Basic	GTBCMM(I)
Variable	GTEDPM(I)
Total Annual Maintenance	TOTM(I)
Present Value	PVTM(I)
Present Value of Total Cost	PVCOST(I)

AVM COST PROGRAM

```
            ┌──────────┐
           / TOTAL    /
          /  AREA    /
         └──────────┘
              │
              ▼
           ◇ TERRAIN ◇
              │
      ┌───────┼───────┐
      ▼       ▼       ▼
   / FLAT /  / ROLLING /  / RUGGED /
      │       │       │
      ▼       ▼       ▼
 PXMLT = 2.4  PXMLT = 1.7  PXMLT = 1
      │       │       │
      └───────┼───────┘
              │
             (4)
              │
              ▼
           ◇ USER ◇
              │
      ┌───────┼───────┐
      ▼       ▼       ▼
  / TOTAL /  / BUS /  / OTHER /
      │       │       │
     (6)    KUTS    NTCR = 0
              │       │
              └───┬───┘
                  ▼
               / NVEH /
                  │
                  ▼
        NO  ◇ RADIOS ◇  YES
      ┌───────────────────┐
      ▼                   ▼
  KRAD = 1             KRAD = 0
      │                   │
      └─────────┬─────────┘
```

(CONTINUED NEXT PAGE)

```
                    ┌─────────────────────────────┐
                   /   NO. OF SQUARE MILES        /
                  /    NO. OF ROUTE MILES        /
                 └─────────────────────────────┘
                              │
                    0 <    ╱─────╲    = 0
                ┌─────────< SQ     >─────────┐
                │          ╲MILES ╱          │
                │           ╲───╱            │
                ▼                            ▼
        ┌──────────────┐            ┌──────────────┐
        │ COST = CLS2  │            │ COST = CLS1  │
        └──────────────┘            └──────────────┘
                │                            │
                └──────────┬─────────────────┘
                           ▼
   ┌───────────────────────────────────────────────────────┐
   │  FOR EACH OF FOUR TECHNOLOGIES (I = 1,4)               │
   │  TOTAL ON-VEHICLE EQUIPMENT COSTS                      │
   │  TLS(I) = (COST + (KCTR*550) + (KRAD*850))*NVEH        │
   │  ON-VEHICLE EQUIPMENT MAINTENANCE COST                 │
   │  TLSM(I) = TLS(I)/10                                   │
   └───────────────────────────────────────────────────────┘
                           ▼
   ┌───────────────────────────────────────────────────────┐
   │  NUMBER OF SIGNPOSTS REQUIRED                          │
   │  NSP(I) = (YSP2(I)*(NUMBER OF SQ.MILES)) + (YSP1*(NUMBER OF │
   │           ROUTE MILES))                                │
   │  TOTAL SIGNPOST COST FOR EACH TECHNOLOGY               │
   │  TSP(I) = NSP(I)*COST PER SIGNPOST                     │
   │  SIGNPOST MAINTENANCE COST                             │
   │  TSPM(I) = TSP(I)/10                                   │
   └───────────────────────────────────────────────────────┘
                           ▼
               ┌──────────────────┐
               │  TSP(4)  = 0     │
               │  TSPM(4) = 0     │
               └──────────────────┘
                           ▼
                  0 =    ╱─────╲    > 0
               ┌────────< RTE    >────────┐
               │         ╲MILES ╱         │
               │          ╲───╱           │
               ▼                          ▼
      ┌──────────────────┐      ┌──────────────────┐
      │ DIST. = SQ.MILES │      │ DIST. = AREA     │
      └──────────────────┘      └──────────────────┘
               │                          │
               └────────────┬─────────────┘
                            ▼
                          ( 4 )
```

(CONTINUED NEXT PAGE)

⑥

NO. OF REMOTE RECEIVERS REQUIRED
NRR = DIST/PX(I)*PXMLT+1

TELCO

TOTAL REMOTE RECEIVER COSTS
TRR(I) = CRR(I)*NRR
ANNUAL REMOTE RECEIVER MAINTENANCE COST
TRRM(I) = TRR(I)/10

4=   TECH   ≠4

BCOM(4) = 0
BCMM(4) = 0

TOTAL BASIC COMMUNICATIONS AND
DATA PROCESSING CAPITAL AND ANNUAL MAINTENANCE COSTS
BCOM(I) = CCOM(I)
BCMM(I) = BCOM(I)/10
BDP(I) = CDP(I)
BDPM(I) = BDP(I)/10

4=   TECH   ≠4

N = (NVEH/500) + 1

PCOM2 = 40
PCOM1 = 8.5

N = (NVEH/250) + 1

```
┌─────────────────────────────────┐          ┌─────────────────────────────────┐
│ INCREMENTAL COMMUNICATIONS      │          │ INCREMENTAL COMMUNICATIONS      │
│ CAPITAL AND ANNUAL              │          │ CAPITAL AND ANNUAL              │
│ MAINTENANCE COST                │          │ MAINTENANCE COSTS               │
│ FOR DEAD-RECKONING              │          │ ECOM(1) = N                     │
│ AVM                             │          │ ECMM(1) = ECOM(I)/10            │
│ ECOM(4) = PCOM*N                │          └─────────────────────────────────┘
│ ECMM(4) = ECOM(4)/10            │
└─────────────────────────────────┘
```

```
┌──────────────────────────┐
│ N = (NVEH/250) + 1       │
└──────────────────────────┘
```

```
┌─────────────────────────────────┐
│ TOTAL INCREMENTAL DATA          │
│ PROCESSING CAPITAL              │
│ AND ANNUAL MAINTENANCE          │
│ COSTS.                          │
│ EDP(I) = CEDP(I)*N              │
│ EDPM(I) = EDP(I)/10             │
└─────────────────────────────────┘
```

```
┌─────────────────────────────────────────┐
│ TOTAL CAPITAL COSTS:                    │
│ TOT(I) = TLS(I) + TSP(I) + TRR(I)       │
│          + BCOM(I) + ECOM(I) +          │
│          BDP(I) + EDP(I)                │
└─────────────────────────────────────────┘
```

```
┌─────────────────────────────────────────┐
│ TOTAL ANNUAL MAINTENANCE COST           │
│ TOTM(I) = TLSM(I) + TSPM(I) + TRRM(I)   │
│           + BCMM(I) + ECMM(I) + BDPM(I) │
│           + EDPM(I)                     │
└─────────────────────────────────────────┘
```

```
┌─────────────────────────────────────────┐
│ PRESENT VALUE TOTAL MAINTENANCE         │────── PRINT
│ PVTM(I) = PV(TOTM(I))                   │
│                                         │
│ PRESENT VALUE OF TOTAL COST             │
│ PVCOST(I) = PVTM(I) + TOT(I)            │
└─────────────────────────────────────────┘
```

(7)

```
┌─────────────────────────────────┐
│ MAINTAIN RUNNING TOTAL          │
│ OF UNIQUE EQUIPMENT             │
│ FOR FINAL WRAP-UP               │
│ (GTLS, GTLSM, GTECOM,           │
│ GTECMM, GTEDP, GTEDPM)          │
└─────────────────────────────────┘
```

(CONTINUED NEXT PAGE)

```
         ┌─────┐          ╱────────────────────────────╲
         │  7  │─────────▶│   NUMBER OF SQ.MILES        │
         └─────┘          │   NUMBER OF RTE.MILES       │
                          ╲────────────────────────────╱
                                        │
                                        ▼
   ┌──────────────────────────────────────────────────────────────┐
   │   NUMBER OF SIGNPOSTS REQUIRED                                │
   │   NSP = YSP2*(SQ.MILES) + YSP1*(ROUTE MILES) + .995           │
   │   COST OF SIGNPOSTS FOR SHARED AREA                           │
   │   GTSP = CSP(I)*NSP                                           │
   └──────────────────────────────────────────────────────────────┘
                                        │
                                        ▼
                    ┌──────────────────────────────────┐
                    │   SIGNPOST MAINTENANCE COSTS      │
                    │   GTSPM(I) = GTSP(I)/10           │
                    │   GTSPM(4) = 0                    │
                    └──────────────────────────────────┘
                                        │
                                        ▼
                              ╱◇╲
                    0=     ╱  SQ.  ╲    >0
           ┌──────────────   MILES   ──────────────┐
           │            ╲         ╱                │
           ▼              ╲◇╱                      ▼
   ┌──────────────────┐              ┌──────────────────────┐
   │  DIST. = AREA    │              │  DIST. = SQ. MILES    │
   └──────────────────┘              └──────────────────────┘
           │                                      │
           └──────────────▶        ◀──────────────┘
                                        │
                                        ▼
   ┌──────────────────────────────────────────────────────────────┐
   │   NUMBER OF REMOTE RECEIVERS REQUIRED                         │
   │   NRR(I) = DIST/(PX(I)*PXMLT) + 1                             │
   └──────────────────────────────────────────────────────────────┘
                                        │
                                        ▼
                                      ◯
                                        │
                                        ▼
                              ╔═══════════════╗
                              ║║   TELCO    ║║
                              ╚═══════════════╝
                                        │
```

(CONTINUED NEXT PAGE)

```
            ○
            │
            ▼
┌─────────────────────────────────────────────┐
│ COST OF REMOTE RECEIVERS FOR SHARED AREA      │
│ GTRR(I) = CRR(I)*NRR                           │
│ REMOTE RECEIVER MAINTENANCE COST               │
│ GTRRM(I) = (GTRR(I)/10) + √DIST*F*120          │
└─────────────────────────────────────────────┘
            │
            ▼
┌─────────────────────────────────────────────┐
│  BASIC COMMUNICATIONS CAPITAL AND ANNUAL      │
│  MAINTENANCE COSTS                             │
│  GTBCOM(I) =   BCOM(I)                          │
│  GTBCMM(I) = GTBCOM(I)/10                       │
│  GTBCOM(4) = 0                                  │
│  GTBCMM(4) = 0                                  │
└─────────────────────────────────────────────┘
            │
            ▼
┌─────────────────────────────────────────────┐
│   TOTAL SHARED DATA PROCESSING                 │
│   CAPITAL AND ANNUAL MAINTENANCE COSTS         │
│   GTBDP(I) = CDP(I)                             │
│   GTBDPM(I) = GTBDP(I)/10                       │
└─────────────────────────────────────────────┘
            │
┌───────────────────────────────────────────────────────────┐
│                                                             │
│  TOTAL CAPITAL COSTS                                        │──── PRINT
│  TOT(I) = GTLS(I) + GTSP(I) + GTRR(I) + GTBCOM(I)          │
│         + GTBDP(I) + GTECOM(I) + GTEDP(I)                   │
│                                                             │
│  TOTAL MAINTENANCE COSTS                                    │
│  TOTM(I) = GTLSM(I) + GTSPM(I) + GTRRM(I) + GTBCMM(I)      │
│          + GTBDPM(I) + GTECMM(I) + GTEDPM(I)                │
│                                                             │
│ PRESENT VALUE TOTAL MAINTENANCE                             │
│ PVTM(I) = PV(TOTM(I))                                       │
│                                                        ┌─┐  │
│ PRESENT VALUE TOTAL COST                               │8│──┤
│ PRCOST(I) = PVTM(I) + TOT(I)                           └─┘  │
│                                                             │
└───────────────────────────────────────────────────────────┘
```

<div align="center">

(CONTINUED NEXT PAGE)

</div>

(CONTINUED NEXT PAGE)

DENOM = DENOM + NVEH
RBS = NVEH/DENOM

SHARE OF BASIC COMMUNICATIONS COST
SHRBC = RBS*GTBCOM

SQ MILES

0=

≠1

TECH

4=

≠4

SHARE OF BASIC COMMUNICATIONS MAINTENANCE COSTS
SHRBCM = SHRBC/16

SHRBCM = 0

SHARE OF BASIC DATA PROCESSING COSTS
SHRDP = RBS*GTBDP
SHARE OF BASIC DATA PROCESSING MAINTENANCE COSTS
SHRDPM = SHRDP/10

PRINT

(END FLOW DIAGRAM)

B-27

TELCO

$$\text{FACTOR} = 0$$

RETURN

NOA = 0
A = 4./3
FACTOR = 0

$$\left(\text{FACTOR} = .3535/2^{(I-1)}\right) \ast (N - NOA) + \text{FACTOR}$$

A = A*3
NACC = NOA + A

N>   NACC   >N

NOA = NACC
$$\text{FACTOR} = \left(.3535/2^{(I-1)}\right) \ast A + \text{FACTOR}$$

$$\text{FACTOR} = \left(.3535/2^{(I-1)} \ast (N - NOA) + \text{FACTOR}\right)$$

RETURN

AVM BENEFIT PROGRAM

COST.
DAT

READ 1
COST RECORD

14

BUS   POLICE   USER   MULTIPLE   DIAL-A-RIDE   TAXI   OTHER

BUS
BEN

POLICE
BEN

DIAL-A-
RIDE
BEN

TAXI
BENEFIT

GENERAL
BENEFIT

```
J = LO, HI

N = 1, K (K = no. of fleets sharing area)

TOTAL CAPITAL SAVINGS
   CSAVE (J,N) = Σ CSAVE (for all fleets)
TOTAL O&M SAVINGS
   OSAVE (J,N) = Σ OSAVE (for all fleets)
TOTAL PERSONNEL SAVINGS
   PSAVE (J,N) = Σ PSAVE (for all fleets)
TOTAL SAVINGS
   TSAVE (J,N) = Σ CSAVE + Σ OSAVE + Σ PSAVE
```

LOSS   LOSS   LOSS   LOSS   LOSS

PRINT

```
TOTAL SAVINGS PER FLEET
ADD START-UP COST TO TOTAL
   MULTI-USER COST.
BENEFIT COST RATIO:
   TOTAL LOW CASE SAVINGS/TOTAL MULTI-USER COST
   TOTAL HIGH CASE SAVINGS/TOTAL MULTI-USER COST
```

PRINT   PRINT   PRINT

14   14   14

VRAT

PRINT

14

PRINT

14

BUS BENEFIT ALGORITHM

(CONTINUED NEXT PAGE)

FORCE
SEM

STATE
SAL
REN

SAL = SAL + REN
SOR = REN/SAL

ENTRY

CHECKER SAVINGS LOW   CHECKER SAVINGS HIGH

STATE
PRINT
SAL
REN

SAL = SAL + REN
SOR = REN/SAL

BONS

PERSONAL SAVINGS LOW   PERSONAL SAVINGS HIGH

(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR: BUS

Savings Source	Layover Reduction	
	Low	High
% Change	PLAY(LO)	PLAY(HI)
Vehicles Saved	TS(LO)	TS(HI)
Capital	VDAT(1)*CSAVE(LO)	VDAT(2)*CSAVE(HI)
O&M	VDAT(1)*OSAVE(LO)	VDAT(2)*OSAVE(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Drivers Saved	VDAT(1)*PCUT	VDAT(2)*PCUT
Salary	((1-SORD)*(PSAVE(LO)	((1-SORD)*(PSAVE(HI)
	-PCHEX(LO))*VDAT(1)	-PCHEX(HI))*VDAT(2)
Overhead & Ben	((SORD)*(PSAVE(LO)	((SORD)*(PSAVE(HI)
	-PCHEX(LO))*VDAT(1)	-PCHEX(HI))*VDAT(2)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST

Savings Source	Load Factor Improvement	
	Low	High
% Change	PCNT(LO)	PCNT(HI)
Vehicles Saved	FS(LO)	FS(HI)
Capital	VDAT(3)*CSAVE(LO)	VDAT(4)*CSAVE(HI)
O&M	VDAT(3)*OSAVE(LO)	VDAT(4)*OSAVE(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Drivers Saved	VDAT(3)*PCUT	VDAT(4)*PCUT
Salary	((1-SOR)*(PSAVE(LO)	((1-SOR)*(PSAVE(HI)
	-PCHEX(LO))*VDAT(3)	-PCHEX(HI))*VDAT(4)
Overhead & Ben	((SOR)*(PSAVE(LO)	((SOR)*(PSAVE(LO)
	-PCHEX(LO))*VDAT(3)	-PCHEX(HI))*VDAT(4)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST

Data Collection

	Low	High
Personnel Saved	CCUT	CCUT
Salary	(1-SOR)*PCHEX(LO)	(1-SOR)*PCHEX(HI)
Overhead & Ben	SOR*PCHEX(LO)	SOR*PCHEX(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Total Savings	Total Above(LO)	Total Above(HI)
Total Costs		
Single User	SCOST	SCOST
Multiple User	MCOST	MCOST
Benefit-Cost Ratios	Total(LO)/SCOST	Total(HI)/SCOST
	Total(LO)/MCOST	Total(HI)/MCOST

Detail Data for Bus

L.F. Improvement (%)	PCNT(LO)	PCNT(HI)
%Buses on Freq. Headway	FHDWY	
L.F. Savings (VEH)	FS(LO)	FS(HI)
1-Way Avg. Run Time	RUNTM	
Layover Time, Pres. & Goals	ALAY RLAY(LO)	RLAY(HI)
Layover Time Veh Savings	TS(LO)	TS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
Insurance	VIC	
Periodics	PRMNT	
O&M Savings: Layover, L.F.	PVIC(LO)	TVOM(LO)
O&M Savings: Layover, L.F.	PVIC(HI)	TVOM(HI)
O&M Savings	OSAVE(LO)	OSAVE(HI)
Checker Force	FORCE	
Retained	REM	
Attrition Rate	ARATE	
Cost per Checker	SAL+BEN	
Checker Savings	PCHEX	
Driver Force	DFORCE	
Overtime(%)	OTIME	
Cost per Driver	SAL+BEN	
Attrition Rate	ARATE	
Current Value of Hours Saved	SVHRS(LO)	
Equiv. Driver Force	FORCE	
Drivers Remaining	REM	
Savings of Drivers Salaries	OTSV(LO)	
PV of Overtime Cut	PVOTS(LO)	
Current Value of Hours Saved	SVHRS(HI)	
Equiv. Driver Force	FORCE	
Drivers Remaining	REM	
Savings of Drivers Salaries	OTSV(HI)	
PV of Overtime Cut	PVOTS(HI)	
Personnel Savings	PSAVE(LO)	PSAVE(HI)

Key for Bus Benefit Algorithm

(J):	Low, High Parameters
FS:	Vehicles Saved Due to Load Factor Improvement
TS:	Vehicles Saved Due to Layover Reduction
VS:	Total Vehicles Saved
DOWN:	Fraction of Fleet in Maintenance (Average)
FHDWY:	Fraction of Fleet on Frequent Headway Routes During Peak
VIC:	Annual Insurance Cost per Vehicle
VOM:	Annual O&M Cost per Vehicle
OSAVE:	Total O&M Savings
PCNT:	Expected Load Factor Improvement
RUNTM:	Average One-Way Runtime
ALAY:	Average Layover Time
RLAY:	Layover Goal
PRMNT:	Fraction of O&M Done According to the Calendar for Each Vehicle
CSAVE:	Total Capital Savings
FORCE:	Initial Checker Force
REM:	Necessary Checker Force Required
CCUT:	Total Checker Reduction
ARATE:	Checker Attrition Rate
SAL:	Average Salary per Checker
BEN:	Average Benefits per Checker
SOR:	Ratio of Benefits to Total Salary for Checkers
PSAVE:	Personnel Savings
VDAT(1):	Ratio of Vehicles Saved Due to Layover Reduction
VDAT(2):	to Total Vehicles Saved
VDAT(3):	Ratio of Vehicles Saved Due to Load Factor
VDAT(4):	Improvement to Total Vehicles Saved
SCOST:	Single-User AVM Deployment Cost
MCOST:	Multiple-User AVM Deployment Cost

POLICE BENEFIT ALGORITHM

COMMON
NRLIEF
NVEH
SCOST
MCOST

PPP
RPS(J)

VEHICLE SAVINGS (LOW) ← VS(J) = (1 - PPP) * NVEH * RPS(J) * (1. - DOWN) → VEHICLE SAVINGS (HIGH)

NXVC(J) = VS(J)
NLY
XCC

CAPSV

VEHICLE CAPITAL SAVINGS (LOW) — CSAVE(J) — VEHICLE CAPITAL SAVINGS (HIGH)

ACPM
PVM
VOM
VIC

O & M SAVINGS (LOW) ← VOM = VOM + VIC
CSAVE(J) = PV(VS(J) * VOM) → O & M SAVINGS (HIGH)

PPV
FORCE
SAL
BEN

SAL = SAL + BEN
SOR = BEN/SAL

ARATE

REM = (. - (VS(J)/FLOAT(NVEH)))
PCUT(J) = FORCE - REM

PATRT

PERSONNEL SAVINGS (LOW) ← PSAVE(J) → PERSONNEL SAVINGS (HIGH)

PRINT

RETURN

(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR POLICE

Savings Source   Response Time Reduction

	Low	High
% Change	RPS(LO)	RPS(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital	CSAVE(LO)	CSAVE(HI)
O&M	OSAVE(LO)	OSAVE(HI)
Subtotal	CSAVE(LO)+OSAVE(LO)	CSAVE(HI)+OSAVE(HI)
Item B/C		
Single User	SUBTOTAL/SCOST	SUBTOTAL/SCOST
Multiple User	SUBTOTAL/MCOST	SUBTOTAL/MCOST
Patrolman Saved	PCUT(LO)	PCUT(HI)
Salary	(1-SOR)*RSAVE(LO)	(1-SOR)*PSAVE(HI)
Overhead+Benefits	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(LO)/MCOST	PSAVE(HI)/MCOST
Total Savings	TOTAL ABOVE	TOTAL ABOVE
System Costs		
Single User	SCOST	SCOST
Multiple User	MCOST	MCOST
Benefit-Cost Ratios		
Single User	TOTAL(LO)/SCOST	TOTAL(HI)/SCOST
Multiple User	TOTAL(LO)/MCOST	TOTAL(HI)/MCOST

Detail Data for Police

% of Miles for Preventive Patrol	PPP	
Low, High % Savings on Response Miles	RPS(LO)	RPS(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
Cost per Mile	ACPM	
Vehicle Miles per Year	PVM	
Insurance Costs per Vehicle	VIC	
Total O&M & Insurance	VOM+VIC	
O&M Savings (PV)	OSAVE(LO)	OSAVE(HI)
Direct Personnel per Vehicle	PPV	
Annual Salary	SAL	
Annual Cost per Person	SAL+BEN	
Attrition Rate	ARATE	
Initial Force	FORCE	
Balance Remaining	REM(LO)	
Personnel Cut	PCUT(LO)	
Balance Remaining	REM(HI)	
Personnel Cut	PCUT(HI)	
Personnel Savings (PV)	PSAVE(LO)	PSAVE(HI)

Key to Police Benefit Algorithm

        J: Low, High Parameters
      PPP: % of Total Mileage Spent in Preventive Patrol
      RPS: % of Mileage Spent in Response to Calls Expected to be Saved
     DOWN: % of Vehicles in Maintenance (Average)
       VS: Vehicles Saved
      XCC: Cost of New Vehicle, Less Salvage Value
      NVL: Expected Vehicle Life
     ACPM: O&M Cost per Mile
      PVM: Annual Miles per Car
      VIC: Annual Insurance Cost per Car
      VOM: Annual O&M Cost per Vehicle
      PPV: Persons per Vehicle
    FORCE: Initial Patrolman Force
      SAL: Average Annual Patrolman's Salary
      BEN: Average Annual Benefits for Patrolman
      SOR: Ratio of Overhead to Total Personnel Costs for Patrolmen
    ARATE: Attrition Rate
      REM: Remaining Patrol Force
     PCUT: Total Force Reduction
    CSAVE: Capital Savings
    OSAVE: O&M Savings
    PSAVE: Personnel Savings

TAXI BENEFIT ALGORITHM
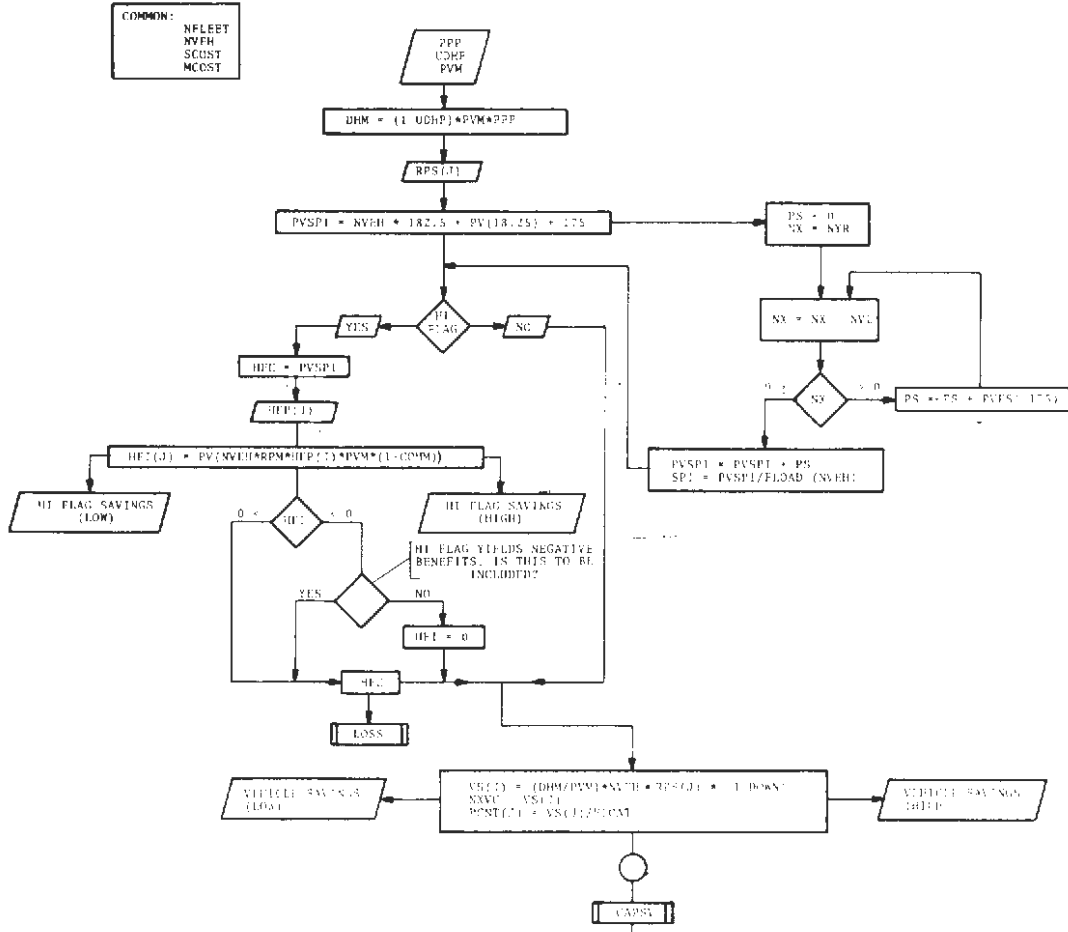
(CONTINUED NEXT PAGE)
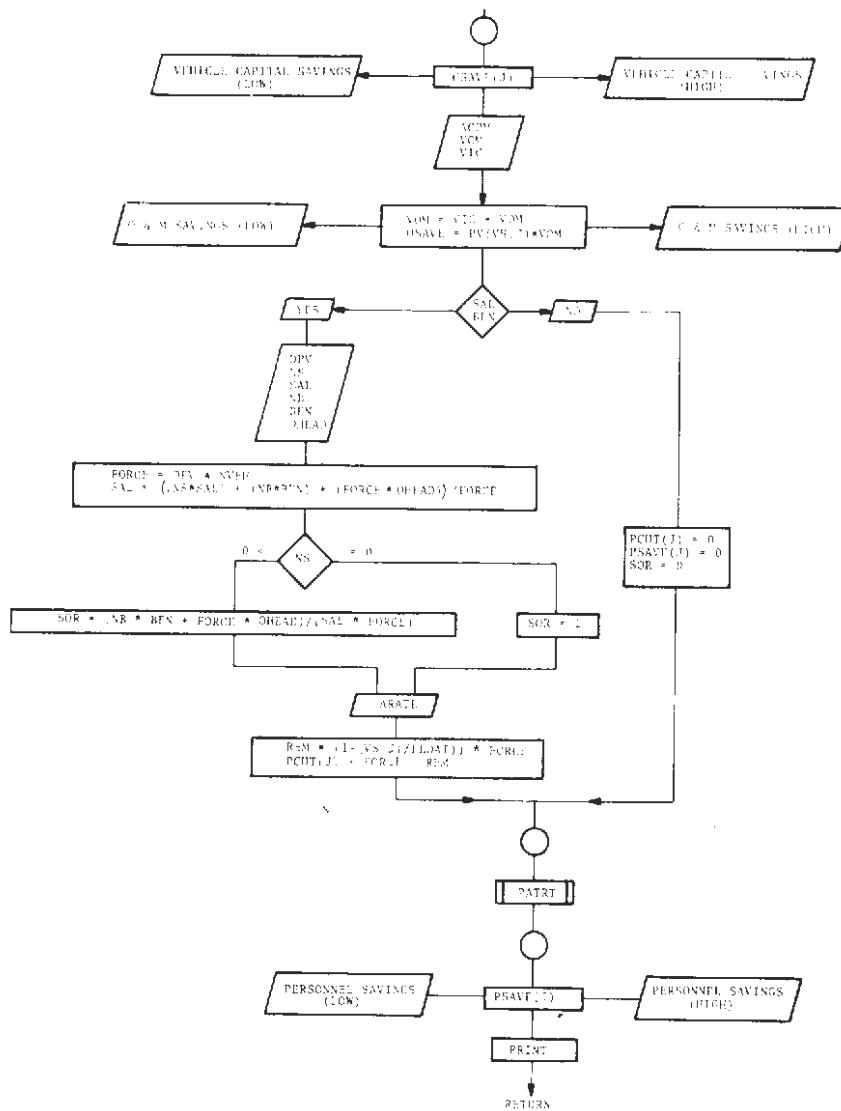
(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR: TAXI

Source of Savings	"High-Flagging" Reduction	
	Low	High
% Change	HFP(LO)	HFP(HI)
Revenue Increase	HFI(LO)	HFS(HI)
Item B/C		
Single User	HFI(LO)/SCOST	HFI(HI)/SCOST
Multiple User	HFI(LO)/MCOST	HFI(HI)/MCOST

	Reduce Dead-Head Miles	
% Change	PCNT(LO)	PCNT(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
O&M Savings	OSAVE(LO)	OSAVE(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Drivers Saved	PCUT(LO)	PCUT(HI)
Salary	(1-SOR)*PSAVE(LO)	(1-SOR)*PSAVE(HI)
Overhead & Ben	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(LO)/MCOST	PSAVE(HI)/MCOST
Total Savings	Total Above(LO)	Total Above(HI)
System Costs	SCOST	SCOST
	MCOST	MCOST
Benefit-Cost Ratio		
Single User	Total(LO)/SCOST	Total(HI)/SCOST
Multiple User	Total(LO)/MCOST	Total(HI)/MCOST

Detail Data for Taxi

Dead-Head Miles (%)	PPP
Unavoidable Dead-Head (%)	UDHP
Average Annual Miles-	PVM
Dead-Head Miles per Vehicle	DHM
Low, High Mileage Savings	RPS(LO), RPS(HI)
Vehicles Saved	VS(LO)
Capital Savings, Vehicles (PV)	CSAVE(LO)
Vehicles Saved	VS(HI)
Capital Savings, Vehicles (PV)	CSAVE(HI)
O&M Cost per Mile	ACPM
O&M Costs per Vehicle	VOM
Insurance Costs	VIC
O&M Savings (PV)	OSAVE(LO) OSAVE(HI)
Drivers	FORCE
Cost per Driver	SAL
Attrition Rate	ARATE
Personnel Cut	PCUT(LO)
Personnel Cut	PCUT(HI)
Personnel Savings (PV)	PSAVE(LO) PSAVE(HI)

Key to Taxi Benefit Algorithm

(J):	High, Low Parameters
PPP:	% of Total Vehicle Mileage that is Non-Revenue Deadhead
UDHP:	% if Total Mileage that is Unavoidable Non-Revenue
PVM:	Annual Vehicle Mileage
DHM:	Avoidable Dead-Head Miles
RPS:	% of Avoidable Dead-Head Miles
PVSPI:	Present Value Cost of High-Flag Equipment
SPI:	Cost of High-Flag Equipment per Vehicle
NX:	Year Counter
NYR:	System Life
NVL:	Vehicle Life
HFC:	Total High-Flag Equipment Costs
HFP:	% Increase in Revenue Expected from "High-Flag" Reduction
HFI:	Increase in Revenue Expected from "High-Flag" Reduction
VS:	Vehicle Savings
DOWN:	% of Fleet in Maintenance(Average)

PCNT: % Reduction in Fleet
CSAVE: Capital Savings
HCPM: O&M Costs per Mile
VOM: Annual O&M Costs per Vehicle
VIC: Annual Insurance Costs per Vehicle
OSAVE: O&M Savings
DPV: Drivers per Vehicle
NS: Number of Drivers on Salary
SAL: Average Annual Salary per Driver
NB: Number of Drivers Receiving Benefits
BEN: Average Dollar Value of Annual Benefits
OHEAD: Average Dollar Value of Annual Overhead for Entire Fleet
FORCE: Total Driver Force
SOR: Ratio of Benefits to Total Salary and Benefits
ARATE: Attrition Rate
REM: Minimum Work Force Required
PCUT: Personnel Attrited
PSAVE: Personnel Savings
SCOST: Single User AVM Deployment Cost
MCOST: Share of Costs of a Multiple User AVM System

DIAL-A-RIDE BENEFIT ALGORITHM
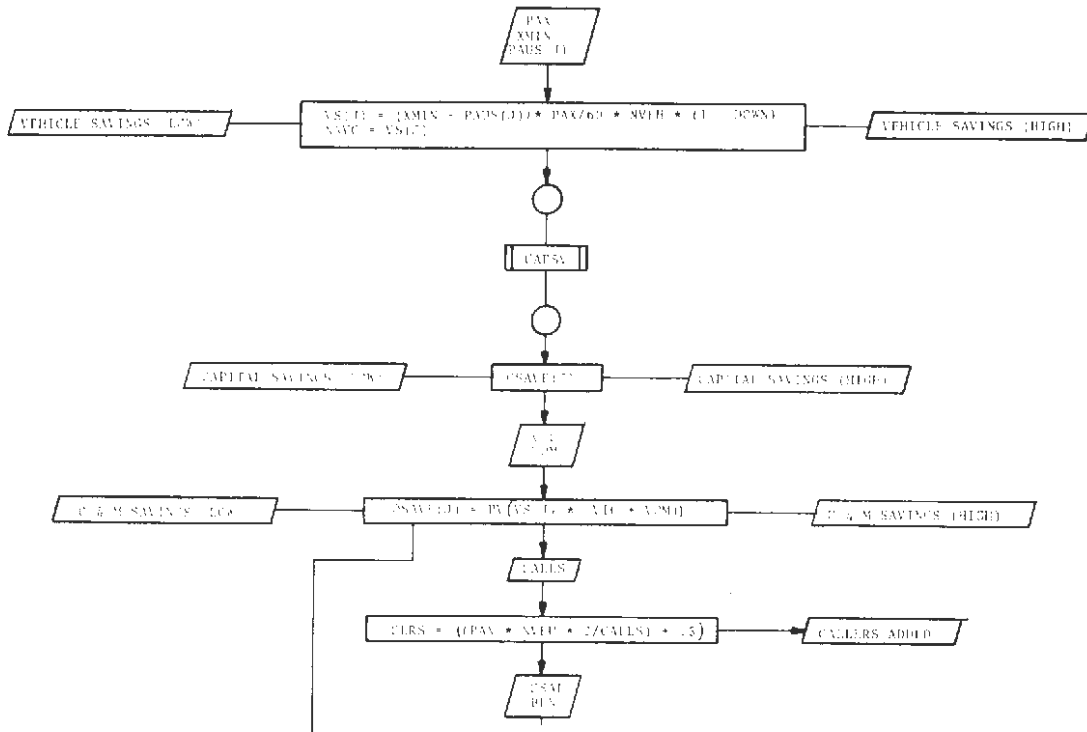
(CONTINUED NEXT PAGE)
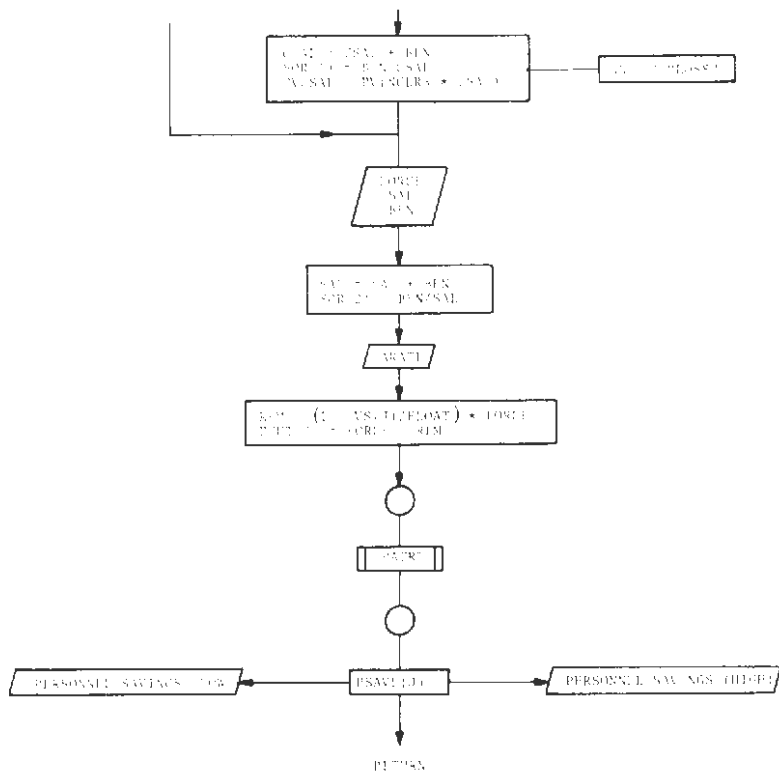
(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR DIAL-A-RIDE

Savings Source   Response Time Reduction

	Low	High
% Change	PCNT(LO)	PCNT(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital	CSAVE(LO)	CSAVE(HI)
O&M	OSAVE(LO)	OSAVE(HI)
Subtotal	CSAVE(LO)+OSAVE(LO)	CSAVE(HI)+OSAVE(HI)
Item B/C		
Single User	SUBTOTAL/SCOST	SUBTOTAL/SCOST
Multiple User	SUBTOTAL/MCOST	SUBTOTAL/MCOST
Personnel Cut	PCUT(LO)	PCUT(HI)
Personnel Savings		
Salary	(1-SOR)*PSAVE(LO)	(1-SOR)*PSAVE(HI)
Benefits	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(HI)/MCOST	PSAVE(HI)/MCOST
Callers Added	CLRS	CLRS
Cost of Callers	CCOST	CCOST
Total Savings	TOTAL ABOVE	TOTAL ABOVE
Total Costs	SCOST	SCOST
	MCOST	MCOST
Benefit-Cost Ratios		
Single User	TOTAL(LO)/SCOST	TOTAL(HI)/SCOST
Multiple User	TOTAL(LO)/MCOST	TOTAL(HI)/MCOST

Detail Data for Dial-a-Ride

Passengers per Hour	PAX	
Dwell Time for Stop (min)	XMIN	
Low, High Dwell Time Goal	PAUS(LO)	PAUS(HI)
Vehicles Saved	VS(LO)	
Vehicles Saved	VS(HI)	
Capital Savings	CSAVE(LO)	CSAVE(HI)
Insurance/Vehicle	VIC	
Periodic Maintenance	VOM	
O&M Savings	OSAVE(LO)	OSAVE(HI)
Calls per Caller per Hour	CALLS	
Callers	CLRS	
Cost per Caller per Year	CSAL+BEN	
Drivers	FORCE	
Cost per Driver per Year	SAL+BEN	
Attrition Rate	ARATE	
Drivers Cut	PCUT(LO)	
Drivers Cut	PCUT(HI)	
Driver Savings	PSAVE(LO)	PSAVE(HI)

Key to Dail-A- Ride Benefit Algorithm

J:	Low, High Parameters
PAX:	Passengers Served Per Hour
XMIN:	Average Dwell Time Per Stop
PAUS:	Dwell Time Goals
VS:	Vehicles Saved
CSAVE:	Capital Savings
VIC:	Annual Insurance Cost Per Vehicle
VOM:	Annual O&M Cost per Vehicle
CSAVE:	O&M Savings
CALLS:	Calls Per Caller Per Hour
CLRS:	Number of Callers Required
CSAL:	Average Annual Salary Per Caller

BEN: Average Annual Benefits Per Caller
SOR(1): Ratio of Benefits to Total Salary Per Caller
PVSAL: Present Value of Total Salary For Callers
FORCE: Driver Force
SAL: Annual Driver Salary
BEN: Annual Driver Benefits
SOR(2): Ratio of Benefits to Total Driver Salary
ARATE: Attrition Rate
REM: Minimum Driver Force Required
PCUT: Total Force Reduction
PSAVE: Personnel Savings

GENERAL BENEFIT ALGORITHM
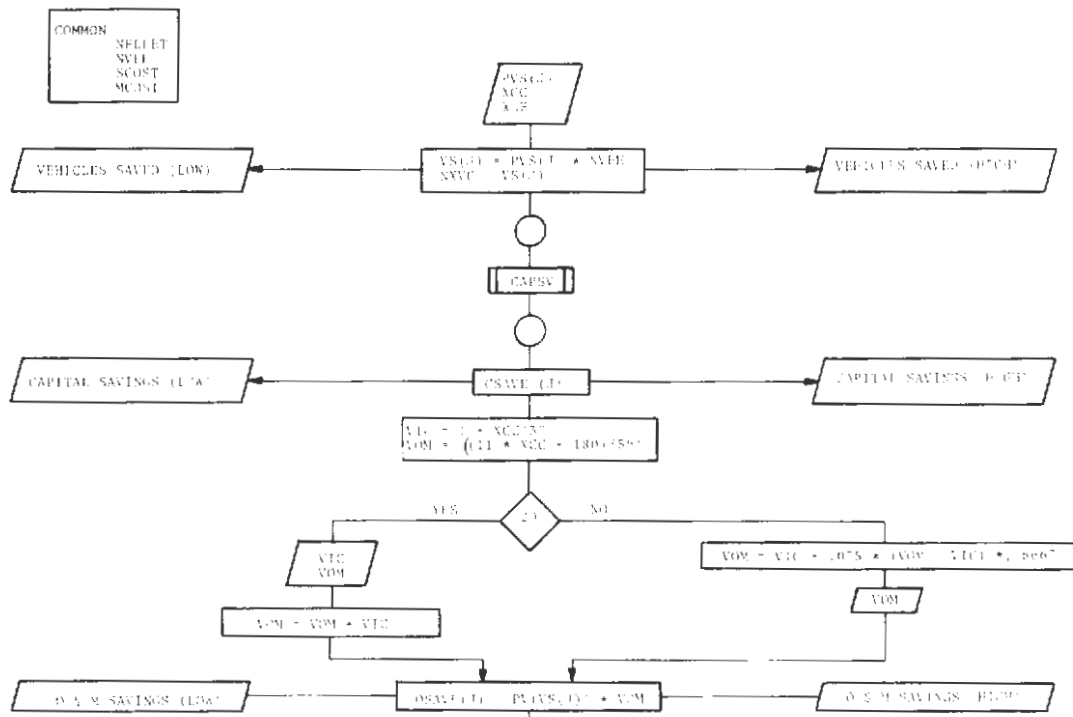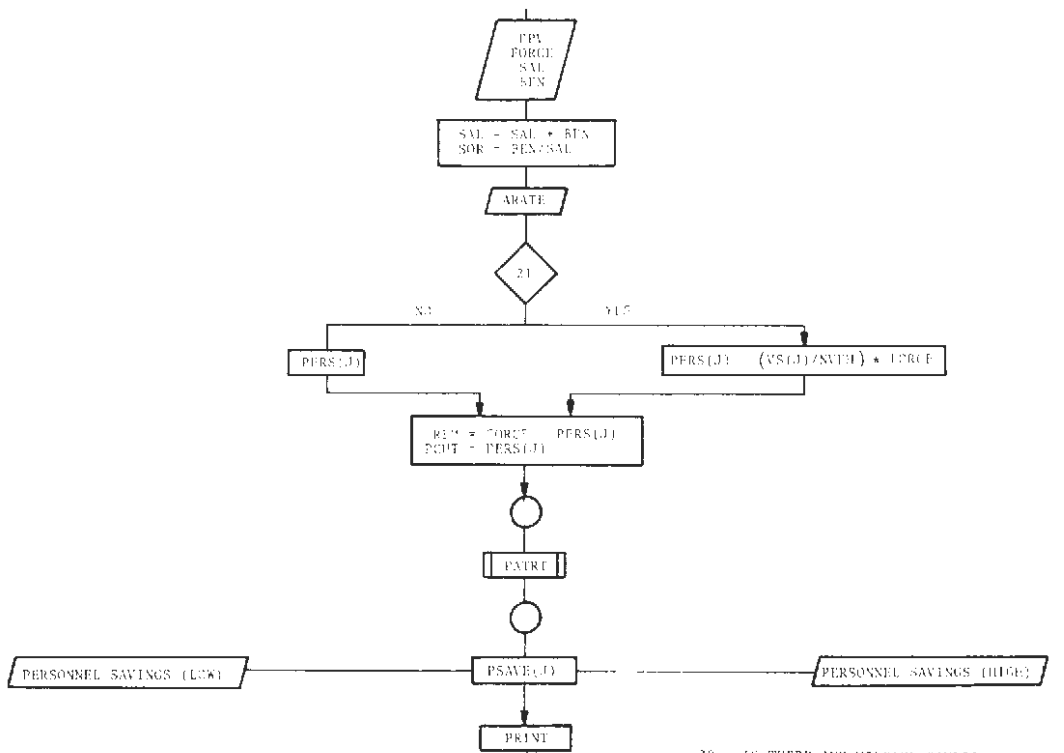
(CONTINUED NEXT PAGE)

B-52

(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR: GENERAL FLEET

	Low	High
% Savings	PVS(LO)	PVS(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital	CSAVE(LO)	CSAVE(HI)
O&M	OSAVE(LO)	OSAVE(HI)
Subtotal	CSAVE(LO)+OSAVE(LO)	CSAVE(HI)+OSAVE(HI)
Item B/C		
Single User	SUBTOTAL/SCOST	SUBTOTAL/SCOST
Multiple User	SUBTOTAL/MCOST	SUBTOTAL/MCOST
Personnel Saved	PCUT(LO)	PCUT(HI)
Salary	(1-SOR)*PSAVE(LO)	(1-SOR)*PSAVE(HI)
Benefits	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(LO)/MCOST	PSAVE(HI)/MCOST
Total Savings	TOTAL ABOVE	TOTAL ABOVE
System Costs		
Single User	SCOST	SCOST
Multiple User	MCOST	MSCOST
Benefit-Cost Ratio		
Single User	TOTAL(LO)/SCOST	TOTAL(HI)/SCOST
Multiple Use	TOTAL(LO)/MCOST	TOTAL(HI)/MCOST

Detail Data for General Fleet

Percent Savings	PVS(LO)	PVS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
Estimated Annual Insurance Costs	VIC	
Estimated Total O&M Costs	VOM	

Full O&M Costs are Applied[1]

O&M Savings	OSAVE(LO)	OSAVE(HI)
Direct Personnel Saved	PCUT(LO)	PCUT(HI)
Average Cost per Person	SAL+BEN	
Personnel Savings	PSAVE(LO)	PSAVE(HI)

Ins. & Periodics are Applied[1]

O&M Savings	OSAVE(LO)	OSAVE(HI)
Direct Personnel Saved	PCUT(LO)	PCUT(HI)
Average Cost per Person	SAL+BEN	
Personnel Savings	PSAVE(LO)	PSAVE(HI)

(1) Output will vary, dependent on whether mileage is saved
or remaining vehicles will travel more miles.

Key for General Benefit Algorithm

J:	Low, High Parameters
PVS:	% Estimated Savings Due to AVM
XCC:	Cost of New Vehicle, Less Salvage
XLF:	Vehicle Life
VS:	Vehicles Saved
CSAVE:	Capital Savings
VIC:	Annual Insurance Costs per Vehicle
VOM:	Annual O&M Costs per Vehicle
OSAVE:	O&M Savings
PPV:	Persons per Vehicle
FOXCE:	Initial Vehicle-Related Force
SAL:	Average Annual Salary
BEN:	Average Annual Benefits
SOR:	Ratio of Benefits to Total Salary
ARATE:	Attrition Rate
REM:	Minimum Required Work Force
PCUT:	Total Force Reduction
PSAVE:	Personnel Savings

PRINT:

BENEFIT-COST SUMMARY FOR: MULTI-USER

Savings Source

	Low	High
User	TSAVE(LO)	TSAVE(HI)
User	TSAVE(LO)	TSAVE(HI)
(for each User)		
Capital Savings	ΣCSAVE(LO)	ΣCSAVE(HI)
O&M Savings	ΣOSAVE(LO)	ΣOSAVE(HI)
Personnel Savings	ΣPSAVE(LO)	ΣPSAVE(HI)
Total Savings	ΣTSAVE(LO)	ΣTSAVE(HI)
System Costs:		
Multi-User	MCOST	MCOST
Benefit/Cost Ratio	TSAVE(LO)/MCOST	TSAVE(HI)/MCOST

LOSS
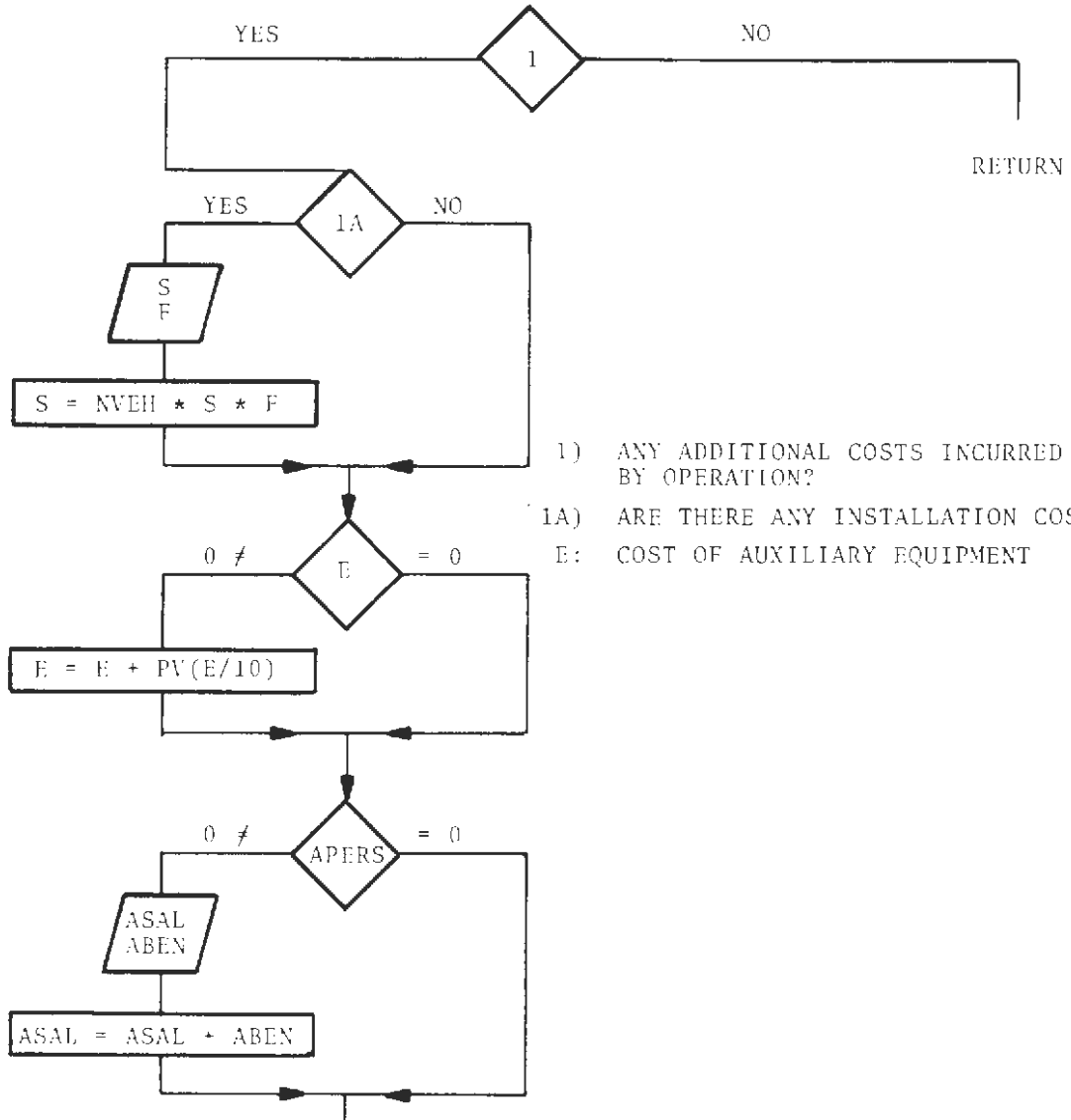
1) ANY ADDITIONAL COSTS INCURRED BY OPERATION?

1A) ARE THERE ANY INSTALLATION COSTS?

E: COST OF AUXILIARY EQUIPMENT

(CONTINUED NEXT PAGE)

```
                              │
                              ▼
              0 ≠        ◇ UPERS ◇        = 0
         ┌─────────────╱             ╲─────────────┐
         │                                          │
    ╱─────────╲                                     │
   │   USAL    │                                    │
    ╲─────────╱                                     │
         │                                          │
         └──────────────────┬───────────────────────┘
                            │
                            ▼
    ┌────────────────────────────────────────────┐
    │  TSAL = APERS * ASAL + UPERS * USAL         │
    │  P = PV(TSAL)                               │
    └────────────────────────────────────────────┘
                            │
                    ╱────────────╲
                   │   APT        │
                   │   PT         │
                    ╲────────────╱
                            │
              ┌─────────────────────────┐
              │     PT = PT + APT        │
              └─────────────────────────┘
                            │
              1 ≤      ◇  PT  ◇      < 1
         ┌─────────────╱        ╲─────────────┐
         │                                     │
    ╱─────────╲                                │
   │    H      │                               │
   │    C      │                               │
    ╲─────────╱                                │
         │                                     │
  ┌──────────────────┐                         │
  │  T = H * C * PT   │                        │
  └──────────────────┘                         │
         │                                     │
         └──────────────┬──────────────────────┘
                        │
                ╱────────────╲
               │     XI       │
                ╲────────────╱
                        │
              ┌──────────────────┐
              │   T = T + XI      │
              └──────────────────┘
                        │
    ┌────────────────────────────────────────────┐
    │  SCOST = SCOST + E + S + P + T              │
    │  MCOST = MCSOT + E + S + P + T              │
    └────────────────────────────────────────────┘
                        │
                     RETURN
```
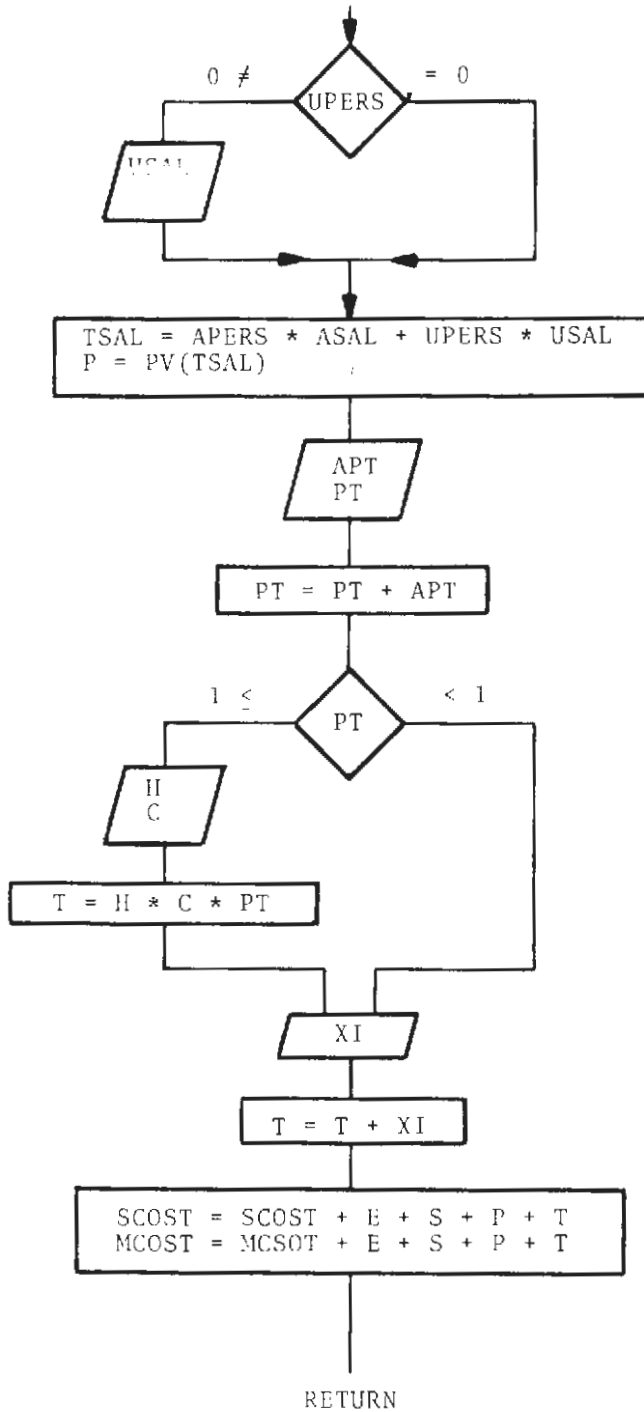
(END FLOW DIAGRAM)

Key for Loss Subroutine

S:	Installation Cost per Vehicle
F:	Fixed Installation Cost
E:	Additional Equipment Costs
APERS:	Number of Persons Added to Perform Additional Functions
ASAL:	Average Salary for Additional Personnel
ABLN:	Average Benefits for Additional Personnel
UPERS:	Number of Employees to Receive Increase in Salary for Additional Duties
USAL:	Additional Cost per Person
TSAL:	Total Additional Salary and Benefits to be Paid
PT:	Number of Persons to be Trained
APT:	Additional Personnel to be Trained
H:	Number of Hours of Training per Person Required
C:	Cost per Hour
T:	Total Cost of Training
XI:	Fixed Training Cost

VRAT

```
L = 0
J = LO,H1
L = L + 1
```

[RATIO TO COMPUTE VEHICLE SAVINGS DUE TO LAYOVER REDUCTION)

[(RATIO TO COMPUTE VEHICLE SAVINGS DUE TO
        LOAD FACTOR IMPROVEMENT)]

```
L = L + 1
\DAT(L) = VSR(J)*DAT(J)
```

```
L = L + 1
VDAT(L) = (1 - VSR(J)*DAT(J)
```

RETURN

CAPSV - CAPITAL COST SAVING SUBROUTINE

```
          NYR
          RATE
COMMON:   NVL
          NVEH
          XCC
          NXVC
          ANNREP
```

```
N = 0
SAVSUM = 0
NVCNT = 0
ANNREP = FLOAT(NVEH)/FLOAT(NVL) + .5
```

(2) → N = N + 1

NYR ≥   N   > NYR → RETURN

NVCNT = NVCNT + ANNREP

NXVC >   NVCNT   > NXVC

NANN = ANNREP   NANN = NXVC   NVCNT + ANNREP

S = NANN * XCC   S = NANN * XCC

```
SAVSUM = SAVSUM + PVFS(S)
N = N + NVL
```

NYR <   N   ≤ NYR → RETURN

NXVC ≥   NVCNT   > NXVC → RETURN

N = N · NVL * K

(2)
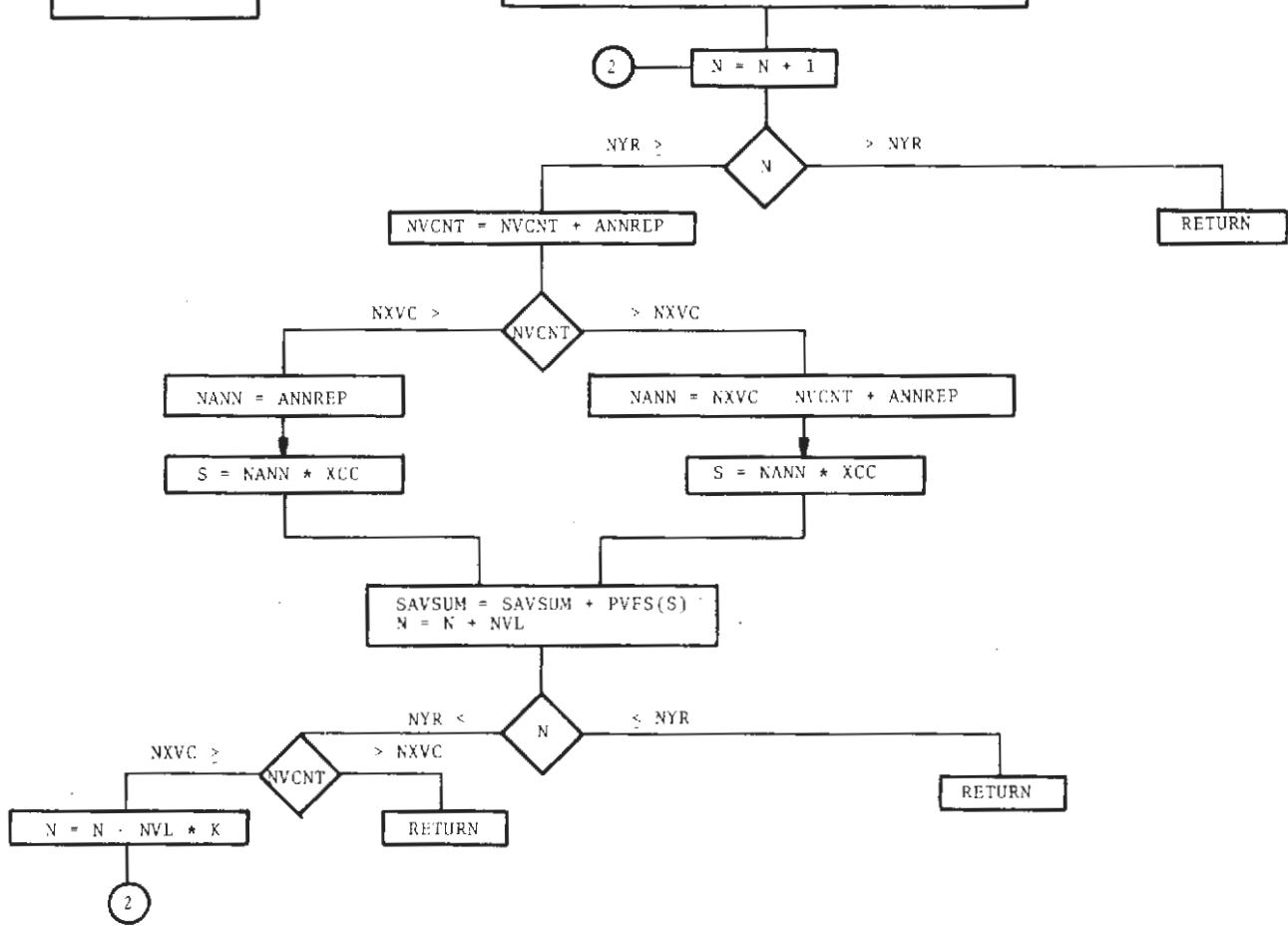
Key to CAPSV Subroutine

       NYR: System Life
      RATE: Discount Rate
       NVL: Vehicle Life
      NVEH: Number of Vehicles in Fleet
       XCC: Capital Cost Per Vehicle, Less Salvage
      NXVC: Number of Vehicle to be Attrited
    ANNREP: Annual Replacement Rate
         N: Year Counter
     NVCNT: Vehicles Saved to Date
    SAVSUM: Present Value Summary of Vehicles Saved
      NANN: Vehicles saved in Year N
         S: Capital Savings

PATRT PERSONNEL SAVINGS SUBROUTINE
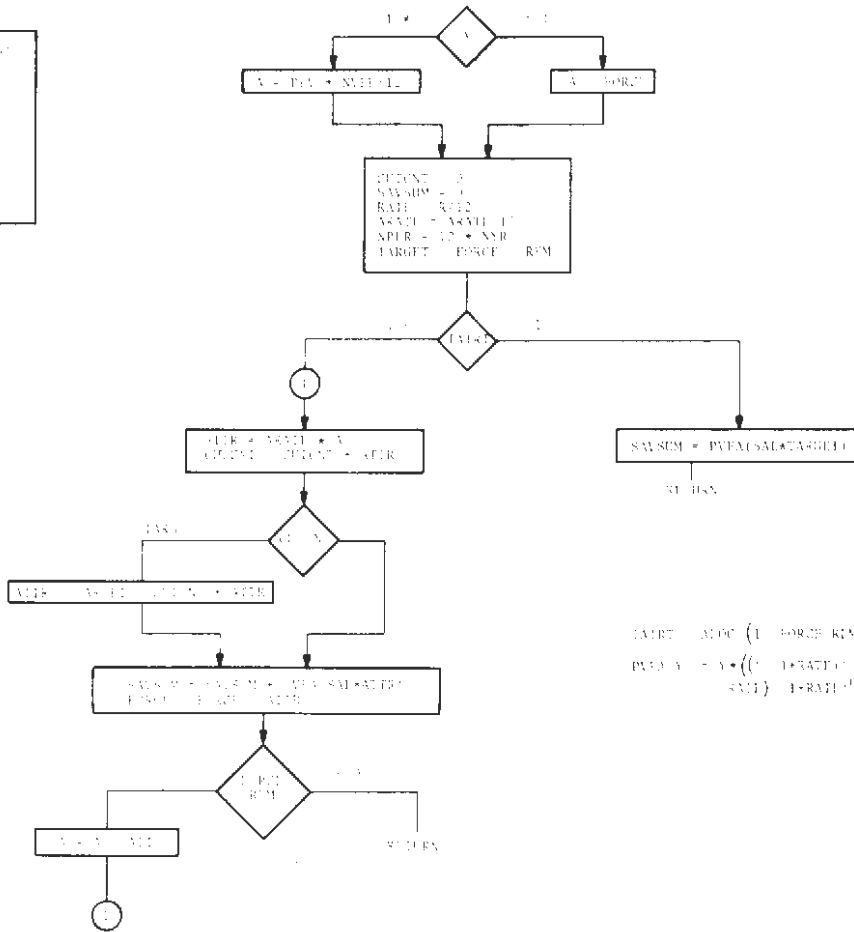
Key to PATRT Subroutine

TATRT:	Year in Which Target is Achieved
ARATE:	Attrition Rate
FORCE:	Initial Work Force
REM:	Minimum Work Force
A:	Attrition Base Force
SAL:	Average Annual Salary
SAYSUM:	Present Value Summary of Personnel Savings to Date
RATE:	Monthly Discount Rate
NPER:	System Life in Months
TARGET:	Attrition Goal
CUTCNT:	Total Attrition Achieved to Date
LVL:	Adjustments For Low and High Case Attrition Base Force
R:	Annual Discount Rate

APPENDIX C

BASE CASE MODEL INPUT-OUTPUT FORMATS

TYPE OF FLEET IS? BUS

INPUT NUMBER OF VEHICLES TO BE EQUIPPED? 2400

WHAT % OF THE BUS FLEET WILL BE EQUIPPED WITH PASSENGER COUNTERS? 5

IS THIS FLEET CURRENTLY EQUIPPED WITH VOICE RADIOS? YES

HOW MANY SQUARE MILES COVERED? 4\4\0

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 3325

FOR BUS   :

	SHARP SIGNPOST	BROAD SIGNPOST	RADIO FREQUENCY (THOUSANDS OF DOLLARS)	DEAD-RECKONING
CAPITAL COST				
ON-VEHICLE EQUIP.	7146.0	2826.0	3906.0	9762.0
SIGNPOSTS	918.0	283.0	1032.9	688.5
REMOTE RECEIVERS	400.0	192.0	160.0	1708.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	29.0
VARIABLE	10.0	10.0	10.0	42.5
DATA PROCESSING				
BASIC	188.0	160.0	152.0	264.0
VARIABLE	620.0	390.0	130.0	1090.0
FLEET TOTAL	9302.0	3876.0	5400.9	13584.0
ANNUAL MAINTENANCE COSTS				
ON-VEHICLE EQUIP.	714.6	282.6	390.6	976.2
SIGNPOSTS	91.8	28.3	103.3	0.0
REMOTE RECEIVERS	40.0	40.2	37.0	191.8
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	2.9
VARIABLE	1.0	1.0	1.0	4.3
DATA PROCESSING				
BASIC	18.8	16.0	15.2	26.4
VARIABLE	62.0	39.0	13.0	109.0
TOTAL ANN. MAINT.	930.2	408.6	561.1	1310.5
PRESENT VALUE	5715.7	2510.7	3447.6	8052.7
PRESENT VALUE OF TOTAL COST:				
	15017.7	6386.7	8848.6	21636.7

THE LOWEST COST SYSTEM FOR BUS   AT $ 6386.7 THOUSAND DOLLARS,
IN COLUMN 2, THE BROAD SIGNPOST SYSTEM

ANALYSIS OF BENEFITS FOR BUS

PEAK LOAD FACTOR IMPROVEMENT IN % - IE, IF BUS NOW AVERAGES 20.0 PASSENGERS
ON BOARD AND WILL IMPROVE TO AN AVERAGE OF 22.1, IMPROVEMENT % = 10.5.
REASONABLE RANGE OF MAXIMUMS IS FROM 2% (BUSES WELL SCATTERED W/O AVM &
LAT. BY NO MORE THAN 2 MINUTES 95% OF THE TIME) TO 69.9% (BUSES "BUNCH"
BADLY W/O AVM, 95% LATENESS LEVEL IS 10 MINUTES). DEFAULT VALUES ARE 2%
(LOW) AND 10% (HIGH).

```
                    LOW %        HIGH %
      IMPROVEMENT = 1,10
```

IT IS ASSUMED THAT 50.07% OF THE BUSES USED IN THE PEAK HOUR ARE DEPLOYED ON
ROUTES WITH HEADWAYS OF LESS THAN 10 MINUTES. NEW VALUE?

IT IS ASSUMED THAT THE AVERAGE ONE-WAY RUN TIME ON A ROUTE IS 68.20 MINUTES.
NEW VALUE?

LAYOVER TIME IS NOW 13.67 MINUTES PER ONE-WAY RUN. NEW VALUE?

THE DEFAULT GOALS ARE, 12.74 MIN. - LOW CASE AND 10.25 MIN. - HIGH CASE.
```
                    LOW        HIGH
NEW VALUES ?
```

DEFAULT VALUE FOR INSURANCE COSTS IS $ 3200. PER VEHICLE PER YEAR.
NEW VALUE?

TOTAL O&M COSTS INCLUDE INSURANCE AND PERIODICS PLUS PREVENTIVE MAINT.
BASED ON MILES, ALL UNSCHEDULED MAINTENANCE, FUEL AND LUBRICANTS, AND
OTHER COSTS SUCH AS TIRES, BATTERIES, ETC. WITH MILEAGE RELATED LIFE.
THE DEFAULT VALUE IS $ 17120. NEW VALUE?

PART OF PERIODIC MAINTENANCE IS PERFORMED STRICTLY ACCORDING TO THE CALENDAR
TO EACH VEHICLE (EG. SEASONAL, MONTHLY, DAILY). DEFAULT VALUE OF THE ANNUAL
COST OF SUCH MAINTENANCE IS 7.5% OF TOTAL MAINT.
NEW VALUE (IN DOLLARS)?

IT IS ASSUMED, FOR THE DEFAULT CASE, THAT THIS PROPERTY HAS A CHECKER FORCE
OF 60. OF WHICH 20. WILL REMAIN ON TO PERFORM OTHER TASKS IN THE SAME
DEPARTMENT. THE BALANCE WILL BE ABSORBED AT AN ATTRITION RATE OF, 10.%.
EACH CHECKER HAS AN ANNUAL SALARY OF 15.80 THOUSAND DOLLARS. THE COST OF
BENEFITS AND OVERHEAD ARE PRESUMED TO BE EQUAL TO THE SAME AMOUNT. YOU WILL
HAVE A CHANCE TO REPLACE THESE VALUES.

     PRESENT CHECKER FORCE ?

     NUMBER TO REMAIN IN DEPARTMENT ?

     ATTRITION RATE (IN %) ?

     SALARY (IN THOUSANDS OF DOLLARS)?

     BENEFITS AND OVERHEAD (IN THOUSANDS OF DOLLARS)?

NOTE: IN THE LOW CASE, THE ATTRITION IS LIMITED TO THE CHECKER FORCE ONLY: IN
THE HIGH CASE, IT IS ASSUMED THAT THE CHECKERS CAN BE TRANSFERRED TO ANY ADMIN-
ISTRATIVE JOB, AND THE ATTRITION SPREAD OVER THE ENTIRE ADMINISTRATIVE STAFF.

IT IS ASSUMED THAT THERE ARE 2.0 DRIVERS PER BUS. IF THAT VALUE IS ACCEPTED,
PRESS CARRIAGE RETURN; OTHERWISE ENTER TOTAL DRIVER FORCE.

WHAT PERCENT OF THE DRIVER PAYROLL IS OVERTIME? (DEFAULT VALUE IS 5%)

COST-BENEFIT SUMMARY FOR: BUS
(DOLLAR VALUES IN THOUSANDS)

SAVINGS SOURCE:	LAYOVER REDUCTION		LOAD FACTOR IMPROVEMENT	
	LOW	HIGH	LOW	HIGH
% CHANGE	6.8	25.0	1.0	10.0
VEHICLES SAVED	7.	22.	10.	91.
CAPITAL $	375.5	1294.4	558.6	5302.8
O&M	70.5	562.7	751.4	5996.4
SUBTOTAL $	446.0	1857.1	1309.9	11299.1
ITEM BENEFIT/COST:				
SINGLE USER	0.070	0.291	0.205	1.769
MULTI-USER	0.070	0.292	0.206	1.776
DRIVERS SAVED	12.	38.	17.	157.
SALARY $	1034.8	3361.1	1539.2	13769.9
OVERHEAD+BEN	233.9	759.7	347.9	3112.2
SUBTOTAL $	1268.7	4120.8	1887.1	16882.1
ITEM BENEFIT/COST:				
SINGLE USER	0.199	0.645	0.295	2.643
MULTI-USER	0.199	0.648	0.297	2.654

	DATA COLLECTION	
	LOW	HIGH
PERSONNEL SAVED	40.	40.
SALARY $	1897.8	3665.8
OVERHEAD+BEN	1897.8	3665.8
SUBTOTAL $	3795.6	7331.6
ITEM BENEFIT/COST:		
SINGLE USER	0.594	1.148
MULTI-USER	0.597	1.153
TOTAL SAVINGS $	8707.4	41490.7
SYSTEM COSTS:		
SINGLE USER	6386.7	6386.7
MULTI-USER	6360.7	6360.7
BENEFIT/COST RATIO:		
SINGLE USER	1.363	6.496
MULTI-USER	1.369	6.523

C-4

TYPE OF FLEET IS? POLICE

INPUT NUMBER OF VEHICLES TO BE EQUIPPED? 1330

IS THIS FLEET CURRENTLY EQUIPPED WITH VOICE RADIOS? YES

HOW MANY SQUARE MILES COVERED? 475

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 0

FOR POLICE   :

	SHARP SIGNPOST	BROAD SIGNPOST	RADIO FREQUENCY (THOUSANDS OF DOLLARS)	DEAD-RECKONING
CAPITAL COST				
ON-VEHICLE EQUIP.	4322.5	1529.5	2128.0	5320.0
SIGNPOSTS	2812.0	1300.6	221.6	85.5
REMOTE RECEIVERS	40.0	24.0	16.0	168.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	0.0
VARIABLE	6.0	6.0	6.0	120.0
DATA PROCESSING				
BASIC	188.0	160.0	120.0	204.0
VARIABLE	372.0	234.0	78.0	654.0
FLEET TOTAL	7760.5	3269.1	2579.6	6551.5
ANNUAL MAINTENANCE COSTS				
ON-VEHICLE EQUIP.	432.3	153.0	212.8	532.0
SIGNPOSTS	281.2	130.1	22.2	0.0
REMOTE RECEIVERS	8.2	7.0	6.2	21.4
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	0.0
VARIABLE	0.6	0.6	0.6	12.0
DATA PROCESSING				
BASIC	18.8	16.0	12.0	20.4
VARIABLE	37.2	23.4	7.8	65.4
TOTAL ANN. MAINT.	780.2	331.5	262.6	651.2
PRESENT VALUE	4794.1	2037.1	1613.5	4001.5
PRESENT VALUE OF TOTAL COST:				
	12554.6	5306.1	4193.1	10553.0

THE LOWEST COST SYSTEM FOR POLICE   AT $ 4193.1 THOUSAND DOLLARS,
IN COLUMN 3, THE RADIO FREQUENCY SYSTEM

ANALYSIS OF BENEFITS FOR POLICE

WHAT PERCENT OF MILES TRAVELLED BY THE POLICE ARE SPENT IN PREVENTIVE PATROL?
(DEFAULT VALUE IS 50.00%.) NEW VALUE?

WHAT PERCENT OF MILES TRAVELLED IN RESPONSE TO CALLS WILL BE SAVED BY SENDING
THE CLOSEST CAR?
                          LOW %   HIGH %
DEFAULT VALUES   2.00   10.00
NEW VALUES?

IT IS ASSUMED THAT O&M COSTS CONSIST OF THE COST OF OPERATIONS AND MAINTENANCE,
INCLUDING FUEL AND LUBRICANTS, SERVICE AND REPAIR AT A TOTAL RATE OF $ .183
PER MILE, WITH   27. THOUSAND ANNUAL MILES PER CAR; AND LIABILITY INSURANCE
(OR COST OF ACCIDENTS) AT $ 0. PER CAR PER YEAR. YOU WILL HAVE A
CHANCE TO REPLACE THESE VALUES.
    COST OF OPERATIONS AND MAINTENANCE PER MILE (IN DOLLARS)?

    ANNUAL MILES PER YEAR PER CAR (IN THOUSANDS)?

    THE ABOVE FACTORS YIELD AN ANNUAL COST OF MAINTENANCE PER CAR OF   4.941
    THOUSAND DOLLARS. NEW VALUE?

    ANNUAL COST OF INSURANCE PER CAR (IN DOLLARS)?

IT IS ASSUMED THAT THERE ARE 3.3 PATROLMEN PER CAR EMPLOYED AT A SALARY OF
21.80 THOUSAND DOLLARS PER YEAR PER PATROLMAN.   BENEFITS AND OVERHEAD ARE
ASSUMED TO COST AN EQUAL AMOUNT. THE DEPARTMENT'S ATTRITION RATE IS 10.00%
PER YEAR. YOU WILL HAVE A CHANCE TO REPLACE THESE VALUES.
    PERSONS PER VEHICLE?

    PATROL FORCE = 4389. PERSONS. NEW VALUE?

    ANNUAL SALARY (THOUSAND DOLLARS)?

    BENEFITS AND OVERHEAD (THOUSAND DOLLARS)?

    ATTRITION RATE?

COST-BENEFIT SUMMARY FOR: POLICE
(DOLLAR VALUES IN THOUSANDS)

SAVINGS SOURCE:	RESPONSE TIME REDUCTION	
	LOW	HIGH
% CHANGE	2.0	10.0
VEHICLES SAVED	11.	53.
CAPITAL	$ 109.6	580.9
O&M	323.0	1615.2
SUBTOTAL	$ 432.6	2196.0
ITEM BENEFIT/COST:		
SINGLE USER	0.103	0.524
MULTI- USER	0.104	0.529
PATROLMEN SAVED	35.	176.
SALARY	$ 4786.9	23332.8
OVERHEAD+BEN	4786.9	23332.8
SUBTOTAL	$ 9573.9	46665.7
ITEM BENEFIT/COST:		
SINGLE USER	2.283	11.129
MULTI- USER	2.305	11.235
TOTAL SAVINGS	$ 10006.5	48861.7
SYSTEM COSTS:		
SINGLE USER	4193.1	4193.1
MULTI- USER	4153.7	4153.7
BENEFIT/COST RATIO:		
SINGLE USER	2.386	11.653
MULTI- USER	2.409	11.763

TYPE OF FLEET IS? TAXI

INPUT NUMBER OF VEHICLES TO BE EQUIPPED? 800←↖←

IS THIS FLEET CURRENTLY EQUIPPED WITH VOICE RADIOS? YES

HOW MANY SQUARE MILES COVERED? 475

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 0

FOR TAXI   :

	SHARP SIGNPOST	BROAD SIGNPOST	RADIO FREQUENCY (THOUSANDS OF DOLLARS)	DEAD-RECKONING
CAPITAL COST				
ON-VEHICLE EQUIP.	2600.0	920.0	1280.0	3200.0
SIGNPOSTS	2812.0	1300.6	221.6	85.5
REMOTE RECEIVERS	40.0	24.0	16.0	168.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	0.0
VARIABLE	4.0	4.0	4.0	80.0
DATA PROCESSING				
BASIC	188.0	160.0	120.0	204.0
VARIABLE	248.0	156.0	52.0	436.0
FLEET TOTAL	5912.0	2579.6	1703.6	4173.5
ANNUAL MAINTENANCE COSTS				
ON-VEHICLE EQUIP.	260.0	92.0	128.0	320.0
SIGNPOSTS	281.2	130.1	22.2	0.0
REMOTE RECEIVERS	6.8	6.1	5.3	20.5
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	0.0
VARIABLE	0.4	0.4	0.4	8.0
DATA PROCESSING				
BASIC	18.8	16.0	12.0	20.4
VARIABLE	24.8	15.6	5.2	43.6
TOTAL ANN. MAINT.	594.0	261.7	174.1	412.5
PRESENT VALUE	3649.7	1607.7	1069.5	2534.6
PRESENT VALUE OF TOTAL COST:	9561.7	4187.3	2773.1	6708.1

THE LOWEST COST SYSTEM FOR TAXI   AT $ 2773.1 THOUSAND DOLLARS,
IN COLUMN 3, THE RADIO FREQUENCY SYSTEM

A PORTION OF VEHICLE MILEAGE IS NON-REVENUE, DEAD-HEAD MILEAGE. THE DEFAULT
VALUE IS 50.00%. NEW VALUE (%)?

IT IS ASSUMED THAT 18.00% OF TOTAL MILEAGE IS UNAVOIDABLE DEAD-HEADING, TRAVEL
FROM THE DESTINATION OF LAST PASSENGER TO THE ORIGIN OF THE NEXT.
NEW VALUE (%)?

THE AVERAGE TAXICAB TRAVELS 50.000 THOUSAND MILES PER YEAR.
NEW VALUE (IN THOUSANDS)?

THE FACTORS ABOVE YIELD AN AVERAGE OF 20.500 THOUSAND MILES OF AVOIDABLE
DEAD-HEADING PER YEAR. WHAT PERCENT OF THOSE MILES CAN BE SAVED BY DISPATCH-
ING THE CLOSEST CAB TO EACH CALL AND OTHER DISPATCHING ECONOMIES DUE TO AVM?
                        LOW %   HIGH %
DEFAULT VALUES   10.00   20.00
NEW VALUES?

TO PREVENT "HIGH-FLAGGING", AT A COST OF   0.470 THOUSAND DOLLARS PER TAXI
(PRESENT VALUE DISCOUNTED OVER 10 YEARS), SEAT-PAD SWITCHES CAN BE INSTALLED
AND CONNECTED TO THE AVM SYSTEM SO THAT THE DISPATCHER IS AWARE THAT A PASSEN-
GER HAS ENTERED THE VEHICLE. IS THIS DEVICE TO BE INCLUDED?
ANSWER YES OR NO. NO

IT IS ASSUMED THAT O&M COSTS CONSIST OF THE COST OF OPERATIONS AND MAINTENANCE,
INCLUDING FUEL AND LUBRICANTS, SERVICE AND REPAIR AT A TOTAL RATE OF $ .093
PER MILE, WITH   50. THOUSAND ANNUAL MILES PER CAR; AND LIABILITY INSURANCE
(OR COST OF ACCIDENTS) AT $ 1475. PER CAR PER YEAR. YOU WILL HAVE A
CHANCE TO REPLACE THESE VALUES.
     COST OF OPERATIONS AND MAINTENANCE PER MILE (IN DOLLARS)?

     THE ABOVE FACTORS YIELD AN ANNUAL COST OF O&M PER CAR OF $ 4.670
     THOUSAND DOLLARS. NEW VALUE?

     ANNUAL COST OF INSURANCE PER CAR (IN DOLLARS)?

DOES THE OPERATOR INCUR COST OF SALARY, BENEFITS OR OVERHEAD FOR ANY DRIVERS
ON THE STAFF?

IT IS ASSUMED THAT THERE ARE 2.1 DRIVERS PER CAR EMPLOYED. THE AVERAGE
DRIVER EARNS 7.63 THOUSAND DOLLARS PER YEAR IN COMMISSIONS. A FEW MAY GET
ONLY MINIMUM WAGE, OR 4.8 THOUSAND DOLLARS PER YEAR. BENEFITS ARE 17.7% OF
THE COMMISSION PAID, OR 1.35 THOUSAND DOLLARS PER DRIVER PER YEAR. THE
COMPANY'S ATTRITION RATE IS 33.00% PER YEAR. YOU WILL HAVE A CHANCE TO
PROVIDE DETAILED PERSONNEL COST INFORMATION.
     DRIVERS PER VEHICLE?

     DRIVER FORCE =   1680.
     DRIVERS ON SALARY?

     ANNUAL SALARY PAID BY COMPANY (THOUSANDS OF DOLLARS)?
     NOTE: DO NOT INCLUDE COMMISSIONS. THE DEFAULT VALUE IS ZERO, OBTAINED
     BY A CARRIAGE RETURN.

     DRIVERS RECEIVING BENEFITS? DEFAULT IS ENTIRE FORCE.

     ANNUAL BENEFITS (IN THOUSANDS OF DOLLARS)?

     OVERHEAD PER DRIVER (THOUSANDS OF DOLLARS)? DEFAULT VALUE IS ZERO.

     ATTRITION RATE?

COST-BENEFIT SUMMARY FOR: TAXI
(DOLLAR VALUES IN THOUSANDS)

SOURCE OF SAVINGS:	"HIGH-FLAGGING" REDUCTION	
	LOW	HIGH
% CHANGE	0.0	0.0

REDUCE DEAD-HEAD MILES

	LOW	HIGH
% CHANGE	4.1	8.2
VEHICLES SAVED	33.	66.
CAPITAL	$ 239.1	485.7
O&M	1238.5	2476.9
SUBTOTAL	$ 1477.6	2962.7
ITEM BENEFIT/COST:		
SINGLE USER	0.533	1.068
MULTI- USER	0.585	1.174
DRIVERS SAVED	69.	138.
SALARY	$ 0.0	0.0
OVERHEAD+BEN	581.5	1147.5
SUBTOTAL	$ 581.5	1147.5
ITEM BENEFIT/COST:		
SINGLE USER	0.210	0.414
MULTI- USER	0.230	0.455
TOTAL SAVINGS	$ 2059.1	4110.1
SYSTEM COSTS:		
SINGLE USER	2773.1	2773.1
MULTI- USER	2523.7	2523.7
BENEFIT/COST RATIO:		
SINGLE USER	0.743	1.482
MULTI- USER	0.816	1.629

IF, FOR ANY REASON, THIS SYSTEM IS NOT A FEASIBLE CHOICE TO GO INTO THE FINAL
WRAP-UP, YOU MAY CHANGE IT BY TYPING A DIFFERENT COLUMN NUMBER AFTER THE
QUESTION MARK.   A CARRIAGE RETURN WILL KEEP THE PRESENT CHOICE.?

ANSWER QUESTIONS ON COST-SHARING WITH 'YES' OR 'NO'.   QUESTIONS ON
'HOW MANY' SQUARE MILES OR ROUTE MILES MUST BE ANSWERED WITH A PORTION OF
TH SQUARE MILES AND ROUTE MILES COSTED FOR THE MULTI-USER CASE.   IF THAT
TOTAL IS EXCEEDED, YOU WILL GET AN ERROR MESSAGE AND MUST START THE SUB-
DIVISION OVER AGAIN.

DO ANY SERVICE AREAS (SQUARE MILES) OF DIFFERENT FLEETS OVERLAP ? YES

ANY AREA SERVED BY 3 USER(S) ? YES

HOW MANY SQUARE MILES? 475

SERVED BY BUS   ? YES

SERVED BY POLICE   ? YES

SERVED BY TAXI   ? YES

DO DIFFERENT FLEETS SERVE OVERLAPPING ROUTE MILES ? NO

ANY AREA SERVED BY 1 USER(S) ? YES

HOW MANY ROUTE MILES ? 2647

SERVED BY BUS   ? YES

SERVED BY POLICE   ? NO

SERVED BY TAXI   ? NO

TYPE OF FLEET IS?   TOTAL

HOW MANY SQUARE MILES COVERED? 475

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 2647

FOR MULTI-USER :

	SHARP SIGNPOST	BROAD SIGNPOST	RADIO FREQUENCY	DEAD-RECKONING
		(THOUSANDS OF DOLLARS)		
CAPITAL COST				
ON-VEHICLE EQUIP.	14068.5	5275.5	7314.0	18282.0
SIGNPOSTS	3447.3	1496.4	936.4	562.0
REMOTE RECEIVERS	400.0	192.0	160.0	1708.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	0.0
VARIABLE	20.0	20.0	20.0	242.5
DATA PROCESSING				
BASIC	188.0	160.0	120.0	204.0
VARIABLE	1240.0	780.0	260.0	2180.0
GRAND TOTAL	19383.8	7938.9	8820.4	23178.5
ANNUAL MAINTENANCE COST				
ON-VEHICLE EQUIP.	1406.9	527.6	731.4	1828.2
SIGNPOSTS	344.7	149.6	93.6	0.0
REMOTE RECEIVERS	88.0	55.2	49.0	254.0
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	0.0
VARIABLE	2.0	2.0	2.0	24.3
DATA PROCESSING				
BASIC	18.8	16.0	12.0	20.4
VARIABLE	124.0	78.0	26.0	218.0
TOTAL ANN. MAINT.	1986.4	829.9	915.0	2344.9
PRESENT VALUE	12205.4	5099.3	5622.5	14408.3
PRESENT VALUE OF TOTAL COST:				
	31589.2	13038.2	14442.8	37586.8

    THE LOWEST COST SYSTEM FOR MULTI-USER   AT $ 13038.2 THOUSAND DOLLARS,
    IN COLUMN 2, THE BROAD SIGNPOST SYSTEM

IF, FOR ANY REASON, THIS SYSTEM IS NOT A FEASIBLE CHOICE TO GO INTO THE FINAL
WRAP-UP, YOU MAY CHANGE IT BY TYPING A DIFFERENT COLUMN NUMBER AFTER THE
QUESTION MARK. A CARRIAGE RETURN WILL KEEP THE PRESENT CHOICE.?

ANSWER QUESTIONS ON COST-SHARING WITH 'YES' OR 'NO'. QUESTIONS ON
'HOW MANY' SQUARE MILES OR ROUTE MILES MUST BE ANSWERED WITH A PORTION OF
THE SQUARE MILES AND ROUTE MILES COSTED FOR THE MULTI-USER CASE. IF THAT
TOTAL IS EXCEEDED, YOU WILL GET AN ERROR MESSAGE AND MUST START THE SUB-
DIVISION OVER AGAIN.   C-12

COMPARISON OF COSTS

FOR EACH FLEET WITH THE LOWEST COST SYSTEM FOR THAT FLEET ALONE ON THE LEFT,
AND EACH FLEET'S SHARE OF THE LOWEST COST MULTI-USER ALTERNATIVE ON THE
RIC :

FOR: BUS	ALONE	SHARE OF MULTI-USER
	BROAD SIGNPOST	BROAD SIGNPOST
	(THOUSANDS OF DOLLARS)	
CAPITAL COST		
ON-VEHICLE EQUIP.	2826.0	2826.0
SIGNPOSTS	283.0	321.6
REMOTE RECEIVERS	192.0	174.3
COMMUNICATIONS		
BASIC	15.0	7.9
VARIABLE	10.0	10.0
DATA PROCESSING		
BASIC	160.0	84.8
VARIABLE	390.0	390.0
FLEET TOTAL	3876.0	3814.6
ANNUAL MAINTENANCE COSTS		
ON-VEHICLE EQUIP.	282.6	282.6
SIGNPOSTS	28.3	32.2
REMOTE RECEIVERS	40.2	50.3
COMMUNICATIONS		
BASIC	1.5	0.8
VARIABLE	1.0	1.0
DATA PROCESSING		
BASIC	16.0	8.5
VARIABLE	39.0	39.0
TOTAL ANNUAL MAINT.	408.6	414.4
PRESENT VALUE	2510.7	2546.1
PRESENT VALUE OF TOTAL COST:	6386.7	6360.7

```
FOR: POLICE                  ALONE          SHARE OF MULTI-USER
                             -----          -------------------
                        RADIO FREQUENCY      BROAD SIGNPOST
                          (THOUSANDS OF DOLLARS)
CAPITAL COST
------------
ON-VEHICLE EQUIP.            2123.0              1529.5

SIGNPOSTS                     221.6               733.6
REMOTE RECEIVERS               16.0                11.1

COMMUNICATIONS
     BASIC                     10.0                 4.4
     VARIABLE                   6.0                 6.0

DATA PROCESSING
     BASIC                    120.0                47.0
     VARIABLE                  78.0               234.0

FLEET TOTAL                  2579.6              2565.5

ANNUAL MAINTENANCE COSTS
------------------------
ON-VEHICLE EQUIP.             212.8               153.0

SIGNPOSTS                      22.2                73.4
REMOTE RECEIVERS                6.2                 3.0

COMMUNICATIONS
     BASIC                      1.0                 0.4
     VARIABLE                   0.6                 0.6

DATA PROCESSING
     BASIC                     12.0                 4.7
     VARIABLE                   7.8                23.4

TOTAL ANNUAL MAINT.           262.6               258.5
PRESENT VALUE                1613.5              1588.2

PRESENT VALUE OF TOTAL COST:  4193.1              4153.7
```

FOR: TAXI	ALONE	SHARE OF MULTI-USER
	RADIO FREQUENCY	BROAD SIGNPOST
	(THOUSANDS OF DOLLARS)	

CAPITAL COST

ON-VEHICLE EQUIP.	1280.0	920.0
SIGNPOSTS	221.6	441.2
REMOTE RECEIVERS	16.0	6.7
COMMUNICATIONS		
BASIC	10.0	2.6
VARIABLE	4.0	4.0
DATA PROCESSING		
BASIC	120.0	28.3
VARIABLE	52.0	156.0
FLEET TOTAL	1703.6	1558.8

ANNUAL MAINTENANCE COSTS

ON-VEHICLE EQUIP.	128.0	92.0
SIGNPOSTS	22.2	44.1
REMOTE RECEIVERS	5.3	1.8
COMMUNICATIONS		
BASIC	1.0	0.3
VARIABLE	0.4	0.4
DATA PROCESSING		
BASIC	12.0	2.8
VARIABLE	5.2	15.6
TOTAL ANNUAL MAINT.	174.1	157.0
PRESENT VALUE	1069.5	964.9
PRESENT VALUE OF TOTAL COST:	2773.1	2523.7

Memorandum

DATE: 7/9/76

In reply
refer to: 421

SUBJECT: Reduction in Headway Variance

FROM: Arthur Priver/421

TO: Dave Reed/234

If a control strategy is applied to buses travelling along a route then the variance of the distribution of headways should be reduced in comparison with the variance that occurs when no control is applied. We will compute the variance reduction for the following specific control strategy. First, a bus is never allowed to leave a stop early. Second, a late bus always tries to catch up to get back on schedule.

Assume that a bus leaves a stop exactly on time and that its arrival time (and consequent departure time) at the next stop is normally distributed about the expected arrival time with a mean of zero and a variance σ_0^2. Then the departure time is given by a truncated normal distribution in which all values greater than 0 (i.e. early departures) are pushed back to 0:

becomes
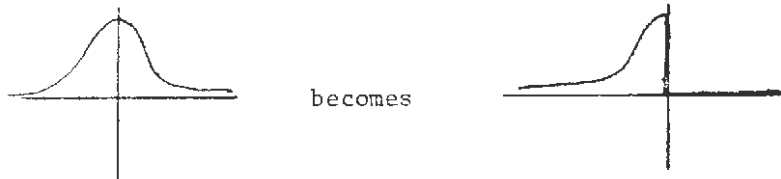
The density function is given by

(1) $\quad f(x) = \begin{cases} (1/\sigma_0 \sqrt{2\pi}) \; e^{-x^2/2\sigma_0^2} & -\infty \leq x < 0 \\ 0 & 0 < x \leq \infty \end{cases}$

The mean of this distribution is given by

(2) $\quad \bar{x} = \int_{-\infty}^{\infty} x \, f(x) \, dx$

$\qquad \bar{x} = \frac{1}{\sigma_0 \sqrt{2\pi}} \int_{-\infty}^{0} e^{-x^2/2\sigma_0^2} \; x \, dx$

Let $u = -x^2/2\sigma_0^2$. Then $du = (-x/\sigma_0^2)dx$, so $x\,dx = -\sigma_0^2\,du$. Hence

$$(3) \quad \bar{x} = \frac{-\sigma_0^2}{\sigma_0\sqrt{2\pi}} \int_{-\infty}^{0} e^{+u}\,du = -\sigma_0/\sqrt{2\pi} .$$

In order to compute the variance σ^2 of the truncated normal we also need to compute

$$(4) \quad E(x^2) \doteq \bar{x^2} = \frac{1}{\sigma_0\sqrt{2\pi}} \int_{-\infty}^{0} x^2 e^{-x^2/2\sigma_0^2}\,dx .$$

By symmetry and since if the integral went from $-\infty$ to ∞ the value would be σ_0^2, we have

$$(5) \quad \bar{x^2} = \sigma_0^2/2$$

Thus

$$(6) \quad \sigma^2 = \bar{x^2} - (\bar{x})^2 = \sigma_0^2\left(\frac{1}{2} - \frac{1}{2\pi}\right)$$

$$= \sigma_0^2\left(1 - \frac{1}{\pi}\right)/2 .$$

The variance of the new headway distribution is reduced from the variance of the initial distribution by a factor of $1/2\,(1 - 1/\pi)$, which is approximately .341.

Computing the variance reduction at the next stop is very complicated, since it involves the convolution of a Normal with a truncated Normal distribution. In view of this difficulty, we will use the assumption that a late bus is trying to get back on schedule, and assume that the variance reduction computed above is the bound at each stop.

Let us now relate the above analysis to the impact on headway and the passenger load factor of keeping the same level of service, as measured by average passenger waiting time, with the computed variance reduction. First note that headway and passenger load factor are linearly related. The load factor (L) equals the number of passengers (P) divided by the number of buses (N). The number of buses is given by the total time (T) divided by the headway (h). Thus L = P/N = P/(T/h) = (P/T)h. Hence, an increase in headway of x% results in a corresponding x% increase in the passenger load factor.

Let h be the headway between buses, σ^2 be the variance of this headway, and W be the average passenger waiting time. We have our previous formula

$$W = \frac{h}{2} + \frac{\sigma^2}{2h} .$$

If we have an initial headway h_0 and variance σ_0^2 and have a new reduced variance σ^2, then for the same level of service (i.e., W = constant) we can compute the corresponding headway h:

$$W = \frac{h_c}{2} + \frac{\sigma_c^2}{2 h_c} = \frac{h}{2} + \frac{\sigma^2}{2h}$$

Then,

$$h^2 - 2hW + \sigma^2 = 0$$

Solving this quadratic equation and using the constraints of motion gives us the single solution

$$h = W + \sqrt{W^2 - \sigma^2} \; .$$

(Note that if $\sigma = 0$ the average waiting time is half the headway, as expected).

From our earlier calculations, we know

$$\sigma^2 = \sigma_c^2 \left(1 - \frac{1}{\pi^2} \right) / 2 \; ,$$

Thus,

$$h = \frac{h_c}{2} + \frac{1}{2 h_c} \left(\sigma_c^2 + \sqrt{(h_c^2 + \sigma_c^2)^2 + \left(1 - \frac{1}{\pi^2} \right) \sigma_c^4} \right) .$$

(Again, note that if $\sigma_c = 0$ then $h = h_c$).

Let us consider one representative case, and set $\sigma_c = 1$. Then, with $1 - 1/\pi^2 = .8986788$, we can compute the following table:

h_0	0.5	1	2	3	4	5	10
h	2.82	2.11	2.52	3.34	4.25	5.2	10.1
Inc. in load factor	464%	111%	26%	11%	6%	4%	1%

This table corresponds to a standard deviation of one minute in the headway. Empirical data from Chicago shows that the standard deviation is approximately the same magnitude as the headway, so the emphasis in using the above table should be placed around $h_0 = 1$ and $h_c = 2$. Thus, the control strategy being considered gives a significant increase in the passenger load factor, even approaching 100% or more.

A. Priver

A. Priver

cc:
421/D. Lev
430/F. Tung
433/B. Blood
234/M. Roos

D-4

EXTENSION OF PRIVER CALCULATIONS TO LONGER STANDARD
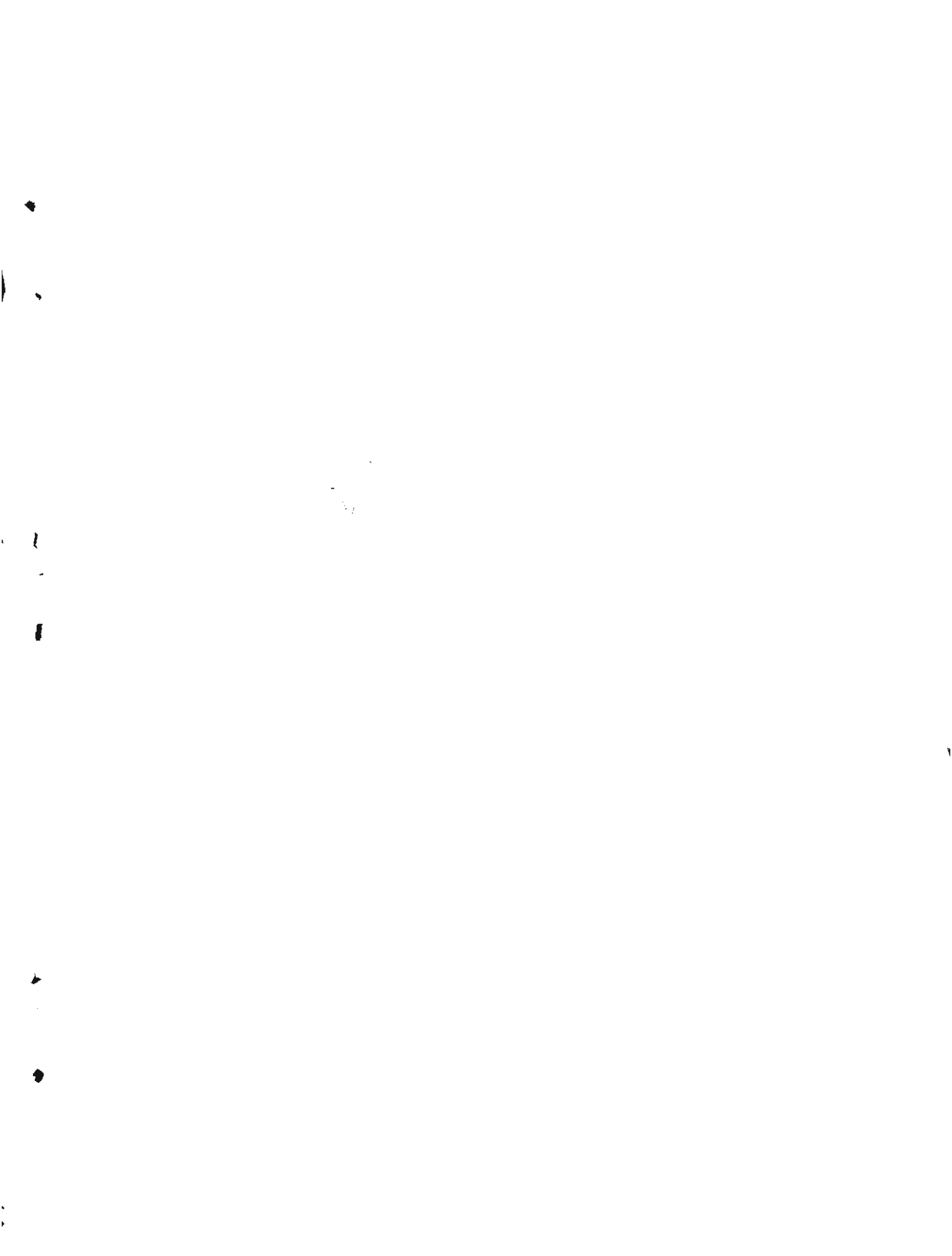# DEVIATIONS FOR 5 AND 10 MINUTE HEADWAYS

σ_ℓ

1	$h_\bullet$	5	10
	h	5.2	10.1
	load factor increase	4%	1%

3	$h_\bullet$	5	10
	h	6.9	10.9
	load factor increase	38%	9%

5	$h_\bullet$	5	10
	h	10.53	12.6
	load factor increase	111%	26%

7	$h_\bullet$	5	10
	h	16.13	15.3
	load factor increase	222%	53%

10	$h_\bullet$	5	10
	h	28.2	21.1
	load factor increase	464%	111%

A Study of the costs and
benefits associated with

U. S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE, CAMBRIDGE, MA. 02142

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

U.S.MAIL

POSTAGE AND FEES PAID

U. S. DEPARTMENT OF TRANSPORTATION

518