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Final Report
December 1977

Volume II.

U.S. DEPARTMENT OF TRANSPORTATION
Urban Mass Transportation Administration

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16. Abstract

This report was produced as part of the Auto Restricted Zone/Multi-User Vehicle Systems Study of the Service and Methods Demonstation Program of the Urban Mass Transportation Administration.

The volume examines multi-user vehicle systems, an innovative form of paratransit services. The report defines the concept, investigates existing experience and evaluates its feasibility as a mode of urban transportation. As a result of a simulated operations analysis and evaluation of existing operations, the concept was found to be infeasible as a major urban transportation mode.

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AUTO RESTRICTED ZONE/ MULTI-USER VEHICLE SYSTEM STUDY

DOT-TSC-1057

FINAL REPORT

VOLUME II

MULTI-USER VEHICLE SYSTEMS: FEASIBILITY ASSESSMENT

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION

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In Association With
CAMBRIDGE SYSTEMATICS INC.
and
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December 1977

This report is prepared as part of the Auto Restricted Zone/Multi-User Vehicle System Study for the Urban Mass Transportation Administration of the U.S. Department of Transportation.

The purpose of the study was to (1) investigate existing experience with auto restricted zones and multi-user vehicle systems, (2) evaluate their feasibility as concepts applicable to urban transportation systems, (3) identify and evaluate potential sites for suitable demonstrated projects, and (4) design demonstration and evaluation programs for selected sites.

This particular report documents the investigation of existing experience and evaluation of key factors and overall feasibility of multi-user vehicle systems. The complete listing of final report documents includes:

- Volume I — Auto Restricted Zones: Background and Feasibility
- Volume II — Multi-User Vehicle Systems: Feasibility Assessment
- Volume III — Auto Restricted Zones: Plans for Five Cities
- Volume IV — Demonstration Site Selection
- Boston Auto Restricted Zone: Technical Appendix
- Burlington Auto Restricted Zone: Technical Appendix
- Memphis Auto Restricted Zone: Technical Appendix
- Providence Auto Restricted Zone: Technical Appendix
- Tucson Auto Restricted Zone: Technical Appendix

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Executive Summary

EXECUTIVE SUMMARY

As part of the Auto Restricted Zone/Multi-User Vehicle System Study sponsored by the Urban Mass Transportation Administration, U.S. Department of Transportation, an evaluation was made to determine the feasibility of utilizing a multi-user vehicle system (MUVS) as an integral part of an urban transportation system.

Various forms of MUVS, such as short-term rental cars, drive yourself taxis, or public bicycle systems, are often proposed as a potential solution to the problems of transportation in urban areas. The basic goal of such proposals is to provide a mode of public transportation that replicates the desirable features of the auto, such as privacy and route and schedule flexibility, without the pollution, congestion, and energy disadvantages of private auto use.

The distinguishing characteristic of MUVS is the provision of small user-operated vehicles for use among a set of fixed, but relatively ubiquitous, terminals in an identified service area. The possible variations in vehicle design and operating environment are numerous. But in all cases, the characteristic that sets MUVS apart from other forms of conventional and paratransit services is that the user serves as the vehicle operator. The potential cost savings from reducing the labor-intensity of public transit services is apparent when one considers that labor comprises approximately one half of bus operating costs and an even greater percentage of taxi operating cost. Other potential benefits of MUVS may also include its low energy consumption, minimal production of pollutants, reduced parking and street space requirements relative to the private auto, and its convenience relative to conventional bus services.

Although MUVS, broadly defined, has been widely used in a variety of special applications (e.g., shopping carts, short-term rental vehicles), operating experience with MUVS as a circulation system in urban areas has been limited. In the few isolated cases where MUVS has been employed in urban areas, the systems have either failed outright on financial grounds or maintained operations on a very small-scale basis without generating sufficient demand to be seriously considered as a viable and significant urban transportation service.

In view of the limited success with MUVS to date, the analysis began with an appraisal of existing experience with MUVS city circulation services to determine whether the limited success with MUVS to date is indicative of inherent weaknesses with the concept or whether it can be attributed to isolated factors which could be overcome in future demonstration projects. The appraisal concludes that neither of the two experiments with MUVS to date—one in Montpellier, France, and the other in Amsterdam, The Netherlands—provided conclusive evidence on the ultimate viability of MUVS. In both instances, a variety of unique and potentially correctable institutional and system design factors limited the potential of the systems. Based upon a thorough analysis of the key factors related to MUVS demand and supply issues and overall feasibility of a successful MUVS demonstration, however, it has been concluded that it is unlikely that MUVS is a viable and promising alternative mode for intra-CBD service with or without auto restrictions. The four basic reasons for this conclusion are the following:

1. Unreliability of Service — Even with relatively large fleet sizes, stochastic variations in customer arrivals and systematic diurnal and directional demand peaking within the service area lead to potentially long vehicle wait times. The variance in customer wait times is also extremely high.

2. Low System Utilization — Even assuming zero terminal vehicle turnaround requirements for refueling or recharging MUVS vehicles, the analyses consistently showed fleet utilization rates to be 15 percent or less. Thus, for the great majority of time, MUVS vehicles would sit idle at terminals.

3. Potentially Large Fleet Size and Terminal Requirements — In order to provide a MUVS service which competes with the door-to-door convenience of taxi (or possibly private auto), terminal densities on the order of over 100 per square mile may be required. The fleet size requirements to avoid inordinately long wait times are extremely sensitive to the directional and diurnal peaking characteristics. In all of the analyses, even with fleet sizes as high as one vehicle per 12.5 person-trips in the service area, temporary vehicle unavailability at selected terminals persisted for as long as a half hour.

4. Potentially High System Cost — In view of the above conclusions, capital costs per trip are very high. Operating costs may also be high relative to alternative modes. Even if self-powered vehicles were deployed, implementing a vehicle redistribution policy to mitigate the effects of directional demands requires the repositioning of a large number of vehicles with correspondingly high labor costs. The analysis of one vehicle redistribution policy required deadheading

trips equal to 12 percent of revenue trips. Moreover, even with high vehicle repositioning during the course of the day, vehicle unavailability at selected terminals remained a critical factor.

These conclusions are derived from both a qualitative and quantitative analysis of multi-user vehicle systems which are discussed in more detail in the main body of the report.

Chapter I

Introduction

CHAPTER I
INTRODUCTION

This report documents the results of an investigation into the feasibility of multi user vehicle systems (MUVS) as a mode of urban public transportation. This investigation was performed as part of the Auto Restricted Zone/Multi-User Vehicle System Study, sponsored by the Urban Mass Transportation Administration. Under Phase I of this study, the consultant team conducted a review of existing experience, an examination of key factors, and an assessment of MUVS feasibility as the first stage in a potential in-depth research and experimentation effort.

The term "multi-user vehicle system" is used here to describe an innovative transportation concept that has been suggested as one solution to the problems of automobile traffic in urban areas. A multi-user vehicle is one which is available to a class of potential users on an "as-available" basis to serve the function that would otherwise be served by a privately-owned vehicle. The concept is an extension of the idea that shared use of a capital-intensive facility (a vehicle) permits allocation of costs across a larger group, thus allowing the vehicle to be available in situations where it would not otherwise be economically feasible. There are, however, many types of vehicles which could be candidates for MUVS operation, including autos, bicycles, mopeds, and electric carts.

The MUVS concept has been presented and discussed in a number of previous articles and investigations, which are listed in the bibliography of this report. In general, these earlier studies have noted the concept's potential for technological and economic feasibility, but have concluded that more analysis was necessary before the MUVS concept could be meaningfully applied to the problems of urban transportation. The present study builds upon this early consideration of the topic through the articulation of MUVS essential elements and the identification and rigorous analysis of the key factors affecting MUVS feasibility.

Chapter II begins with the discussion of the goals and objectives of the MUVS concept. Seven specific transportation and environmentally-related objectives are presented within the basic MUVS goal. Next, a number of characteristics are identified and classed as essential MUVS elements. The discussion of these elements presents an operational definition of the concept to be tested in this investigation. The chapter goes on to consider the existing applications of the MUVS concept, characteristics of operating environments, and the impacts of modal competition on MUVS success.

Chapter III extends this discussion through the detailed examination of the existing experience with MUVS as a CBD circulation service. Two European systems are explored—one in Amsterdam, the other in Montpellier, France. Institutional factors, operating area characteristics, and vehicle designs are detailed for each system, in addition to descriptions of operating policies and fare structure. The relative strengths and weaknesses of each system are identified and compared.

Chapter IV documents the analysis of key factors in MUVS feasibility. After key factors are identified and discussed, four types of analyses are performed. The static demand analysis hypothesizes fixed MUVS demand levels and determines the resulting fleet size and performance tradeoffs. In the static supply analysis, the process is inverted. A disaggregate demand model is employed to relate the probability that a traveler will choose MUVS for a non-home-based trip as a function of a specified MUVS level of service. The following stochastic analysis of MUVS abandons the unrealistic assumptions of the static analyses, which only examine MUVS operation under the best possible circumstances. In the stochastic analysis, a simulation approach is used to explore the performance of MUVS under variable demand and level of service conditions. In the final dynamic supply-demand equilibrium analysis, a disaggregate mode split model is imbedded in the simulation routine, so that MUVS demands are determined as a function of current variable level of service conditions. The purpose of the analysis is to evaluate the equilibrium supply and demand characteristics of an MUVS circulation service in an ARZ environment.

The report closes with a summary of the principal results and major conclusions on the feasibility of MUVS as a significant addition to the range of widely available urban transportation modes.

Chapter II

Multi-User Vehicle Systems: An Organizational Framework

CHAPTER II

MULTI USER VEHICLE SYSTEMS: AN ORGANIZATIONAL FRAMEWORK

In the introduction, an MUVS was described as a set of vehicles offered to a class of potential users on an "as-available" basis for trips between fixed terminals. The individual user would serve as the operator of the vehicle. "Multi-user" means a series of sequential individual users, not a multiple occupancy vehicle. An MUVS is not a conventional bus, dial-a-ride, taxi, jitney, or minibus. The MUVS concept has been described elsewhere as a user-operated taxi, short-term rental car, or as a public auto system. These terms convey the central feature of such a system, the availability of a vehicle for short-term rental for quick trips around town, but narrowly focus on the automobile as the vehicle to be provided for hire. This chapter will discuss a wide range of possible goals, essential elements, and operating contexts for potential future applications of the MUVS concept.

GOALS AND OBJECTIVES

The basic goal of an MUVS is very similar to the general goal framework enunciated for auto-restricted zones. The overall societal goal is the improvement in the quality of life in urban areas. Seven specific objectives have been identified for MUVS which relate this general social aim to the role of transportation in the urban environment. The objectives advanced for the creation and operation of an MUVS include:

1. To alleviate congestion and improve traffic flow
2. To increase mobility
3. To provide an additional choice of mode
4. To reduce air pollution from vehicle emissions
5. To reduce noise
6. To conserve energy
7. To reduce land requirements for parking

Like any transportation system, the MUVS is intended to increase the general mobility of the population. The system is intended to replicate the desirable features of present-day auto use such as mobility, route flexibility, speed, manageable cost, and door-to-door convenience. The basic MUVS aim is to capture these advantages for the user while simultaneously reducing the social costs of congestion, noise, and pollution associated with auto use.

ESSENTIAL ELEMENTS

Within the broad definition advanced earlier for MUVS, a number of characteristics have been identified which can be termed essential elements. These characteristics constitute an operational definition of the MUVS concept.

User Operation

This characteristic of MUVS serves to distinguish MUVS from a number of other paratransit services that also offer individualized point-to-point service such as taxi, dial-a-ride, or jitney. Within this definitional framework, many examples can be found of existing MUVS systems ranging from shopping carts to the large-scale commercial car rental companies. As conceived for urban use, the MUVS can best be described as a hybrid between the existing commercial car rental companies and taxi services.

The commercial car rental services represent the widest spread application of a true MUVS but differ from the urban concept in the degree of control exercised in screening potential users and the duration of use and the length of trip. Taxi services typically have trip lengths and durations consistent with envisaged urban MUVS applications but lack the characteristics of user operation.

Vehicle Type

Vehicles considered for MUVS operation are relatively small in overall dimensions and seating capacity. Propulsion would be more efficient in terms of energy consumption and pollution than the conventional auto. Vehicles under consideration for potential application include bicycles, scooters, and mopeds, as well as electric cars.

Fixed Terminal Network

It is assumed that the vehicles operate on a terminal-to-terminal basis as opposed to an ubiquitous vehicle availability mode of operation. This restriction is imposed for two reasons:

1. Terminal-to-terminal operation facilitates guarding against theft, vandalism, and unauthorized use of MUVS.
2. Terminal-to-terminal operation allows for vehicle redistribution if necessary.

Fleet Operation

MUVS vehicles would be operated as a fleet with centralized maintenance and redistribution functions. Vehicle flows would be monitored and to some extent controlled through a central information system. Users would be paying not for a vehicle but for the use of a vehicle from the available fleet.

Vehicle Availability

In some existing applications of the MUVS concept, the use of a vehicle is restricted to a narrow class of potential users. In light of the objectives articulated above for MUVS, the investigation reported on here presupposed wide availability of MUVS vehicles to a large segment of the population. The exact nature of such user restrictions is a direct function of vehicle capital costs and design speed, so that classes of potential users cannot be specified without knowledge of a particular MUVS operating context and vehicle type employed.

MUVS OPERATING CONTEXT

Several issues arise when MUVS systems are considered for application. These are primarily concerned with operational factors required to make the system attractive and efficient compared to other means of transportation. In this regard, it is useful to define the operating environment for which an MUVS is most suited.

Service Specification Envelope

Like other transportation systems, MUVS operates within a set of limiting factors, or constraints, which specify an "envelope" in which the service functions. Four principal constraints can be identified for MUVS operation:

1. Operating Cost — Unless there are strong service or environmental reasons which override direct economic costs, the MUVS concept is appropriate when other public transport modes cannot provide similar service at less cost. Situations of medium to high volumes between two terminals or many terminals along a linear path are the domain of traditional bus services and are not applicable to MUVS service. MUVS service is more appropriate when demand is relatively low for any point-to-point trip and destinations are diverse.

2. Redistribution — Uneven distribution leads to low vehicle productivity and additional operating costs for redistribution. These problems will occur when there is significant unbalanced demand over an operating interval. Thus, the ideal MUVS application would be in an area with balanced demand between terminals.

3. Fleet Size — In order to provide an attractive service, delay associated with vehicle availability must be kept to a minimum. The fleet available at any single terminal must, therefore, approach the level of peak demand, and a substantial fleet must be provided for significant usage. With less expensive vehicles, a large fleet could be provided at a reasonable demonstration cost. More costly vehicles seriously limit the potential of MUVS.

4. Use Area — While there are no theoretical constraints on the size of the area in which an MUVS vehicle may be used, there are practical considerations related to need for the service and availability of vehicles. The substitutability of walking for a vehicle trip probably defines the lower limit for MUVS use. In areas under 1,500 x 1,500 feet, it seems likely that the time required to check-out, drive, and check-in the vehicle would limit demand for MUVS service. At the other end of the scale, too large an area involves long trip durations, thus requiring larger fleet sizes to insure vehicle availability, and also increases the probability of unbalanced demand. Based on Manhattan cab experience, 75 percent of all taxi trips are less than two miles in length. This suggests an MUVS area of one to two square miles which probably represents a desirable size for an MUVS service with an average trip duration of 5-15 minutes.

Existing Applications: A Taxonomy

Investigation into the existing experience with the concept of MUVS has uncovered a number of existing systems. Current systems are of two types, generic and specific. The term generic is applied to the set of existing MUVS systems that use a particular vehicle and operate in a similar manner. An example of a generic system would be rental bicycles which operate in a fairly similar recreational context throughout the country. A specific application, on the other hand, is a particular system and its operating location which is distinguished because of the vehicle used or certain operating practices. An example would be the Atlanta Pedal Pool, a bicycle pool for city employees, which is held separate from the generic rental bicycles because of specific features of its operation, despite the fact that the vehicle is the same in both cases.

For the purposes of this study, 15 existing applications of the MUVS concept have been organized and classified into four categories. The 15 applications representing a mix of generic and specific systems were selected to illustrate the various options that exist in the broad range of current systems. Table 1 presents the 15 applications grouped into four categories: carts, rental vehicles, pool vehicles, and recreational vehicles.

Operating Environments: A Qualitative Analysis

One of the primary considerations in the design and analysis of a multi-user vehicle system is its operating environment. The existing applications of MUVS illustrate the various types of operating context that are available and their importance to successful operation. The term "operating environment" describes a set of conditions that structure the performance of the system. These conditions consist of a combination of several variables including the availability of alternate modes, the degree of closure, and the size and boundedness of the service area. This information for the existing applications of MUVS is summarized and presented in Table 2.

Table 1
Existing Applications of the MUVS Concept: Four Classes

I. CARTS

- A. Grocery
- B. Baggage
- C. Strollers

II. RENTAL VEHICLES

- A. With One-Way Option
    - 1. Rent-A-Car
    - 2. WITKARS — Amsterdam
    - 3. TIP — Montpellier
    - 4. Rental Trailers and Trucks
- B. Single Terminal
    - 1. Rental Bicycles
    - 2. Rental Mopeds — Bermuda
    - 3. Golf Carts

III. POOL VEHICLES

- A. Motor Pools
- B. Pedal Pool — Atlanta

IV. RECREATIONAL

- A. Skates
- B. Bumper Cars
- C. Boats

Table 2
Characteristics Of MUVS Operating Environments

Characteristics Of MUVS Operating Environments	MUVS Concept Application														
	Carts			Rental Vehicles							Pool Vehicles		Recreational		
	Grocery Carts	Baggage Carts	Strollers	Rent-A-Car	Witkar	TIP	Rental Trailers	Rent-A-Bike	Moped	Golf Carts	Motor Pool	Pedal Pool	Skates	Bumper Cars	Boats
Degree of Closure to Other Vehicles	●	●	◕	◔	◑	◑	◔	◑	◕	●	◔	◔	●	●	●
Degree of Climate Control	●	●	◕	◔	◔	◔	◔	◔	◔	◔	◔	◔	●	●	◔
Degree of Terrain Control	●	●	●	◔	◔	◔	◔	◑	◔	◑	◔	◔	●	●	●
Relative Size of Area	◔	◔	◑	●	◕	◕	●	◕	◕	◑	◕	◑	◔	◔	◔
Degree of Physical Boundaries	●	●	◕	◔	◔	◔	◔	◔	●	◕	◔	◔	●	●	●
Degree of Performance Boundaries	◕	◕	◕	◔	●	◔	◔	◑	◑	●	◔	◑	◕	●	●

● greatest

⊕ least

A description of the major characteristics of MUVS operating environments would include:

- Presence of Alternative Modes — The existence of available modal alternatives to the MUVS is a key variable in forecasting system success. The presence and relative attractiveness of other modes within the proposed service area are important in two ways. Depending upon the characteristics of these alternatives, they may compete with MUVS for users, and for road space. Thus, the presence of a alternatives can affect the level of MUVS utilization directly, by attracting potential MUVS users, and indirectly through the effects of congestion and increased MUVS travel time performance. In addition, if the MUVS vehicle is small, slow, or unenclosed, users may feel vulnerable when competing with other vehicles for road space, and thus form a reluctance to use the system on safety grounds.

- Degree of Closure — The presence of available alternatives is closely linked to a principal characteristic of the operating environment— the degree of closure. The existing applications of MUVS exhibit a range of operating environments that can be described as open or closed. Basically, an operating environment is closed if walking and the MUVS are the sole modes of transport permitted. Such an environment is closed to all other forms of vehicular movement. This is one extreme on the closure scale but represents a situation that is very prevalent with existing applications of MUVS. Several of the most successful MUVS applications operate in closed environments, which are otherwise exclusively pedestrian areas. Grocery and baggage carts perform needed functions within the confines of a store or airline terminal. In the same way, golf carts at a country club and children's strollers at a shopping center provide mobility within pedestrian zones. Clearly, the absence of competing modes in these situations maximizes the position of the MUVS to attract the largest possible usage.

  It would be incorrect, however, to conclude that MUVS can only succeed in a closed environment, protected from all competition. Several of the existing applications of the MUVS concept function quite well in a completely open operating environment. In this situation, the MUVS is but one of many different types of transportation services operating in a given area. MUVS vehicles compete for passengers and road space with a wide variety of other vehicles. Rental cars and trailers are excellent examples of widely available and profitable MUVS which operate over city streets and interurban highways with other cars, taxis, buses, and trucks. The Atlanta Pedal Pool and the conventional motor pool are also examples of MUVS that operate over a public network which is open to any licensed vehicle.

- Climate and Terrain Control — After closure, a second group of operating environment characteristics centers around the degree of control exercised over climate and terrain. MUVS operating environments range from sheltered to completely unprotected. The stores, shopping centers, and transportation terminals, which comprise the operating environments for the carts class of MUVS, are entirely artificial environments. The temperature and humidity are controlled; there is no wind, precipitation, or difficult terrain. The entire environment is created as a shelter to facilitate pedestrian movements. At the other end of the scale, Witkars are one of several systems which operate in all kinds of weather over the topography of the street network. Golf carts are an MUVS that operate within an intermediate state of protection, following a path over a terrain-modified course and are seldom used in severe weather.

- Area Size and Bounds — The third set of principal characteristics of MUVS operating environments is concerned with the size and "boundedness" of the service area. In size of service area, the existing applications of the MUVS concept again exhibit a wide range of options. The cart systems usually operate within the smallest areas which range from several thousand square feet to two or three blocks. Other systems, such as rental cars, have an almost unlimited service area. Perhaps more important is the degree of "boundedness" imposed on the perimeter of the service area. Boundaries can be of three types: physical, regulatory, and performance. The rental mopeds in Bermuda remain within the designated service area because of the physical barrier of the island's geography. In a similar fashion, metal fences may be installed around supermarkets in order to physically restrain the grocery cart at a certain point. Motor pool vehicles, however, are generally restrained by only a regulatory boundary, a rule that prohibits the use of a vehicle outside of a certain area. The PROCOTIP system in Montpellier was controlled by a regulatory boundary that proved to be ineffective. The Witkar system operates within a similar rule-defined service area but has the added advantage of a performance boundary. Because of the limited range of the electric vehicle, the Witkar cannot be driven more than a few kilometers from the service area.

These componments of the operating environment have significance for other aspects of the MUVS as well. Operating environment, vehicle type, and degree of user restriction are three interdependent variables in every MUVS. If certain factors in the operating environment are given, specific vehicle types and forms of user restriction will emerge as being preferable to others.

MODAL COMPETITION TO MUVS

As a new transportation mode being introduced into the urban pattern, MUVS must fulfill a currently unmet need or provide an existing service at lower cost. A successful system would be tested in an area where MUVS can be perceived as improving the level of mobility. The factors which will influence success are varied, each constraining the potential applications yet offering differing opportunities.

To attract a substantial number of users, MUVS will need to offer an attractive, high quality, simple service at a cost comparable to existing services. Considering MUVS vis-a-vis existing modes, it is possible to identify these various features.

Taxi

This is the current mode most similar to MUVS. In areas of dense activity, it is ubiquitously available and, in fact, can be summoned by phone. The traveler is relieved of the need to operate the vehicle and the need to find terminal facilities. Door-to-door service is provided.

Since an MUVS would not be available by reservation or on-call but would require self-operation and parking at the destination, it is unlikely that a level of service equal to or higher than that of the taxi can be maintained. To attract patronage, the MUVS must either operate in an environment which excludes cabs or provide service at a lower cost. This effectively sets an upper limit on the cost per trip of an MUVS system.

Bus

Properly utilized, this can be the most energy efficient mode and the one which uses the least street space per passenger. The quality of service is lower than the taxi since it requires riding with others, waiting for a vehicle, intermediate stops, and lack of door-to-door service. Cost per trip, however, is significantly lower than taxi. Since walk time to the vehicle and waiting time are critical elements, bus is most suited for high-density trip patterns where high frequency can be maintained. MUVS, then, should be considered in areas with diverse destinations such that reasonable bus headways cannot be economically provided.

Walking

Although not typically considered in transportation analysis, walking is an integral part of the transport system serving as the collection-distribution mode for all mechanized systems and as the single mode for entire trips in areas of compact activity. For most people, walking is considered only over short distances of less than 1/4-1/2 mile or a five to ten minute journey. Trips longer than this either are not made or make use of another mode in addition to walking. Since walking involves neither costs, reliance on vehicle schedules, or any wait time for a vehicle, it offers a high degree of utility for short trips. For an MUVS system to compete with walking it must, therefore, be designed to serve longer trips and/or offer travel time or comfort advantages.

Private Auto

If available, then private auto offers much the same service as would be provided by the MUVS vehicle. Costs for vehicle parking are an added factor, but these may be offset by the costs of MUVS system use. The key lies in vehicle and parking availability. The primary MUVS market will be those who do not have their car in close proximity or could not find parking at the desired destination, perhaps because of an auto restricted zone (ARZ).

The MUVS would have a competitive advantage over the private auto in situations where there are persons for whom an auto is not available such as transit commuters making lunch hour intra-CBD trips, auto drivers and riders for whom the auto is not easily accessible, intra-ARZ tripmakers, or in cases where short-term parking capacity is scarce and/or expensive in the MUVS service area.

Existing Rental Car Services

Service is similar, but costs are excessive due to high minimum charges and the complexity of the check-out/in process. There is nothing at present which would preclude an existing rent-a-car company from entering the urban MUVS market. Either these companies have not perceived this as a viable market or feel that the costs associated with facilities and management preclude a profitable operation.

The successful MUVS operation should, therefore, show a substantial reduction in overhead costs from those of existing car rental operations. Areas in which this can be achieved are cost of the vehicle, vehicle storage facilities, and check-in/out processing. Table 3 presents a summary of the competitive features of MUVS with respect to the general characteristics of the various modes with which it might compete.

Summary

Each of the MUVS systems listed in Table I is designed to provide a service that is attractive to a class of users in a specific operating environment. The qualitative analysis in this section has identified the types of MUVS systems best suited to a variety of operating environments. The wide variety of MUVS vehicle types that have been employed in different applications in the past strongly suggests that a careful analysis of the particular characteristics of a proposed MUVS demonstration site be studied in order to assess the feasibility of alternative MUVS services.

The preceding paragraphs discussed a variety of factors that would include the viability of a CBD circulation MUVS service. These factors included size of the service area, competing modal services, and travel demand patterns. Chapter III explores the particular characteristics of two multi-user vehicle systems actually functioning as CBD circulation services in a European context.

Table 3
Modal Competition to MUVS

Existing Modes		MUVS
Mode	General Characteristics	Competitive Characteristics
Taxi	● Operator provided ● High level of service ● High cost per trip	● Lower cost service ● Less pollution
Bus	● Operator provided ● Moderate level of service ● Low cost per trip ● Suited to high-density trip patterns	● Serves diverse destinations ● Privacy
Walk	● No operator required ● Suitable for short trips ● No cost per trip ● High reliability	● Suited to longer trips ● Travel time advantage
Private Auto	● Self operation ● Parking required ● High level of service ● Low perceived trip cost	● Parking provided ● Serve non-auto availability ● Less pollution
Rental Auto	● Self operation ● Parking required ● High level of service ● High costs	● Lower costs ● Parking provided ● Simple check-out/in

Chapter III

Existing Experience with MUVS for CBD Circulation Service

CHAPTER III

EXISTING EXPERIENCE WITH MUVS FOR CBD CIRCULATION SERVICE

Multi-user vehicle systems, serving as a CBD circulation service, have been implemented on a limited scale in two European cities. The PROCOTIP system in Montpellier, France, commenced operations in the fall of 1971 as a private endeavor. The system ceased operation due to financial difficulties in the spring of 1973. During its year and a half of service, the scale of operation varied from 16 to 30 vehicles with 17 terminal stations. The Witkar system in Amsterdam, The Netherlands, also a private endeavor, was initiated in the spring of 1973 with one station on a three-month trial basis. In October 1975, the Witkar system consisted of 35 vehicles and 5 stations, with plans for further expansion.

This chapter is intended as a review and critical appraisal of the characteristics of these two prototypical MUVS city circulation services in order to identify key factors contributing to their limited success.

MONTPELLIER MUVS

Montpellier is a historic, medium-sized city of 200,000 people in the south of France. The central area is old and compact, containing a mix of residential and business land uses. Narrow and crowded streets in an irregular pattern impede traffic flow with resultant congestion and low travel speeds. Within the central area, walking is often the fastest means of travel.

Within this setting, the Societe Cooperative de Consommation Anonyme organized and implemented a multi-user vehicle system, referred to by the acronyms PROCOTIP (Promotion Cooperative du Transport Individuel Public), or simply, TIP.

System Characteristics

The PROCOTIP system was designed to make small automobiles available within the central area and its immediate environs to a predetermined membership group on a short-term rental basis. The vehicles were located in designated parking areas at selected locations. A member could use any of the vehicles on an as-needed and as-available basis, paying for the service in relation to its usage. Vehicle repairs, service, fuel, and insurance were provided by PROCOTIP.

Service was initiated in August 1971, with 16 vehicles and 17 stations. Each station had facilities for parking from three to five vehicles. During the year and a half that PROCOTIP was in operation, the vehicle fleet was expanded to 30. One month before service was terminated, 10 additional stations were added.

Institutional Characteristics

The PROCOTIP system was organized as a cooperative. It was formed by the engineer who invented the vehicle's mechanical metering device and an associate in the insurance business. They were able to generate sufficient capital from banking, insurance, and other institutions, as well as a general membership drive to finance an initial effort.

It was generally recognized from the start that the system would require financial subsidy. The French government provided limited assistance ($20,000), but after extensive investigation decided against continued financial support. The city government limited their support to granting the necessary permission for the system to operate and providing space for the 17 stations. The city bus system at that time was operating without a subsidy, and there was little interest in subsidizing the PROCOTIP system.

Membership in the cooperative responsible for PROCOTIP reached a maximum of 350 persons, but the actual number using the facilities varied between 50 and 100. The basic membership fee was around $10, except toward the end of the service period when it was raised substantially. The predominant class of people using the system were upper income professionals for whom the PROCOTIP vehicle served as a second car.

Equipment Characteristics

The PROCOTIP system utilized four passenger standard production Simca 1000 cars leased from the manufacturer. The vehicles were powered by a gasoline engine which offered no significant environmental benefits. The vehicle cost in 1971 was about $2,000.

As the payment system, a mechanical device known as a TIP meter was installed in each vehicle. The TIP meter is a patented device invented by one of the founders of the cooperative. Upon entering a vehicle, a plastic token was inserted into the TIP meter. The token rotated within the meter at a rate determined by the engine speed. As the token rotated, the edge was physically ground down by the meter, thereby reducing its value. Upon reaching a destination, the portion of the token remaining could be removed and used at a future time. One token was good for approximately 11 miles of travel. They could be purchased in advance at several outlets.

Substantial problems were encountered with the mechanical device which mutilated the token, necessitating continuing development costs throughout the service period. A small camera was later added to photograph the number on the key when it was inserted by the user into the ignition.

The station facilities consisted of 3 to 5 spaces reserved for PROCOTIP vehicles at 17 selected locations. At some locations, street spaces were used, while others were located in off-street lots. They were distinctly marked for PROCOTIP use, but neither the police nor PROCOTIP enforced the restriction. With an acute shortage of parking spaces in the central area, the abuse occurrence of normal cars utilizing spaces reserved for PROCOTIP vehicles was high, creating a situation in which a user often did not have a parking space available.

Operational Characteristics

A potential user, after becoming a member of the cooperative, had only to have a key issued to him and a supply of tokens purchased in advance in order to utilize the vehicles. Since the rate at which the token was destroyed was related to distance traveled and not time, a user could tie up the availability of a vehicle for extended periods of time without incurring costs for the period in which he was not actually traveling in the vehicle. Individual cases indicate that (at times) vehicles were used for trips far from the central area and were also left parked for long periods in areas where they were not readily available for reuse.

The vehicles were serviced by the cooperative. For maintenance repairs and other servicing, they were driven to a central yard. Refueling was done by a cruising tanker operated by the cooperative. A light on the outside of the vehicle was used to indicate a low fuel supply. Insurance was carried for bodily harm, but not on the vehicle itself.

The user costs consisted of an initial membership fee of about $10. This was later changed to a seasonal fee plus the mileage-based charge associated with the purchase of tokens. A token costing $2 in 1971 was good for about 11 miles of travel for a unit cost of 18 cents per mile.

During the period of operation, the vehicles were used an average of 100 miles per week per vehicle. Receipts from the system amounted to about $600 per month, while expenses equaled $7,000 to $10,000 per month, including leasing, maintenance, operation, inventor's fee, and development costs for the TIP meter. These levels of cost for the related fleet size and level of utilization suggest a cost per mile in excess of $2, compared to the 18 cents per mile actually charged. By making some cost cuts and other favorable financial actions, it was estimated that the system could break even at a utilization rate of about 400 miles per week per vehicle, which, based upon an average trip length of 2 miles, suggests the need for 30 users per day per vehicle.

With the noted imbalance between costs and receipts, and without financial support from public agencies, the PROCOTIP system ceased operations in the spring of 1973 at the end of one and a half years of operation.

Summary of Significant Factors

A review of the experience of the PROCOPTIP system as a CBD circulation service in Montpellier suggests several factors which are significant in the provision of such a service:

- Service Area — The area being compact, the climate good, and walking as the dominant mode of transport, limited the potential market for MUVS.
- Congestion — The street network was ill-suited for vehicular flow and the PROCOTIP vehicle was subjected to the same congestion as other non-walk modes.
- Parking — Abuse of parking regulation at terminals was common, thereby removing the advantage of a readily available space.
- Charges — Charges to the user were based upon mileage alone, with no penalty for prolonged periods during which the vehicle was not in use. The user charge per mile was about as high as could be assessed in order to remain competitive with other modes but did not approach actual costs.
- Vehicle Availability — With a maximum of 35 vehicles at 17 stations and some vehicle hoarding, the probability of a vehicle being available when and where needed was low.
- Market — The users tended to be of a middle and upper income level where everyone had one car, and the PROCOTIP system served to replace the need for a second car.
- Equipment — The vehicle offered no significant environmental advantage and mechanical difficulties with the TIP meter caused difficulties in the early phase of the service period.
- Scale — The scale of operation was very small with insignificant impacts.

AMSTERDAM MUVS

Amsterdam, with a city population of nearly one million people and a regional population of approximately two million, is well-known as a major urban center. The inner area of Amsterdam is a national treasure of pre-19th century structures, built around a series of semi-circular canals. This area comprises about 3.2 square miles with a mix of shopping, office, and University activities, as well as a resident population of 70,000 persons. The area is well served by public transportation with a very high usage of bicycles and pedestrianways. The inner area suffers from a high degree of traffic congestion and an acute shortage of available parking. It is estimated that on a normal day there are 30,000 parked cars in the inner area, 10,000 of which are illegally parked. The manner in which every available space is used for parking demonstrates the adverse impacts of private auto use in the city.

Within this context, the Cooperatieve Vereniging Witkar U.A. organized and implemented a multi-user vehicle system referred to as Witkar (white car). While the concept of the Witkar system is similar to that of PROCOTIP, the organization and implementation techniques are quite different. The system is intended to serve trips within the inner area which are too long for walking. It is planned to meet the needs of people living within the area and those who arrived by transit and are without an automobile, as well as those arriving by car but not using it for internal trips because of the severe shortage of parking.

System Characteristics

The Witkar system is designed to make small electric vehicles, as shown in Photograph 1, available within the inner city area to a predetermined membership group on a short-term rental basis. The vehicles are available at special terminals at selected locations throughout the inner area. A qualified member can use any vehicle on an as-needed and as-available basis, paying for the service in relation to his use of the vehicle. The Witkar Cooperative provides all repairs, servicing, and insurance.

Service was initiated in March 1973, with one station and four vehicles on a three-month trial basis. The next stage, virtually completed in the fall of 1975, expanded the number of stations to five (station spacing 800 to 1,200 meters) with a total of 35 vehicles. Plans call for further expansion to 15 stations and 105 vehicles within the near future with an ultimate system possibly involving as many as 100 stations, spaced only 250 to 300 meters apart. Each station has seven vehicles with space for three more. The distribution of the five present stations and the ten proposed within the inner city is illustrated in Figure 1.

Photo 1
Witkar Vehicles Recharging at a Terminal

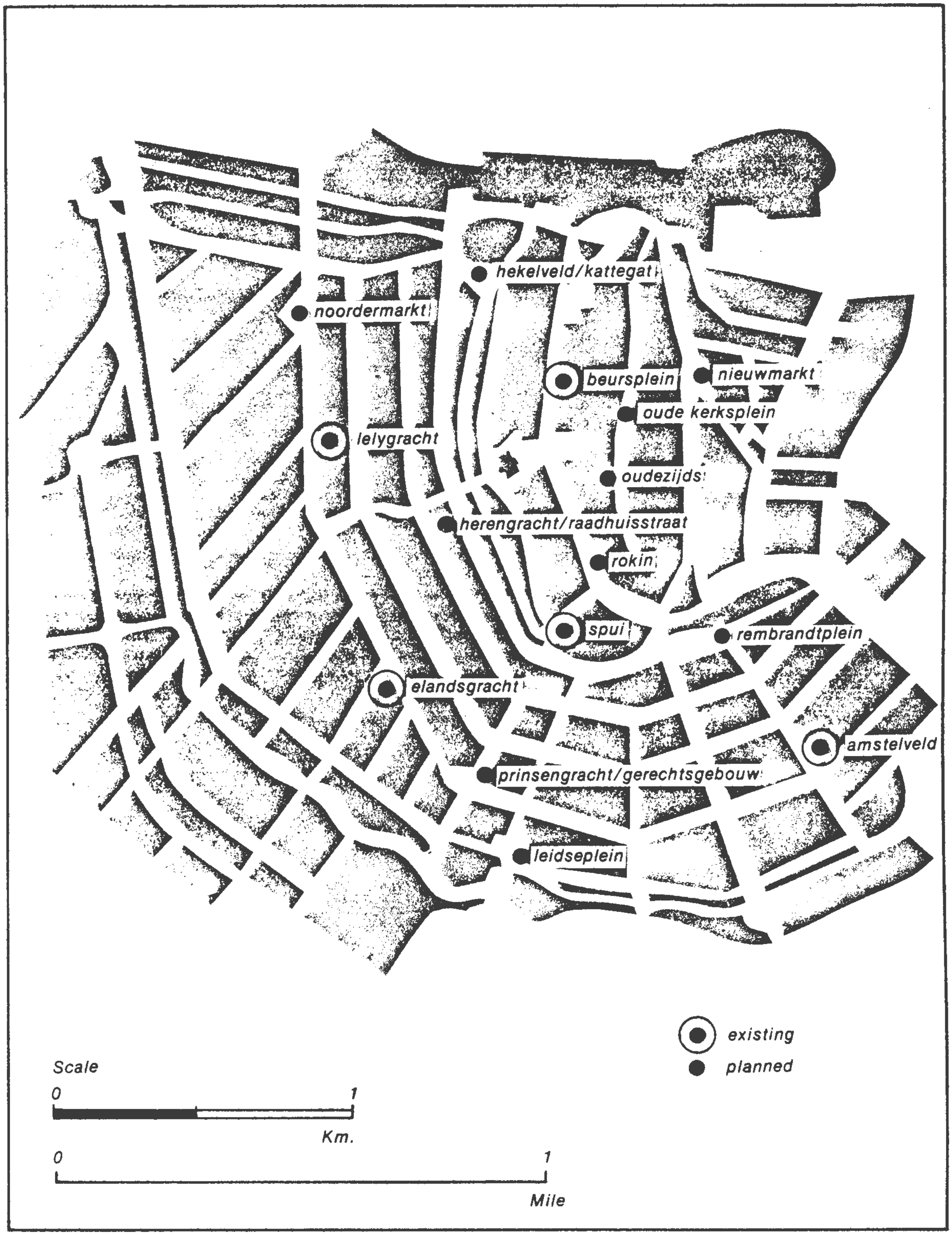


Figure 1
Witkar Station Distribution
Amsterdam

Institutional Characteristics

The Witkar system, similar to PROCOTIP, is organized as a cooperative. The motivating force behind the project is a mechanical engineer, who is a former City Council member, and a long-time activist in urban planning. Nearly all development and operating costs date been borne, to date, by the cooperative with funds coming from membership fees and private companies, including a bank, insurance company, and newspaper. The cultural department of the national government has provided some financial assistance, and the city government has limited its support to necessary permission for the system to operate and provision of space for the stations. Significant financial support from either local or national public agencies has not occurred up to the present time.

The cooperative is run by a board elected by the members. A steering committee, with members from both local and national governments, private companies supporting the system, and the board, provides overall direction and control of the system.

More than 3,400 persons have become members of the cooperative, involving the payment of a membership fee of $10. An additional fee of $10 is charged for a key which provides access to the system. About half of the members are from the inner area of Amsterdam, another 30 percent are from other areas of the City, and 20 percent from outside Amsterdam. At present, most of the members of the cooperative are young people with motives more idealistic than utilitarian.

Equipment Characteristics

The Witkar vehicles were designed specifically for MUVS use in Amsterdam. The design criteria called for small, easy to operate, low pollution vehicles which would give users a sense of the environment, similar to a pedestrian or bicycle experience, rather than a feeling of separation from the urban environment such as is experienced in conventional automobiles. The resulting vehicle is a small, electric-powered, two-seater with limited luggage space.

The vehicles, illustrated in Figure 2 and Photograph 1, are about 7 feet tall, 6 feet long, and 4.5 feet wide. The body is made of polyester and fiberglass on a steel chassis, producing a low center of gravity for good vehicle stability. The cost of a Witkar, complete with all the equipment necessary for central control booking is $4,500. Its life is figured at three years, with expectations of it lasting for at least five years. The revenue derived over a five-year period from advertisements on the top of the vehicle is sufficient to cover its cost.

The current vehicle, representing the fourth vehicle design modification, travels at a top speed of 22 mph. A seven-minute charge is required for a trip of 2.5 miles. The Witkar can travel up to seven miles on a single charge. The use of electric power places a theoretical limit on the utilization rate of system because the vehicle can not be immediately reused after a trip. To date, the vehicle recharge time has not been a constraint on system performance since customer demand has not approached system capacity.

The Witkar system functions strictly in a terminal-to-terminal mode of operation necessitated by the electrical recharge requirements. The stations are simple, inexpensive, and unobtrusive as shown in Photograph 2. A typical curbside station, utilizing the area designated for automobile parking, occupies 60 feet of space. This is the equivalent of three normal parking spaces but is sufficient to accommodate 10 Witkars. A typical station layout is illustrated in Figure 3.

Vehicles exit from the front of the queue and enter from the rear. As a vehicle enters the station, overhead contacts supply DC current to recharge the batteries. As one vehicle leaves the station, the vehicles remaining in the queue advance automatically to provide parking space at the end of the queue. The characteristics of the station design are such that it is not possible for conventional automobiles to enter the station, and even if they could they would be blocked by Witkars in front and behind, thus insuring that station facilities are used only by Witkars and increasing the probability of parking being available.

The cost per station is $16,000, including necessary street work performed by the city but billed to the cooperative. The life of a station is figured at 10 years.

Length: 1760 mm
Width: 1420 mm
Height: 1950 mm
Wheelbase: 1340 mm
Batteries: Nickel/Cadium
Weight: 390 Kilos
With Batteries
Acceleration: 20 Meters
in 5 Sec.
Other: Polyester &
Fiberglass Body
Steel Chassis
Sliding Doors
Heated Windows

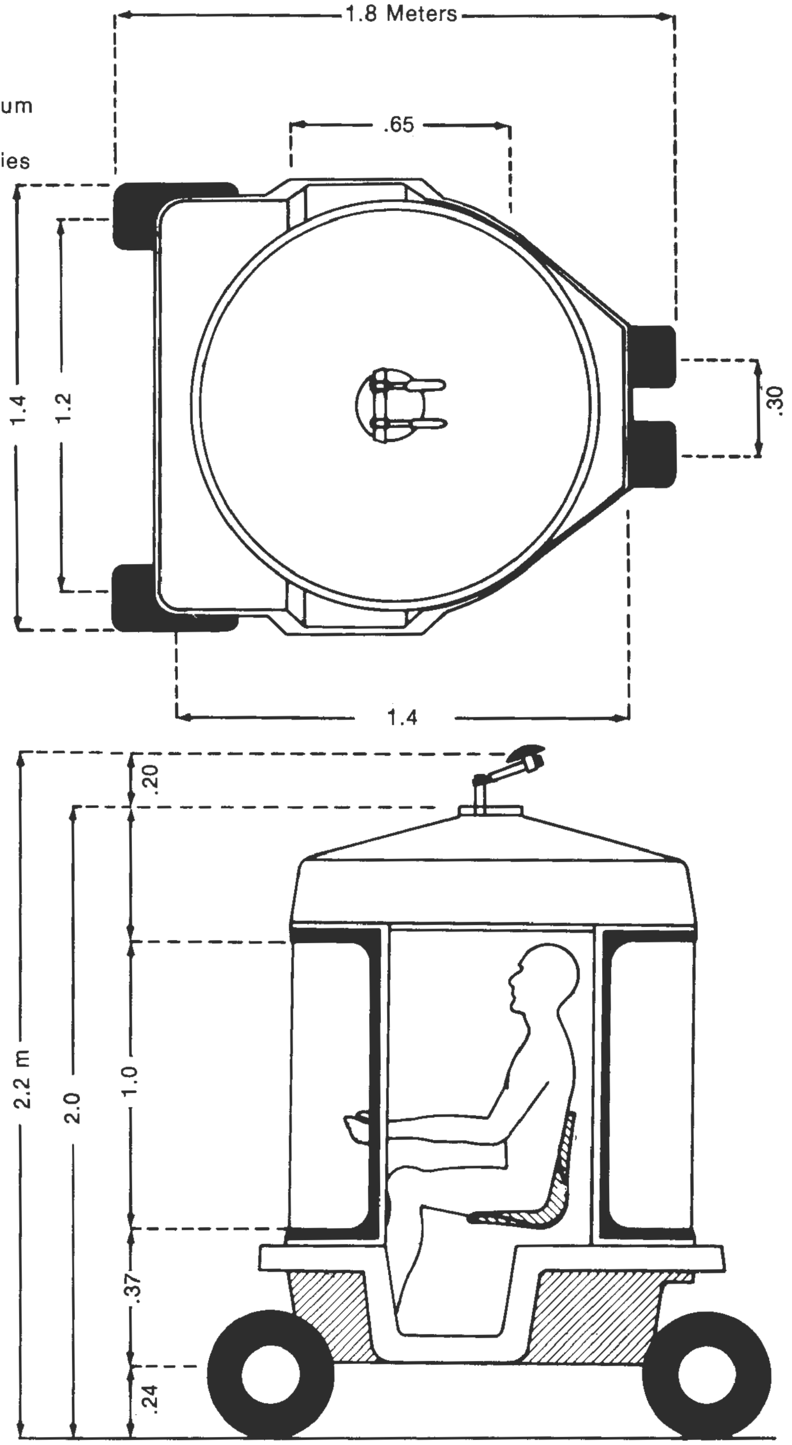


Figure 2
Witkar Specifications

Photo 2
Witkar Terminal: Environmental Design

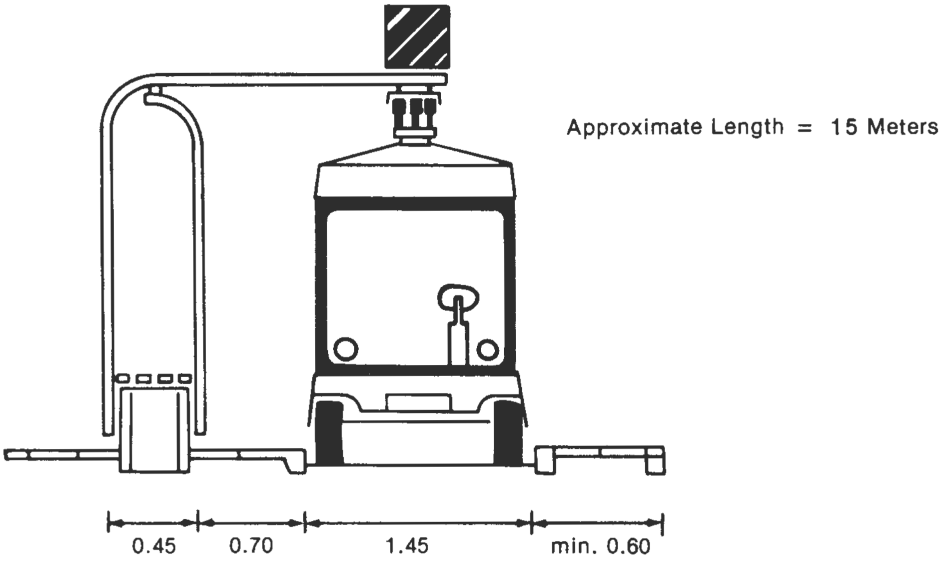


Figure 3
Witkar Station Dimensions

All but one of the existing stations are of a temporary nature, requiring little alteration or new construction. One station was semi-permanent in that some effort was made to landscape it and have it blend with the surroundings. It is intended that stations will ultimately be designed to fit their immediate environment and serve as a focal point for other services, such as phones, notices, snacks, etc.

The five existing stations are being tied into central control equipment which will utilize a digital computer for fleet control, dispatching, charging, and billings. The cost of the central control equipment with capacity to handle a system of 30 stations with 210 vehicles is approximately $40,000.

Operational Characteristics

A potential user, after becoming a member of the cooperative and obtaining a membership card, inserts the card in a selection pole at the station and indicates his desired destination. Central control checks the account to verify that it is current and retains any stolen cards. The computer also checks if a parking space is available at the desired destination and if so, issues a key for the first car in the queue. If no parking space is available, the customer is advised to choose an alternative destination.

Issuance of the key marks the start of the period of hire. The customer unlocks the vehicle and drives it away. The vehicles remaining in the queue advance automatically. Enroute, the driver may stop to park the vehicle without fear that any other club member will take his vehicle because he has the only key that will fit it.

The customer delivers the vehicle to the selected destination, inserts the key in the selection pole device, and the period of hire is ended. The computer determines the period of hire, and the associated cost is billed to the customer's central account as identified on his magnetically coded membership card.

The cooperative maintains a contract with a motorist organization for emergency servicing; major servicing is done by the vehicle manufacturer. Full coverage insurance with $40 deductible is also provided. The charge to the customer for the use of the Witkar system, beyond the membership fees, is billed at $0.04 per minute of use. Average usage is about 10 minutes for an average trip cost of $0.40. Since the charge is based upon the amount of time the vehicle is away from a designated terminal, a customer who makes a stop during his trip continues to pay for the period the vehicle is parked. This discourages intermediate stops for more than a brief period. The ultimate intent is to provide adequate station coverage so that a person making an extended stop could check the vehicle into an appropriate station and obtain another vehicle when he desired to continue his trip.

In the fall of 1975, the Witkar system was not yet tied into the central control equipment. Stations were being manned by voluntary help, with all administrative work also being done free of charge. As it is presently operated, a customer indicates his desired destination and the attendant checks by phone if a parking space is available. If it is, the attendant records the driver's license number, membership number, departure time, and other data on a ticket. He issues a key to the customer who then drives to the selected destination, and presents the ticket to the attendant. The period of usage is determined, the cost is figured, and the customer pays the attendant directly.

The hours of operation are limited to 11 a.m. to 5 p.m., but will be expanded to 24 hours when the system is controlled by the computer and the need for a station attendant is eliminated. Vehicles are presently in use 15 percent of the time.

Present costs to operate the system are not indicative of true costs, since nearly all attendant, administrative, and some service functions are provided free by members of the cooperative. It is estimated that a breakeven point for a system of 15 stations with 110 vehicles would be utilization, 3 hours per day per vehicle, at a charge of $0.06 per minute.

Summary of Significant Factors

In many respects, the Witkars system appears to have overcome the faults that plagued the MUVS system in Montpellier. The Witkars system is better managed, has a stronger base of support in the community, and is being promoted more vigorously. The vehicles are better suited to MUVS service and parking is guaranteed. The system is open to a larger pool of potential customers, offering the potential of a financially realistic price structure. Several factors characterizing the Witkar are significant:

- Service Area — As in Montpellier, the prime competitor of the Witkar is walking, so that Witkar is not likely to substantially reduce traffic congestion.
- Congestion — Witkar does not operate in an ARZ environment and thus is subject to the same severe local street congestion experienced by conventional automobiles.
- Equipment — The vehicles have been plagued with mechanical breakdowns in the early stages of operation. Design changes have made several improvements. The vehicles are attractive, quiet, non-polluting, and well-suited for their intended role.
- Parking — Parking space at destination is checked to insure availability prior to departure. Parking restrictions at stations are enforced.
- Vehicle Availability — Present redistribution procedures are an informal program of redistribution by attendants at days' end, a procedure that would soon become more complicated as the system expanded.
- Scale — The scale of operation is too limited to identify any significant impacts. The scale of operation and the level of volunteer help do not permit a true assessment of its financial feasibility.
- Charges — Charges based upon time seem to work out more satisfactorily than the experience that PROCOTIP had with distance. With installation of computer control, a flexible fare schedule including time and distance charges, peak-hour pricing, and reduced charges for trips to destination terminals with depleted vehicle stocks, could be adopted.

A summary comparison of the Witkar and PROCOTIP system is presented in Table 4.

Table 4
Comparison of Two MUVS Systems

	TIP System, Montpellier, France	WITKAR System, Amsterdam
Operating Environment	Downtown circulation system (vehicles could be taken outside of the service area).	Downtown circulation system only
Service Area Coverage	Approximately one square mile of central core city	Approximately 1.2 square miles of central core city
Vehicle Type	Standard Simca 1000 automobile leased. 1971 cost of $2,000.	Specially designed electric vehicles, six feet in length. 1974 cost is $4,500.
Number of Vehicles	35	Staged implementation: presently 35 vehicles, with ultimate capacity of 1,200 vehicles.
Terminal and Support Facilities	17 parking stations but vehicles can be left on street.	Presently 5 stations being expanded to 15 with a projection of 100 stations. Also serve as recharging stations. Vehicles must be left at station.
Vehicle Availability Control	No special provision	Presently manually regulated. Planned computer network controlling terminal space allocation.
Vehicle Redistribution	No special provision	Potential facility for forming vehicle "trains" of up to 5 vehicles. Vehicle redistribution performed either by user (for a discounted fare) or by operator.
Vehicle Speed	Standard automobile	15-20 mph
Pollution Characteristics	Standard automobile	Electric vehicle; no local CO/HC/NO_x emissions.
Price Mechanism	Keyed to engine speed (roughly on a distance basis except for engine idling). Eighteen cents per mile.	Time charges at a rate of $0.04 per minute. Potential for charge based upon both time and distance.
Usage Restrictions	None	Vehicles must be recharged after 45 minutes of use. Maximum travel distance on one charge is 7 miles.
Entry Restrictions for Users	Closely restricted	Open. Requires membership fee of $10.00 and a key deposit fee of $10.00.

Chapter IV

Analysis of Key Factors in MUVS Feasibility

CHAPTER IV
ANALYSIS OF KEY FACTORS IN MUVS FEASIBILITY

A multi-user vehicle system may be described in terms of its operating environment, fixed facility system characteristics, vehicle design characteristics, and operating policy. These characteristics of an MUVS will have a direct bearing on the system's level of service, costs, and patronage. The purpose of this section is to identify in quantitative terms the key factors influencing the performance of and the demand for a multi-user vehicle system.

Two static analysis frameworks are discussed in this section. The first approach focuses on the fleet size and operating policy requirements for an MUVS to serve given demand patterns at pre-specified levels of service. The second analysis framework parametrizes MUVS supply characteristics and determines resulting demand levels.

KEY FACTORS: IDENTIFICATION

Figure 4 identifies the key features of an MUVS system. As shown at the top of the figure, there are four generic system descriptor categories that serve to define the operation of a multi-user vehicle system. These are described in turn.

The Operating Environment

The size and type of service area, the service hours, and the nature of transport restrictions in the service area jointly describe an MUVS operating environment. Each one of these factors has a direct bearing on MUVS demand and performance. The service hours of the MUVS will determine the types of demand patterns in the MUVS service area. If the system operates all day, it will be available for morning and evening work peak-hour travel. This type of travel is highly directionally and diurnally peaked. For MUVS to serve a significant proportion of these trips, a substantial fleet of vehicles would be required. During the off-peak periods when fewer trips are made and demands are less peaked directionally and diurnally, a smaller fleet size would serve.

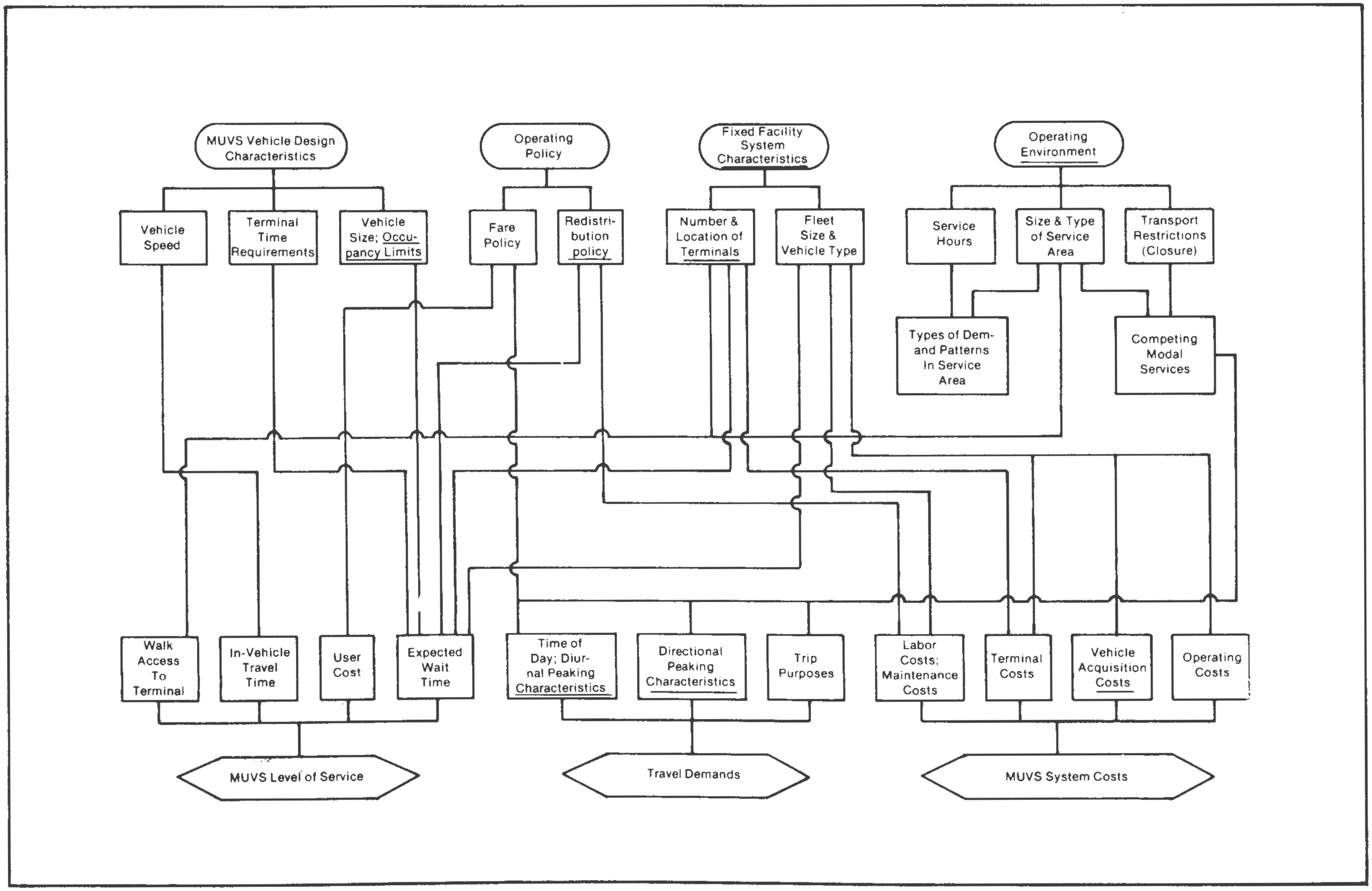


Figure 4
MUVS System Description

Four types of users comprise the potential demand for MUVS service within a well-defined CBD cordon. The first potential user type are work commuters who would use MUVS for transportation between a fringe parking lot, or a line-haul conventional transit stop and the place of work. This demand type would be characterized by relatively high directional peaking and point-to-point non-stop use. The second user type represents shoppers using MUVS for intra-cordon movement to a single shopping destination before the return trip to the line-haul mode. Here too, demand will be directionally peaked, although not as marked as with work usage. The third user type are shoppers who would use MUVS for intra-cordon movements between terminals. In applications where MUVS vehicles could be reserved for a relatively long period of time, this demand type could result in vehicle "hoarding." The fourth potential user type consists of worker travel within the service area. This demand could be expected to be highly peaked around the noon hour, but not necessarily directionally peaked. Table 5 summarizes the characteristics for each of the four potential MUVS user types.

The peak period system capacity requirements and associated probable over-capacity during off-peak periods is an important issue. Thus, an evaluation of MUVS must involve a determination of the consequences of operating an MUVS system during peak, off-peak, or both periods of the day.

The size and type of service area has an equally important bearing on the viability of a multi-user vehicle system. Throughout the analysis, it is assumed that the type of area evisaged for MUVS service is a central business district (CBD) with MUVS providing intra-CBD circulation. In this context, if the MUVS service area is too small, walk trips would compete effectively with MUVS, particularly if service queues and/or street congestion detracted from MUVS level of service. On the other hand, as the service area grows, the terminal and vehicle fleet size requirements expand rapidly. In order to keep the maximum walk distance to an MUVS terminal at a specific level, the number of terminals grows in proportion to the service area. In the case of a square service area, a doubling of the perimeter would require that the number of terminals be quadrupled in order to maintain a constant maximum walk access distance. Vehicle fleet requirements are also sensitive to service area size. With large service areas, the average length of an MUVS trip is likely to be longer, thus increasing vehicle stock requirements.

Table 5
Characteristics Of Potential MUVS Demand

Demand Type	O-D Trip Pattern	Peaking Characteristics	Competitive Modes/Facilities	Other Demand Characteristics
Work Commute Distributor/Collector	Pkg. Lot/Transit Stop To Worksite. Few Tours.	Highly Directionally And Diurnally Peaked.	Alt. Pkg. Lot Or Transit Stop. Combined With Walk Or Other Access Mode	Number Of Person Trips Independent Of System LOS
II Shopping Trip Distributor/Collector	Same As Above	Somewhat Lesser Peaked Than Work Commuter Use. Exacerbates Directional Peaking In The P.M. Peak	Same As Above	Trip Frequency And Destination Choice Depends On LOS. Convenience Of Transporting Parcels A Factor In Mode Choice
III Shopping Trip Intra-cordon Circulation	Terminal-To-Terminal, Multistop Shopping Tours.	Relatively Little Peaking Diurnally Or Directionally	Walk Or Other Access Mode	Same As Above
IV Worker Circulation	Worksite Based Simple Or Complex Tours	Highly Peaked During Lunch Hour But Not Directionally Peaked	Walk Or Other Access Mode	Same As Above

Finally, transport restrictions, or the degree of closure, in an MUVS service area will have a dual effect on MUVS performance and patronage levels. First, MUVS level of service will be directly affected by the extent of street congestion due to competing modes (primarily automobile). Secondly, the demand for MUVS will depend on the nature of competing modal services. A review of the experience with the MUVS services in Montpellier and Amsterdam suggest that neither system operated in an environment conducive to successful MUVS service. In both systems, there were no restrictions on auto use within the service area which caused heavy street congestion and a limited MUVS potential. In addition, the service areas were relatively small, enhancing the competitive advantage of walk trips.

Fixed Facility System Characteristics

Number and location of MUVS terminals is a key design factor that will affect the costs and level of service of a multi-user vehicle system. The principal effect of terminal density and location on level of service is in the walk access characteristics to and from MUVS stations. MUVS can never provide the door-to-door convenience of a taxi service. Relative to fixed-route transit systems such as a bus or jitney, however, MUVS could provide equivalent or superior service, depending on bus route coverage of the CBD and the distribution of MUVS terminals. Bus stops would be more accessible than MUVS terminals, but MUVS could offer better route flexibility and greater travel speed.

Given the possibility of temporary vehicle unavailability at MUVS terminals with resultant queue buildup, walk access characteristics can have a significant effect on traveler mode choice behavior. In the majority of cases, the walk to and from the origin of MUVS terminal would simply be added to the straight line O/D walk distance. In systems with a high tendency for temporary queuing at terminals, the inconvenience of the walk access component of MUVS travel would detract from the demand for MUVS service, particularly for short trips. The average walk distance to MUVS terminals is inversely proportional to the square of the terminal density in an MUVS service area.

Vehicle fleet size is another critical factor affecting MUVS level of service and cost. The determination of an appropriate fleet size represents a tradeoff between system cost and level of service; a greater vehicle stock will increase cost, but generally improve the level of service. A critical link exists between vehicle fleet size and expected MUVS wait time. A vehicle stock that is inadequate to serve MUVS demand will lead to user queuing at terminals. On the other hand, attempting to provide enough vehicles to eliminate the possibility of user wait times may result in high vehicle acquisition costs and low system utilization during low demand periods.

Vehicle Design Characteristics

As discussed earlier in this report, the taxonomy of MUVS comprises a wide range of possible vehicle types from bicycles to electric-powered automobiles. Each vehicle type will be characterized by a maximum vehicle speed, a maximum passenger occupancy, and terminal time requirements. These characteristics will directly affect the level of service afforded by the system and indirectly affect vehicle fleet size requirements. Vehicle speed has an obvious relation to MUVS travel time characteristics. However, it should be noted that for the short trips served by an MUVS intra-CBD circulation system, vehicle speed limitations should not be an important factor in determining traveler mode choice behavior. For example, the difference for a 1/2-mile trip in in-vehicle time between a vehicle whose average speed is 7 mph, such as a bicycle, and an electric car with a 12 mph average speed is only 1.8 minutes. Moreover, in a congested, mixed traffic pattern, the maximum speed of an MUVS vehicle may not be the determining factor of MUVS travel time. Increases in attainable vehicle speeds, however, can have a beneficial effect on reducing MUVS vehicle fleet size requirements. The faster a vehicle can complete a passenger trip, the more trips per hour a single vehicle can service. Thus, for a given level and distribution of MUVS demand, fewer vehicles would be required for relatively fast vehicles.

The length of required vehicle turn-around or terminal time has a similar effect on vehicle fleet size requirements. Electric vehicles which need to be recharged after each trip impose a maximum system utilization rate. Human-powered vehicles, while slower than electric-powered vehicles, may have a higher productivity as measured by the potential number of trips per hour due to negligible terminal time requirements.

Finally, the occupancy limits of an MUVS vehicle will have a major effect on MUVS fleet size requirements and demand. If a significant portion of potential MUVS users travel in multiple member parties, then MUVS vehicles with one- or two-person occupancy limits will not adequately serve this market. On the cost side, the tradeoff in determining vehicle size is between large, relatively expensive vehicles and a large number of small, relatively inexpensive vehicles.

MUVS Operating Policy

Two aspects of a multi-user vehicle system operating policy are of particular importance: fare policy and the vehicle redistribution policy. The variants in fare policy include flat fares, mileage-based charges, time-based charges, or combinations of these strategies. A given policy will have direct effects on the demand for MUVS use. A flat fare policy will encourage MUVS use for relatively long trips while a time or mileage-based fare will enhance the utility of MUVS for relatively shorter trips. The fare policy may be designed to enhance the efficiency of MUVS vehicle distribution. For example, during periods of temporary queues at selected terminals, discounts might be offered to users destined to the vehicle-depleted stations.

The rules governing redistribution of vehicles is another component of a multi-user vehicle system operating policy. At one extreme, an MUVS could be operated with no explicit vehicle redistribution policy: the distribution of vehicles in the system would be determined solely by the origin-destination pattern of user trips. At the other extreme, a variety of policies designed to reduce vehicle depletion at selected stations could be undertaken by the system operator. The method of "dead-heading" vehicles may vary. For some vehicle types, the vehicles may be coupled in trains of up to 5 or 10 units and towed by a lead unit. For other systems, the only feasible method would be to use a truck to redistribute vehicles between terminals. In any event, the design of a vehicle redistribution policy involves a tradeoff between fixed costs and operating costs. Faced with directionally peaked demands, where vehicle depletion at terminals may be a problem, one alternative is to employ a sufficiently large number of vehicles at a high fixed cost to "withstand" the directional peaks with no vehicle redistribution. Alternatively, a smaller number of vehicles could serve the same directionally peak demand if a vehicle redistribution policy were adopted with its attendant labor and operating costs. The MUVS vehicle type employed is a critical factor in this operating versus fixed cost tradeoff. In a system using a low acquisition cost vehicle like bicycles, it may be loss costly to flood the service area with vehicles rather than employ a staff to carry out a vehicle redistribution policy. With higher initial cost vehicles, economics may favor using a smaller vehicle stock and implementing an explicit redistribution policy.

STATIC DEMAND ANALYSIS

This section explores the tradeoffs among multi-user vehicle system design characteristics in quantitative terms. It begins by parameterizing MUVS demand levels and determining the resulting fleet size and performance tradeoffs. Later in the analysis, MUVS level of service characteristics are parameterized, and the resulting MUVS demand levels are determined.

In the static demand analysis, a level of demand is assumed in order to examine the interaction of the various components involved in the supply of MUVS service. The results can be used in assessing the feasibility and costs entailed in the provision of a certain level of MUVS service. Four relationships are reviewed here:

1. The effects of service area size and the number of terminals on average walk access distances to MUVS terminals
2. The effects of vehicle speed and terminal time on fleet size requirements and system utilization
3. The effects of diurnal peaking on fleet size and utilization
4. The effects of asymmetric demand on fleet size

Service Area, Terminals, and Walk Distance

For any given MUVS terminal, a square service area is assumed, centered around the terminal with walk origins uniformly distributed within the area. Furthermore, assume that walkers must follow a "rectangular" walk pattern following a square street grid. Under these conditions, the average walk distance in a square MUVS service area is simply half the edge length of the square, and the distribution of walk distances varies between 0 and L. For a rectangular capture area of dimensions L_1 and L_2, the results are similar: average walk distance is $\frac{L_1 + L_2}{4}$ and the maximum walk distance is $\frac{L_1 + L_2}{2}$.

Analysis indicates that the average walk access distance to MUVS terminals is directly proportional to the inverse of the area served by the terminal. Accordingly, walk distances are extremely sensitive to initial increases in terminal density, but will become increasingly insensitive to continued terminal saturation, as shown in Figure 5. For example, in a 24 x 24 square city block area with two MUVS terminals, the average walk distance, assuming uniformly distributed trip production locations, would be nine blocks. With four terminals evenly spaced within the area, average walk distance would decrease by 33 percent to six blocks. Two additional terminals, a total of six, would decrease average walk distance by only 17 percent to five blocks. In order to operate a system that competes with the convenience of modes that offer door-to-door service would require an extremely large number of terminals. An MUVS system that offered an average of a one-block walk at trip origins and destinations would require a terminal density of one per four square blocks or 144 terminals.

Vehicle Speed, Terminal Time, and Fleet Size

For a given vehicle speed, network spacing, and turnaround time at the terminals, the MUVS fleet size requirement to eliminate waiting is a linear function of a uniform and symmetric demand between terminals. In a similar way for a given interterminal demand rate and vehicle speed, the MUVS vehicle fleet size required to eliminate queuing is a linear function of terminal time. The MUVS vehicle fleet size required to eliminate queuing is inversely related to vehicle speed. This implies that vehicle fleet size requirements will not be extremely sensitive to vehicle design speeds in the range of 10-20 mph. These relationships are illustrated in Figure 6.

System utilization, as defined by revenue vehicle hours divided by total vehicle hours, is limited by vehicle terminal time requirements and vehicle speed. From the analysis, it is clear that as terminal time requirements become a large fraction

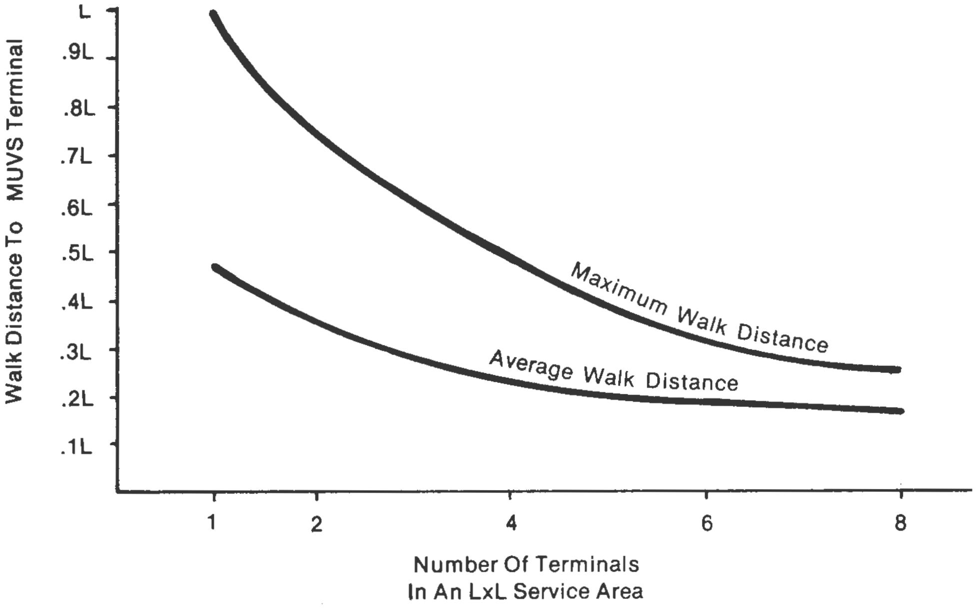
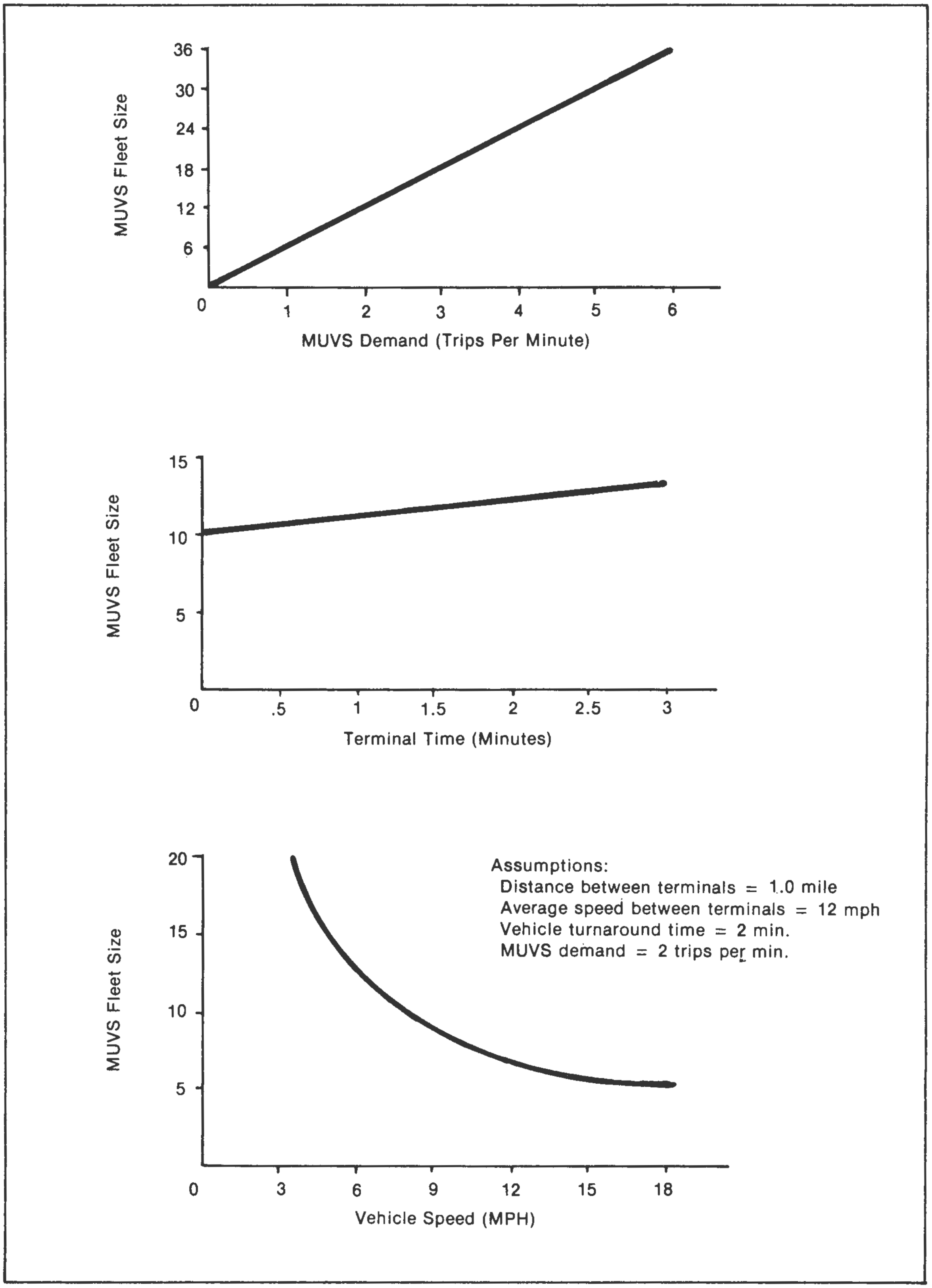


Figure 5
Walk Distance As A Function Of Terminal Density



Assumptions:
Distance between terminals = 1.0 mile
Average speed between terminals = 12 mph
Vehicle turnaround time = 2 min.
MUVS demand = 2 trips per min.

Figure 6
Fleet Size Determinants

of round trip vehicle travel time between any two terminals, the utilization rate decreases. Preliminary evidence from the operation of the Amsterdam Witkars system suggests that the electric recharge time following a one-mile trip is two minutes. Assuming an additional terminal time of one minute to cover customer check-in procedures and an average vehicle speed of 15 mph, the maximum attainable utilization rate of the Witkars multi-user vehicle system is less than 57 percent. This ceiling rate pertains only when the system is fully utilized, i.e., there is always a customer waiting for a vehicle. In actual situations, demand peaking and asymmetrical demand patterns would cause system utilization to be lower.

Diurnal Peaking, Fleet Size, and Utilization

As indicated earlier in Table 5, two of the four potential MUVS demand types, work commuter distributor/collector service and worker circulation during lunch hour, are characterized by significant diurnal peaking characteristics.[1] In general, the fleet size requirements to fully serve daily peak-hour demands are higher than the vehicle fleet that could adequately serve a uniform demand rate. The required vehicle fleet size to ensure zero or minimal wait times increases rapidly as the degree of peaking increases. In typical urban travel patterns where trips to the CBD in the morning and evening peaks represent as much as 75 percent of total daily CBD-destined travel, peak-hour MUVS fleet size requirements may be double that required if demand was spread evenly over the travel day. System utilization rates and costs per vehicle trips are also directly related to diurnal peaking characteristics.

Figure 7 indicates the relationship of fleet utilization to diurnal peaking characteristics. The maximum attainable fleet utilization rate occurs for uniform demand rates. The maximum utilization rate is a function of average MUVS trip times and vehicle terminal time requirements. For the conditions assumed in Figure 5, the utilization rate for uniform demand is 57 percent. As demands become increasingly diurnally peaked, additional vehicles are required which sit idle during slack demand periods. Thus, as shown in Figure 8, fleet utilization decreases rapidly.

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[1] The term "diurnal peaking" is used in this report to denote the variations in travel demand over the course of the day.

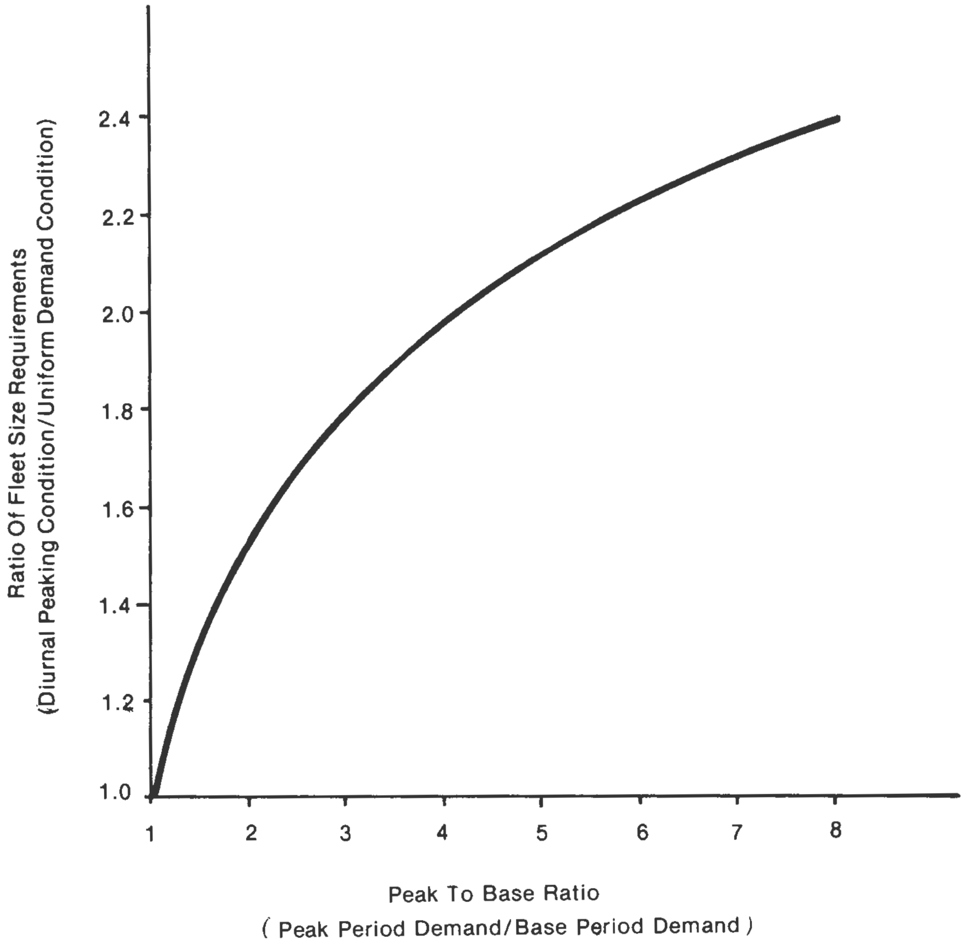

Figure 7
Fleet Size As A Function Of Diurnal Demand Peaking Characteristics

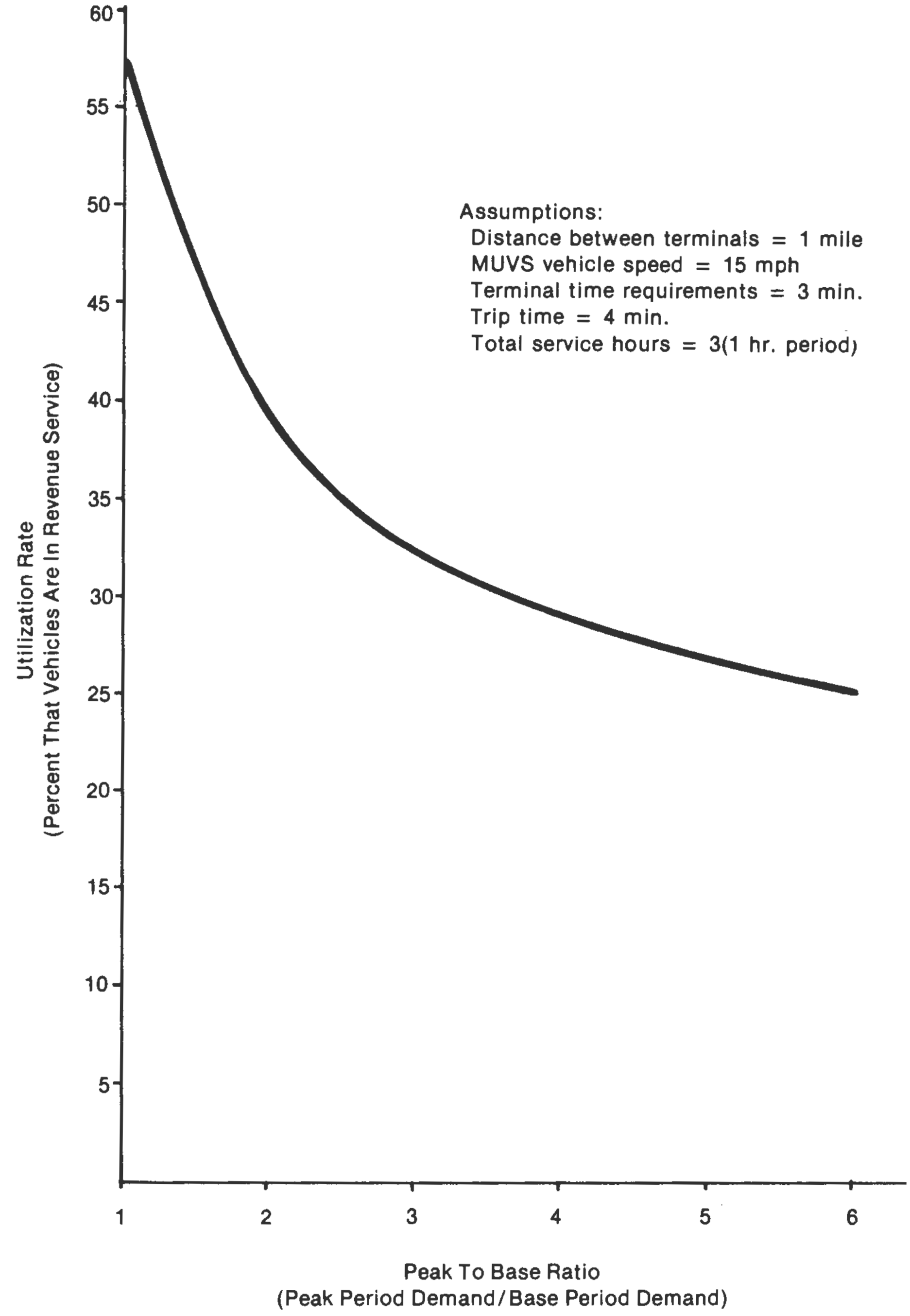

Figure 8
Effects Of Diurnally Peaked Demands On MUVS Fleet Utilization

For a peak to base ratio of 3, for example, the system fleet of vehicles are sitting idle for more than two-thirds of the duration of the service period.

Asymmetric Demand and Fleet Size

In the absence of an explicit vehicle redistribution policy, sustained asymmetric MUVS flows will lead to a depletion of vehicles at the terminals with the higher customer arrival rates. The analysis of the fleet size requirements with respect to MUVS demand asymmetry is similar to the previous analysis of diurnal peaking. Accordingly, a directional peaking factor between two terminals is defined as the ratio of the respective demand rates. The number of additional vehicles required to fully serve an asymmetric demand pattern is a function of the duration and intensity of the asymmetric flow.

Asymmetric MUVS demands can significantly increase fleet size requirements. Figure 9 illustrates the additional fleet size requirements under varying directional peak conditions and durations of demand asymmetry. As shown, even slightly unbalanced flows, if sustained for long periods of time, have a marked effect. For example, if a demand for MUVS trips split directionally at 2.4 and 1.6 trips per minute in the two respective directions and the demand imbalance is sustained for three hours, the vehicle fleet size required is more than four times as great as when the same total demand was evenly divided in the two directions of flow. Similar results are obtained for greater demand asymmetry over shorter periods of time. In morning and evening peak travel periods when demands could be highly directionally peaked for periods of up to three hours, MUVS vehicle fleet size requirements are extremely high as shown in Figure 9. Conversely, extended asymmetric demands will lead to extremely low fleet utilization rates as the vehicles at terminals where demand rates are low will sit idle.

STATIC SUPPLY ANALYSIS

The preceding section discussed fleet size requirements and performance characteristics for several demand patterns. In all of the preceding discussion, MUVS demands were taken to be fixed, and fleet size requirements to ensure zero wait

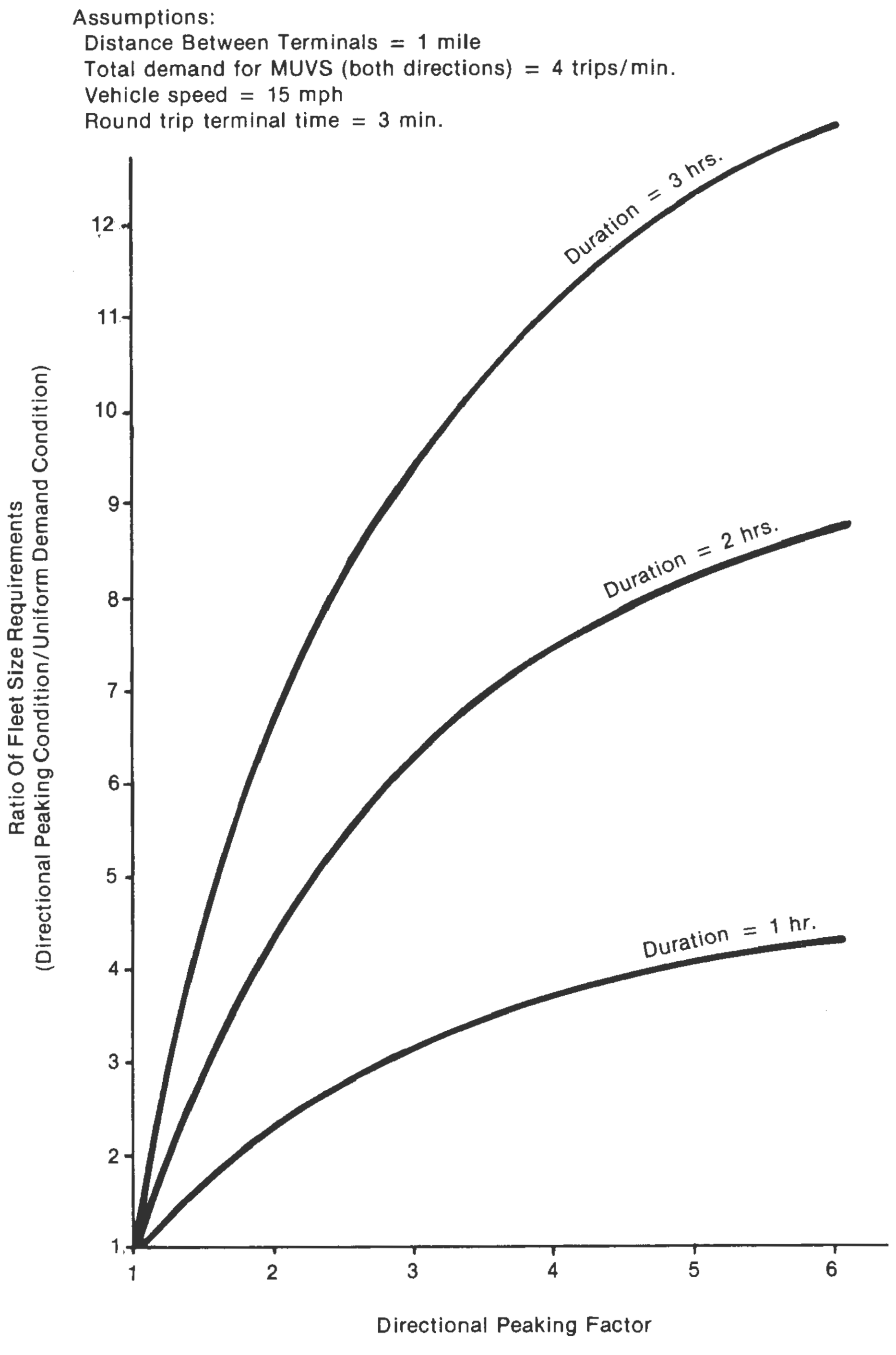

Figure 9
Effects Of Asymmetric Demands On MUVS Fleet Size

times were derived. In actual operating environments, zero wait times may not be attainable in view of the random nature of customer arrival patterns; that is, short-term customer bunching may occur, or diurnal and directional peaking may cause temporary vehicle depletion at terminals. It is unrealistic to assume that MUVS customers will wait indefinitely for a vehicle. Nor is it realistic to assume that all potential customers would walk long distances in order to gain access to an MUVS terminal. The demand for MUVS will depend on the MUVS operating environment, the vehicle design characteristics, the fixed facility characteristics and the operating policy. Each of these factors will ultimately affect the level of service of MUVS and its competing modes and thus influence system demands.

In the following section, the demand for MUVS service is related to the key level-of-service measures of system performance. As in the preceding discussion, this static supply analysis is not an equilibrium analysis. The potential market share for MUVS is projected for assumed level of service. Ultimately, the demand for MUVS vehicles and the system level of service is the result of a supply-demand equilibrium process. Due to its complexity, no attempt is made to analyze MUVS equilibrium system performance within the framework of static analysis. Rather the treatment of equilibrium performance is treated with simulation analysis later in this report.

The key factors influencing the demand for MUVS are:

- Walk access characteristics to MUVS terminals
- Expected wait times to acquire a vehicle
- Speed and vehicle travel time afforded by MUVS
- Fare charged for MUVS service

Each of these four level-of-service characteristics is related to the system description of MUVS presented in the earlier identification of key factors. MUVS service area size and terminal spacing will affect user walk access characteristics. Expected wait time will be directly related to the vehicle fleet size. In-vehicle travel times will depend on the design of the MUVS vehicle, and the fare seen by the user will derive from the system's fare policy.

In order to evaluate the effects of these factors on MUVS demand, a disaggregate demand model describing non-home-based mode choice behavior was employed. This model relates the probability that a traveler will choose MUVS for a non-home-based trip as a function of the level of service of MUVS with that of competing modes. The better the level of service of MUVS relative to competing modes, the greater the probability a traveler will choose MUVS for a non-home-based trip. Although several calibrated disaggregate mode choice models currently exist, the present model was chosen for this analysis because it represents travel behavior for non-home-based trips, a trip purpose that characterizes the predominant potential MUVS demand. The model was originally calibrated on Milwaukee data describing the choice between auto and bus travel. However, since the underlying structure of the model is based on a causal theory of individual travel behavior, the estimated parameters indicating traveler sensitivity to in-vehicle and out-of-vehicle travel times and out-of-pocket costs is appropriate for the analysis of MUVS mode split.

The model was used to investigate the effects of MUVS terminal density, MUVS vehicle speed, vehicle wait times, and alternative MUVS fare policies on the demand for multi-user vehicle systems. Most of the analyses consider binary mode choice, MUVS versus walk. In investigating the effects of vehicle wait times, however, a third mode, bus, was added to the analysis.

The Effects of Terminal Density on MUVS Demand

Consider a square MUVS service area one mile on each side. As discussed earlier, the number of terminals in a service area will directly affect the walk access time to MUVS terminals. Using the relationships derived earlier for average walk distances to MUVS terminals as a function of terminal density, MUVS mode splits were derived for various terminal densities and trip distances, assuming the following level-of-service characteristics:

- MUVS fare = 30 cents (flat fare)
- No vehicle wait times
- Check-in, check-out procedures at terminals take one minute
- MUVS speed = 10 mph, walk speed = 2.5 mph

As illustrated in Figure 10, MUVS mode share is greater for longer trip distance with any terminal density. For short trips of 1/4 mile or less, even with extremely dense terminal coverage, MUVS mode split is less than 20 percent, assuming no vehicle wait times. Thus, for the majority of travelers, walking from origin to destination for short trips is more convenient than walking to an MUVS terminal, checking out a vehicle, paying a 30-cent fare, riding to another terminal, and walking to the final destination.

For longer trips, MUVS provides a more competitive service. It is apparent though from Figure 10 that there is a critical mass effect of terminal density on potential MUVS demand. With very few terminals (two to four) in the service area, MUVS will not capture a significant mode split. Once a certain minimal number of terminals is provided, MUVS demand is relatively insensitive to the provision of additional terminals. For example, with ten terminals evenly spaced in the service area, MUVS could capture about 75 percent of the one-mile trips, assuming that trip ends are uniformly distributed in the service area. Tripling the number of terminals would increase the MUVS mode share to 90 percent, an increase of only 17 percent in the MUVS demand for one mile trips.

The results are consistent with the static demand analysis presented earlier. It is clear that average terminal access walk times become increasingly insensitive to continued terminal saturation. It should be noted, however, that in real operating environments, it is not the average, but the distribution of walk access characteristics over potential MUVS customers that will determine actual system usage. As such, the results of Figure 10 reflect an aggregate bias. The magnitude of the aggregate error, however, is not so large as to obscure the general conclusions of the static demand analyses presented earlier.

The Effects of Vehicle Speed on MUVS Demand

Vehicle speeds do not have a significant effect on potential MUVS patronage. In the demand model, of the three components of level of service, travelers' mode choice behavior is least sensitive to variations in in-vehicle travel time. Moreover, for the short trip distances in an MUVS service area (one mile or less), the absolute

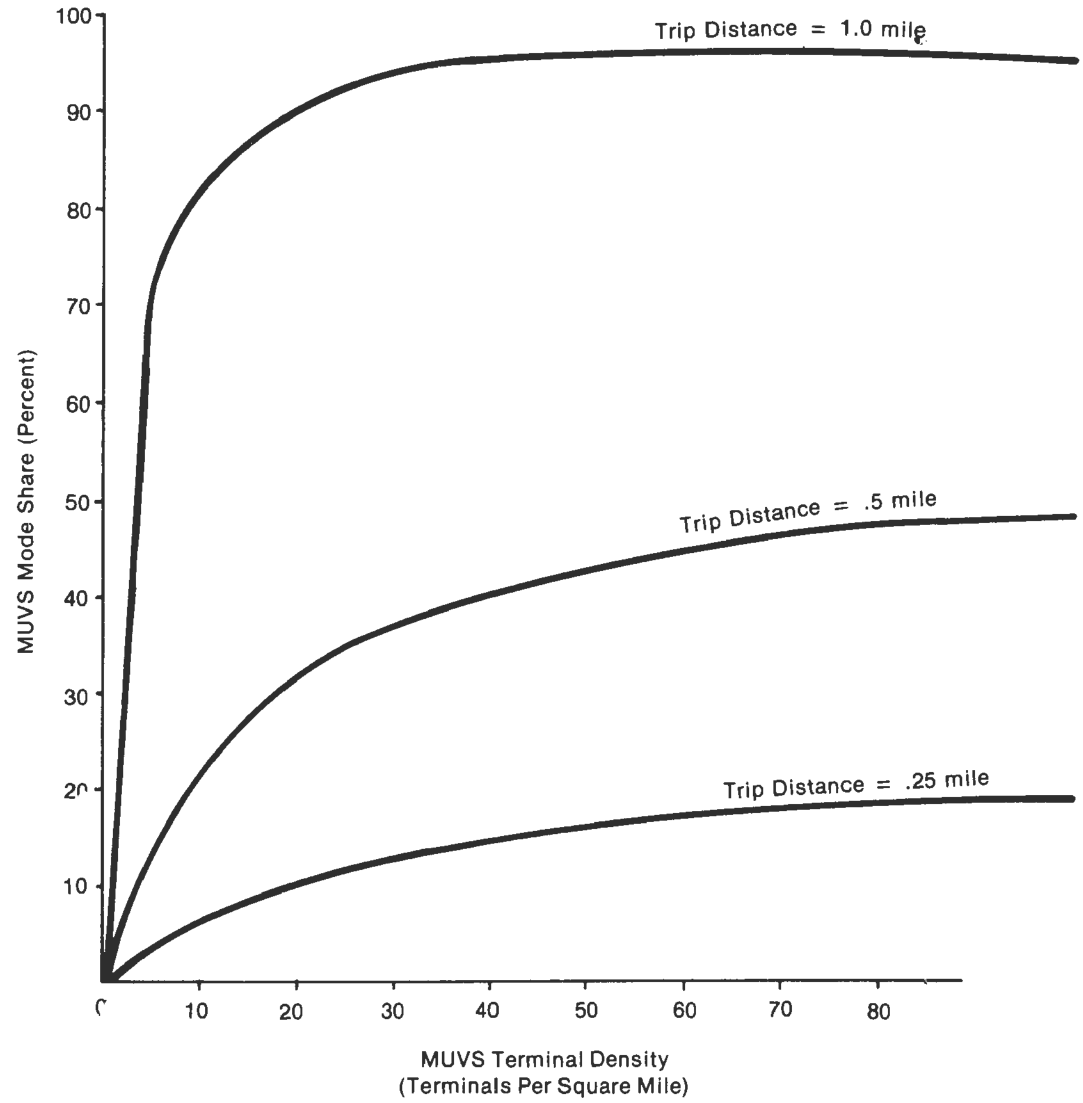

Figure 10
Effects Of Terminal Density On MUVS Demand —
Binary Mode Split, MUVS Versus Walk

differences in travel time corresponding to different vehicle design speeds will not be large.

Figure 11 illustrates the lack of variation in potential MUVS demand which occurs with respect to MUVS speed. As in the preceding analysis, walk speed was assumed to be 2.5 mph, MUVS fare was set at 30 cents, check-in procedures at MUVS terminals were assumed to take one minute, and no vehicle wait times were assessed. For this analysis, MUVS terminal walk access times were assumed to be six minutes, corresponding to a terminal density of 16 per square mile.

The demand for MUVS shows little sensitivity to vehicle speed. This is particularly true for short trips where walking captures the majority of travel, and for long trips where MUVS would be the predominant mode choice. But even for the in between distances where MUVS and walk are competitive modes, vehicle speed minimally affects mode choice. Doubling vehicle speed from 10 to 20 mph would only increase the MUVS demand for 1/2-mile trips by 7 percent. It is apparent that vehicle speed is not a critical factor in determining system patronage levels. Terminal access walk times, MUVS fare policy, and vehicle wait time characteristics are all more influential in determining potential multi-user system patronage levels.

The Effects of Alternative Fare Policies on Potential MUVS Demand

The preceding demand analyses assumed a flat fare for MUVS use. Alternatively, MUVS fares could be charged on a straight mileage basis as in the Montpellier TIP system or as a flat fare plus a mileage-based charge like that used by many taxi companies. Each of these fare structure will have a differential effect on MUVS demand for short and long trips.

Figure 12 identifies the mode share for MUVS trips over distances of 1/4 to 1 mile in length in response to three alternative fare policies:

- Policy 1 — flat fare (30 cents)
- Policy 2 — mileage-based fare (60 cents per mile)

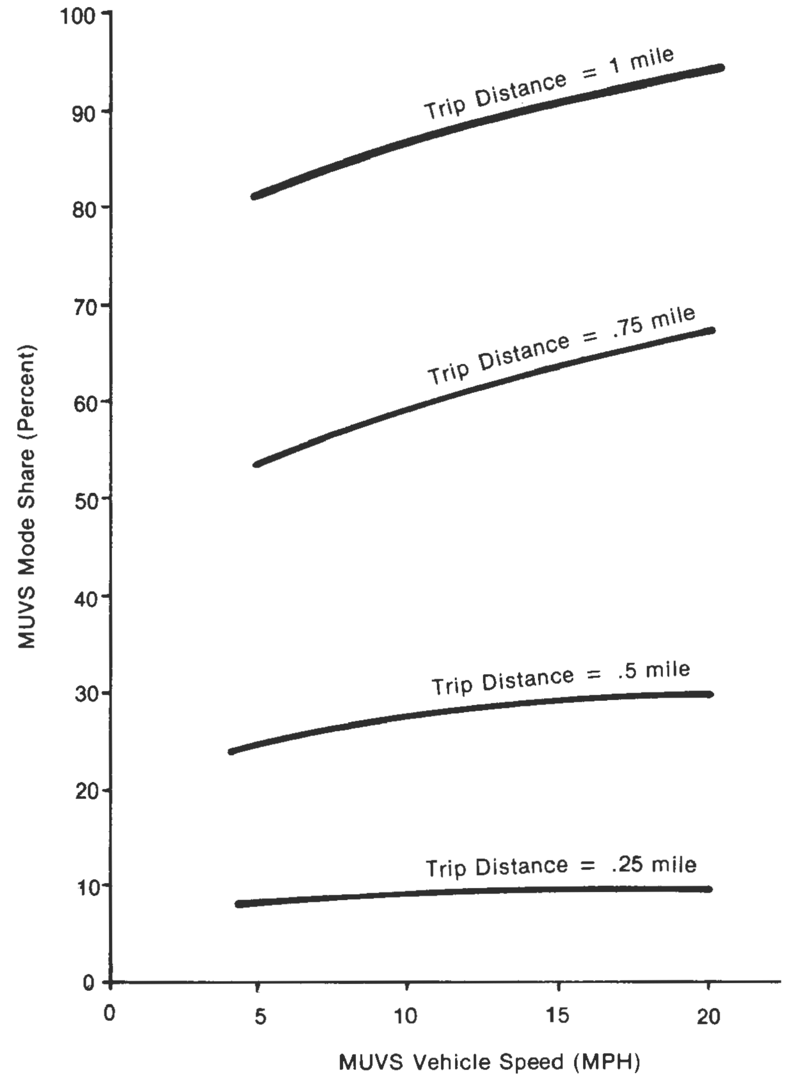

Figure 11
Effects Of Vehicle Speed On Mode Split —
Binary Mode Split, MUVS Versus Walk

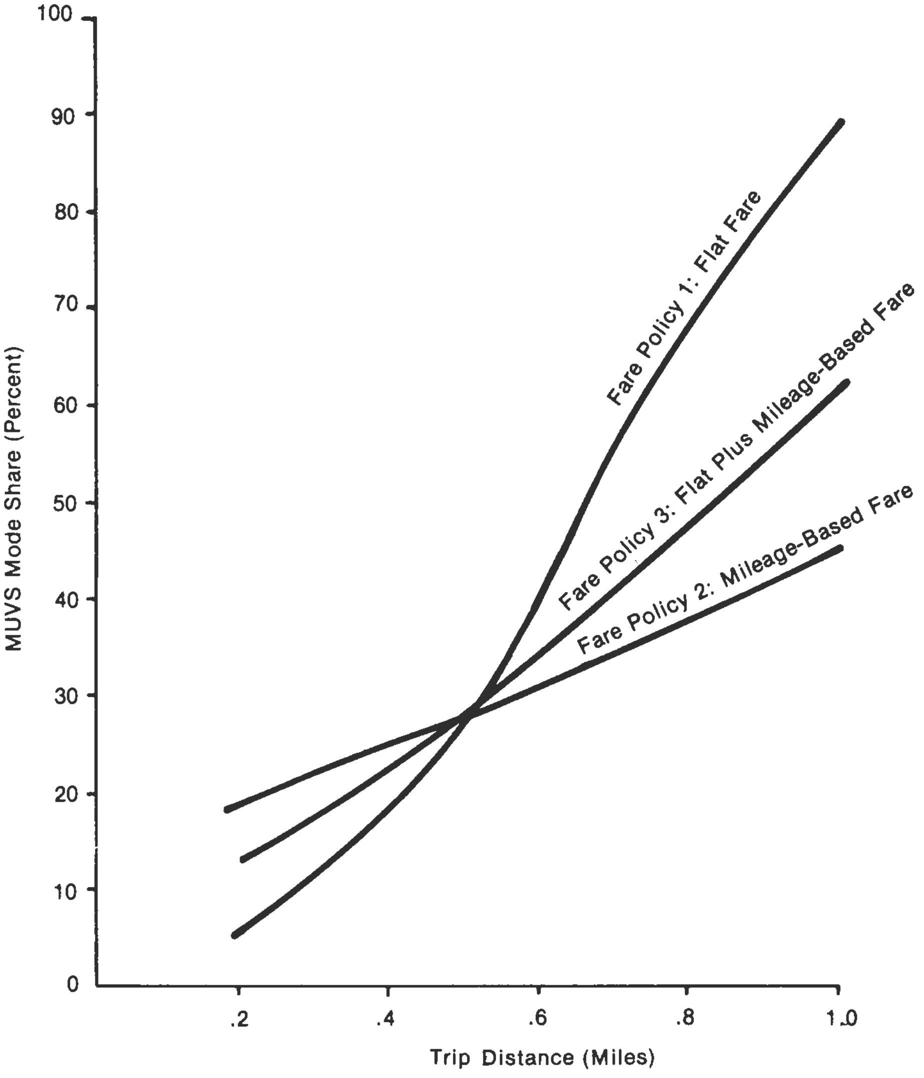

Figure 12
Effects Of Alternative Fare Policies On MUVS Demand

- Policy 3 — flat fare plus mileage-based fare (10 cents plus 40 cents per mile)

The mode share for MUVS for 1/2-mile trips is the same for each of the three policies since at this distance each policy yields the identical 30-cent fare. Of the three alternatives, the flat fare policy yields the highest demand for relatively long MUVS trips and the lowest demand for short trips, because on a per-mile basis, the flat fare policy systematically favors longer travel. At the other extreme, a straight mileage-based fare increases the patronage of MUVS for short trips and results in a significant reduction of MUVS patronage on one-mile trips. This is as expected; for the mileage-based fare policy, the charge for a 1/4-mile trip would be half the resulting charge under the flat fare policy. For the longer one mile trips, the mileage-based charge is double the flat fare charge. The demand for MUVS with a combination flat plus mileage-based charge falls roughly halfway between the demands for MUVS under the two alternative single component fare structure.

From this analysis, it is evident that MUVS demands are highly sensitive to fare policy. Depending on the trip length distribution of the potential MUVS travel market, an appropriate fare policy can be chosen to enhance the attractiveness of the MUVS service. Straight mileage-based charges will be most attractive to users of MUVS for short trips. Alternatively, flat fares will discourage MUVS use for short trips and attract patronage for trips over longer distances.

Effects of Vehicle Wait Times on the Demand for MUVS

In the static demand analyses, it was shown that MUVS fleet size requirements were extremely sensitive to diurnal and directional peaking of travel demands. Alternatively, this implies that in the absence of an adequate vehicle stock, MUVS wait times may grow very rapidly under peaked demand conditions. In all of the preceding supply analyses, MUVS wait times were assumed to be zero. In Figure 13, the effects of increasing MUVS vehicle wait times are shown for trip distances between 1/4 and 1 mile in length. It is immediately apparent that the demand for MUVS is highly sensitive to vehicle wait times.

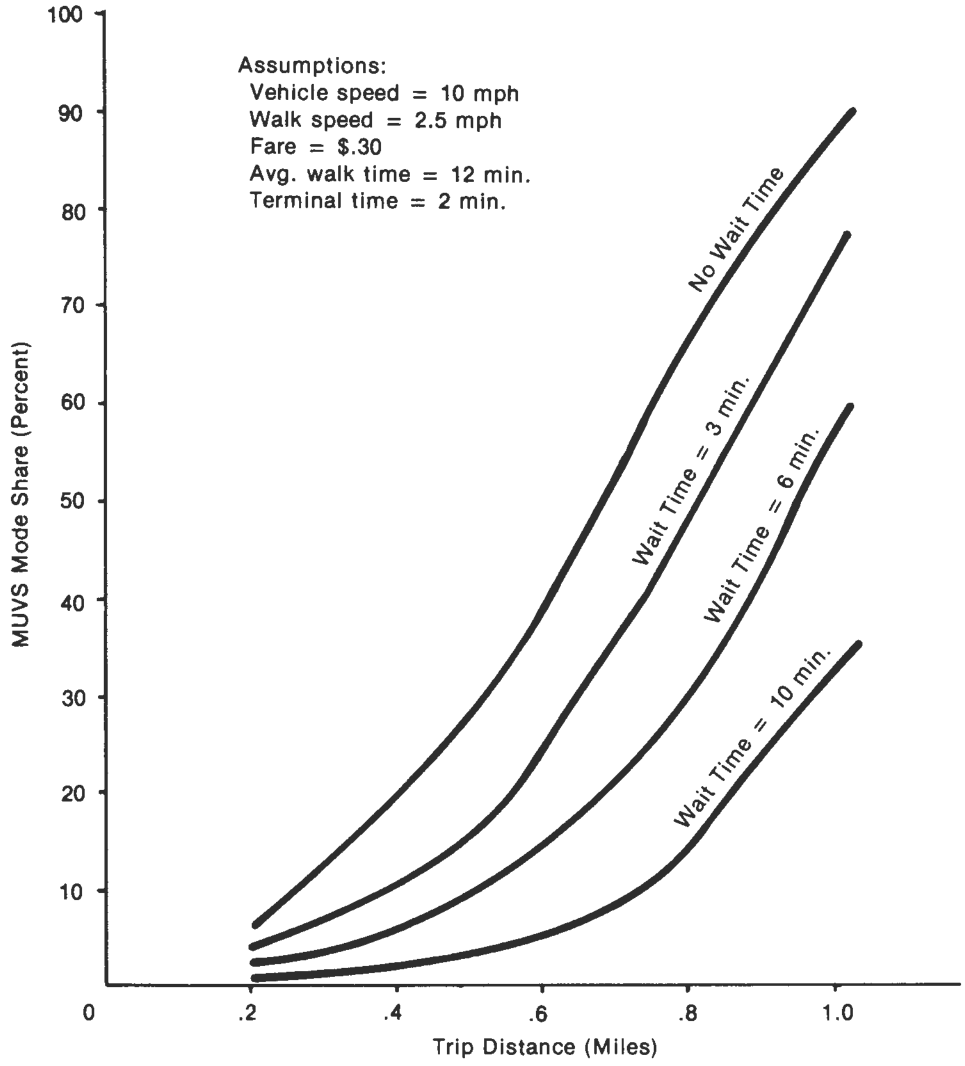

Figure 13
Effects Of Vehicle Wait Times On MUVS Demand — Binary Mode Split, MUVS Versus Walk

For short trips, the MUVS mode share may become negligible for any significant vehicle waiting times. In trips of half-mile length, doubling the waiting time to gain access to an MUVS vehicle from 3 to 6 minutes roughly halves potential MUVS patronage. And even for long trips of one mile or more, vehicle wait times significantly affect potential MUVS patronage.

The importance of MUVS waiting time on system demand is even more apparent when the availability of a third mode, bus, is introduced. With respect to multi-user vehicle systems, the level of service afforded by a bus system is relatively insensitive to directional and diurnal demand peaking. For the purposes of the present comparative analysis, the following characteristics of bus service were assumed:

- Bus fare = 20 cents
- Bus walk access time at origin and destination stop = 4 minutes
- Bus headways = 5 and 10 minutes
- Bus speed = 5 mph (allowing for bus route circuitries)

Figure 14 shows the change in demand for MUVS as a function of various MUVS waiting times and bus headways.

Figure 14 indicates several interesting points. First, the availability of an alternative vehicle mode significantly affects MUVS patronage. Even under favorable operating conditions when MUVS vehicle wait times are zero, the MUVS mode share for a 3/4-mile trip is only 28 percent in a three-mode setting, compared to 60 percent when walk is the only competing mode. Secondly, increasing vehicle wait time for MUVS has a more significant effect on potential MUVS patronage when bus is available than when walk is the only other mode. An increase in MUVS wait time from zero to 3 minutes decreases MUVS's mode share for 3/4-mile trips by 43 percent.

In the two-mode analysis, an increase in MUVS wait time from 0 to 3 minutes decreased its mode share by only 30 percent. Finally, for the assumed bus operating characteristics in the present analysis, bus always attracts a greater patronage than MUVS, even when bus headway is assumed to be 10 minutes and MUVS has

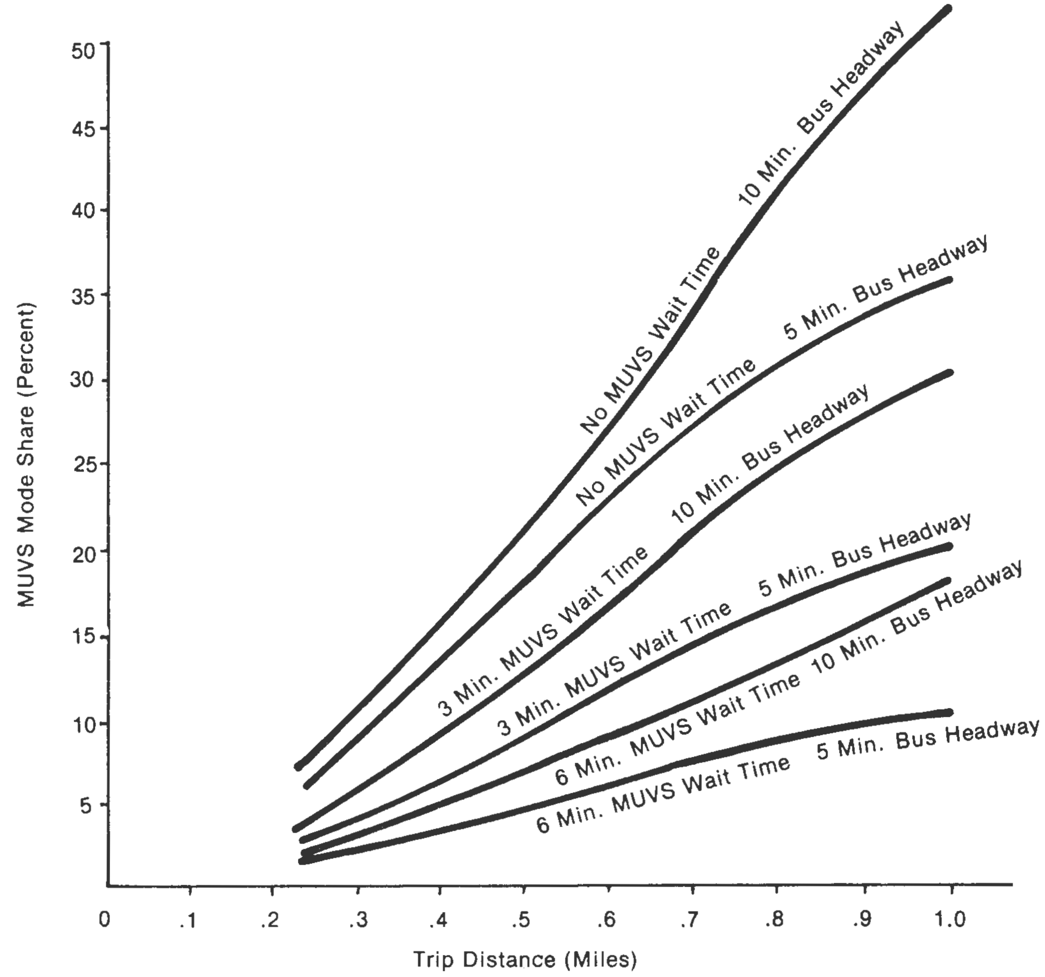

Figure 14
Effects Of Vehicle Wait Times On MUVS Demand — Three Mode Analysis: MUVS, Bus And Walk

no vehicle wait time. While this does not conclusively demonstrate that bus offers superior service to MUVS, it does strongly suggest that the degree of service area closure to other modes discussed earlier will significantly affect system patronage.

One final point should be made with respect to MUVS waiting times. In actual operating environments, there is a large variance associated with MUVS waiting times. Since the system operates on no fixed schedule, and vehicle distribution in this case depends solely on the origin-destination pattern of its users, a potential customer who arrives at an MUVS terminal at which there are no vehicles will have little idea what actual wait time may be experienced. There is, of course, past experience to draw on. If, on the average, a user has found that vehicles arrive at a particular station at the rate of one per minute, and a potential customer is the fifth member in a queue, the mode choice decision may be based on an expected five minute wait time for MUVS. However, as the simulation analysis in the following section demonstrates, MUVS terminal wait times exhibit a high variance. This variance itself is a characteristic of MUVS level of service as it indicates the reliability of the system. Even though the average wait time at MUVS terminals is relatively low, if the variance of wait time is high, travelers who must arrive at their destination at fixed times may elect to use alternative modes.

STOCHASTIC ANALYSIS OF MULTI USER VEHICLE SYSTEMS[1]

The analysis framework of the previous sections was a static approach, assuming a fixed set of demand or a fixed level of service. In reality, neither the arrival rate of potential MUVS customers nor the attainable speeds of vehicles is constant. Both demand and level of service are subject to wide variations, even if their mean values are relatively stable. Consequently, the supply-demand equilibrium process of MUVS operation inherently involves queuing behavior. As such, it is not always possible to trace out continuous supply functions of MUVS performance as was done in the static analysis framework. This section discusses a simulation approach to analyzing the demands for and performance of a multi-user vehicle system.

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[1] The term "stochastic" is used here to denote random variability and change.

Simulation is a technique for determining the performance of dynamic systems that are subject to continual variations in supply and demand characteristics. In the case of an MUVS simulation, the events that characterize the performance of a particular system are:

- The arrival of customers at MUVS terminals
- The departure of vehicles from MUVS terminals
- The arrival of MUVS vehicles at destination terminals

In general, these events are described in the simulation framework by specifying an arrival pattern of potential customers comprising the mean and distribution of customer arrival rates, the service process or the speeds that vehicles can travel and thus process customer demands, and a set of queuing rules that govern which customers get which vehicles in the event of queue formation.

Effects of Stochastic Demand Variations on MUVS Performance

In order to assess the importance of stochastic fluctuations in MUVS demand rates on system performance, a set of simple simulations were performed and the results are summarized in Table 6. Each simulation run represents three hours of simulated clock time. In each case, the mean arrival rate of customers and the standard deviation of MUVS customer inter-arrival times was held constant at two customers per terminal per minute. The different row entries in Table 6 correspond to three simulations each of three different MUVS fleet sizes for a two and four terminal analysis. In each simulation, the distance between all terminals was assumed to be one mile and the speed of the MUVS vehicle was set at 10 mph. Using the static relationships for the fleet size to eliminate vehicle wait times, it was determined that 12 vehicles were required at each terminal. Simulations were also performed for 18 vehicles per station, a 50-percent vehicle surplus, and for 24 vehicles per station, a 100-percent vehicle surplus.

For each simulation, Table 6 summarizes the following statistics:

1. The mean vehicle wait time for all customers.
2. The mean vehicle wait time for customers who queued at terminals. This value should be greater than the previous mean as it does not average in customers whose wait time was zero.

Table 6
The Effects of Stochastic Demand Variation on MUVS Performance

No. of Stations	No. of Veh./ Percent Veh. Surplus	Mean Wait All Customers	Mean Wait Queued Customers	Max Queue Length	Percent of Customers Who Queued	Mean Wait Times: Scheduled Trips	Max. Wait Times: Scheduled Trips	Standard Dev. of Wait Times	No. Queued at End of Simulation
2	12/0	4.86	6.67	46	73	4.20	21.1	5.42	46
2	12/0	4.47	5.77	50	78	3.60	19.0	4.72	66
2	12/0	3.45	4.10	19	84	3.30	9.4	2.55	27
2	18/50	2.71	7.64	40	36	2.40	17.6	4.98	32
2	18/50	1.97	6.22	32	32	1.80	15.6	3.68	21
2	18/50	.47	2.20	13	21	.47	6.6	1.19	0
2	24/100	3.80	8.59	34	23	1.70	16.1	4.13	26
2	24/100	2.45	5.59	26	23	1.20	12.2	2.76	15
2	24/100	.09	1.26	7	7	.09	3.5	.42	0
4	12/0	6.88	8.07	75	85	5.90	29.0	6.70	130
4	12/0	6.72	8.04	44	84	6.20	22.7	5.25	78
4	12/0	6.88	8.59	47	80	6.40	28.7	6.91	64
4	18/50	2.72	6.89	58	39	2.30	24.5	4.87	72
4	18/50	1.81	3.79	28	48	1.70	13.6	2.74	37
4	18/50	2.96	6.89	36	43	2.70	19.6	4.60	46
4	24/100	1.74	8.59	48	20	1.40	20.6	3.87	47
4	24/100	.60	3.17	21	19	.60	10.9	1.61	17
4	24/100	1.50	5.44	27	28	1.40	14.7	2.94	25

3. The maximum queue length that occurred at any of the terminals during the course of the three-hour simulation.

4. The percent of customers who had to wait for some amount of time for a vehicle.

5. The mean wait time for scheduled trips. This average does not include customers who were still queued in at the termination of the three-hour simulation. Thus, the accumulated wait times of all customers still in line at the end of the three-hour period is not figured into this average. Except in cases where all terminal queues were cleared at the simulation end, this average will be lower than the mean wait time given above.

6. The maximum wait time experienced at any of the terminals for scheduled trips.

7. The standard deviation of wait times for all scheduled trips. This standard deviation includes all trips where no waiting occurred.

8. The number of customers still in queues at the termination of the three-hour simulation.

9. The fleet utilization rate defined as the percent of total vehicle hours, three hours times the number of vehicles in the system, that vehicles are in revenue service.

It should be noted that if customer arrivals were exactly evenly spaced at two per minute per terminal, the theoretical values of the first eight statistics above, measuring wait time means and standard deviations and queue lengths, would be zero. The theoretically derived values of fleet utilization rates are 100 percent for 12 vehicles per terminal, 67 percent for 18 vehicles per terminal and 50 percent for 24 vehicles per terminal. However, examination of Table 6 indicates that significant queuing and correspondingly high wait times result from stochastic variations in MUVS demand.

In particular, the following points are noted:

- When the minimum number of vehicles to serve an evenly spaced MUVS demand are provided, stochastic variations in customer arrivals can result in an average wait time for all customers of over four minutes in the two terminal simulation, and nearly seven minutes in the four station simulation.
- For this vehicle fleet provision, on an average, more than three-fourths of the potential MUVS customers have to wait for as much as 21 minutes

for a vehicle in the two station simulation. With a four station system, over four-fifths of the potential customers would have to wait for as much as 29 minutes to gain access to a vehicle.

- Maximum queue lengths are extremely high, as many as 50 customers in the two station simulation and 76 in the four customer simulation.

- The system wait time characteristics manifest high variance in two dimensions. First, for any given simulation, the standard deviation of wait times is greater than the mean wait time. This may be interpreted as indicating that on any given day, a potential MUVS user would experience a large uncertainty in knowing how long one would have to wait to access a vehicle. Secondly, the average wait times for identical conditions vary significantly from simulation to simulation. This result may be interpreted as indicating that wait time characteristics differ substantially from day to day, even under similar supply and demand conditions. Consequently, a potential MUVS user would have difficulty in ascertaining what order of wait times could be expected, based on continued experience with the system.

- Substantial increases in vehicle fleet sizes do not eliminate queuing. In fact, even when twice as many vehicles are provided as would be necessary to serve an evenly spaced demand, on average, approximately one-fifth of the potential MUVS users would have to queue at terminals for as much as 20 minutes. For customers who do queue, the average wait time could be as much as eight minutes.

- Increasing the vehicle stock generally decreases average vehicle wait times. However, this is at the expense of system utilization. As expected with the minimally required number of vehicles to serve the specified demand rate, fleet utilization is nearly 100 percent. Doubling the fleet size for the same demand rate reduces fleet utilization to approximately 50 percent.

It is concluded from these analyses that the performance of multi-user vehicle systems is significantly affected by stochastic variations in customer arrivals. All of the analyses summarized in Table 6 simulated the performance of MUVS in its most favorable potential operating environment, that of uniform but stochastic, symmetric demands. Similar experiments or alternative demand patterns that were diurnally and directionally peaked provided even more dramatic evidence that variations in the rate of customer arrivals cause severe bottlenecks at MUVS terminals.

EQUILIBRIUM ANALYSIS OF MULTI USER VEHICLE SYSTEMS

This section describes a dynamic supply-demand equilibrium analysis of multi-user vehicle systems. The analysis is dynamic in the sense that a simulation approach is used to trace out the time-dependent variations in MUVS performance. Equilibrium is treated by "imbedding" a disaggregate mode split model in the simulation routine so that MUVS demand is determined as a function of current and varying level-of-service conditions.

The purpose of the analysis is to evaluate the equilibrium supply and demand characteristics of an MUVS circulation service in a representative urban ARZ environment. The decision to solely represent MUVS in an auto-restricted operating environment in this section was based on two considerations. First, as noted previously, the most favorable operating environment for MUVS is one in which it does not compete with other modes such as private auto, taxi, and bus. As will be shown here, even in the assumed favorable operating environment where MUVS has a vehicular monopoly on potential demand, the service is poorly utilized. Under the circumstances, the viability of an MUVS service in an open CBD, where it would compete with several existing modes, appears highly questionable. Even under the most favorable terms, MUVS may not be able to provide a reliable intra-CBD circulation service.

The second reason for directing attention to MUVS in an ARZ setting is the interest of this project in investigating the accessibility within auto restricted zones. There may be a need for providing some form of vehicular service within ARZ's of relatively large scale. MUVS is one alternative system to meet that need. In an unrestricted CBD, the role that MUVS would serve is not so clear. The assessment of the two European CBD MUVS services concluded that in neither system was there an identifiable travel market for the multi-user vehicle system.

A case study approach is employed in this section. First, a representative CBD area is hypothesized to be completely auto-free for base case analysis. This area is taken to be one square mile containing nine MUVS terminals. Demand patterns for five distinct diurnal time periods spanning the period from 7 a.m. to 7 p.m. are developed for the analysis. Following this analysis, a series of policy variants are considered in successive case studies. In particular, the second case study considers the effects of increasing the MUVS vehicle stock in the nine-terminal network. In the third case study, the size of the service area is increased from one square mile to 2.25 and four square miles respectively to assess the impacts of area size on MUVS demand and performance. Case study four returns to the original service area size and considers the transport impacts of alternative MUVS fare policies. Finally, case study five evaluates the effects of a specific MUVS vehicle redistribution policy performed on a period-by-period basis. In conjunction with the second case study, this analysis investigates the critical tradeoff between fleet size and redistribution policies.

Case Study One: Base Case

Figure 15 depicts the base case study area, representative of a square central business district, one mile on a side. MUVS circulation within the area is served by a network of nine terminals. Assuming a square grid street pattern, the distance between terminals ranges from .38 to 1.4 miles. In this base case, access to the ARZ occurs primarily at terminals 1-4, termed modal interchange points. Two modes for intra-CBD circulation area are considered in this analysis—walk and a multi-user vehicle system. Each MUVS terminal is associated with a rectangular service zone; any MUVS traveler ultimately destined to a particular zone is assumed to use the MUVS terminal in that zone.

It is assumed that the representative CBD contains a mix of retail shopping and employment activities which are relatively denser in the center of the area. The period to be studied spans the 12-hour period from 7 a.m. to 7 p.m. However, because travel patterns over this period are not uniform, five distinct travel periods were considered as described below.

Morning Peak (7 a.m.-9 a.m.) — In typical urban areas, this period is characterized by both directional and diurnal peaking. Based on studies of urban diurnal travel patterns, this two-hour period was assumed to comprise 24 percent of the total 12-hour person trips. Moreover, since the predominance of travel is assumed to be work commuters, the flow is asymmetric. The major flow direction is from the fringe access zones 1-4 to the remaining areas.

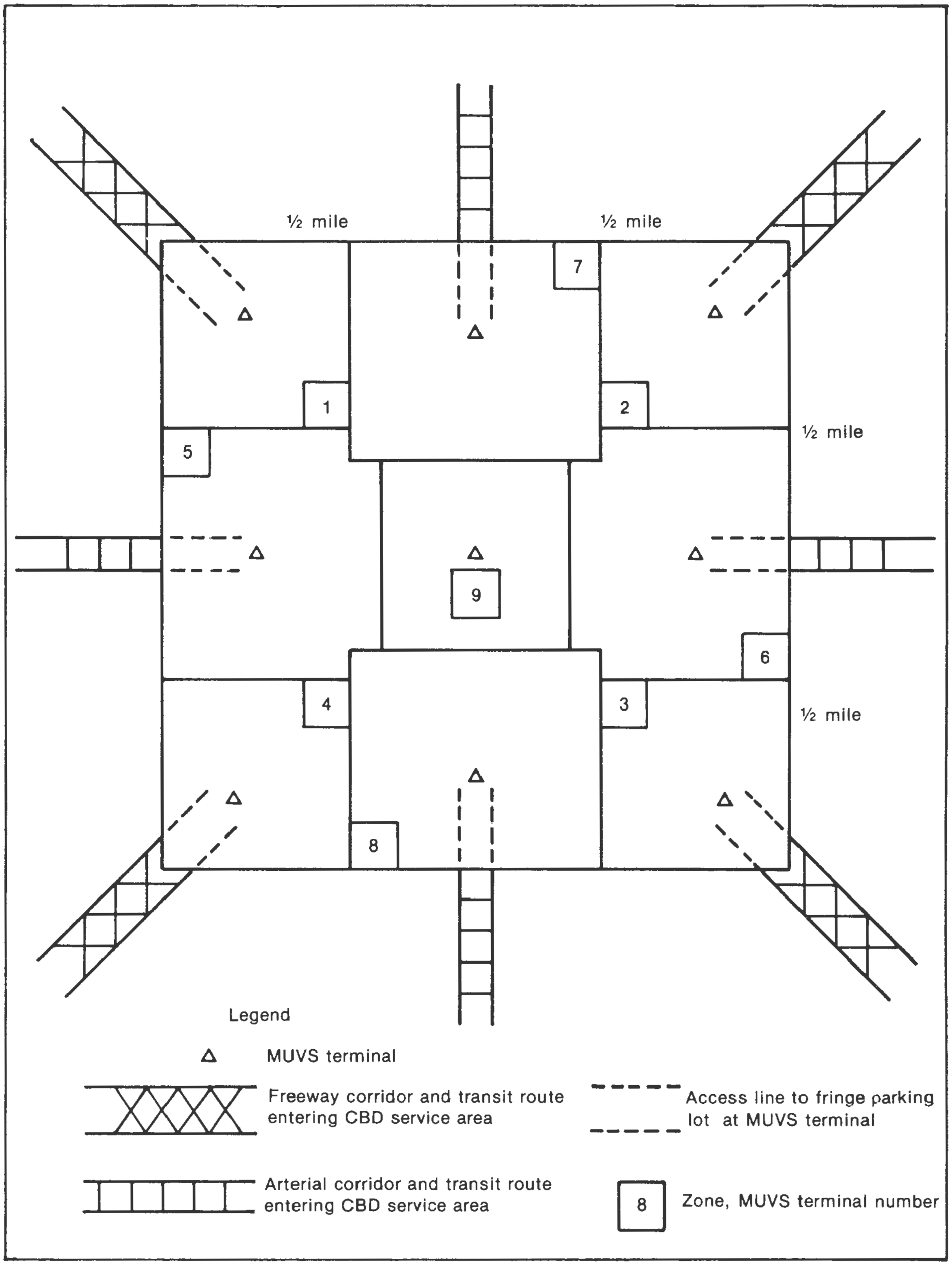

Figure 15
Schematic MUVS Terminal Network In An ARZ

Mid-Morning Off Peak (9 a.m.-11:30 a.m.) — Travel in this period is lighter than the morning peak (12 percent of total trips), and less directionally peaked. Fringe zones 1-4 still generate a disproportionate number of trip productions, reflecting a number of shopping travelers entering the CBD during the off-peak.

Lunch Time Peak (11:30 a.m.-2:30 p.m.) — This period is diurnally peaked with 17 percent of the total 12-hour period person trips, but relatively uniform with respect to origin-destination directional flows. These flows are representative of worker travel within the CBD during lunch hours, and shopper travel within the CBD.

Mid-Afternoon Off Peak (2:30 p.m.-4 p.m.) — This is the shortest time period and has the fewest number of trips, with only 11.5 percent of total productions. Travel in this period is more directionally peaked than the previous period, with the major flow direction inward to the CBD center.

Afternoon Peak (4 p.m.-7 p.m.) — This period is characterized by the highest diurnal and directional travel peaks. Over 35 percent of the total 12-hour trips occur during this period and the predominant flow direction is outward from the CBD center.

Figures 16 and 17 summarize the diurnal and directional peaking demand patterns assumed for this case study. Directional peaks are represented in terms of an index which varies between zero and one with the lower limit representing perfectly symmetric flows and the upper limit representing conditions where all flows are in one direction.

The base case analysis was run with a total of 10,000 trips and assumed a total of 200 MUVS vehicles. Ninety percent of these vehicles were assigned to terminals 1-4 at the start of the simulation to accommodate the high inbound directional flow in the morning peak period. The results of the base case analysis are summarized in Table 7 and are described below for each of the five analysis time periods:

- Morning Inbound Peak — As indicated in Table 7, the inbound directional peaking of travel during this period results in significant customer queuing at terminals 1-4, despite the fact that these terminals initially started with 90 percent of the 200 MUVS vehicles. Nearly

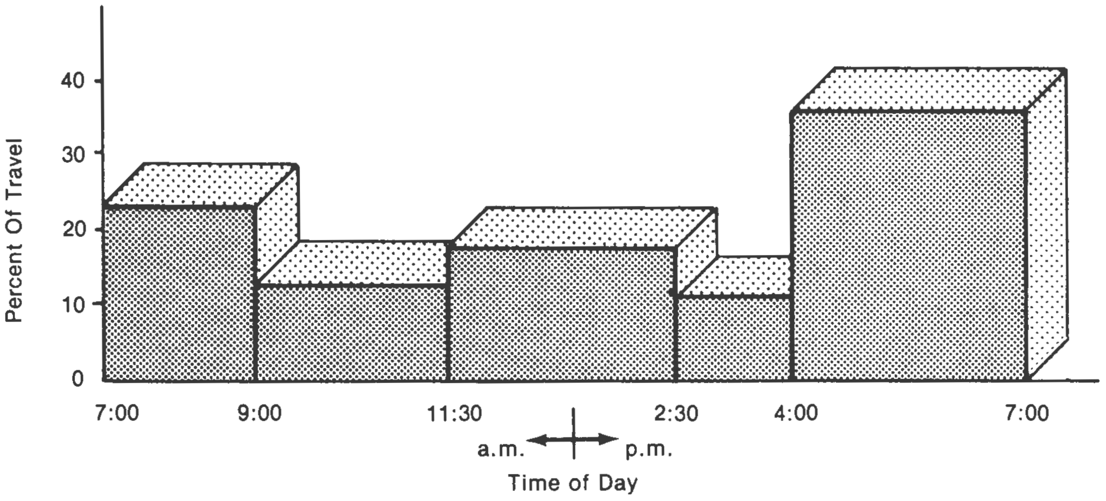

Figure 16
Base Case Diurnal Peaking Characteristics

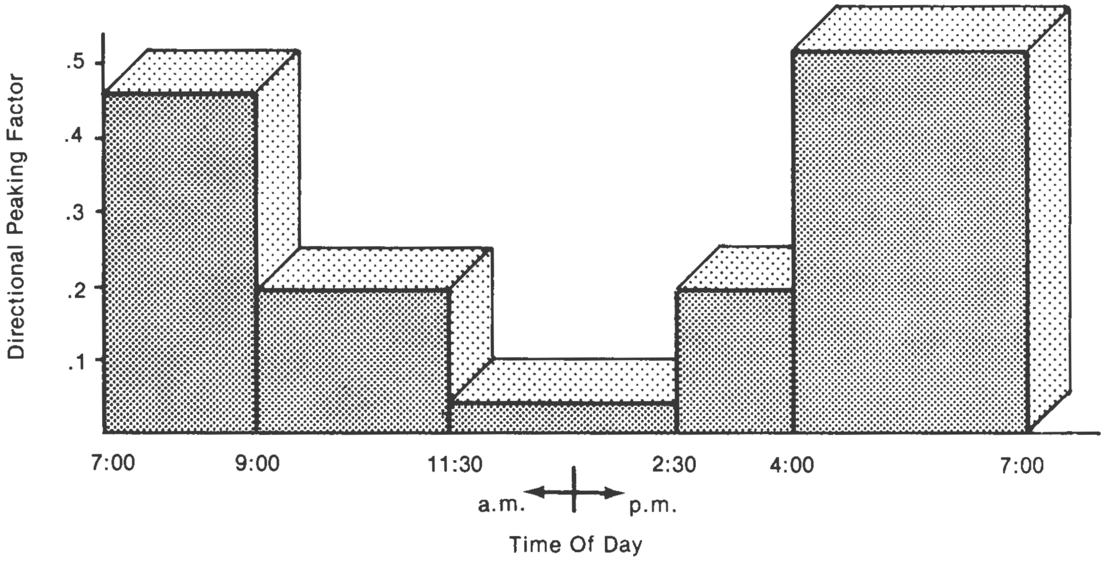

Figure 17
Base Case Directional Peaking Characteristics

Table 7
Base Case Analysis Results

	AM Peak	AM Off-Peak	Noon Peak	PM Off-Peak	PM Peak	All Periods
Total Trips	2,410	1,439	1,646	1,268	3,467	10,230
Percent MUVS Mode Split	30.70	36.40	48.30	36.20	28.80	34.40
Percent of MUVS Customers Queued at Terminals 1-4	43.90	39.90	29.60	82.46	1.70	40.00
Percent of MUVS Customers Queued at Terminals 5-8	0.00	0.00	0.00	0.00	39.60	12.00
Percent of MUVS Customers Queued at Terminal 9	0.00	0.00	0.00	0.00	98.90	21.90
Percent of Customers Queued at All Terminals	30.70	37.20	8.90	31.60	27.40	25.90
Mean Wait All Customers (min.)	1.63	2.70	.72	2.04	2.47	1.88
Mean Wait Queued Customers (min.)	5.32	7.26	8.06	6.46	9.05	7.25
Max Wait Time (min.)	22.60	27.90	31.60	31.60	33.10	33.10
Percent Utilization Rate	14.78	3.38	10.16	11.73	12.75	11.28
Number of Veh. at Terminals 1-4	0	0	14	0	177	177
Number of Veh. at Terminals 5-8	138	174	149	168	0	0
Number of Veh. at Terminal 9	39	12	15	0	0	0
Total Revenue	$222.00	$157.00	$238.50	$137.70	$299.40	$1,054.80

44 percent of the customers entering the CBD/ARZ at terminals 1-4 and using MUVS for access to their worksite had to wait for an available vehicle. Subsequently, vehicle surpluses occurred at the remaining terminals with the result that none of the customers at terminals 5-9 experienced any queuing. At the end of the first time period, all vehicles were distributed among terminals 5-9.

Average wait time for customers on vehicle queues was five minutes. It should be stressed that in the simulation analysis, a disaggregate mode choice model splits total trip productions between the two analysis modes; walk and MUVS. It was assumed in this and succeeding analyses that travelers perceive an average wait time of three minutes per queued customer. In view of the fact that average wait time for queued customers was higher than three minutes, the analysis results probably overstate potential MUVS patronage. Moreover, in the analysis, there is no provision for customer balking. Balking refers to situations where a traveler initially decides to join a queue at a MUVS terminal, but after waiting for some period of time, leaves the queue and walks to the desired destination. From Table 7, it can be seen that some MUVS travelers had to wait for as much as 23 minutes during the morning peak to gain access to a MUVS vehicle. In reality, a significant proportion of potential MUVS customers would probably balk before waiting over 20 minutes for a vehicle, particularly passengers with trip distance of less than a mile, where the walking time is less than 23 minutes. These analysis results, therefore, probably overstate potential MUVS patronage.

The utilization rate during this period was 15 percent, a relatively low figure considering that a significant vehicle shortage occurred during the morning inbound peak. The low utilization of MUVS vehicles is a result of directionally peaked demands. Overall, MUVS mode split during this period was 31 percent.

- <u>Mid-Morning Off Peak</u> — Although fewer trips are made during this period than the preceding period, queuing characteristics are more severe. This is because the predominant travel flow direction, although less directionally peaked than the preceding period, is still inbound from the modal interchange terminals and morning peak demands depleted all vehicles at these terminals. Thus, it can be seen that nearly 90 percent of terminal 1-4 customers had to wait for an available vehicle. Accordingly, the corresponding wait time for vehicles in this period was high: an average of 7 minutes per queued customer and a maximum of nearly 28 minutes.

Because of the continued asymmetric demand, MUVS fleet utilization is again low, at 8 percent. Over 37 percent of potential customers had to wait for vehicle availability during this period, up from 31 percent in the preceding period, and revenue dropped to $157 from $222 in the preceding period. At the end of the period, all vehicles were distributed between terminals 5-9. Thus, as in the first period, asymmetric travel flows depleted all vehicles at terminals 1-4.

- Lunch Time Peak — As indicated, the most favorable service environment for a multi-user vehicle system operating without an explicit vehicle redistribution policy is one where demands between origins and destinations are relatively uniform. The third period of this base case analysis, the lunch time travel period, comes closest to a symmetric distribution of travel demands.

  Accordingly, it is not surprising that during this period, MUVS achieved its highest mode share, 48 percent. Queuing during this period was not severe. At five of the nine terminals, vehicles were immediately available for potential MUVS customers. The only queuing that did occur was at terminals where all vehicles had been depleted at the end of the preceding period. Average wait time for customers who had to queue was relatively high, however, over 8 minutes. Although total trip productions were not as high as in the first period, total MUVS patronage and revenue were higher in this period, another indication that MUVS is best suited to serving symmetric demand patterns. System utilization during the lunch time period was 10 percent; and, although up from the preceding period where demands were more asymmetric, it was still relatively low.

- Mid-Afternoon Off Peak — In the preceding period, where demands were relatively symmetric within the nine-zone ARZ network, none of the MUVS terminals were depleted of vehicles at period end. Nonetheless, because the mid-afternoon off-peak period is characterized by an inbound demand asymmetry and only 8 percent of the vehicles were located at the major modal interchange terminals at the end of the preceding period, this period is characterized by significant terminal queuing.

  Over 30 percent of potential MUVS customers had to wait during this period for an available MUVS vehicle. Accordingly, MUVS patronage during this period was only 36 percent, down from 48 percent in the preceding period. For customers who did queue, the average wait time was nearly 7 minutes.

- Afternoon Outbound Peak — This period is characterized by the highest diurnal and directional peaks of the 12-hour, 5-period day. The predominant flow direction is outbound from the high density central CBD/ARZ (terminal 9). However, since the previous period also had an unbalanced outbound flow from terminal 9, this terminal had no vehicles at the start of the afternoon peak. Accordingly, this period is characterized by severe peaking characteristics.

  Nearly 100 percent of potential MUVS customers from the central CBD/ARZ need to wait for as much as 33 minutes to access a vehicle. Average wait time per queued customer is over 9 minutes, the highest of the five periods. Because of the extremely high vehicle wait time, MUVS patronage during the afternoon outbound peak, 29 percent, is the lowest of the five periods. Fleet utilization is only 13 percent, despite the fact that MUVS patronage and revenues are highest during this period. As evidence of the directional peaks during this period, all vehicles end up at the fringe terminals (1-4) at the end of the p.m. peak period.

Case Study Two: Increasing Fleet Size

In the base case analysis, significant queuing occurred in each of the periods in which directional peaking occurred. This case study briefly investigates whether increases in the stock of MUVS vehicles can overcome the wait times associated with stochastic variations and diurnal and directional peaks in travel demand. Table 8 summarizes the period-by-period analysis of an MUVS system with 400 vehicles, twice the number of vehicles employed in the preceding analysis. In each period, the terminals where bottlenecks occurred in the base case analysis persist in the current analysis. Average wait times per queued customer are nearly identical to the case with only 200 vehicles. Similarly, maximum wait times do not decrease appreciably. Total patronage and system revenues do increase but only by 12 percent, with a 100-percent increase in vehicles. Fleet utilization rates, however, decrease by almost 100 percent which results in a higher total cost per trip.

Table 9 summarizes the simulation results of the same MUVS network and demand pattern with fleet size ranging from 200 to 800 vehicles. Only full-day summaries are presented in the table. As can be seen, even with large increases of as much as 400 percent in the stock of vehicles, temporary vehicle depletion at selected terminals is not avoided. Although the number of customers who have to wait for a vehicle does decrease significantly with increasing fleet sizes, the average wait per queued customer and maximum wait times remain relatively constant. Moreover, total system patronage does not nearly keep pace with fleet size increases. An increase in fleet size by 400 percent leads to an increase in system patronage by only 28 percent. As expected, fleet utilization decreases in nearly direct proportion to fleet size given the asymmetry of the demand pattern. In short, increasing fleet size over a wide range does not eliminate vehicle depletion at terminals in the face of stochastically varied asymmetric demands.

Table 8
Base Case Fleet Size = 400

	AM Peak	AM Off-Peak	Noon Peak	PM Off-Peak	PM Peak	All Periods
Total Trips	2,410	1,439	1,646	1,268	3,467	10,230
Percent MUVS Mode Split	40.70	36.40	48.60	36.40	35.70	39.10
Percent of MUVS Customers Queued at Terminals 1-4	18.10	90.30	28.60	82.50	1.51	29.70
Percent of MUVS Customers Queued at Terminals 5-8	0.00	0.00	0.00	0.00	20.50	7.60
Percent of MUVS Customers Queued at Terminal 9	0.00	0.00	0.00	0.00	44.80	14.70
Percent of Customers Queued at All Terminals	14.00	37.40	8.63	30.60	16.60	18.70
Mean Wait All Customers (min.)	.74	2.70	.68	1.64	1.34	1.32
Mean Wait Queued Customers (min.)	5.28	7.22	7.91	5.37	8.07	7.05
Max Wait Time (min.)	22.00	27.90	31.60	31.60	31.60	31.60
Percent Utilization Rate	9.48	4.10	5.00	5.76	7.91	6.38
Number of Veh. at Terminals 1-4	0	0	5	0	377	377
Number of Veh. at Terminals 5-8	258	294	282	293	0	0
Number of Veh. at Terminal 9	119	92	91	73	0	377
Total Revenue	$294.00	$157.20	$240.00	$138.30	$371.40	$1,200.90

Table 9
Base Case with Fleet Sizes = 200—800

	200 Vehicles	400 Vehicles	600 Vehicles	800 Vehicles
Total Trips	10,230	10,230	10,230	10,230
Percent MUVS Mode Split	34.40	39.10	43.70	48.10
Percent of MUVS Customers Queued at Terminals 1-4	40.00	29.70	23.56	16.50
Percent of MUVS Customers Queued at Terminals 5-8	12.00	7.60	6.09	3.00
Percent of MUVS Customers Queued at Terminal 9	21.90	14.70	7.74	3.50
Percent of Customers Queued at All Terminals	25.90	18.70	14.40	9.30
Mean Wait All Customers (min.)	1.88	1.32	.94	.57
Mean Wait Queued Customers (min.)	7.25	7.05	6.55	6.15
Max Wait Time (min.)	33.10	31.60	31.60	31.60
Percent Utilization Rate	11.28	6.38	4.72	3.88
Number of Veh. at Terminals 1-4	177	377	576	770
Number of Veh. at Terminals 5-8	0	0	0	0
Number of Veh. at Terminal 9	0	377	0	0
Total Revenue	$1,054.80	$1,340.90	$1,340.40	$1,475.40

Case Study Three: The Effects of ARZ Size

Table 10 illustrates the effects of increasing ARZ service area sizes on MUVS supply and demand. For the purposes of this analysis, the origin-destination demand pattern and the number of terminals was held constant for each area size. In general, as the service area increases, the total intra-area trips may be expected to increase. The purpose of this analysis is to determine how a given MUVS system would perform in different size areas. Increasing area size with a fixed number of terminals decreases terminal density and thus increases average walk-to-terminal access times. Terminal access times were increased in this analysis in accordance with the larger capture area for each terminal. While increased terminal access time would tend to decrease MUVS patronage, in large areas trip distances tend to be longer. With longer distances, walking becomes less attractive relative to MUVS.

The analysis indicates that as the area size increases all other factors held constant, MUVS patronage tends to increase. Two different service area sizes are depicted in Table 10, a square service area of 2.25 square miles and another of 4 square miles. For a 200-vehicle system, MUVS mode share increases from 40 to 47 percent as area size increases from 2.25 to 4 square miles. It is apparent that passengers are willing to tolerate increased terminal access walks to avoid walking the long distances from actual origin to destination in expanded service areas. It should be noted that as area size increases, average MUVS travel times increase. This implies that each vehicle can service fewer customers per hour so that, for a fixed fleet size, customer queuing increases as a function of area size.

This behavior is borne out by the results shown in Table 10. As the area size increases from 2.25 to 4 square mile with either 200 or 400 vehicles, the number of queued customers, the average wait time, and the maximum wait time increase. Fleet utilization also increases with larger area size because, on an average, the vehicles are on the road for a longer time per trip.

The analysis results indicate that as the size of the service area increases, the number of MUVS vehicles required to maintain a constant wait time performance

Table 10
Effects of Different Service Area Sizes

	Service Area = 2.25 Sq. Miles		Service Area = 4 Sq. Miles	
	200 Vehicles	400 Vehicles	200 Vehicles	400 Vehicles
Total Trips	10,230	10,230	10,230	10,230
Percent MUVS Mode Split	40.40	46.70	44.70	51.00
Percent of MUVS Customers Queued at Terminals 1-4	50.00	38.70	53.70	44.20
Percent of MUVS Customers Queued at Terminals 5-8	12.80	8.40	13.90	10.10
Percent of MUVS Customers Queued at Terminal 9	38.20	17.70	36.30	17.40
Percent of Customers Queued at All Terminals	31.90	22.90	33.50	25.60
Mean Wait All Customers (min.)	3.03	2.03	3.94	2.82
Mean Wait Queued Customers (min.)	9.52	8.89	11.78	11.01
Max Wait Time (min.)	40.50	40.50	46.60	41.80
Percent Utilization Rate	19.65	11.17	28.48	15.91
Number of Veh. at Terminals 1-4	164	364	154	354
Number of Veh. at Terminals 5-8	0	0	0	0
Number of Veh. at Terminal 9	0	0	0	0
Total Revenue	$1,239.90	$1,434.30	$1,371.30	$1,565.10

increases significantly. For the 200-vehicle system, average wait time for the one square mile area was 5 minutes, compared to 12 minutes in the four square mile area. This difference would probably be even greater if a more realistic assumption were made regarding the total number of intra-area trips as a function of area size.

Case Study Four: The Effects of Fare Policy

Table 11 summarizes the effects of three alternative fare policies on MUVS equilibrium demand and supply. In each case, the original one square mile, nine-terminal network was employed with two alternative fleet sizes, 200 and 400 vehicles. The three fare policies tested were a 30-cent flat fare, a straight mileage-based fare of 60 cents per mile, and a combination flat-plus-mileage-based fare of 10 cents plus 40 cents per mile.

As discussed earlier, these fare policies have a differential effect on trips of different distances. The flat fare favors MUVS used for longer trips, while the straight mileage-based fare encourages MUVS use for shorter trips. The equilibrium analysis bears out the theoretical findings of the static analysis. Under the flat fare policy, average MUVS trip distance was 0.79 miles, compared to an average distance of 0.68 miles under the mileage-based fare policy. Average trip distance under the combination fare strategy was 0.73 miles. The three fare policies yield identical user costs for trips of 1/2-mile. The great majority of trips in the assumed network, however, are longer than this distance so that for most trips, the 30-cent flat fare policy yields the least expensive user cost. Accordingly, this fare policy had the highest MUVS mode share, 34 percent for the 200-vehicle system, and 39 percent for the 400-vehicle system.

The other two fare policies, although attracting fewer users, yielded higher system revenues. The greatest revenues were achieved with the combination fare policy. Average fare per trips under this policy was almost 40 cents. The fact that this higher fare per trip yielded higher MUVS system revenues is indicative of MUVS demand price inelasticity.

Table 11
Effects of Alternative Fare Policies

	Base Case Network with 200 Vehicles			Base Case Network with 400 Vehicles		
	30¢ Flat Fare	60¢/Mile	10¢ + 40¢/Mile	30¢ Flat Fare	60¢/Mile	10¢ + 40¢/Mile
Total Trips	10,230	10,230	10,230	10,230	10,230	10,230
Percent MUVS Mode Split	34.40	30.80	32.40	39.10	35.40	36.90
Percent of MUVS Customers Queued at Terminals 1-4	40.00	34.00	35.30	29.70	24.80	26.20
Percent of MUVS Customers Queued at Terminals 5-8	12.00	11.60	12.40	7.60	5.90	7.50
Percent of MUVS Customers Queued at Terminal 9	21.90	15.50	16.60	14.70	12.20	13.90
Percent of Customers Queued at All Terminals	25.90	21.80	23.10	18.70	15.20	16.70
Mean Wait All Customers (min.)	1.88	1.18	1.36	1.32	.79	.94
Mean Wait Queued Customers (min.)	7.25	5.40	5.89	7.05	5.23	5.66
Max Wait Time (min.)	33.10	35.80	35.80	31.60	35.80	35.80
Percent Utilization Rate	11.28	8.74	9.87	6.38	5.02	5.60
Number of Veh. at Terminals 1-4	177	182	181	377	382	381
Number of Veh. at Terminals 5-8	0	0	0	0	0	0
Number of Veh. at Terminal 9	0	0	0	0	0	0
Total Revenue	$1,054.80	$1,263.87	$1,282.67	$1,200.90	$1,451.39	$1,455.33

Case Study Five: The Effects of Vehicle Redistribution

The preceding case studies provide strong evidence that asymmetric demands may lead to significant customer queuing at MUVS terminals with correspondingly high wait times. It was shown in Case Study Two that even large increases in vehicle stocks may not eliminate these temporary vehicle depletions at stations.

Vehicle depletion is the result of three factors:

1. Stochastic variations in customer arrivals with the possibility of "bunching" of customer arrivals.
2. Systematic unbalanced flows between MUVS terminals within any given time period.
3. Misallocation of vehicles at the beginning of a time period. The distribution of vehicles at terminals at the end of one time period is inappropriate for serving the demand pattern in the following period.

There is little that a system operator could do to control the first two factors contributing to customer wait times other than increase the vehicle stock. This approach is costly; overall fleet utilization decreases with little increase in patronage or decrease in queuing.

An operating policy could be adopted to attempt to mitigate the effects of compounding asymmetric flows across time periods. In particular, if vehicles could be redistributed either continuously or periodically in anticipation of future system demands and current vehicle distribution, it might be possible to improve system performance. One possible redistribution policy is being examined here.

The analysis is somewhat unrealistic in that no time penalty was assessed for vehicle redistribution. Essentially, the simulation of system performance was run separately for the five analysis time periods. At the beginning of each period, vehicles were assigned to each terminal according to the rule described below. The rule for vehicle distribution is based on two considerations:

1. The greater the overall demand asymmetry in the network, the greater is the proportion of vehicles that should be assigned to all terminals with a net demand and "outflow."

2. Vehicle should be assigned to individual terminals in proportion to their demand asymmetry relative to other terminals.

Table 12 summarizes the results of a five-period, 200-vehicle simulation with vehicle redistribution performed before each period. Overall, the performance of the system is significantly improved over the case without a vehicle redistribution policy. In all but the first and last periods, where significant directional peaking occurs, system wait times are negligible. Total MUVS patronage over the five periods increased to 38 percent from the base case level of 34 percent. Significantly, the fraction of MUVS customers who queued was only 14 percent, down from 26 percent in the base case. Vehicle depletion during the first and last periods continued to be a problem, even with vehicle redistribution. This indicates that even when an active policy of redistributing vehicles is undertaken, highly directionally peaked demands will continue to cause queues in an MUVS operation. Again, this is not readily overcome by increasing the vehicle stock. As shown in Table 13, which summarizes the results of a 400-vehicle MUVS system with redistribution, peak demand periods continued to have significant queuing.

Although the performance of the MUVS system improves somewhat with vehicle redistribution, it should be stressed that costs of implementing such a policy may be extremely high. For example, in the 200-vehicle simulation shown in Table 12, the redistribution policy calls for deadheading 472 vehicles over the course of the day. This represents fully 12 percent of the revenue trips. Depending on the method of redistribution, a relatively large staff may be needed to perform this task, thus mitigating the natural advantage of user-operated multi-user vehicle systems with respect to labor costs. For a more detailed description of the analysis process and modeling relationships used in the quantitative evaluation, the reader is referred to the separate MUVS Technical Memorandum prepared for the project.

Table 12
Effects of Vehicle Redistribution: 200 Vehicles

	AM Peak	AM Off-Peak	Noon Peak	PM Off-Peak	PM Peak	All Periods
Total Trips	2,410	1,422	1,697	1,339	3,599	10,487
Percent MUVS Mode Split	30.70	51.70	49.60	52.40	26.30	37.90
Percent of MUVS Customers Queued at Terminals 1-4	43.90	10.50	2.90	4.30	0.00	14.30
Percent of MUVS Customers Queued at Terminals 5-8	0.00	0.00	0.00	0.00	54.00	14.20
Percent of MUVS Customers Queued at Terminal 9	0.00	0.00	13.40	0.00	50.50	14.30
Percent of Customers Queued at All Terminals	30.70	5.60	2.60	2.30	27.50	14.27
Mean Wait All Customers (min.)	1.63	.25	.11	.14	2.89	1.09
Mean Wait Queued Customers (min.)	5.32	4.35	4.03	6.38	10.49	7.60
Max Wait Time (min.)	22.60	14.20	23.00	17.60	40.20	40.20
Percent Utilization Rate	14.78	11.18	10.18	17.57	12.79	12.73
Number of Veh. at Terminals 1-4	0	0	53	16	186	186
Number of Veh. at Terminals 5-8	138	152	118	103	0	0
Number of Veh. at Terminal 9	39	33	9	45	0	0
Total Revenue	$222.00	$223.80	$252.60	$210.30	$283.50	$1,192.20

Table 13
Effects of Vehicle Redistribution: 400 Vehicles

	AM Peak	AM Off-Peak	Noon Peak	PM Off-Peak	PM Peak	All Periods
Total Trips	2,410	1,442	1,697	1,339	3,599	10,487
Percent MUVS Mode Split	40.70	54.10	50.30	54.40	32.30	42.90
Percent of MUVS Customers Queued at Terminals 1-4	18.10	0.00	0.00	0.00	0.00	5.80
Percent of MUVS Customers Queued at Terminals 5-8	0.00	0.00	0.00	0.00	30.40	10.30
Percent of MUVS Customers Queued at Terminal 9	0.00	0.00	11.90	0.00	31.10	11.80
Percent of Customers Queued at All Terminals	14.00	0.00	1.40	0.00	18.50	8.10
Mean Wait All Customers (min.)	.74	0.00	.02	0.00	1.88	.64
Mean Wait Queued Customers (min.)	5.28	0.00	1.16	0.00	9.90	7.88
Max Wait Time (min.)	22.00	0.00	4.20	0.00	40.20	40.20
Percent Utilization Rate	9.48	5.86	5.15	9.14	7.73	7.16
Number of Veh. at Terminals 1-4	0	111	157	136	386	386
Number of Veh. at Terminals 5-8	258	219	214	176	0	0
Number of Veh. at Terminal 9	119	49	10	55	0	0
Total Revenue	$294.00	$234.00	$256.20	$218.40	$348.60	$1,351.20

Chapter V

Summary and Conclusions

CHAPTER V
SUMMARY AND CONCLUSIONS

THE CONCEPT

This report has examined in depth the feasibility of an innovative concept often proposed as one solution to the problems of transportation within congested urban areas. A multi-user vehicle system (MUVS) is a paratransit mode of public transportation which consists of a fleet of small user-operated vehicles available for rental use between terminals within a well-defined service area. The concept has been referred to elsewhere as a self-drive taxi or as a public auto system. Although this report considered a wide array of potential vehicles, and not just automobiles, the basic concept examined here is similar to the various short-term rental cars or drive-yourself taxi schemes discussed in the literature.

A number of essential elements have been identified which constitute an operational definition of the multi-user vehicle system concept. User operation is the characteristic that distinguishes MUVS from a number of other individualized point-to-point transportation services such as taxi, dial-a-ride, or jitney. The vehicles considered for MUVS use are seen as relatively small and energy-efficient and could conceivably include such vehicles as bicycles, scooters, mopeds, and electric cars. The system would operate from a fixed terminal network in order to facilitate vehicle redistribution and guard against theft or vandalism. MUVS vehicles would be operated as a fleet providing the first available vehicle to fill each request for service. In addition, the use of an MUVS vehicle would be available to the public and not narrowly restricted to particular income or affinity groups.

OBJECTIVES

A basic goal of an MUVS would be the improvement of urban transportation through greater mobility and reduced automobile traffic. The byproducts of auto dependency, such as congestion, air pollution, and acres of downtown parking, have long been recognized as major contributors to the degradation of the urban environment.

The difficulty of attracting auto drivers to conventional fixed-route transit services, however, has led to the consideration of MUVS as an innovative mode of public transportation that offers the attractive features of the automobile without its disadvantages. The underlying rationale is that private autos could be made obsolete in congested downtowns if an MUVS offering an equivalent level of service was provided as a substitute.

Unlike users of conventional transit, the MUVS customer could travel in privacy, choose a route, make intermediate stops if necessary, or proceed directly to the destination, all without depending on fixed schedules or routes. The benefits of such a new urban transportation option could include increased urban mobility, improved air quality, and more efficient use of land and energy. In addition, it has been suggested that the presence of such a convenient public transit mode as MUVS could increase the viability of conventional fixed-route transit services by reducing the need for auto drivers to bring a car downtown. MUVS could build transit ridership by narrowing the level-of-service gap between public and private transport modes.

EXISTING EXPERIENCE

The foundation of the MUVS concept is actually a familiar one. The individual short-term use of a public vehicle on an as-needed basis is commonly accepted in several everyday situations. Grocery carts and golf carts function as MUVS within closely limited service areas. At a larger scale, rental cars, trucks, and trailers are among the many vehicle types offered for public use within the operating format characteristic of multi-user vehicle systems. Although these systems vary widely in purpose, availability, and vehicle hardware, the characteristics of their organization and operation as systems are similar, classifying them all as MUVS.

Even though the multi-user vehicle system concept is generally familiar, experience with MUVS in the context of urban transportation is very limited. In central business district (CBD) circulation service, MUVS have been implemented on a small scale in two European cities. The PROCOTIP system operated in Montpellier, France, from 1971 to 1973. This system operated a fleet of 16-30 vehicles from 17 terminal stations. Vehicles were available to the 350 members of a private cooperative which owned and operated the system. Due to low utilization of vehicles and consequent low return on investment, the operation ceased after 18 months.

The WITKAR system of Amsterdam is the only example of an MUVS in operation today as a CBD circulation service. In the fall of 1975, 35 vehicles were available for use between the 5 stations within the 3.2-square mile service area in central Amsterdam. The system features small electric cars which require a 7-minute charge for a trip of 2.5 miles. As in Montpellier, use of the vehicles is restricted to members of the private cooperative which owns and operates the system. The WITKAR system only operates during off-peak travel hours and indications are that vehicles are utilized only 15 percent of the available time. Revenues do not cover operating costs despite the fact that labor is provided free by volunteers.

FEASIBILITY ANALYSIS

Using the essential elements and basic operating characteristics that had been identified, a series of feasibility tests were devised. Various simulations of MUVS were performed with a mathematical model to determine fleet size requirements, waiting times, and levels of vehicle utilization under a range of typical operating conditions. MUVS demand levels were calculated for an auto restricted zone operating context that excluded most other modes of travel. MUVS performance was examined under a "best case" assumption that held demand to an even rate balanced among all terminals and also under a "typical case" assumption that investigated the effects of demand peaking at certain terminals and at certain times of the day. The importance of travel speed, one of the principal characteristics of the type of vehicle employed, was assessed for its implications for MUVS demand. Throughout the analysis, however, the major focus was not on forecasting the number of users such a system could attract, but on the evaluation of the operating performance of MUVS under a range of realistic conditions. Thus, the emphasis was primarily on the question of actual capability to serve and only secondarily on the assessment of probable MUVS demand.

CONCLUSIONS

The report has presented a review of existing experience with MUVS systems, an investigation of the key factors related to MUVS and an assessment of its feasibility as an element of an urban transportation system. The information presented was drawn from first-hand contact with existing MUVS systems and their organizers, as well as from published material on MUVS and mode split analysis data for actual cities. A brief summary of the principal results of each stage of the investigation includes the following:

1. <u>The Viability of the MUVS Concept Has Been Demonstrated in a Wide Range of Applications</u> — The concept of shared used of a given facility (vehicle) is not new. There are a large number of past and present experiences, ranging from short rentals to temporary cart usage to automobile rentals which indicate that MUVS is a desirable, operable, and economically feasible concept in some cases.

2. <u>The Concept of MUVS, However, Has Only Been Successful in Specific and Limited Service Environments</u> — A review of current MUVS systems indicates that the more successful ones are operating within a very limited context. Each system is designed to serve a very specific need within an operating environment to which it is well suited. Golf carts, for example, serve very well for their intended situation, but are less suited to the primary service offered by grocery carts or for automobile rentals, as they are commonly used.

3. <u>Existing Experiences with the MUVS as a CBD Circulation Element Have Had Limited Success</u> — The Amsterdam Witkar and the Montpellier TIP systems represent the only existing experience with MUVS service in a general transportation CBD operating environment. The latter system failed due to heavy financial losses within two years of operation. The Amsterdam system, while still operating, has yet to achieve substantial ridership. Several common factors have limited the success of these systems, including:

    - Compactness of the service area

    - Competition for potential MUVS patronage from existing CBD modes, notably private auto and walking

    - Excessive street congestion in the MUVS service area, resulting in MUVS speed lower than walk speed for many trips

    - Small fleet size

    - Lack of interchange facilities linking MUVS fringe terminals to highway or transit service to the area

- Lack of prior marketing or feasibility studies
- Lack of active cooperation from governmental agencies

4. The Most Favorable Operating Environment for MUVS Service is in Conjunction with an Auto Restricted Zone — The existence of competing vehicle modes such as taxi, bus, and auto limits the potential demand market for MUVS service for two reasons. First, by virtue of competing for congested CBD roadspace in mixed traffic patterns, MUVS speeds may not be significantly higher than walk speed during peak travel conditions. Second, to the extent that alternative modes are available to travelers, MUVS patronage will be reduced, particularly if temporary vehicle depletion at selected MUVS terminals create large MUVS wait times.

5. Within A Certain Range, MUVS Vehicle Speed Does Not Critically Affect Potential Patronage — Demand analyses suggest that a traveler's mode choice behavior is relatively insensitive to in-vehicle travel time changes. Because of the relatively short trip distances within CBDs, even significant increases in vehicle design speed from 10 to 20 mph do not result in large absolute time savings. Moreover, because of the possibility of congestion in MUVS operating environments, theoretical MUVS vehicle design speed may not be attainable during peak travel periods. Walking speed, of course, defines the lower limit of average travel speed via MUVS.

6. Alternative Fare Policies Can Have a Significant Effect on MUVS Patronage — Demand analyses indicate that alternative fare policies differentially affect MUVS trips of differing trip lengths. In general, flat fares encourage MUVS use for relatively long trips (and discourage MUVS use for short trips). Alternatively, straight mileage-based fares generally favor short trip MUVS use relative to longer trips. Within each fare policy, however, MUVS demand is price inelastic. Over a fairly wide range, increasing MUVS fares will increase system revenue.

7. Stochastic Variations in Customer Arrivals May Lead to Long Queue Lengths — Even if demands are uniform and symmetric between all MUVS terminals, random variations in customer arrivals may significantly alter equilibrium MUVS supply and demand characteristics. If all demands for MUVS service are evenly spaced, the required number of vehicles to eliminate customer queueing is a simple linear function of demand rate, vehicle speed, and trip distance. For the same average rate of customer arrivals, variations in customer arrivals will generally result in temporary vehicle depletion at terminals, even if fleet size is increased by 400 percent. Thus, the elimination of MUVS vehicle wait times in the face of stochastically varied demands does not appear to be a realistic system objective.

8. <u>Diurnal and Directional Demand Peaking Significantly Affect MUVS Performance</u> — In actual operating environments, potential MUVS demands will not only be variable events, but systematic diurnal and directional demand peaks will occur. These demand peaks critically affect MUVS performance. For any given fleet size, the greater the directional or diurnal peaks in demand, the less efficient is the MUVS service. In particular, average vehicle wait times increase rapidly as peaking of demand becomes more severe. As in the previous conclusion, even significant increases in fleet size and/or the imposition of a vehicle redistribution policy mitigate, but fail to eliminate vehicle depletion at selected terminals.

In summary, the basic conclusion of the feasibility of MUVS is that while it is serving specific needs in particular situations, it is unlikely that MUVS could provide a vital and viable modal alternative for intra-CBD service with or without auto restrictions. This finding of negative feasibility for MUVS is based on the following overall conclusions:

- <u>Unreliability of Service</u> — Even with relatively large fleet sizes, stochastic variations in customer arrivals and systematic diurnal and directional demand peaking within the service area lead to potentially long vehicle wait times. The variance in customer wait times is also extremely high.
- <u>Low System Utilization</u> — Even assuming zero terminal vehicle turnaround requirements for refueling or recharging MUVS vehicles, the analyses consistently showed fleet utilization rates to be 15 percent or less. Thus, for the great majority of time, MUVS vehicles would sit idle at terminals.
- <u>Potentially Large Fleet Size and Terminal Requirements</u> — In order to provide a MUVS service which competes with the door-to-door convenience of taxi (or possibly private auto), terminal densities on the order of over 100 per square mile may be required. The fleet size requirements to avoid inordinately long wait times are extremely sensitive to the directional and diurnal peaking characteristics. In all of the analyses, even with fleet sizes as high as one vehicle per 12.5 person-trips in the service area, temporary vehicle unavailability at selected terminals persisted for as long as a half hour.
- <u>Potentially High System Cost</u> — In view of the above conclusions, capital costs per trip are very high. Operating costs may also be high relative to alternative modes. Even if self-powered vehicles were deployed, implementing a vehicle redistribution policy to mitigate the effects of directional demands requires the repositioning of a large number of vehicles with correspondingly high labor costs. The analysis of one vehicle redistribution policy required deadheading trips equal to 12 percent of revenue trips. Moreover, even with high vehicle repositioning during the course of the day, vehicle unavailability at selected terminals remained a critical factor.

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