HIGHWAY RESEARCH RECORD

Number 415

Mass Transportation: Application of Current Technology

6 reports
prepared for the
51st Annual Meeting

Subject Area

84 Urban Transportation Systems

HIGHWAY RESEARCH BOARD

DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

Washington, D.C. 1972

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ISBN 0-309-02087-5
Library of Congress Catalog Card No. 72-9817
Price: $2.20
Available from
Highway Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

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FOREWORD

A number of real-world tests and demonstration projects under way are aimed at improving the capabilities of public transportation through the application of current technology. The papers presented in this RECORD should be of special interest to city officials, transit operators, traffic engineers, and others concerned with the efficient movement of people. The six papers report on immediate action programs that can be used to help solve congestion problems now.

Howard describes Ontario's GO Transit rail and bus commuter system, a balanced, coordinated network of public transportation. Recent additions include express bus extensions to the rail service and a dial-a-bus feeder service at one of the suburban stations. In its fifth year of operation, GO Transit carries 9 million passengers a year.

Gurski and Stuart present a case study of a novel transportation concept for Milwaukee County. The study emphasizes an automated dual-mode bus transit system. The paper summarizes the results and conclusions of the socioeconomic evaluation part of the study. The study found the dual-mode transit concept to be an attractive alternative offering many significant advantages over a modern conventional bus rapid transit.

The Twin City area of Minneapolis and St. Paul is in the process of implementing a bus metered freeway system in the I-35W corridor. Hoffman describes how the buses will be given preferential access to the freeway through special bus ramps and an override of the ramp meter. Automobiles will be metered onto the freeway only when their presence will not reduce the desired level of service.

The next two papers report on two separate and very successful projects where freeway lanes have been set aside for the exclusive use of buses. Fisher describes the Shirley Highway express bus demonstration in the Washington Metropolitan Area. A series of improvements in the preferential treatment of buses has led to travel time savings of 5 to 30 minutes and resulted in a substantial gain in bus patronage. Results of travel surveys in the corridor are discussed, and early indicators of the modal choice are described.

Goodman and Selinger report on the 2½-mile exclusive bus lane project between the New Jersey Turnpike and the Lincoln Tunnel. The average flow in the peak period on this single traffic lane has been almost 35,000 persons, with the average for a 1-hour peak approaching 22,000 passengers—one of the highest lane-passenger volumes measured anywhere. The authors include a discussion of the ongoing survey program coordinated with the overall North Jersey/Mid-Manhattan Urban Corridor study.

A man-computer interactive graphic system for planning node-oriented transit systems is described by Rapp. The system is implemented in a real-time computer environment with a cathode-ray tube on which the various effects of a particular design are immediately displayed. With this system the user can explore and assess a broad range of multiple-attribute alternatives in a short time.

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GO TRANSIT: A NEW APPROACH TO URBAN TRANSPORTATION

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•GO Transit, Ontario's government-sponsored rail and bus commuter system, carried more than 9 million passengers last year. Now in its fifth year of operation, the success of this experiment in public transportation rests in large measure with the foresight and planning by the province during the early 1960's.

Until last year, the east-west rail commuter service constituted the prime components of GO operations. Then, in 1970, GO Transit took another important step toward expansion and integration of the regional transportation system with the addition of an express bus commuter service and a dial-a-bus feeder service.

Ontario recognized the need for a comprehensive review of transportation planning in 1962 and initiated the Metropolitan Toronto and Region Transportation Study, one of the first large-scale approaches to urban transportation planning undertaken in Canada. Some 3,200 square miles were involved in the study, extending to the neighboring cities of Hamilton, 40 miles west of Toronto, Oshawa, 30 miles east, and Barrie, 60 miles to the north. Estimates placed population growth in this region at 6.5 million by the year 2000; and metro Toronto alone has a population of more than 2 million people.

Early in the study program, and in parallel with its interest in other modes of transport, consideration was given to the possible use of existing regional rail facilities to supplement highways, particularly for heavy commuter movement to and from central Toronto. At the time there was little knowledge of the passenger-carrying capabilities of these rail lines, and therefore an engineering study was conducted to determine the potential of various routes to handle significant commuter traffic volumes.

With rail service available, would the auto-oriented commuter make use of it? This was the question faced by the study group in 1964, once it had determined the physical feasibility of a commuter rail network. The few existing suburban trains operated by Canadian National Railways offered little useful evidence because their number was so limited that appeal to the auto commuter was severely restricted. The same limitations applied to some intercity trains that were used to a minor extent by Toronto commuters.

A 42-mile portion of Canadian National Railways lakeshore rail lines between Oakville and Pickering seemed to offer the greatest promise for a successful suburban service because of the existing and potential population characteristics of the corridor and the physical feature of the rail line itself. Attention was focused on this route.

Canadian National Railways agreed to operate trains under contract to the Ontario government along the Canadian National right-of-way. In effect, CN would run the day-to-day operations while the government would specify the type of service, fares, schedules, and other policies; supply the capital; pay operating costs; and receive the revenues.

In 1965, based on recommendations of the study, the provincial government gave the go-ahead for an east-west commuter rail service along the lakeshore between Oakville and Pickering, and the Ontario Department of Highways was given the responsibility for implementation and administration of the new service. Phase I of the Ontario government's new approach to urban transportation was now under way.

The commuter service needed an image. A design group was formed to produce a distinctive identification of all aspects of the new operation, and thus was born Government of Ontario Transit, called GO Transit for short. GO Transit's symbol—a stylized G and O in bright green linked together by the white horizontal bars of the letter T lying on its side—now appears on everything connected with the system, from tickets to locomotives.

As 1965 progressed, so did detailed planning of the myriad items that had to be considered in the development of this totally new mass transportation concept. This included such activities as station locations and property acquisition, design and construction of rolling stock, railway construction engineering, scheduling and consists, maintenance requirements, crew arrangement, labor negotiations, fare structure and ticketing, promotion, and many more.

The project was developed in just 24 months from the date of the announcement to proceed, in May 1965, until inauguration in May 1967. Specially designed GO equipment was constructed that included 54 streamlined aluminum coaches, nine self-propelled commuter cars, and eight 3,000-horsepower diesel-electric locomotives. The 85-foot long cars will accommodate 94 seated passengers each and have thermostatically controlled air-conditioning, heating, and ventilating systems.

Prior to the opening of the service in May 1967, an extensive 4-week promotional campaign was undertaken. Its purpose was to develop the specific advantages of GO service over auto commuting. The advertisements were warm and friendly, with a slightly whimsical appeal. They were designed to help offset preconceptions of commuter travel and to establish the GO service as socially desirable, modern, and relaxing. The ads highlighted the contrast with the frustrations and anxieties of auto commuting.

A total of 4,440 free parking spaces have been provided at the 12 stations located along the 44-mile section between Oakville and Pickering. Stations are located close to major arteries to provide easy access for people in the area. The new GO stations consist of 900-foot platforms to accommodate 10-car trains, heated shelters spaced one car length apart, and a ticket office constructed of prefabricated aluminum and glass panels, finished in green enamel. Pedestrian underpasses were built to enable passengers to cross from one platform to the other without danger.

Passenger convenience was the prime consideration in devising GO Transit schedules. Trains run 18 hours a day 7 days a week. During rush-hour periods on weekdays, trains run at 20-minute intervals, and in off-peak periods a basic hourly service operates. Trains operate on the push-pull principle, eliminating time-consuming turnarounds at the end of each run.

By September 1967 the GO Transit commuter rail service was in full operation. Surveys had indicated that an estimated 15,000 passengers per weekday would use the service. This figure was surpassed almost immediately, and the volume rose past the 17,000 mark by January 1968. Over 20,000 passengers per day are now being carried on the rail service.

One of the effects of the increasing popularity of the GO Transit rail service was congestion in the parking lots at the suburban stations. One of the recommendations of the transportation study was that a feeder bus service be tested in conjunction with the rail service. If a successful feeder bus service could be implemented, some of the problems associated with parking-lot capacity could be eliminated.

Phase II of the GO Transit story commenced on July 6, 1970.

Because it both was a well-delineated community and had no existing bus service when the GO Transit service started, Bay Ridges was considered the most appropriate of all the GO station neighborhoods in which to test a feeder bus. Following a promotional campaign that covered every residence in the Bay Ridges community, a many-to-one dial-a-bus service was implemented on July 6, 1970, with the one destination or origin being the GO station. Service was provided to every GO train arriving and departing from the Pickering station. Service was, therefore, required 19 hours a day 6 days a week, and for 15 hours on Sunday. As mentioned previously, the GO trains operate on hourly headways between Pickering and Toronto at all times except during the weekday peak periods. In the peak periods the trains arrive and depart from Pickering every 20 minutes. This change in train headway means that, although the off-peak service can be maintained with one bus covering the whole community, additional buses are required in the peak periods. These additional buses are added in until there is a total of four in operation, with each one being assigned to one of four zones.

In this small community of approximately 15,000 persons, it was obviously unrealistic to consider the need for a sophisticated computerized dispatching system. Instead a manual system employing a single dispatcher in radio contact with each driver was introduced. In practice, a potential patron is required to phone the dispatcher at least 1 hour before his train to book a seat on a minibus. At this time the dispatcher tells him when, to within 5 minutes, the bus will pick him up. The dispatcher plots all requests for pickups on a zoned map of Bay Ridges, which is then passed on to the driver who uses it to schedule his route. In the case of emergency calls made less than 1 hour before the train departure time, the dispatcher can radio the bus direct with the information. If a patron fails to appear when the minibus reaches his home, the driver will contact the dispatcher, who will then telephone the patron to find out what is delaying him. Reservations for dial-a-bus service can be made by regular customers for a week in advance.

The equipment being used in the experiment is a converted Ford Econoline window van. Various conversions were made to the standard vehicles before they were put into service in the experiment. A 75-inch floor-to-ceiling clearance was provided by adding a fiberglass raised roof, complete with one window in front and two on each side. The seating layout consists of 11 vinyl-covered seats. The seats are arranged so as to provide additional standing room for three or four people and space for a luggage rack.

The fare for the dial-a-bus service is 25 cents cash or 10 tickets for $2.00 for adults and 15 cents for children under 12.

A local service addition to the experiment was made on February 22, 1971, when a limited form of a many-to-many service was provided between the morning and evening peak periods. This service requires the use of two buses and is designed to give service to the GO station and to any other destination in Bay Ridges.

Patronage on the dial-a-bus feeder service to and from the GO train doubled during this first year of operation. An average of 250 passengers per day were carried at the start of the service. This figure now averages well over 500 per day. In addition, between 75 and 100 passengers per day are being carried on the local service. Passenger surveys indicate that 60 percent of the market is making use of dial-a-bus as a feeder system to and from the GO trains.

The need for parking-lot expansion has undoubtedly been delayed by the introduction of the feeder service.

In September 1970, Phase III of the GO Transit plan was introduced. At that time GO Transit express bus services began to operate between Hamilton and the Oakville GO terminal and between Oshawa and the Pickering GO terminal. These express buses connect with all GO train arrivals and departures. Twenty 44-passenger buses were purchased for this service. All are equipped with air-conditioning and environmental improvement equipment. Between Pickering and Oshawa, intermediate stops are made at Ajax and Whitby. On the Hamilton-to-Oakville service one intermediate stop is made at Burlington. New modern bus terminals have been constructed, and parking facilities have been provided within the interchanges of the freeways over which these express bus services operate.

GO Transit bus commuter services were also introduced in September 1970 in the area north of Toronto. The northern GO bus service links the towns of Newmarket, Aurora, Oak Ridges, and Richmond Hill with Toronto's subway, the main bus terminal, and GO Transit rail service at Union Station.

The total capital cost of the GO Transit system has been $30 million, of which $25 million has been spent on the rail service and $5 million on the bus services. This is in contrast to the $16 million-per-mile cost of Toronto's elevated Gardiner Expressway through the downtown core and the $7 million-per-mile cost of the 12-lane MacDonald Cartier Freeway bypass across the northern half of the city.

Surveys indicate that GO Transit has had a significant effect in attracting people to lakeshore communities, and, as a direct result, residential and commercial developments have been stimulated in areas with convenient access to GO stations.

GO Transit operations have provided and are providing guidelines for transit planners in Ontario, enabling them to work toward a balanced coordinated network of public transportation embracing all modes of transport to meet the needs of the people of Ontario.

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DUAL-MODE TRANSPORTATION: A CASE STUDY OF MILWAUKEE

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A socioeconomic case study analysis of the Milwaukee metropolitan area, in which a hypothetical dual-mode transit system was compared with a modern, conventional bus rapid transit plan designed to meet the area's needs as forecast to 1990, showed the dual-mode transit concept to be an attractive alternative offering many significant advantages. It was concluded that dual-mode transit systems offer significantly higher service quality (ability to attract riders), higher labor productivity, competitive fares, benefits exceeding costs, greater attainment of regional development goals and objectives, a high degree of operational flexibility to meet varying transportation needs, and, possibly most important, growth potential with good cause to expect a long-term trend of increasing utilization, increasing total benefits, and increasing economic operating margins. It was also concluded that other medium-to-large metropolitan areas nationwide may enjoy even greater relative benefits from this technology.

•THE Milwaukee County Dual-Mode Systems Study was conducted under a $300,000 study grant issued to Milwaukee County by the U.S. Department of Transportation, Urban Mass Transportation Administration. The study was initiated in January 1971 and completed 12 months later. The overall study objective was, in brief, to assess the merit of the dual-mode concept from a socioeconomic viewpoint, to assess its technical implementation feasibility in terms of presently available technology, and to specify an initial centerline plan for dual-mode implementation.

The overall study effort consisted of three major activities: a technical evaluation, a socioeconomic evaluation, and a dual-mode transit demonstration planning effort corresponding to the study objectives. These areas of activity are documented in three separate volumes and a summary report (17). The basic approach to the socioeconomic evaluation of dual-mode transit, the subject of this paper, has been to use a comparative analysis method, contrasting the performance, cost, benefits, and regional goal attainment factors associated with a hypothetical dual-mode system with those of a modern bus rapid transit plan. The referenced bus rapid transit system is representative of the most cost-effective application of conventional bus technology possible for Milwaukee. It is currently being considered for implementation as a result of the recommendations made in the Milwaukee County Mass Transit Technical Planning Study, a three-year effort completed in June 1971 under a $500,000 local, state, and federal jointly funded study grant (1).

DUAL-MODE CONCEPT DEFINITION

Dual-mode as a transportation concept has many facets. The dual-mode concept has been proposed in widely varying contexts over the last decade—large public transit buses (Metromode), private vehicles (Urbmobile, StaRRcar), palleted automated transport (PAT), public automobile rental (PARS), and others—depending on the application objective as perceived by the designer. These diverse potential applications are illustrative of the potential of dual-mode for fulfilling many different urban transportation needs (2, 8, 10, 12, 14-16).

In simplest terms, dual-mode is defined as a guideway-vehicle system that permits two modes of vehicle operation: fully automatic (driverless) operation on a specially equipped guideway and manual (driver-controlled) operation in mixed traffic in the normal manner on conventional roadbeds. The varied applications each have in common this unique characteristic of dual-mode—vehicle operation both on and off an automated guideway. The dual-mode concept thus embodies what may be termed the "customary" benefits of an automated captive-vehicle transportation system while still retaining the flexibility of the conventional street vehicle—free to operate over any street, independent of the availability of special guideway facilities.

Among the various alternatives for the initial implementation of a dual-mode system—transit vehicles, private vehicles, automated pallets, special service vehicles, and public rental vehicles—transit appears to be the logical mechanism for the introduction of dual-mode technology into the urban community. A detailed discussion of the merits of transit as an initial dual-mode demonstration is presented in Volume 4 in the overall report series (17) and also is summarized briefly in the following:

1. At the present time the technology required for a dual-mode transit system (which requires a guideway of relatively low capacity) is available, and a system of rather limited scope would, in itself, possess a high degree of utility.
2. In addition, a relatively high ratio of user benefits to costs could be achieved in early transit applications.
3. An added advantage of transit over private vehicles for initial dual-mode implementation is the fact that the system operator retains a high degree of control over the transit vehicle, thereby ensuring that proper maintenance is enforced and that critical control devices are not subject to tampering.

Consequently, the socioeconomic case study analysis discussed in the succeeding paragraphs treats primarily the benefits associated with an initial dual-mode transit system, featuring relatively small (19-passenger) dual-mode transit buses—probably the first stage of dual-mode evolution. However, in addition, a preliminary estimate of the additional benefits achieved when a dual-mode guideway system is made available to the private dual-mode vehicle user is also presented.

SOCIOECONOMIC EVALUATION: STUDY APPROACH

A case study approach was used for the socioeconomic evaluation of a hypothetical dual-mode transit system, with the Milwaukee metropolitan area providing a "real world" data base for the analysis. As a result of other comprehensive regional and local planning studies, the Milwaukee area offered a wealth of demographic, economic, land use, and transportation data that were used in the case study, permitting the performance, benefits, regional goal attainment, and cost characteristics of a dual-mode transit system to be contrasted with a conventional modern bus rapid transit plan (1). This reference system represents the most cost-effective transit system application for Milwaukee that is possible with currently available bus or rail transport technology.

Two major studies that were used extensively in the case study are the Milwaukee County Mass Transit Technical Planning Study and the Southeastern Wisconsin Regional Planning Commission (SEWRPC) Land Use-Transportation Plan for 1990 (1, 11). In essence, the SEWRPC regional land use-transportation plan, the result of an extensive 4-year study completed in 1966, set forth alternative land use development patterns, corresponding transportation demand forecasts, and supporting transportation system plans for the Southeastern Wisconsin region projected to the year 1990. The recommended plan cited the need for Milwaukee County to begin assessing alternative means of implementing a rapid transit system that would meet the travel demands forecast within the region for 1990, while effecting a better balance between highway and transit use.

As a result, Milwaukee County, under a $500,000 study grant awarded in 1968, initiated the Mass Transit Technical Planning Study, which was completed in June 1971. After considering many possible transit system alternatives, the conclusion of the study was that a modern bus rapid transit system would be best suited for the area's needs, particularly in view of the changing travel patterns, the highly dispersed, low-density character of new land use development, and the need to ensure a flexible system plan.

This proposed new transit system for Milwaukee, referred to subsequently as the rapid transit plan or the conventional bus rapid transit system, was used as a comparative reference for the socioeconomic case study analysis.

The case study evaluation included consideration of transport demand (ridership), service levels (or system performance), transport-related benefits and costs, and attainment of regional development objectives. The results and conclusions of each of these areas of analysis are summarized here. Volume 3 of the report series contains the analysis method, assumptions, and more detailed results.

The general approach to the analysis has been to (a) establish performance objectives for the dual-mode transit system; (b) simulate the performance and loading of a 1990 dual-mode network, using the comprehensive transit-highway regional planning models and recommended future land use pattern available at SEWRPC; (c) determine capital and operating costs for the system, based on the hardware design concept definition developed in Volume 2; and (d) combine these cost-performance-demand data in an analytical framework consistent with that used for the conventional bus rapid transit plan so that a meaningful comparative analysis could be performed.

The basic premise on which the case study was based is that the dual-mode transit concept should be oriented toward providing the highest quality transit service possible in order to ensure that an increased number of "choice" riders would be attracted to the system. The study indeed indicated that this could be achieved and would result in higher benefits as well as higher, but justified, costs. This high quality of service operating strategy led to the definition of a relatively large, 110-mile guideway network, a relatively small dual-mode transit vehicle, and close operating headways, features that may not be an appropriate strategy in all urban situations.

Thus, a second facet was introduced into the case study, consisting of a preliminary sensitivity analysis that considered variations in vehicle size, choice of service characteristics, network scope, and alternative operating strategies. This analysis served to illustrate the broad spectrum of alternatives that could characterize any given dual-mode transit system configuration and operating strategy, depending on the objectives to be achieved. This high degree of flexibility, offering options not open to conventional systems, may well be the greatest asset of this novel transportation concept.

The effect on transit system costs and fares due to the incorporation of private dual-mode vehicles within the system, subsequently referred to as the mixed vehicle system, was also examined. This analysis illustrated the economic merit of a unique aspect of the dual-mode concept—the potential for use of the guideway facility (and right-of-way) not only by transit vehicles but also by properly equipped private automobiles and other commercial vehicles. Some of the more significant results of these analyses are presented in this paper, without discussion of assumptions and method, which are contained in the Volume 3 report (17).

The remainder of this paper is organized into four parts. First, the dual-mode and reference conventional bus rapid transit systems used in the case study are described. Next, the case study comparative analysis results, based on simulation data obtained from the regional models and cost-operating data obtained from the technical evaluation (Volume 2), are presented. Third, a summary of the results of the cost-performance sensitivity analysis and an assessment of the economic impact of the private dual-mode vehicle on the transit system are given. The paper is concluded with a summary of overall findings and conclusions.

DESCRIPTION OF THE MILWAUKEE CASE STUDY SYSTEM

Geographical Region

The geographical scope of the case study system was chosen to be the metropolitan Milwaukee transit service area as identified by the 1990 rapid transit plan. This transit service area centers on the City of Milwaukee, is bounded by Lake Michigan on the east, and includes the urban, suburban, and urbanizing fringe areas to the north, south, and west of the city, covering a rectangular area measuring approximately 12 by 24 miles. According to the regional plan, a total population of 1,850,000 is forecast within the transit service area by 1990, generating an average daily travel demand of 4,050,000 internal person trips, as contrasted with the estimated 1970 population of 1,350,000 and an average daily travel demand of 2,900,000 internal person trips.

Study Time Frame

The year 1990 was chosen for the case study for two important reasons. First, the conventional rapid transit plan, while staged for initial implementation in the mid-to-late 1970's, was designed to serve the 1990 land use pattern of the service area and by 1990 may be expected to provide its "full-scale" service characteristics and benefits. Second, and possibly most important, the rapid transit plan is entirely compatible with the dual-mode transit concept so that it conceivably could evolve by 1990, in part or completely, to a dual-mode system. Thus, it was logical to investigate the relative cost-performance-benefits-goal attainment characteristics of the two systems under the 1990 conditions.

It is important to recognize that, as noted earlier, dual-mode transit is only one aspect of the dual-mode concept. Therefore, even under 1990 conditions, the dual-mode system reflects attractive benefits that are only in an infancy stage, whereas the conventional bus rapid transit plan illustrates benefits that are represented in their full maturity, and in all likelihood represent the maximum benefits attainable within the confines of conventional bus system technology. The importance of this factor, intangible though it may seem, should not be underestimated.

System Description

The rapid transit plan recommended in the Milwaukee County Mass Transit Technical Planning Study is based on the use of modern, gas turbine-powered, 53-passenger transit buses (similar to the General Motors RTX prototype), which operate primarily on existing streets and freeways, providing efficient and rapid point-to-point line-haul service. In the most heavily congested transportation corridor, the east-west freeway (Interstate 94), a transitway approximately 8 miles in length, was recommended for the exclusive use of rapid transit vehicles. It was further recommended that the transitway and vehicle design have provision for automatic lateral steering control, in order to minimize the width of the right-of-way required for the transitway. Although the rapid transit plan system promises to provide attractive and efficient line-haul service, a limitation in its service features for many potential users lies in the fact that it does not include neighborhood collection-distribution operation in most cases. Rather, it relies primarily on the availability of an auto for park-ride or kiss-ride or on the use of local feeder buses to provide access to rapid transit stations.

The dual-mode transit system is also based on a rubber-tired transit vehicle, but of considerably smaller size, approximately 19-passenger capacity (all seated). The dual-mode system, rather than operating solely on existing streets and freeways, operates primarily on an exclusive transitway or guideway under fully automatic (driverless) control. The exception to guideway operation is, of course, the manual operation mode under driver control on arterial streets, where the dual-mode system, again in contrast to the rapid transit system, offers neighborhood collection-distribution service, providing virtually door-to-door, no-transfer transit availability.

Both systems are based on a fixed schedule-fixed route operation concept. However, the dual-mode system inherently has the growth potential of evolving to a demand-actuated, dynamically routed system, which is likely to be less practical under the conventional bus rapid transit plan.

A summary of operating and physical characteristics differentiating the two systems is given in Table 1.

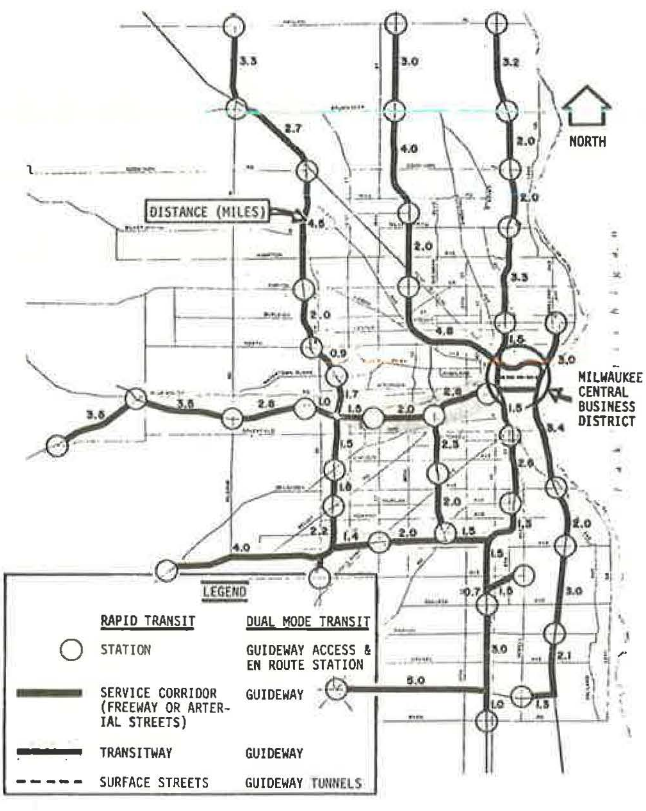
The major service corridors for the rapid transit plan, including the locations of main-line stations, are shown in Figure 1. Figure 1 also illustrates the 110-mile guideway network which, after careful deliberation, was chosen to overlay identically the same transportation service corridors as were originally identified by the regional plan and subsequently refined in the technical transit planning study. The circles in Figure 1 indicate the rapid transit station stops and also illustrate the points of access and departure for dual-mode vehicles to and from the guideway system.

Table 1. Comparison of dual-mode and rapid transit system characteristics.

Characteristic	Conventional Bus Rapid Transit	Dual-Mode Transit
1. Operating Concept		
Operating mode	Manually operated on existing freeways	Automatic operation on exclusive guideways, manual operation on local streets
Operating strategy	Fixed route, fixed schedule, point-to-point service	Fixed route, fixed schedule, door-to-door service
Operating headways during peak hour (min)	5	5
Number of routes	40	264
Maximum main-line speed (mph)	60-70	60-70
2. Vehicle Description		
Propulsion type	Gas turbine	Electric drive
Vehicle passenger capacity	53	19
3. Configuration		
Vehicles required	381	2,585[1]
Number of guideway (transitway) miles	8	110
Number of major park-ride lots	37	5[2]
Number of main-line stations[3]	40	40
Number of neighborhood pickup and destination distribution points off the main line	100 (approx.)[4]	3,500 (approx.)
Primary mode of access to system	Via park-ride	Via neighborhood pickup

[1] Required to service a ridership level estimated to be approximately double that of the rapid transit plan.
[2] Selected park-ride facilities would be provided at a few undetermined locations.
[3] Located at the guideway or along the rapid transit route.
[4] Several rapid transit routes would include limited neighborhood pickup service.

Figure 1. Service corridors for the dual-mode and rapid transit systems.



Guideway/Transitway Facilities

The exclusive transitway proposed in the rapid transit plan is also shown in Figure 1. Also shown, for the dual-mode transit system, are the two guideway tunnels necessary to serve the central business district. In order to better characterize the nature of the 110-mile guideway network, preliminary estimates of the distribution of right-of-way requirements by real estate type, and the type of guideway construction envisioned, were made. It should be observed that almost 80 percent of the required guideway mileage can possibly be aligned within available rights-of-way in freeway corridors, railroads, or on vacant land. Most of the guideway facility (about 75 percent) can be constructed essentially at grade or in open cuts, with appropriate grade separations, rather than requiring a more costly underground or elevated approach.

MILWAUKEE CASE STUDY EVALUATION: RESULTS AND CONCLUSIONS

In this section, a comparative evaluation of the conventional bus rapid transit system and the dual-mode transit system is presented. The evaluation is based on the dual-mode network simulation results obtained from application of the SEWRPC transportation simulation models, the dual-mode system costs as determined by the system definition study, and the aforementioned local and regional planning studies. The evaluation is presented under four discussion topics: transit service, transport-related benefits, regional goal attainment, and system operating and capital costs.

Transit Service Characteristics

The transit service characteristics of the dual-mode system, as contrasted with the conventional bus rapid transit plan, are described in terms of demand, system accessibility, and trip characteristics.

Demand for Transit Service—The demand for dual-mode transit service, obtained from a simplified mode split forecasting procedure, is summarized in Table 2, which shows a projected ridership level for the dual-mode system that is approximately double that of the conventional system. The apparent reasons for this significant increase in ridership will be described shortly. In brief, however, the dual-mode transit system provides a significantly higher quality of service such that former automobile users are likely to be attracted to transit.

These ridership projections are, of course, highly dependent on the assumptions employed in the mode choice model, and therefore projections for any new system must be viewed cautiously. The marketplace provides the only true test of ridership attraction for such a new system. It was not the purpose of this study to explore the many subtleties of mode choice, so the ridership forecast is regarded as preliminary.

The mode choice model employed was based on locally determined travel time diversion data (transit/auto travel time ratios) used in the regional planning studies and on an additional multiplying factor, assumed to be a linear function of trip length, intended to reflect additional ridership attraction due to the unusual comfort-convenience features of the dual-mode system. In brief, it was assumed that seating for all, arrival-time certainty, and reduced transfers would together be at least half again as important as travel time for longer transit trips, but of relatively little significance for shorter trips. These factors, taken collectively, are thought to be treated conservatively (9) so that the ridership levels forecast by the simulation are judged to be reasonable.

Accessibility to Transit Service—As mentioned previously, both systems provide transit service to the same geographic area, but the route resolution provided by each system—that is, the typical distance the average commuter must travel to have access to the conventional rapid transit or dual-mode bus—is much different. The dual-mode transit system provides considerably greater accessibility and availability than the conventional bus alternative. This result may be attributed to the following three factors:

1. The conventional bus rapid transit system does not provide extensive collection-distribution service. It assumes that an auto or local feeder bus will be available to transport most would-be transit riders to the nearest rapid transit station. This assumption, of course, is not always tenable, and its transfer requirements are undoubtedly

a factor in the decline of transit ridership nationwide. It is a necessary assumption, however, for a transit system based on a large (53-passenger) bus, because that type of vehicle cannot efficiently serve the entire service area surrounding each station in a collection mode. Even if it could, the time required to fill the bus by stopping at many low-demand, scattered neighborhood stops would undoubtedly be viewed negatively by most commuters.

2. It is an inherent feature of the dual-mode transit concept that rapid transit service can extend beyond the main-line, heavily traveled corridor by leaving the guideway network, reverting to manual operation under driver control, and proceeding into dispersed neighborhood areas to provide virtually door-to-door neighborhood collection-distribution service. This service becomes practical not only because of the dual-mode capability of the vehicle but because of its relatively small size, permitting many more neighborhood routes to be provided. The relatively small vehicle size is significantly related to the dual-mode concept in that, as will be shown later, the economic benefit of automated (driverless) guideway operation provides a significant increase in system productivity, because the driver pool is focused only on collection-distribution service, with the line-haul function being provided under fully automatic control. The simulation indicated that vehicles traveled on the guideway network (no driver cost) approximately 70 percent of their operating time.

3. Because of the lesser dual-mode vehicle passenger capacity (approximately one-third of the conventional rapid transit bus, in this case), the dual-mode transit system requires almost three times as many vehicles in order to service the same peak-hour travel demand. As noted previously (Table 2), however, the demand for dual-mode service slightly more than doubled. As a result, during the 1990 morning rush hour in Milwaukee, the dual-mode system would have 2,585 vehicles in service, whereas the conventional rapid transit bus system would require only 381 vehicles. Thus, the dual-mode system has the potential of offering almost seven times (2,585/381) as many routes or, alternatively, providing seven times the frequency of service on a given system of routes during the peak hour. As presented earlier in Table 1, the dual-mode system offered 264 routes, whereas the conventional bus rapid transit system provided 40.

In summary, the dual-mode transit system provides greater availability and accessibility because, in contrast to the conventional bus rapid transit plan, the dual-mode system provides collection-distribution service and at the same time also has more vehicles operating on more routes.

Trip Distance and Speed—The average transit trip distance, travel time, and speed during the peak hour are shown in Figure 2. It can be seen that the dual-mode transit system has about a 10 percent shorter trip time for an equivalent trip distance, but that travel time comparisons vary for different trip components (collection, line-haul, distribution). Note also that the travel distribution pattern changed on the dual-mode system, for reasons that will be discussed subsequently, resulting in a longer average transit trip length.

Average trip speed is also shown in Figure 2. This does not represent vehicle speed, but rather door-to-door travel time, including walk and wait times as well as on-board vehicle time. For the case study conditions, the average walking distance on a dual-mode route to a neighborhood dual-mode stop was assumed to be less than one-quarter mile, and an average wait time, during the peak hour, was assumed to be 2.5 minutes. It can be observed from Figure 2 that the speed advantage of the dual-mode trip is also about 10 percent.

It should be noted, however, that the average trip speed on the conventional bus rapid transit system is primarily dependent on the availability of an automobile for a portion of the trip. (If the rapid transit system is served by local feeder bus—not the case for most forecast trips in Milwaukee—the total transit trip time is further increased by about 11 minutes, in which case the dual-mode transit shows a 30 percent speed advantage.) It should also be noted from Figure 2 that the dual-mode system has the potential of continually improving average trip speed consistent with technological advances. In contrast, it appears likely that the conventional bus rapid transit system can only decline in performance as freeway traffic densities increase, unless an investment is made in more miles of exclusive transitway.

Thus, the trend of the conventional bus rapid transit system appears likely to be one of either decreasing performance or increasing cost. On the contrary, as will be seen subsequently, the dual-mode transit system is more likely to exhibit an increasing performance trend with decreasing costs.

Trip Distribution—Although the dual-mode transit system showed an average trip time savings during the peak hour of less than 10 percent, the typical time saved ranged from 3 percent to 17 percent, depending on the trip destination. Figure 3 shows the distribution of peak-hour trips by destination category and the corresponding trip time reduction offered by the dual-mode system.

Transfer Requirements—Another important characteristic of the average transit trip is the number of transfers required to arrive at the desired destination. If fewer transfers are required, increased comfort, convenience, and reliability of travel can be expected. Figure 4 shows a significant reduction in the number of transfers required in the dual-mode system. Note particularly that 94 percent of the commuters boarding the conventional bus rapid transit system require a transfer from either their auto or a local feeder bus. The remaining 6 percent of rapid transit riders live within walking distance of a rapid transit station. The dual-mode transit system required considerably fewer origin transfers—only 21 percent. Overall, the rapid transit plan required an average of 1.2 transfers per trip whereas dual-mode transit required only 0.5 transfer per trip (and only 0.3 transfer for an equivalent distance average trip).

Comfort and Convenience Factors—There are several important differences in the comfort and convenience aspects of the two systems. These are intangible factors, but nonetheless are significant, as indicated by consumer preference surveys (9). The following are some of the considerations:

1. Comfort—The vehicle interior comfort features of both systems are likely to be the same; however, the dual-mode system offers a comfort advantage on two accounts. First, and most important, as previously discussed, the availability of a one-seat, no-transfer ride is a significant comfort and convenience advantage. Second, the ride quality associated with automatic control on the guideway is likely to be more comfortable because of congestion-free, virtually constant-speed travel.

2. Reliability of service—The certainty of the transit system consistently achieving scheduled pickup times and corresponding trip completion times is likely to be higher in the dual-mode system as compared with the conventional bus rapid transit system. This potential for high reliability of service is attributed to the exclusive guideway concept and the system automatic control concept that is based on the maintenance of a rigorous, precise operating schedule.

3. Convenience—Certainly the dual-mode system offers a higher degree of convenience for most transit riders because of its door-to-door, essentially no-transfer service and also because of its greater availability due to the larger number of routes and vehicles.

Transport-Related Benefits

The annual user benefits that relate directly to transportation—travel time savings, avoidance of accident costs, avoidance of private vehicle operating and parking costs—are shown in Figure 5 for both systems. The methods and assumptions employed are presented in more detail in Volume 3 of the report (17). The significant factor to be noted is the relative difference between the two systems, rather than the absolute dollar benefits. Note particularly that the annual savings in the value of travel time accrued to the highway user in the case of the dual-mode system is greater than the corresponding savings to the dual-mode transit user. This is the result of a significant reduction in freeway peak-hour volume (approximately 14 percent) and a corresponding increase in average freeway speeds. This is a particularly important benefit because it increases the effective useful lifetime of existing freeway systems.

Similarly, there are user costs associated with any transportation system. These annual user costs are illustrated in Figure 6. The relatively high travel-time loss

Table 2. Peak-hour travel characteristics.

Peak-Hour Characteristic	Rapid Transit Plan	Dual-Mode Transit	Growth Factor
Person trips	31,237	61,605	2.0
Vehicle-miles	16,503	70,615	6.7
Vehicle-hours	381	2,585	6.8
Driver-hours	381	784	2.1
Driver-hours per vehicle-mile	0.036	0.011	0.3

Figure 2. Transit trip lengths and speeds for the dual-mode and rapid transit systems.

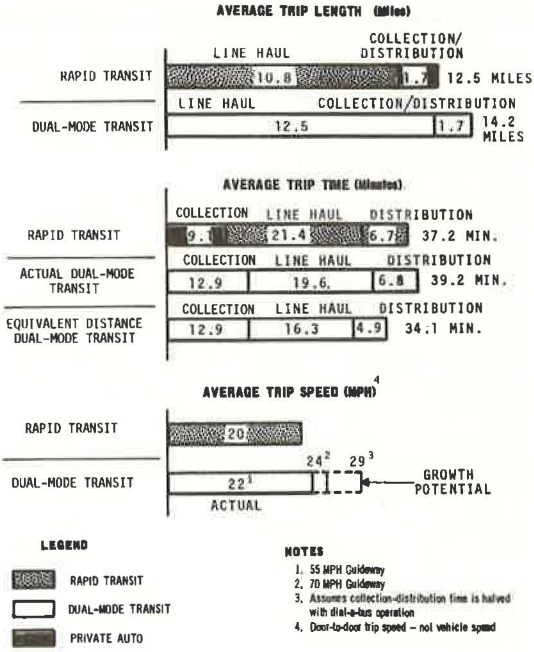
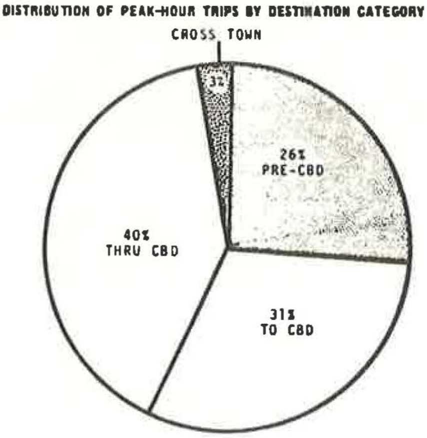


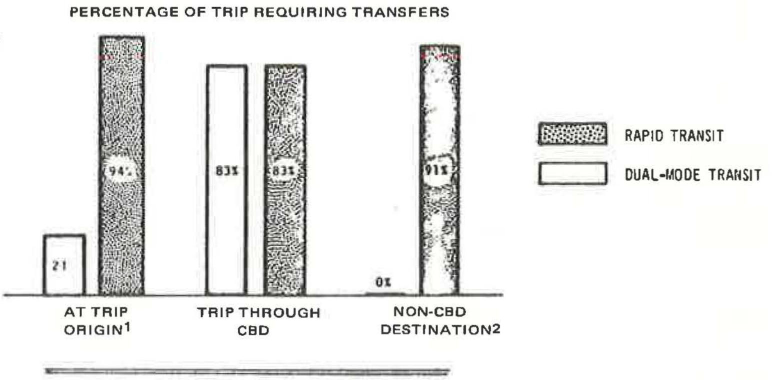
Figure 3. Distribution of peak-hour trips and dual-mode trip time savings relative to the rapid transit system.



DUAL-MODE TRIP TIME REDUCTION BY DESTINATION CATEGORY

TRIP TYPE	DUAL-MODE TRANSIT TRIP TIME REDUCTION (%)
PRE-CBD	13%
TO CBD	3%
THRU CBD	17%
CROSS TOWN	14%

Figure 4. Comparison of transfer requirements for the dual-mode and rapid transit systems.



NOTES:

1. Most rapid transit trips originate via park-ride or local bus trips to the transit station, whereas most dual-mode trips originate on neighborhood pickup routes.

2. Non-CBD destinations are reached via the dual-mode system by direct crosstown service or by one transfer in the CBD. The rapid transit system typically requires two transfers—one in the CBD and the second to a local feeder bus distribution system in the vicinity of the ultimate destination.

associated with the dual-mode system is attributed to the so-called choice rider—one who has other alternatives available but chooses transit. Most choice riders will actually lose time via dual-mode or rapid transit as compared to the travel time they would achieve via automobile. Unless congestion levels on freeways are inordinately high, which is not the case in Milwaukee, travel characteristics by private automobile generally represent an exceptionally high standard for a transit system to compete with. Thus, these travel time "losses" are not unexpected.

It is seen from Figures 5 and 6 that the dual-mode transit system offers significantly higher transport-related benefits as compared with the conventional bus rapid transit plan. The costs, however, are also higher. But in both cases the benefits exceed costs.

It is concluded, then, that the dual-mode transit system, although capable of offering greater benefits, also has proportionately greater costs. This should be viewed, however, with the perspective that the dual-mode transit transport benefits will represent only a portion of total potential transportation benefits. As discussed later, when the dual-mode guideway system begins to accommodate other vehicle types—further increasing system revenue and further reducing existing freeway loadings—overall community benefits are likely to continue to increase.

As will be seen in the succeeding section, the quantifiable transport benefits of a transportation system are by themselves an inadequate basis for determining the relative merit of competing systems. Urban planners are becoming increasingly cognizant of the need to also address broader regional goals and objectives.

Regional Goal Attainment

The degree to which both case study transit systems meet the regional transportation objectives and supporting standards, as identified by SEWRPC in their regional land use and transportation planning study, is given in Table 3. It can be observed from Table 3 that the dual-mode transit system meets or exceeds the achievement of the conventional bus rapid transit plan in almost all areas cited.

Possibly the greatest benefit offered to the community by the dual-mode transit system would be the increased availability of transit service, thereby providing increased access to jobs, health care, and educational and recreational opportunities, eventually leading to overall improvement in socioeconomic conditions. On a longer term basis, the guideway facility, having an excess capacity that can absorb future demand, will be a definite asset for the community in terms of efficient land resource utilization. The high-capacity guideway can reduce the need for additional freeway facilities as existing facilities become overburdened.

Possibly the greatest advantage of the conventional bus rapid transit system, in terms of regional goal attainment, is that it is based almost entirely on the use of existing traffic facilities and requires very little acquisition of new land.

In summary, the dual-mode transit system appears to better fulfill most regional goals, with the sole exception of right-of-way requirements. Dual-mode right-of-way acquisition will, on a long-term basis, however, reduce the need for arterial street, highway system, and freeway expansion, whereas any new right-of-way for the conventional bus system will only directly serve the transit user.

System Operating Costs, Capital Costs, and Fares

Annual Capital Costs—Comparative annualized capital costs and relative cost distributions, assuming 50-year, 25-year, and 15-year amortization schedules at 6 percent, for fixed facilities, stations, and vehicles respectively, are shown in Figure 7. It is seen from the figure that the cost distributions for both systems are nominally the same and that the dual-mode transit system in terms of absolute costs requires a substantially greater investment, primarily because of the high guideway investment.

In comparing these costs, it should be remembered that the service levels provided by the dual-mode transit and the conventional rapid transit systems are not equivalent. An examination of the relative labor productivities of the two systems emphasizes this particular point. Table 2 gave the relative number of vehicle-miles, vehicle-hours, and driver-hours utilized in each of the two systems during the peak hour. Note that,

Table 3. Regional goal attainment of dual-mode and rapid transit systems.

Regional Goals and Objectives	Rapid Transit Plan Evaluation	Dual-Mode Transit Evaluation
1. Improve selected socioeconomic conditions through improved accessibility[1].	All of the standards are met except that the entire service area does not have a maximum of 40 minutes travel time to all universities. The majority of transit trips (~75 percent) originate via an auto ride from the trip origin and subsequently transfer at a park-ride station.	The average transit trip is reduced by 3.1 minutes (8 percent), correspondingly increasing the degree to which each of these standards is met. Longer average trip length also indicates a higher level of achievement. Dual-mode eliminates the need for a private auto trip, local bus travel (if available), or a walk to the transit system. This is particularly important to disadvantaged neighborhoods. Thus, the dual-mode availability should significantly improve neighborhood accessibility to increased jobs, education, health care, and other opportunities.
2. Enhance, through improved accessibility, existing and planned high-intensity land-use development.		
A. Regional centers to be connected to the CBD.	All major centers are served.	Same level of achievement as noted above. The route configuration is identical.
B. Service to existing land uses to be emphasized.	All major nonresidential developments are served. Transitway serves high proportion of special generators.	
3. Achieve a positive environmental impact in terms of system aesthetics and reduced air and noise pollution.		
A. Transit facilities should minimize harmful effects on the environment.	No perceivable detriments to the environment are apparent.	Same.
B. Minimize noise levels.	Interior and exterior noise levels are reduced. Transit vehicle noise is along existing freeways so new barriers are not created. External vehicle noise is 90 percent of conventional bus.	Noise reduction (both interior and exterior) will be considerably greater through use of smaller, less powerful transit vehicle.
C. Minimize air pollution.	RTX emissions are 33 percent of conventional bus and 15 percent of automobile. Per passenger carried, RTX is 200 times more efficient than automobile without pollution control device.	Air pollution reduction will be considerably greater through electric power on guideway, which will carry two-thirds of total vehicle-hours.
D. Minimize disruption on aesthetics of buildings, vistas, etc.	No major vistas are violated or views of buildings and landmarks obscured.	May not be fully achieved (detailed right-of-way location is not identified).
4. Minimize the disruption of desirable existing neighborhoods and communities.		
A. Transit facilities to preserve desirable existing facilities.	Routes are on or adjacent to existing barriers. Disruption of recommended transitway is minimal.	Detailed right-of-way locations studies were not undertaken. However, it is estimated that 50 percent of the network could lie astride existing freeways and another 15 percent along existing railroads and utility lines. Separate right-of-way is one-half to one-third of freeway requirements.
B. Preserve historic buildings.	No historic buildings are taken.	Impact is unknown, probably small.
C. Preserve park areas.	No major park is intruded upon.	Impact is unknown, probably small.
D. Minimize acreage acquired for transit.	No new land is needed for modified transit. Ride-park facilities are on vacant land or air rights except in one location. Transitway utilizes vacant areas or railroad right-of-way for the bulk of its length.	Detailed right-of-way location studies not undertaken. Possibly one-third of network right-of-way needs would require new land acquisition. Once committed, however, the availability of the guideway facility should serve to absorb excess capacity demands made on existing freeways, thereby deferring the need for continued rapid expansion of freeway facilities.
E. Enhance multiple use of land.	Transitway and railroad are proposed for same right-of-way. Joint projects analyzed for all station areas. State Fair Park and Model Cities area show greatest potentials. The modified rapid system is almost totally within the freeway right-of-way.	Increased ridership accelerates the desirability of key station areas for joint development.
F. Provide outlying parking area.	Park-ride lots are provided at all transit stations where any demand was established; a total of 33,000 spaces were provided.	Acreage requirements for these facilities will be greatly reduced.

[1]Transit should provide access to essential services according to the following: (a) 30 minutes to 40 percent of employment; (b) 35 minutes to three retail areas; (c) 40 minutes to major medical centers; (d) 40 minutes to regional recreation; (e) 40 minutes to vocational and higher educational centers.

Figure 5. Annual transport benefits for the dual-mode and rapid transit systems.

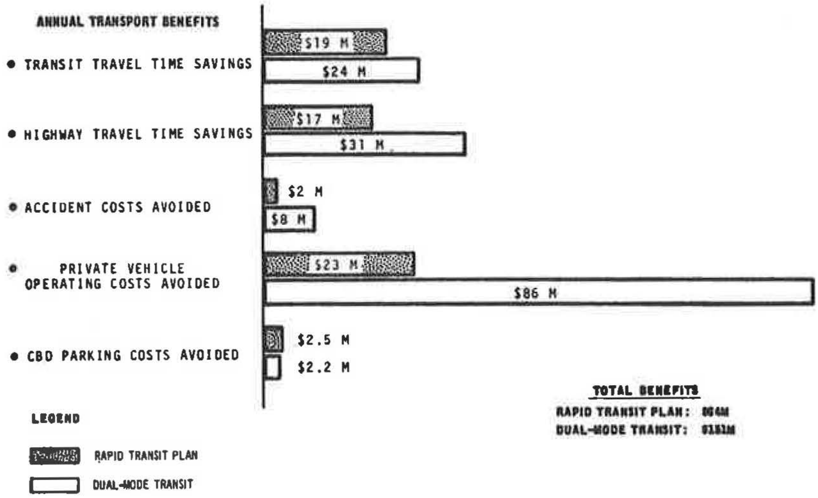


Figure 6. Annual transport costs for the dual-mode and rapid transit systems.

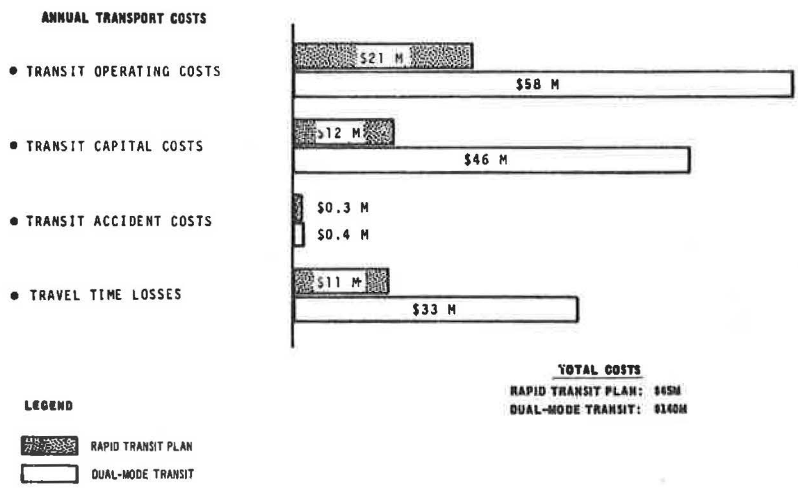
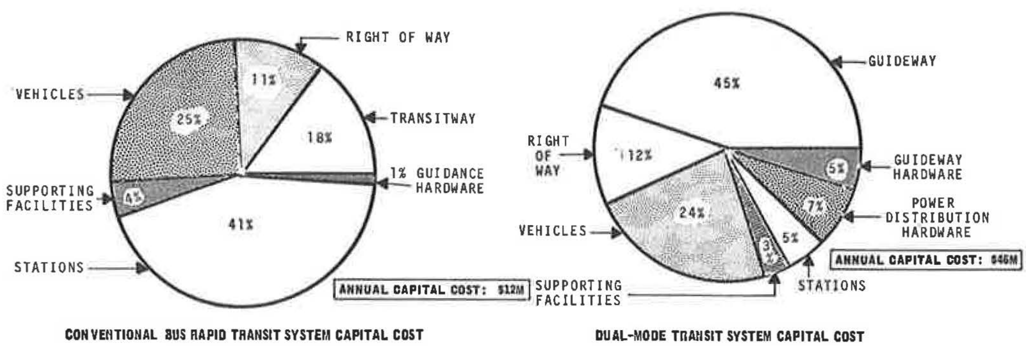


Figure 7. Annual capital cost and cost distributions for the dual-mode and rapid transit systems.



in a given hour, there are more than six times as many dual-mode vehicles traveling more than six times as many vehicle-miles and requiring only twice the number of drivers. In short, there are many more dual-mode vehicles going many more places, as previously discussed, with considerably fewer driver-hours per vehicle-mile required.

Annual Operating Costs—The annual operating costs and the corresponding cost distributions for the dual-mode and conventional bus rapid transit systems are shown in Figure 8. It is seen that the dual-mode system has more than twice the operating cost (for twice the ridership level) of the conventional bus rapid transit system. Note that the various cost components remain roughly in the same proportions and that dual-mode driver costs still represent about 31 percent of total operating costs. It will be shown subsequently that this added cost is the price for a high quality-of-service operating strategy. Other alternative operating strategies are available that could lower the operating cost of the dual-mode system to below that of conventional bus rapid transit, assuming that compromises in service levels can be tolerated accordingly.

Fares—If a flat fare structure is assumed, the fare required to cover all operating costs for one person-trip (an average distance of 14.2 miles on the dual-mode system) will be only 60¢, as shown in Figure 9. If both capital and operating costs are to be covered by fare-box revenues, a fare of $1.08 is required. This fare is not to be confused with an actual fare that is likely to be charged to the commuter. This fare includes total system costs, which are not normally entirely defrayed by fare-box revenue alone. Note also that this fare, on a per-passenger-mile basis, is very comparable to the cost of the conventional bus rapid transit system.

Figure 8. Annual operating costs and cost distributions for the dual-mode and rapid transit systems.

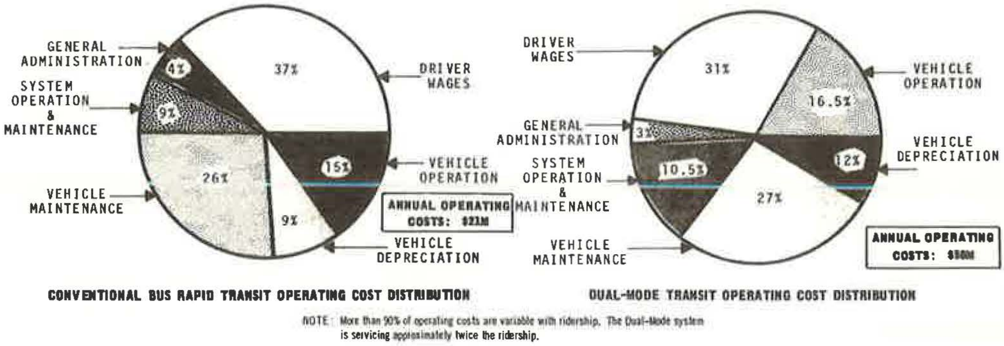
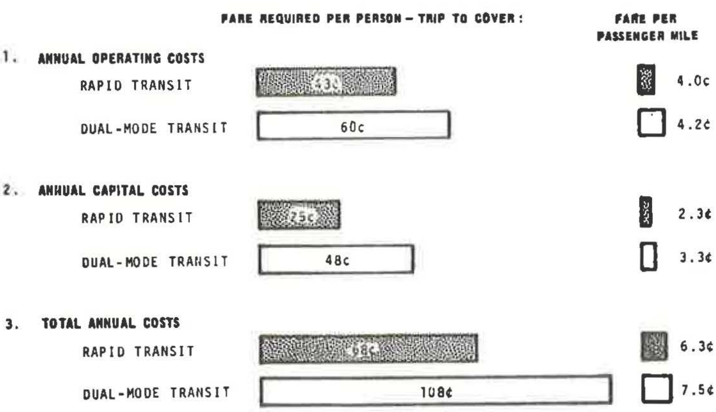


Figure 9. Fare requirements for the dual-mode and rapid transit systems.



SENSITIVITY ANALYSIS AND FUTURE GROWTH POTENTIAL

Sensitivity Analysis

In reviewing the previous case study results, it should be noted that the dual-mode transit system operating strategy and service characteristics were chosen in order to achieve a very high quality of service. It is important to recognize that there are many other, alternative dual-mode system configurations and operating strategies that might have been chosen to achieve other service levels. Although it was not possible to examine these alternatives in depth, some estimates have been made of system cost-performance sensitivities to changes in selected operating and configuration factors. Sensitivity to forecast ridership levels was also examined. Highlights of this analysis include the following preliminary findings:

1. A halving of ridership would increase operating costs per passenger by 6 percent and capital costs per passenger by 61 percent (total required fare of $1.40).
2. A doubling of ridership would reduce operating costs per passenger by 2 percent and capital costs per passenger by 25 percent (total required fare of 94¢).
3. Required fares and transport benefits were most sensitive to changes in main-line speed. An increase from the simulated 55 mph to 70 mph could reduce the total fare by 10 percent while increasing benefits by 21 percent.
4. An increase in guideway mileage (or number of guideways) from 110 miles to 165 miles would increase annual capital costs by 21 percent, total required fare by 4 percent, and annual transport benefits by 15 percent. This increase would also improve the benefit-cost ratio.
5. An increase in vehicle size to 53 passengers per bus could reduce operating costs per passenger by 33 percent (to less than those under the rapid transit plan) while increasing capital costs per passenger by 6 percent (total required fare of 91¢). There would be a somewhat detrimental effect upon the benefit-cost ratio, however.
6. Other service characteristics, such as headways, station spacing, network scope or coverage, and proportion of captive vehicles (no manual-mode operation), were also examined and generally showed less significant impact on system costs and benefits.

A more comprehensive discussion of these cost-performance characteristics is given in the Volume 3 report (17). These results illustrate two important points: first, the dual-mode system chosen for the case study comparative analysis could readily be made even more cost-effective with further study, and, second, the dual-mode transit system offers a wide latitude of operational flexibility.

Assessment of Initial Economic Impact of Private Vehicle

The potential added revenue to the dual-mode transit system due to the incorporation of the private dual-mode vehicle was also examined in the case study. In addition to dual-mode transit, private dual-mode vehicle ridership on the guideway network was also forecast with the aid of local transportation forecasting models. It was assumed that the early versions of dual-mode private vehicles would likely be premium priced, and, as a result, the likelihood of having access to a dual-mode vehicle was assumed to be a linear function of the forecast number of autos per household. Using this assumption, together with travel time diversion curves, the patronage of the guideway system was estimated. During the peak hour, in 1990, the critical link loading (transit and private vehicles) on the entire 110-mile guideway network was found to be only about 2,000 vehicles per hour per lane—a fraction of the maximum theoretically attainable capacity of the guideway.

In spite of the relatively light guideway loading, significant economic and other benefits result in the mixed-vehicle system. After taking into account added capital costs for new facilities (such as interchanges and separate downtown distribution segments) required to accommodate the private vehicle, as well as increased guideway operating costs, revised fare requirements were determined. Under the assumption that fares would be equalized between private vehicle and transit users (in which case the transit operation is being subsidized by private vehicle users), the former operating cost (fare) per person trip of 60¢ is reduced to 30¢. After taking capital costs into account, total annual costs could be completely recovered with a fare of 61¢ per person or vehicle trip.

SUMMARY OF SOCIOECONOMIC EVALUATION CONCLUSIONS

The case study analysis showed a hypothetical dual-mode transit system to be superior to the conventional bus rapid transit system in terms of performance:

1. Ridership doubled;
2. Trip time decreased an average of 8 percent, ranging from 3 to 17 percent;
3. Transfers were significantly reduced (from 94 percent to 21 percent for trip origins);
4. Collection-line-haul-distribution service, virtually door-to-door, was provided;
5. System availability increased more than sixfold (more neighborhood routes); and
6. Comfort and convenience improved.

In terms of user costs and benefits, the dual-mode system had higher costs with commensurately higher total benefits. Both systems showed annual benefits exceeding costs.

From the viewpoint of productivity, the dual-mode transit system showed more than three times the productivity of the conventional bus rapid transit system. More than six times the number of vehicle-miles of service were provided by the dual-mode system, requiring only twice the number of drivers. This is attributed to the fact that 70 percent of the time the vehicles are operated in a driverless mode, so that the driver pool focuses solely on the provision of manual collection-distribution service.

Fares required to cover all operating costs (including vehicle depreciation) were 60¢ for the dual-mode system as compared with 43¢ for the conventional bus rapid transit system. Although the dual-mode system required a higher fare, the fare increase appears very likely to be acceptable to the consumer because it is a small increase in proportion to the significantly higher quality of service offered.

The sensitivity analysis illustrated a high degree of operational flexibility in the dual-mode transit concept, providing operational strategy options not available in conventional systems (such as dynamic neighborhood routing, captive versus off-guideway operation trade-offs, and trade-offs among various dimensions of high-quality door-to-door service).

Possibly most important, the dual-mode system can serve not only transit but the total urban transportation need. Consideration of a relatively small loading of private vehicles (i.e., in addition to transit vehicles) on the case study system showed the potential for significantly increased revenues—a possible subsidy for transit—as well as increased benefits for the community.

It is concluded that the hypothetical dual-mode system would be an attractive alternative to (or extension of) the conventional bus rapid transit system proposed to serve 1990 Milwaukee transit needs. The system also has desirable characteristics that would appear to be of value for most other medium-to-large metropolitan areas nationwide.

It is concluded from the high level of benefit-cost performance and the achievement of regional goals characteristic of the dual-mode transit system, as evidenced in the case study results, that dual-mode offers attractive advantages as a transportation system for the urban community.

ACKNOWLEDGMENTS

This paper is based on work performed as part of the Milwaukee County Dual-Mode Systems Study, funded under an Urban Mass Transportation Administration grant. The recommendations and conclusions of this study do not necessarily reflect the views of the U.S. Department of Transportation. The final project reports of the Milwaukee County Dual-Mode Systems Study are currently under review by the Urban Mass Transportation Administration.

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20-24

I-35W URBAN CORRIDOR DEMONSTRATION PROJECT: BUS-METERED FREEWAY SYSTEM

Ronald G. Hoffman, Transit Liaison Section, Minnesota Department of Highways

•THE Urban Corridor Demonstration Program has served as a catalyst in 11 major metropolitan areas in bringing together the resources of transit and highway agencies to undertake projects aimed at relieving peak-hour traffic congestion. We in the metropolitan area of Minneapolis-St. Paul are proud to be a part of this program.

The concept being developed in the Twin City Metropolitan Area was originally formulated by the Texas Transportation Institute (1). The TTI report concluded that the bus-metered freeway system was technically feasible at a number of sites, one of which was the Interstate 35W corridor, south of the Minneapolis central business district.

When Secretary John A. Volpe of the U.S. Department of Transportation announced the Urban Corridor Demonstration Program in January 1970, he stated that the purpose of the program was to test and demonstrate the use of available tools, including the programs of the Urban Mass Transportation Administration and the Federal Highway Administration, in attacking the peak-hour traffic congestion in corridors leading to and from central business districts. Based on the previous work done by the Texas Transportation Institute, a proposal to the Department of Transportation was submitted in March 1970 to conduct final planning for demonstration of the bus-metered freeway concept in the I-35W corridor. We were granted urban corridor planning funds in June 1970 for the first phase of a five-phase program. This first phase was completed in September 1971, and we are proceeding with the detailed design of the project components with construction to take place in 1972 and 1973. We plan to be operational during the third quarter of 1973.

Two proven concepts are to be combined in this project: one is express bus operation and the other is surveillance and control of freeways. As part of this project, facilities will be provided adjacent to the freeway for park-ride, kiss-ride, and transit transfer locations. Buses will be given preferential access to the freeway through special bus ramps and an override of the ramp meter (Fig. 1). As a bus approaches the meter, its presence will be detected by a detector in the bus ramp. The signal will then dwell on red for the automobiles until such time that the bus has passed the merge point of the auto-bus ramp. Automobiles will be metered onto the freeway only when their presence will not reduce the desired level of service. The metering rate will be determined and controlled by a central computer through the use of volume detectors along the freeway. Figure 2 shows a widened ramp allowing the bus to bypass automobiles. We will use this type of ramp configuration at locations where present right-of-way widths are not sufficient to provide a physical barrier between the auto and bus ramps. It is our desire to minimize the cost of the project by not buying additional right-of-way except for the use of park-ride facilities.

The I-35W corridor is one of five freeway corridors that will eventually serve downtown Minneapolis (Fig. 3). At the present time I-35W south and I-94 east are the only segments of freeway open to traffic. I-35W north of downtown is under construction, I-94 north is in the design phase, and a corridor study is under way for I-394 west of the central business district.

The I-35W demonstration corridor extends 16.5 miles south of the Minneapolis central business district (Fig. 4). Two major Interstate routes cross the corridor: I-94 is directly south of the central business district, and I-494 intersects I-35W at approximately the midpoint of the corridor. County Road 62 is a crosstown freeway having a common section with I-35W for approximately ¾ mile. The demonstration project was extended westerly along County Road 62 because it serves the Southdale shopping gure 1. Preferential bus access to freeway system.

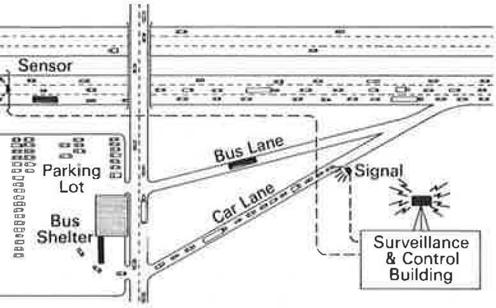


Figure 2. Wide ramp for bus bypass.

gure 3. St. Paul-Minneapolis metropolitan area.

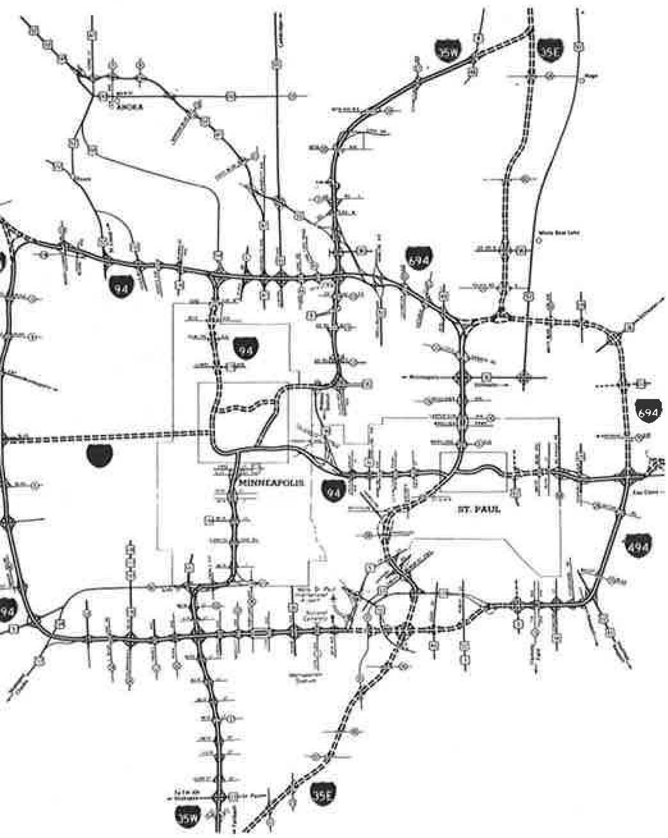
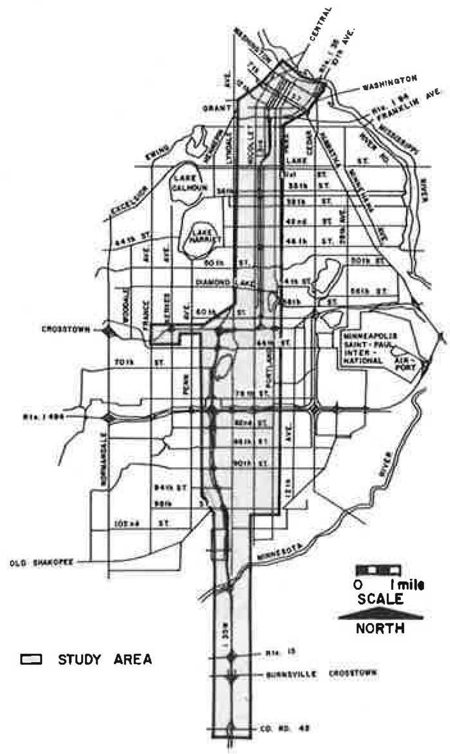


Figure 4. I-35W urban corridor demonstration project.



center, a major traffic generator in this area. The high volumes of traffic on County Road 62 make it necessary to include that portion of this roadway in our surveillance and control project. This corridor has a good system of parallel streets north of the Minnesota River that provide good alternate routes to I-35W. No convenient alternate routes are available south of the Minnesota River.

Beginning at the south end of the project we have 10.5 miles of four-lane freeway, extending from County Road 42 to the beginning of the common section at County Road 62 (Fig. 5). The freeway then widens to six lanes for 2.5 miles through the common section and north to 46th Street. At 46th Street an additional lane is added in each direction, giving eight lanes that feed traffic into and out of the I-94 area.

Figure 6 shows the 6:00 a.m. to 9:00 a.m. peak-period volumes. These volumes are rather low at the southern end of the project but increase as you approach I-494. Note that the volumes drop from 8,891 to 7,321, or 1,570 vehicles, in the I-494 interchange area. Because of this decrease in volume, we will not have to meter I-494. Note also that the volume of traffic entering the central business district is approximately 60 percent of that just south of I-94.

The percentage of traffic with trip destinations within the central business district is shown in Figure 7. Although all of the traffic north of I-94 must enter the central business district, only 65 percent is destined for a location within the central business district. The reason for this is that the freeway system north and west of the central business district has not been completed.

Travel time studies were conducted as part of the corridor transportation inventory for both the morning and evening peaks. The average travel time in the morning peak for the 16.5 miles was 26 minutes, with the greatest time recorded as 30 minutes and the lowest as 17 minutes. The average travel time for the evening peak was 25 minutes, with a high of 26 minutes and a low of 18 minutes. Although the average speed is approximately 40 mph, there are problem areas where delays occur. The first critical section for the northbound traffic in the morning peak is in the Minnesota River area. Speeds drop as trucks have difficulty climbing the 3.0 percent grade out of the river valley. A truck lane is to be constructed as a solution to this problem. This will not be a part of the demonstration project, however. The combination of the County Road 62 common section and the Minnehaha Creek bridge causes another major delay. Heavy weaving volumes exist in the common section. The Minnehaha bridge does not have the full shoulder width, which creates a psychological speed restraint. The average speed in this section drops to 20 mph. The major delay for the evening southbound traffic exists in the section near 46th Street. A lane is dropped at 46th Street, but volume studies show only one-half lane of traffic actually exists. Speeds remain between 25 and 30 mph through the Minnehaha bridge area. The speed then gradually increases to the end of the project. Two goals of the demonstration are to decrease the average travel time to 18 minutes or an average of 50 mph for the 16.5 miles and to increase the minimum speed to 40 mph in all sections.

Besides the travel time studies and traffic volume studies in this corridor, we also conducted a transit travel demand study and I-35W origin-destination study. From these we obtained transit travel demand and patronage data, transit rider characteristics, and a summary of the travel patterns of those using transit. The I-35W origin-destination study included such things as trip purpose, auto occupancy, number of people living in the household, car ownership, age, and income for the auto users. The inbound origin-destination survey was taken during the morning peak at two ramps exiting into the downtown area as well as at the ramp at 31st Street, which is just south of the downtown area.

The data from the Fifth Avenue and Eleventh Street-Grant Street exits in the downtown area document travel patterns for those vehicles whose destination was the Minneapolis central business district. The data from 31st Street document travel patterns for trips to major generators south of the CBD and also provide data on vehicles going downtown via 31st Street and one of the parallel streets.

The survey technique used for this study was to record the license plates of automobiles using these ramps. The names and addresses of owners of the automobiles were then obtained from the motor vehicle registration files, entered on a mail-out

Figure 5. I-35W corridor dimensions.

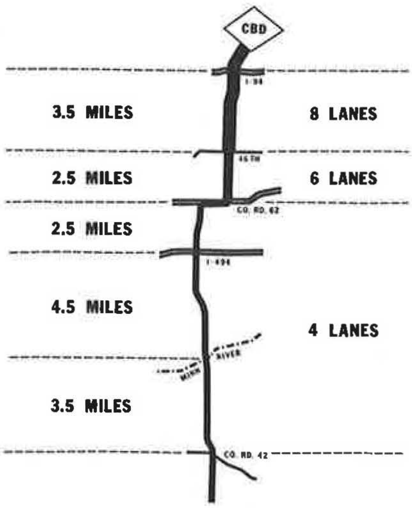


Figure 6. I-35W traffic volumes, northbound, morning peak.

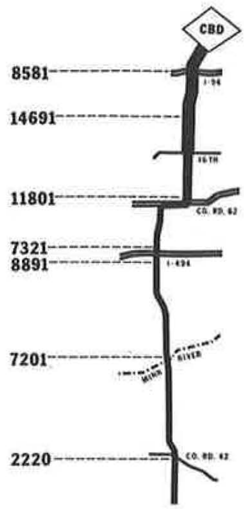


Figure 7. Percentage of CBD-bound traffic, morning peak.

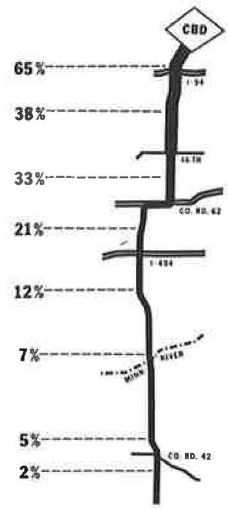
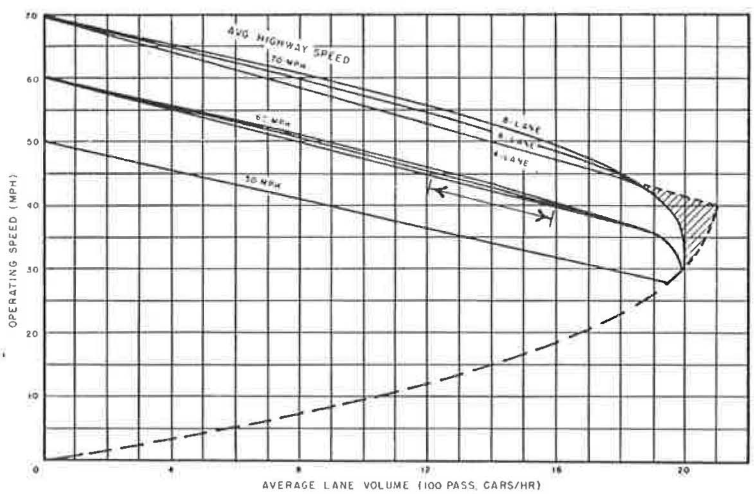


Figure 8. Speed-volume curve showing proposed improvement.



mail-back postcard, and sent to the highway user. These cards were mailed out within 48 hours of the time the license plate was recorded.

As a result of the data collection and analysis work on this project, it is recommended that we proceed with implementation. The final plan has recommended 12 proposed new routes for express bus service. It is estimated that the 12 proposed new routes and the revised existing express lines together will carry about 6,000 passengers on a typical weekday. Many of these passengers will be switching from existing local bus service; however, slightly more than one-third of the total riders will be former auto users. It is a goal of the project to capture 15 percent of the auto drivers and auto passengers in the corridor in the peak periods. In order to initiate the transit plan, 48 transit vehicles will be necessary to provide the recommended level of service; 34 of these buses will be for the 12 proposed new routes and 14 for the revised existing express lines. We will construct seven new bus ramps to provide preferential access for the buses. Three park-ride facilities have also been recommended as part of the project.

We will be experimenting with two types of express bus operations. The first one is to use the express bus for pickup and delivery of patrons along the city street system. The second operation will involve only a stop at a park-ride facility and then express into the downtown area. It is also recommended that the freeway surveillance and control system be programmed to operate at lower volumes and higher speeds than systems currently in operation throughout the country. Figure 8, a standard speed-volume curve, shows that the maximum of 2,000 vehicles per hour is achieved at approximately 30 mph. We expect to back off on this curve to a speed of approximately 40 to 45 mph to guarantee the travel time of the buses and the autos entering the freeway system. By doing this we hope to attract more patrons to the express buses.

The capital cost for all elements of the recommended bus-metered freeway system is $4,731,000. The control center building and equipment, the surveillance and control components, the television system we expect to use, and the communication system are estimated to cost $1,703,000. The recommended transit service plan consisting of transit vehicles, exclusive bus ramps, park-ride facilities, waiting shelters, and bus-stop signs is estimated to cost $3,028,000.

At the present time we have received a grant to construct the surveillance and control center. The architect has nearly completed the plans for this building, and we expect to let a contract soon.

Interstate (90 percent) funds have been approved for the design and installation of the freeway surveillance and control equipment as well as for the special bus ramps. Funding for the buses required for this project is expected to come from the Urban Mass Transportation Administration. Because of the fine cooperation that we have had with the Federal Highway Administration as well as with the Urban Mass Transportation Administration, we are proceeding on this project on a very optimistic schedule and expect to be in full operation in approximately 20 months.

REFERENCE

1. A System to Facilitate Bus Rapid Transit on Urban Freeways. Texas Transportation Institute, Dec. 1968.

25-37

SHIRLEY HIGHWAY EXPRESS BUS ON FREEWAY DEMONSTRATION PROJECT

Ronald J. Fisher, Urban Mass Transportation Administration,
U.S. Department of Transportation

This paper describes a series of improvements that have given buses preferential treatment leading to travel time savings of 5 to 30 minutes. These improvements have been implemented over the past 2 years along a 9-mile section of I-95 (Shirley Highway) linking Northern Virginia with downtown Washington, D.C. Bus routes experiencing these time savings have gained approximately 4,000 more riders, most of whom have a choice between taking a bus or driving an automobile. Over half of the increase has occurred in the past several months following the opening of the full length of exclusive roadway for buses in the median of the Shirley Highway and the implementation of eight new express bus routes. Results of two travel surveys in the corridor made at the beginning and end of this period are discussed, and early indicators of the modal choice shift are described. Additional surveys are scheduled at 4- to 6-month intervals over the next few years. The types of analyses and data that will be available for general use by urban transportation planners are presented in preliminary form. The cost and revenue associated with the increased commuter traffic is analyzed using a five-parameter cost allocation procedure to provide preliminary guidelines for the financial requirements of similar improvements designed to attract more commuters to bus service.

•IT IS commonly recognized that the congestion of traffic in the nation's major cities is unacceptable and can be relieved only if large numbers of motorists will abandon peak-hour travel in their private automobiles and make use of mass transit instead. The U.S. Department of Transportation, through the Urban Mass Transportation Administration (UMTA) and the Federal Highway Administration (FHWA), is demonstrating various methods to attract motorists into public buses. A very important inducement is the significant reduction in trip time from boarding point to destination. This can be achieved by giving the bus preference over the automobile. UMTA in partnership with FHWA has placed emphasis on this solution and is conducting demonstrations to prove its success and to measure the effects. The largest and most promising demonstration is the use of express buses on an exclusive bus lane that has been operating for over 2 years on Shirley Highway, a major artery between Washington, D.C., and its Northern Virginia suburbs.

Planning for the project began in 1964 with discussions by a group representing the District of Columbia, the Virginia Highway Department, two bus companies, the Regional Regulatory Authority for Transit, the Regional Rapid Transit Authority, and the FHWA. As a result of these discussions, proposals for express bus service were incorporated in the reconstruction plans for Shirley Highway.

The same agencies again met and agreed in early 1968 to proceed with a detailed study. A steering committee to guide the study was established, consisting of a member and an alternate from each of the following agencies: Washington Metropolitan Area Transit Commission, Washington Metropolitan Area Transit Authority, Washington Metropolitan Area Council of Governments, Virginia Department of Highways, Northern Virginia Transportation Commission, District of Columbia Department of Highways, AB&W Transit Company, and the WV&M Coach Company. The FHWA and UMTA are represented in an advisory, non-voting capacity.

This steering committee was assigned responsibility for the determination of overall policy. It also selected the consultant (Howard, Needles, Tammen and Bergendoff) to perform the work and approved their detailed study design.

The study evaluated all travel in the Shirley Highway Corridor to find out how bus rapid transit could best be provided and to determine its feasibility within two separate time periods. The first period covered the last stages of the Shirley Highway reconstruction (1969-1975). The second was the post-reconstruction period, when a new important factor had to be taken into consideration: the completion of the Metro rail rapid transit system, which will raise complicated questions of integrating bus and rail rapid transit service.

The steering committee has maintained a high level of active support and collaboration in top-level policy guidance. As a result, the plan for express bus operations recommended for the interim period while Shirley Highway is being reconstructed is now operational. The committee continues to function now that the project is under way and serves to resolve those problems that involve several of the operating partners in the project.

FHWA, through the Virginia Department of Highways, has constructed the exclusive bus lane in the median. With funds provided by UMTA, the Northern Virginia Transportation Commission (NVTC) has purchased the new buses needed for the demonstration, and the buses are operated under contract by the AB&W Transit Company. Other bus companies, notably Continental Trailways, Colonial, WV&M, and Greyhound, are also permitted use of the exclusive bus lane.

LOCATION AND DESCRIPTION

The area influenced by the project is known as the Shirley Highway Corridor, a broad, wedge-shaped section of Northern Virginia extending from Washington, D.C., to Woodbridge, 25 miles to the south. Its area is approximately 160 square miles, with a population of approximately 600,000. It includes portions of Arlington and Fairfax Counties and the cities of Alexandria, Falls Church, and Fairfax, all major suburbs of the Nation's Capital. At the northeastern end of the corridor are the region's major employment centers: the Pentagon, the rapidly growing Crystal City complex, and the central business district of the District of Columbia, where there are three major terminal areas for the commuter buses. The three Washington terminals combined provide close access to over 270,000 jobs, a number predicted to be over 300,000 by 1975. Figure 1 shows the corridor area and Figure 2 the routes and terminals in the District of Columbia.

There are several major highway facilities in the corridor that handle commuter traffic radiating northward to downtown Washington. The principal facility is I-95, the Shirley Highway. It is in the median of this freeway that a roadway is now available for the exclusive use of buses. That roadway is composed of two 12-foot-wide reversible highway lanes for a little over half the distance and a single temporary 17-foot-wide highway lane for the remainder of the distance into Washington.

The median will eventually consist of two reversible lanes most of the distance from Springfield, Virginia, to downtown Washington—a distance of about 12 miles. At present, the last 4.5 miles of the roadway approaching Washington is being reconstructed (see "Temporary Busway" in Fig. 3). In approximately 2 years this lane will be replaced by two reversible lanes joining those now existing south of this temporary lane. The comparative travel times for buses and automobiles in both the morning and evening peak periods and on various sections of the roadway are also shown in Figure 3.

The pattern of bus routes collecting commuters in Northern Virginia and feeding into the busway is shown in Figure 4. Also shown are proposed locations for fringe parking that are now under development.

Figure 5 shows a bus operating on the completed reversible lanes of the exclusive bus roadway and passing the long queue of vehicles that back up on Shirley Highway during the morning peak travel period. The scene is approximately 5 miles from downtown Washington and the bus shown here will reach that destination in about 10 minutes. By contrast, the cars shown here will take over 30 minutes to travel the same distance.

Figure 1. Area of busway influence and major inbound destinations.

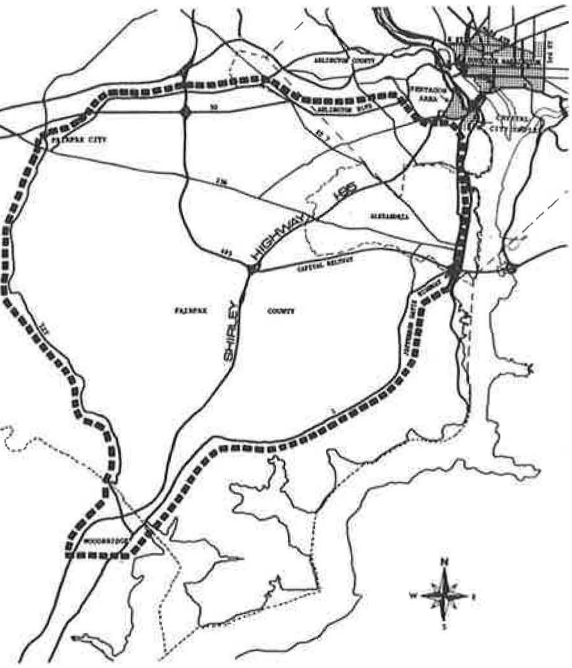


Figure 2. Peak-period bus routes to Washington terminals.

Figure 3. Auto and bus peak-hour travel times on Shirley Highway.

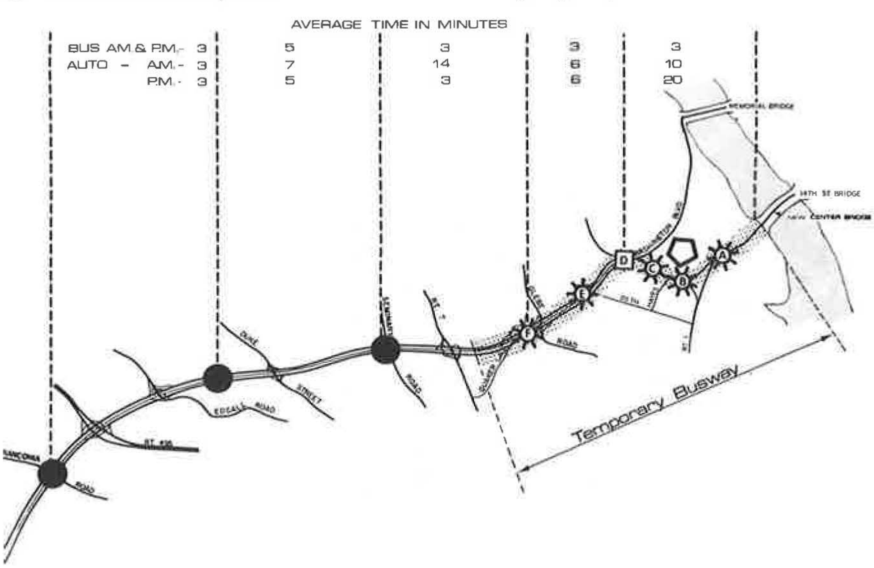


Figure 4. Peak-period bus routes and fringe parking locations.

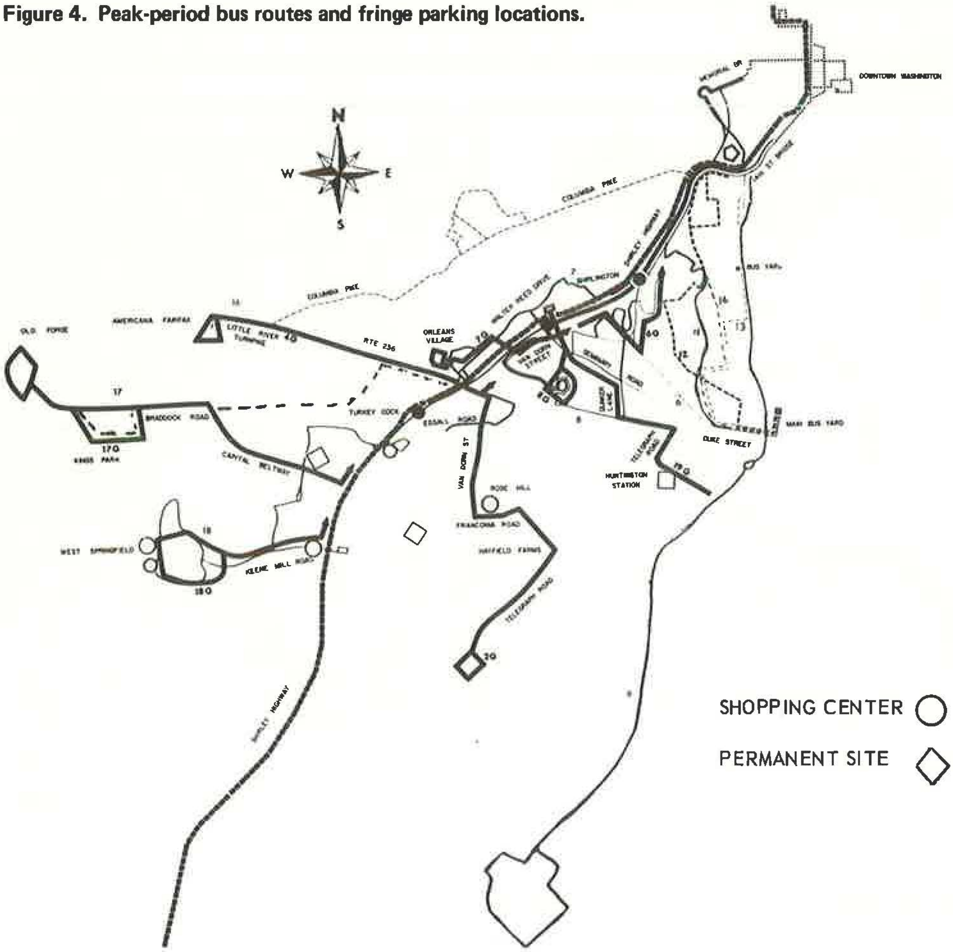
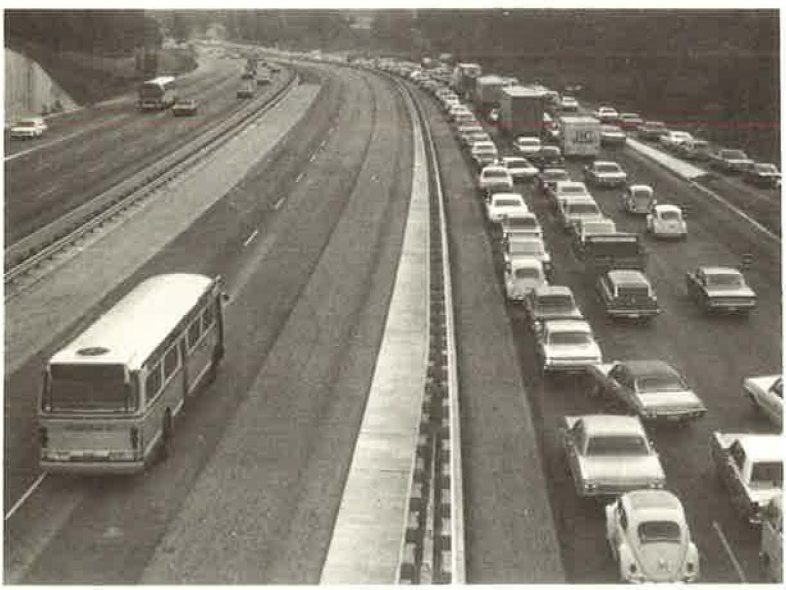


Figure 5. Shirley Express bus on reversible lanes.



As buses on the exclusive bus roadway approach Washington, they have a choice of two bridges over the Potomac. The great majority of buses use a new bridge built for the eventual reversible-lane operation (indicated by the heavy solid line in Fig. 2). As these buses exit from the bridge, they merge with regular traffic on 14th Street into downtown Washington. Buses may also leave the exclusive lane at point D in Figure 2 and proceed by Washington Boulevard to Memorial Bridge.

In Washington, curb lanes along the routes of the express buses are reserved for them and for right-turning automobile traffic. Ongoing construction of the Metro occasionally makes it necessary to make slight modifications in these plans (Fig. 6) to accomplish the most efficient bus circulation.

The flow of express bus traffic just described is reversed in the evening peak period, and the Shirley Highway median carries express buses in the opposite direction.

The three principal terminal points in Washington for the Shirley corridor service are shown in Figure 2 where they are marked with a T. The lower right terminal area in southwest Washington is convenient to about 60,000 jobs; the mid-terminal area (the Federal Triangle) is within walking distance of about 50,000 jobs; and the upper terminal area at Farragut Square is within walking distance of about 160,000 jobs.

PROJECT EVALUATION

The evaluation of the project performance is based on a set of goals established in the planning stages and refined as the project became operational. An evaluation team undertook to study traffic on Shirley Highway, the characteristics of bus riders and motorists, travel times for both buses and automobiles, changes in commuters' modes of travel, and their attitudes toward the new system. Cost factors were also analyzed.

The major project goals and objectives are to (a) divert motorists to the Shirley bus service; (b) develop a viable service that will continue after the demonstration; (c) reduce travel time for all commuters; (d) reduce air pollution; (e) increase reliability of service; and (f) improve mobility for young, old, handicapped, and low-income travelers.

The object of the evaluation is to measure project performance in terms of progress toward meeting these goals. The evaluation team also collects data required for a better understanding of the phenomena underlying achievement of certain of the goals. For example, those variables that may affect modal shifts will be monitored throughout the project. Also, to better understand project costs, a chart of accounts for operating expenditures is being maintained; a preliminary analysis of these costs is given later in this paper.

A substantial number of bus passengers use the roadway, as indicated in Figure 7. The graph shows distinct incremental increases in bus passengers occurring in September 1970 and April 1971; each coincides in time with the opening of new sections of the exclusive bus roadway and the rerouting of buses that had up to those dates been operating in mixed traffic.

These incremental jumps in ridership should not, of course, be interpreted as traffic growth or diversions between bus routes. Most of the genuine passenger growth has been and continues to be on those routes serving the southern part of the corridor. A substantial increase in bus service for this area occurred in June 1971 through the addition of 30 new buses on new express routes. Service increased in February 1972 with the addition of 20 more new buses and will be expanded by at least two increments of 10 to 20 buses later in 1972.

Peak-period ridership in this southern sector has risen by more than 4,000 persons since September 1969. Taking into account all the AB&W buses operating over portions of the exclusive roadway, more than 12,000 passengers in each peak period are experiencing the benefit of time saving in commuting. Some 1,200 additional people traverse the exclusive bus roadway on other private carrier buses during each of the peak periods.

To evaluate demonstration projects of the magnitude of the Shirley project requires monitoring of numerous phenomena and the employment of several different techniques of data gathering. All of the following data-gathering efforts are under way by the evaluation team: postcard origin and destination (O&D) surveys; screen-line counts; bus passenger counts; travel time diaries; accounting summaries; schedule-adherence checks; and product-evaluation surveys. An attitude survey is also being planned.

The O&D survey is the major part of the effort and the most costly. This type of inquiry is essential, however, for obtaining empirical data on the modal shifts that the project is causing.

Checkpoints have been established at appropriate locations on the major arteries in the corridor and approximately 2 miles from Washington. At these counting sites, shown in Figure 8, a sample of passing motorists is periodically surveyed. Drivers are identified by their license plates and mailed questionnaires to be answered and mailed back. Screen-line counts are conducted in the spring, summer, and fall of each year. Two O&D surveys have been completed—in April and October 1971—and a third is scheduled for the fall of 1972. At least one or two more O&D surveys will be conducted in 1973 or 1974.

A computer file of all the data collected is being compiled. Very detailed bus and highway networks are being coded to simulate the comparative travel times and costs for each O&D survey respondent. The actual mode choice decision is of course available on the completed survey form. Data on the independent variables that may affect this decision will be placed in the record for each survey respondent; these independent variables are given in Table 1. The evaluation team will analyze these data and describe the influence the variables have on mode choice in future project reports. It is hoped that this reporting will be helpful to transportation planners in other parts of the country who must estimate the impact of a similar type of transportation improvement for their area.

EVALUATION RESULTS: PRELIMINARY DATA

Firm statistics concerning the project cannot be reported until about 1974. However, preliminary data indicating the general trends are presented here. No doubt there will be adjustments of the results reported here as more data and more analyses become available.

The statistics compiled over the longest period of time are derived from the screen-line counts that began in the spring of 1970. The percentage of person trips crossing the seven screen-line stations by bus is shown in Figure 9. It should be noted that an eighth station has been added for Beltway traffic and may be included in the screen-line statistics pending further analysis. The percentage of person trips by bus stayed at about 21 percent during 1970 but increased in 1971 to a little over 27 percent. Absolute screen-line counts are given in Table 2.

It cannot, of course, be assumed that everyone counted is a potential bus user. A gross comparison of auto and bus person trips across the screenline does not properly indicate how well the bus service in the corridor is competing with the automobile. Motorists making through trips, for example, crossed the screenline but could not possibly use the Shirley bus service. These are trips that neither started nor ended in the corridor or in downtown Washington. Also, trips may start in the corridor but have destinations in areas not served by bus.

Accordingly, the evaluation team adjusted the statistics, and the preliminary estimate is that two-thirds of automobile person trips crossing the screenline are actual potential express bus riders. These are designated as the "market". Those who use the buses are placed in a category designated the "market share". The growth of this group is shown in Figure 10, which indicates that the percentage of all potential bus-using motorists who graduated to actual bus riding increased from 29 percent in October 1970 to 32 percent in April 1971 and to an estimated 36 percent in October 1971.

During the same period the absolute number of bus passengers increased from 14,200 to 16,300. Very significantly, simultaneously the number of automobile person trips declined by an even more substantial number—from over 50,000 in October 1970 to 43,000 in October 1971.

The greatest change occurred on Shirley Highway itself where, as shown in Figure 11, the number of automobile person trips declined from a little over 12,000 in October 1970 to about 7,500 automobile person trips a year later. By contrast, bus passengers increased from 4,300 people to 7,800 people during the same period. Not all of this increase, however, represents growth in overall bus use because in that period existing

Figure 6. Peak-period priority lanes in downtown Washington.

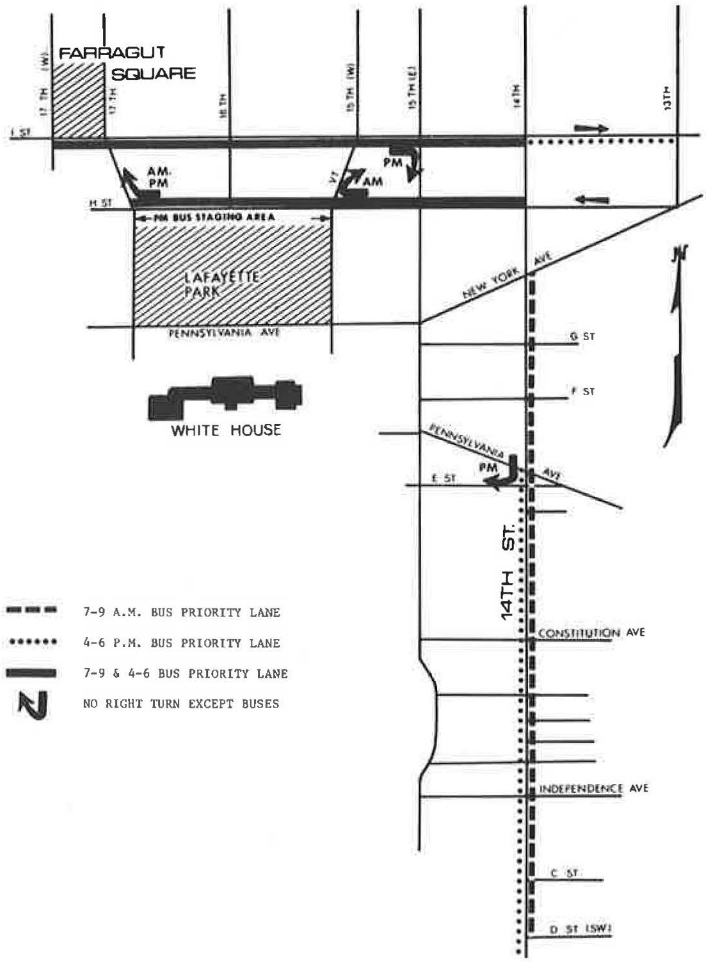


Figure 7. Total passengers using busway during 6:30-9:00 a.m. period.

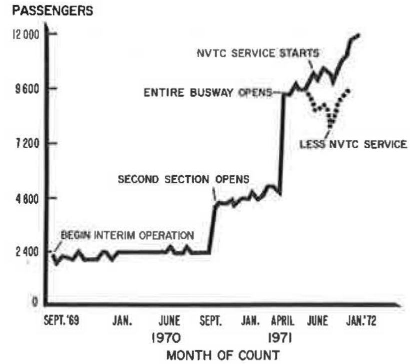


Table 1. Data file.

System Characteristics:
Differential commute time
Differential commute cost
Out-of-vehicle time
Transit fare
Special advertising
Transfers
Park-ride availability
Project vehicle
Zone Characteristics:
Residential density
Parking cost
Traveler Characteristics:
Household income
Sex
Age
Auto available
Trip Characteristics:
Auto needed on job
Distance to CBD

Figure 8. Corridor person movement counting sites.

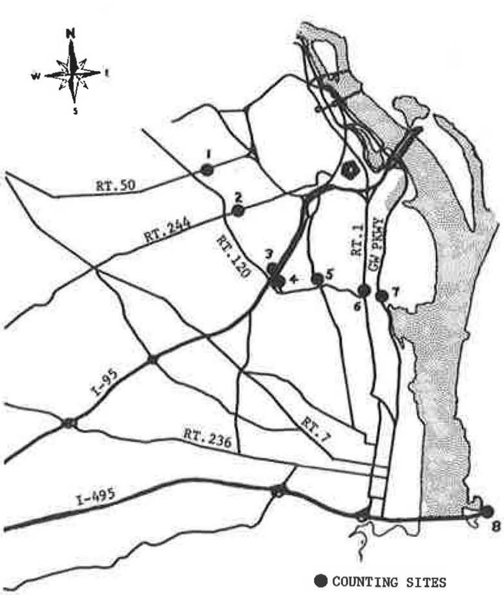
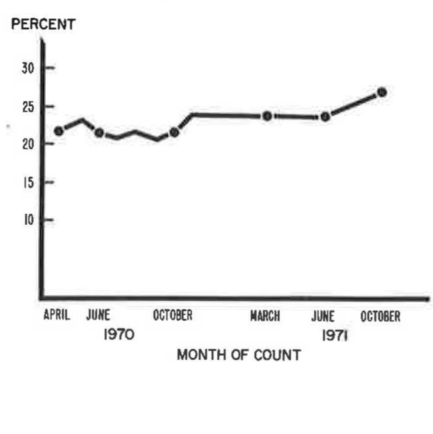


Figure 9. Percent person trips by bus crossing screenline during 6:30-9:00 a.m. period.



bus routes were diverted to the Shirley Highway to take advantage of newly completed sections of the exclusive busway.

This modal shift has caused a historic change in the balance of traffic being carried by public and private modes on Shirley Highway. The volume of morning peak-period person trips carried by buses on Shirley Highway exceeded the volume carried by automobiles for the first time in October 1971. The absolute numbers and percentages are given in Table 2. The car occupancy figures, also appearing in Table 2, have declined both for Shirley Highway and overall, but the change was slight: from 1.37 to 1.34 persons per car on Shirley Highway and from 1.41 to 1.35 persons per car in the combined sample from all screenline stations for the year between October 1970 and October 1971. The evaluation team is investigating the variation that occurs in these figures by screenline station and by season and the effect the project bus service has on reducing car pools.

COMMUTER PROFILES

Characteristics of commuters in the corridor and their attitudes toward modes of travel are, of course, extremely important factors for the evaluation study. Information has been developed from both the April and October 1971 surveys.

The October survey contained an open-ended query designed to elicit from motorists unguided attitudes toward the concept of an exclusive roadway for buses now being demonstrated on Shirley Highway. Although there were some very lengthy negative comments, three-quarters of the motorists commented favorably about the concept. A substantial negative reaction was expected from motorists using Shirley Highway who experience the daily frustration of seeing buses speeding by on the wide-open bus roadway while they are caught in heavily congested bumper-to-bumper traffic. Surprisingly, even two-thirds of these motorists commented favorably on the concept.

A profile of the bus commuter and the automobile commuter emerges from the data given in Table 3. Here, too, attitudes are measured, although this time both bus users and motorists were queried. The scale used for the measurement of attitude needs some explanation: a score of 1 signifies a very positive attitude about transit, and 4 signifies a very negative attitude. As might be expected, bus users were found to have more positive feelings about transit than automobile users. Both groups appear to be more positive about transit in the October survey than they were in the initial survey in April.

The profile data reveal that nearly three-quarters of the automobile commuters are male whereas the bus commuters are about evenly divided between the sexes. The automobile commuters also have higher incomes, as expected, but the bus commuters are not too poor and their average income increased between the two surveys by nearly $1,000. This rise in average income implies that a substantial number of well-to-do motorists became bus riders between April and October.

The bus users have been further subdivided in Table 4 into Shirley and non-Shirley subpopulations. The Shirley bus users are defined as those riding buses that enter the busway at Shirlington Circle or further south. In other words, they make substantial use of the busway, using it for 4 miles for more. All the other bus users are in the category of non-Shirley bus users.

It can been seen in Table 4 that the profile of the Shirley user resembles that of the automobile commuter. He is richer, has more cars per household, and has more choice than the non-Shirley bus user. The Shirley bus rider has a more favorable attitude about transit, and again both Shirley and non-Shirley bus users are more favorable toward transit in the October than in the April survey. A substantial portion of Shirley users previously drove alone, about one out of five. A smaller portion, nearly one out of eight, came from car pools. About half of the bus users did not make the trip before, and half the Shirley bus users reported in October that they began using the bus only since June 1971. Even a quarter of the non-Shirley users reported that they started using the bus after June 1971. There is undoubtedly a lot of shifting between modes as well as between home and job locations. Washington probably has above-average job mobility, and the evaluation team is analyzing this factor in more

Table 2. Screen-line counts.

Statistic	Auto Persons	Total Vehicles	Auto Occupancy	Bus Passenger	Total Persons	Bus Percent
Shirley Highway Screenline Station						
October 1970	12,210	8,906	1.37	4,353	16,563	26.28
October 1971	7,564	5,662	1.34	7,824	15,388	50.84
Difference	-4,646	-3,244	-0.03	+3,471	-1.175	+24.56
Total Screenline						
October 1970	50,508	35,724	1.41	14,248	64,756	22.0
October 1971	42,937	31,740	1.35	16,308	59,245	27.5
Difference	-7,571	-3,984	-0.06	+2,060	-5,511	+5.5

Figure 10. Portion of potential bus market using transit "market share".

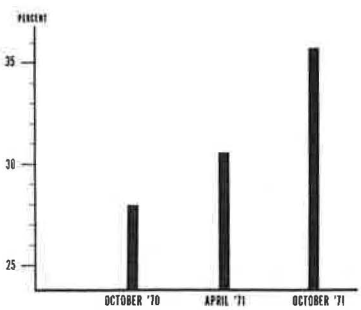


Figure 11. Auto and bus person trips during 6:30-9:00 a.m. period.

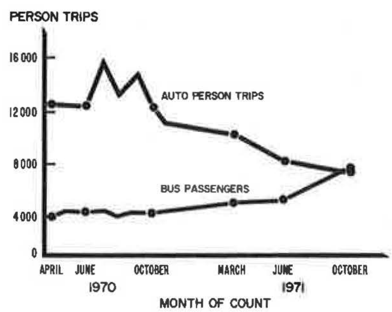


Table 3. Bus and auto commuter profiles.

Characteristic	Bus April	Bus October	Auto April	Auto October
Percent male	49	54	73	74
Household income (dollars)	15,500	16,400	19,500	19,100
Cars per household	1.1	1.3	1.7	1.7
Attitude score (1.0 very positive)	1.9	1.6	2.7	2.4
Percent captive (no auto)	33	24		
Percent choice (auto available)	52	57		
Percent auto available but hardship[1]	14	16		

[1]The person had an auto available for his trip but at some inconvenience to others.

Table 4. Bus survey results.

Characteristic	Shirley April	Shirley October	Non-Shirley April	Non-Shirley October	Shirley Passenger Description
Household income (dollars)	16,300	16,900	15,200	16,100	Richer
Attitude score (1.0 very positive)	1.7	1.5	1.9	1.8	Favorable to bus
Cars per household	1.2	1.3	1.1	1.2	More cars per household
Percent choice	59	62	44	48	More choice
Percent captive	24	21	37	36	Less captive
Percent park-ride	8	16	7	9	More park-ride
Previous mode (percent):					
Drove alone	23	18	16	12	
Car pool	12	13	11	11	
Another bus	17	20	13	14	
No trip	48	49	60	62	
Began bus after June 1971 (percent)		52		26	

detail. This dynamic situation provides an opportunity to gain new riders for transit because commuting habits are frequently changing. It also represents a challenge to keep potential and existing transit users informed about available transit service.

The automobile user profiles are as given in Table 5. The most striking finding is the high percentage of those paying no parking costs—over half. Those who pay are charged, on the average, over $1 per day, which is about three-quarters of the average round-trip transit fare. Also, about one in five automobile users indicate that they need their car during the day, which reduces the possibility that they could be attracted to transit. Finally, about a quarter of the automobile users in the October survey said they have tried transit; 19 percent answered this question affirmatively in the April survey.

REASONS FOR SWITCHING BETWEEN MODES

Among the most important findings of the October survey were the principal reasons stated for switching travel modes. The listing given in Table 6 of the major reasons cited by former automobile users for becoming bus users is divided into the two sub-populations defined earlier: Shirely and non-Shirley bus users. The categories are self-explanatory except possibly the "traffic" category, which represents comments pertaining to driving discomfort, traffic congestion, and other related adverse conditions. Automobile costs and parking costs are stated as major reasons for changing to the bus, especially by the non-Shirley users, who do not have the higher speed service to attract them.

In Table 7 are the reasons given by automobile users who have tried the bus but did not stay with it. The weight given to the first four categories is about evenly divided. Three categories relate to the service. Speed and convenience of the service can be improved with routing and schedule changes, although often at increased cost. The fares charged for the service definitely cannot be reduced without compromising the project objective of developing a viable service. It is noteworthy that half the people who responded that the buses were too expensive had free parking. Automobile comfort and privacy were also important reasons stated for changing back to the automobile mode. UMTA is attempting to counter the first of these objections by making the bus interior more spacious and attractive. The seating capacity has been reduced from 51 to 47, providing more leg room. The seats have been widened by 1 inch to 18 inches in the new buses and reached what is considered the optimum width of 19 inches for the buses put into service in February 1972. The importance of inclement weather cited in Table 7 may be diminished with the provision of bus shelters that will be built at key locations in the corridor during 1972. The effect of these various efforts in winning back bus riders as well as in attracting new customers will continue to be monitored. The successes and failures in dealing with these reasons for shifting back to the automobile will be analyzed and reported in the future.

ALLOCATION OF PROJECT OPERATING EXPENSES

The expense of operating the new Shirley Express bus service is recorded in separate accounts kept by the AB&W Bus Company. These accounts are important in themselves as a management tool to control costs. Also, like many transit operations in other metropolitan areas, the Shirley service is heavily commuter-oriented, a situation that causes severe peak demands on labor and equipment. This circumstance has associated pricing implications that should be analyzed. A key part of the analysis involves determining the cost impacts of these peak commuter loads on the transit operation. These costs might also be contrasted with other means for meeting the demand, such as constructing additional highway lanes. It is therefore considered important to allocate these costs back to the basic transit operation in order to compare revenues and costs both by route and by time of day.

In an initial effort to allocate these costs, five operating parameters have been identified as explaining the variation in operating expense by route and by time of day (peak versus off-peak). The five parameters are as follows:

1. Vehicle-miles—assign certain variable costs;
2. Platform hours (the time the operator is on dispatch including deadheading to and from his run)—assign certain variable costs;
3. Transit passengers—assign certain variable costs;
4. Transit vehicles—assign certain fixed or semi-fixed costs; and
5. Vehicle operators—assign certain fixed or semi-fixed costs.

An analysis was made of each expense-account item, and a portion of each or the whole expense was assigned to one or more of these five parameters. For example, fuel costs vary by the amount of miles operated; therefore 100 percent of the fuel costs was assigned to the vehicle-miles parameter. Not all of the expense-account items are that straightforward. In some cases, considerable judgment is required. For example, all of the straight salary costs for vehicle operators have been assigned to the platform hours parameter, which in turn is measured by route for both the peak and off-peak operation. Some may argue that, because the bus driver is guaranteed 8 hours of pay regardless of whether or not he is needed in the off-peak, a portion of his straight salary costs should be assigned to the vehicle operator parameter, so that the semi-fixed nature of that salary cost could be reflected in the expense allocation to the peak-period operation. The evaluation team will continue to study this aspect of the problem.

The semi-fixed bus driver labor costs (overtime, retirement, vacation, and other benefits) are assigned to the vehicle operator parameter. Other fixed or semi-fixed costs such as insurance, taxes, and building maintenance are assigned to two parameters—transit vehicles and vehicle operators. In turn these two parameters are determined only for transit routes in the peak period. The logic underlying this allocation is derived from the scope of the transit operation; i.e., the number of vehicles and the size of maintenance and storage facilities are determined by the requirements to meet peak-period demand. The variable expenses are assigned to the other three parameters (miles, hours, passengers) that are determined by route in both the peak and off-peak periods. The results obtained for the off-peak operation are close to what one might term the marginal cost of that operation. In other words, one could actually realize a profit if the off-peak revenues exceeded those costs. If revenues are less than those costs, the value of the social benefit needed to justify the operation will be more accurately represented than is customary with conventional cost analyses.

The initial results of this approach to the cost analysis are shown in Table 8. A similar analysis is being made of the Blue Streak Express Bus Demonstration in Seattle, Washington, also being sponsored by UMTA, and the results will be reported in an interim report for that project. As shown in Table 8, about 60 percent of the operating expense is spread across all routes for both peak and off-peak operations. The remaining 40 percent of the expense is assigned only to the peak-period bus operation. After further analysis of the data the evaluation team may weigh the portions to further reduce the marginal cost of the off-peak service. Also, it should be noted that the depreciation expense for the buses has not been assigned. If these costs were assigned, it would be consistent with the logic of this cost analysis to assign all of the depreciation costs to the transit vehicle factor, which would increase peak-period costs by about 15 percent.

As the result of this initial cost analysis, it can be seen in Table 8 that the weighted unit cost per mile varies from $0.80 to $1.27 for peak-period routes. It is estimated to be considerably less costly to operate off-peak routes, which are within a range of only $0.43 to $0.50 per mile.

Table 9 gives the net result of this approach and reveals the estimated profitability by route with data based on project statistics for September and October 1971. It is noteworthy that there is a substantial surplus of revenues over expenses for the peak-period routes, great enough in October even to cover the off-peak loss.

Finally, in Figure 12 one major factor that affects profitability (speed) is plotted against the weighted unit operating cost for each route. There is a reasonably good straight-line relationship. Obviously, if the speed of the service is increased, there is more opportunity to get second trips in the peak period, thus raising driver and

Table 5. Auto survey results.

Description	April	October
Submode:		
Drive alone (percent)	50	51
Alternate driver (percent)	14	13
Driver with passengers (percent)	13	12
Passengers (percent)	23	24
Vehicle Parking Cost:		
Zero (percent)	55	55
Paying average (dollars)	1.15	1.10
Need car during day (percent)	19	17
Have made trip by bus (percent)	19	24

Table 6. Reasons for switching from auto to bus.

Reason	Shirley (percent)	Non-Shirley (percent)
Traffic	24	22
Car pool dissolved	9	25
Bus faster	35	6
Moved, changed jobs	16	20
Auto cost	9	8
Parking cost	7	19
Total	100	100

Note: Data are those given by choice riders—i.e., persons who had an automobile available for the trip.

Table 7. Reasons for switching from bus to auto.

Reason	Percent
Inconvenient	19
Bus too expensive (50 percent have zero parking cost)	18
Bus slower	17
Car comfort, privacy	16
Weather	8
Irregular hours	8
Car pool formed	6
Evening service poor	4
Other	4
Total	100

Table 8. Preliminary unit results of expense allocation.

Factor	Percent of Expenses	Unit Cost
Miles	17	$0.13 per mile
Hours	35	$4.61 per hour
Operators	25	$23.20 per day
Vehicles	16	$14.52 per day
Passengers	7	$0.05 per passenger
Variation in weighted unit cost per mile:		
Peak period		$0.80 to $1.27
Base day		$0.43 to $0.50

Figure 12. Operating cost versus average speed of Shirley Express bus routes.

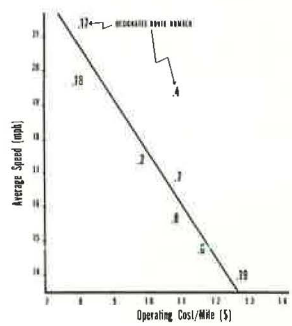


Table 9. Cost and revenue by route (dollars).

Route		September Expense	September Revenue	September Net Revenue (Loss)	October Expense	October Revenue	October Net Revenue (Loss)
Peak Period							
2G	Hayfield Farms	7,009	4,822	(2,187)	6,041	5,006	(1,035)
4G	Heritage Mall	5,715	6,903	1,188	5,729	7,678	1,949
6G	Parkfairfax	4,552	4,486	(66)	3,478	4,372	894
7G	Lincolnia	8,274	10,474	2,200	7,475	10,369	2,894
8G	Shirley Duke	5,445	4,356	(1,089)	4,140	4,157	17
17G	Kings Park	6,628	7,121	493	5,984	8,246	2,262
18G	Springfield	8,411	10,171	2,060	7,338	10,657	3,319
19G	Huntington	4,309	3,884	(925)	3,248	3,744	496
	Subtotal	50,343	52,017	1,674	43,433	54,229	10,796
Base Day							
1A&B	Northern Virginia Loop	4,621	1,215	(3,406)	4,081	636	(3,445)
17G	Kings Park	3,362	1,239	(2,123)	2,974	903	(2,071)
18G	Springfield	3,452	2,025	(1,427)	3,107	1,788	(1,319)
	Subtotal	11,435	4,479	(6,956)	10,162	3,327	(6,835)
	Grand total	61,778	56,496	(5,282)	53,595	57,556	3,961

vehicle productivity. Unfortunately, other factors that cannot be simply represented in a graph of this nature must also be analyzed. The route length and the duration of the peak-period demand are especially important. The cost of operating Route No. 4 is plotted to the right of the straight-line relationship. It is a good example of the effects of the factors just mentioned. Demand is more peaked on this route, and, even though it has a relatively high average speed, second trips in the peak period cannot presently be scheduled within the demand period.

These figures give a very brief introduction to the cost analysis work under way; more detailed results will be reported in the future.

CONCLUSION

The Shirley Express Bus Demonstration is a partnership of many agencies. There has been a substantial change in the mode choice for commuters in the corridor, and this phenomenon is being monitored closely. The overall project performance in meeting certain goals is being reported. Key independent variables that may explain the changes taking place are being analyzed and reported. In addition, the economic impact on transit operations of the largely commuter-oriented service is being analyzed using a unique approach. Reporting over the next 2 or 3 years should provide a valuable source of basic data and analysis results for transit operators and transportation planners. This paper is intended to be a preliminary outline of the type of reporting that can be expected.

ACKNOWLEDGMENTS

This project is a partnership at both federal and local levels. Two people primarily responsible for initiating the project were Don Morin of the Federal Highway Administration and James Echols of the Washington Metropolitan Area Council of Governments. As the project progressed toward implementation, James Bautz and Stan Price of the Urban Mass Transportation Administration made significant contributions to improve project operations and guide the development of a high-quality evaluation plan. John Crain, a private consultant, finalized the development of the project evaluation plan. The plan is being implemented under the leadership of Gerry Miller, Ralph Schofer, and Keith Goodman of the National Bureau of Standards under contract to UMTA.

Project operations (highway and transit) involve the close cooperation of several organizations. First, the local sponsor of the demonstration is the Northern Virginia Transportation Commission. Their project manager, Irving Smith, has kept the project on schedule and in the process has solved many problems. He is assisted by Dave Erion and Jack Crawford of the NVTC staff. Mike James, a private consultant, has been especially helpful in planning new routes and developing a procedure to analyze transit operating expenses. The AB&W Transit Company is under contract for the actual operation of the bus service; their general manager, Dick Lawson, and staff have been instrumental to the success of the transit operation. Finally, a major element of the project, the busway, was implemented and is being kept operational under the skillful guidance of Ken Wilkenson of the Virginia Department of Highways. In the District, Jack Hartly and his staff in the D. C. Department of Highways are responsible for the busway operation on the new center-span bridge and approaches as well as the operation of the priority bus lanes along District streets.

38-48

THE EXCLUSIVE BUS LANE ON THE NEW JERSEY APPROACH TO THE LINCOLN TUNNEL

Leon Goodman and Carl S. Selinger, The Port of New York Authority

The planning, design, and operation of the reverse-flow exclusive bus lane on New Jersey Route I-495 are described. Multi-agency participation is discussed, and a brief history of events leading to the bus lane implementation is given. Elements of the extensive public information program are described, and costs, benefits, and first-year operating statistics are presented for the ongoing bus lane project. The results of an extensive series of evaluation surveys—both traffic and attitude—document the success and widespread support of the project. Elements of the plan for permanent operation of the project are discussed.

•THE I-495 exclusive bus lane on the New Jersey approach to the Lincoln Tunnel, opened on December 18, 1970, has completed a successful first year of operations. The regular operation of this bus rapid transit system has become an accepted part of the regional transportation system, enabling up to 35,000 daily commuters to reach their Manhattan jobs more reliably, some 10 to 25 minutes quicker than before. In this age of the "commuter revolution", it is quite a contrast to hear reports of bus passengers applauding and cheering as they arrived at the Port Authority Bus Terminal in New York City. This initial enthusiastic public response has been followed by numerous letters of praise and favorable press reports.

Buses use the bus lane on the 2½-mile section of the Interstate 495 approach to the tunnel during the morning peak period of each workday. The additional eastbound lane, for buses only, is one of the three lanes that ordinarily carry traffic in the westbound direction. These lanes have light use during the period on weekday mornings when the exclusive bus lane is in operation. This change provides four lanes for New York-bound traffic.

To evaluate the exclusive bus lane's effect on traffic operations and transportation users, a comprehensive before-and-after survey program was developed. Surveys of traffic operations included traffic volumes, travel times and speeds, bus and auto occupancies, and bus-terminal operations. To determine the effects on the people involved, various attitude surveys were also conducted.

Recognizing the satisfactory operating record, the favorable public response, and positive evaluation surveys, it has been determined that the one-year "experimental" project should be continued on a permanent basis. Part II of the project—installation of a permanent traffic control device system—is being considered for extension beyond the already completed preliminary engineering plans and cost estimates.

MULTI-AGENCY PARTICIPATION

Many agencies have worked together on the bus lane project to show how advanced traffic operation techniques can help to increase the capacity of highways for mass transit. The U. S. Department of Transportation financed installation of the necessary traffic controls for the bus lane, its first obligation of federal funds under the Urban Corridor program. (The bus lane is part of the North Jersey/Mid-Manhattan Urban Corridor Demonstration Project.) The New Jersey Turnpike Authority provided at its own expense a bus access roadway from Turnpike Interchanges 16 and 17 in Secaucus to I-495 (Figs. 1 and 2).

The New Jersey Department of Transportation, the Port of New York Authority, and the Turnpike Authority are participants in the project, which is being administered by the Tri-State Regional Planning Commission. At Tri-State's request, project direction is handled by Port Authority staff. The overall traffic control plan for operation of the bus lane was prepared by a technical committee representing the participating agencies and the Hudson County Police Department. The Port Authority, which is operating the bus lane, has consulted with police from the four municipalities through which the lane extends—Secaucus, North Bergen, Union City, and Weehawken. Operating costs for the first year have been shared between the Port Authority and the New Jersey Department of Transportation, with the Turnpike Authority providing direct policing and maintenance assistance in the bus access roadway areas.

BACKGROUND OF PROJECT

Although installation of the I-495 bus lane "hardware" was achieved in only $2\frac{1}{2}$ months, studies of an exclusive bus lane on the New Jersey approaches to the Lincoln Tunnel date back to 1963. In December of that year, the Port of New York Authority prepared a report evaluating several bus lane schemes and recommending in essence the plan implemented. The report also suggested a series of field tests to determine the feasibility of the concept.

Field tests were conducted in 1964 and 1965. The first 4-day experiment, in September 1964, simply closed the "exclusive lane" to westbound traffic and determined that the remaining westbound lanes had sufficient capacity to function with the median lane closed. The second and most critical phase of testing, in December 1965, involved a 3-day test of actual roadway operations, using maintenance trucks as "buses". It was concluded that the eastbound movement of the trucks in the "reversed" lane did not adversely affect westbound traffic. The findings were presented in a December 1965 report on both phases of the tests prepared by the Port Authority for the participating agencies.

Based on the significant success of the field tests, a January 1967 report outlined and strongly recommended the exclusive bus lane plan. It was not immediately implemented at that time although studies of this and alternate bus lane plans were continued. In late 1970, New Jersey Transportation Commissioner John Kohl determined that, based on a July 1970 report by his Bureau of Research and Evaluation, the exclusive bus lane should be implemented as soon as practicable. To accomplish this, it was decided to implement the reversible bus lane scheme now in operation (essentially the plan presented in the January 1967 report).

PUBLIC INFORMATION PROGRAM

A comprehensive public information program was developed and carried out as a joint effort of the participating agencies. News releases were issued at various times within the $2\frac{1}{2}$-month period preceding the bus lane opening. These releases generated considerable coverage in newspapers, radio, and television. Climaxing these efforts, a preview of bus lane operations for press and public officials was conducted on the day before opening day. Supplementing the general press releases, bus lane advisory material was distributed to specific interest groups—i.e., motorists, bus drivers, and bus passengers.

Two separate handouts were distributed to motorists at the Lincoln Tunnel and Turnpike plazas to inform them of the upcoming operation and to encourage switching to bus transit for their commuting trip. The first handout was distributed about 2 weeks prior to the beginning of operations on December 18; the second handout was timed several days in advance of the bus lane opening. The multicolored, 4- by 11-inch cards were distributed at toll booths of the Lincoln Tunnel and New Jersey Turnpike.

Special efforts went into the bus driver information program, since much of the success of the bus lane depended on their positive participation. This was part of an intensive bus driver-bus company orientation. Distributed through the bus companies several weeks before operations, the bus driver handout explained the project, told what special guide signs to look for, and indicated the bus lane "rules". A map of the project was included on the reverse side of the card. In addition, a large version of the bus lane map was posted in each bus garage. On this map, the approach roads to the bus lane were shown with bold red lines and arrows.

The bus passengers were extremely well-informed about the upcoming bus lane operation through extensive advance press coverage. In addition, the Port Authority Bus Terminal devoted an issue of its "Terminal Topics" bulletin to the lane. The issue was distributed in the Terminal the night before opening day for maximum interest. It achieved this goal, and copies were exhausted almost immediately.

PROJECT COSTS AND BENEFITS

Costs

The exclusive bus lane project was financed under a $500,000 allocation from the U. S. Department of Transportation. This allocation provided for development and implementation of bus lane traffic control devices under the Part I plan, the survey program and evaluation, preliminary engineering for Part II, administration, and project direction and coordination. In addition, the New Jersey Turnpike provided a $134,000 bus access roadway from Turnpike Interchanges 16 and 17 in Secaucus to I-495.

Total operating and maintenance expenses for the first full year were approximately $176,000. Operating costs during this first year were shared by the New Jersey Department of Transportation and the Port of New York Authority.

Benefits

Significant benefits are being realized by bus commuters. The I-495 bus lane is literally "making time" for road users, particularly bus passengers. The 10-minute time-saving during the peak period amounts to more than 1½ days (37½ hours) of time for each bus commuter during the average 225-day working year. Equally important is the newly created reliability of bus service in the entire corridor.

And what is the value of this travel-time saving? Typical of many studies, the Stanford Research Institute recently developed a value of time for a commuter of approximately $2.82 per hour per person. In the case of the exclusive bus lane, an average commuter would theoretically value the 10-minute time-saving at almost 50¢. From these figures, which are certainly conservative for the higher income New York area, the exclusive bus lane is now returning in a year more than $100 worth of "time" to each peak-period bus commuter. Thus, the 35,000 daily commuters who use the lane benefit to the tune of roughly $3.9 million annually.

Along with environmental and social factors, engineers use calculations of project benefits such as these to evaluate the desirability and economic feasibility of projects. As the so-called benefit-cost ratio gets higher, the public receives a greater return on the investment. With the approximate exclusive bus lane project total cost for the first year of $810,000 (including capital and first-year operation and maintenance) and the bus passenger benefits of about $3.9 million, the benefit-cost ratio, even if the project only operates for the 1-year contract period, is 4.8. However, based on its enthusiastic public acceptance, the bus lane operation is continuing and has become a regular part of the regional transportation system. Assuming a 5-year amortization period (at 6 percent interest), which would be appropriate for a project of this type, the estimated annual cost (assuming $200,000 annual operation and maintenance) is reduced to $350,000. Therefore, the benefit-cost ratio increases to a resounding 11.2.

Aside from these exercises in arithmetic, the exclusive bus lane has had a tremendous psychological impact on 35,000 bus commuters. It is hard to measure the effects of travel-time reliability, the elimination of insecurity, the better planning of time, and the exhilarating feeling of bypassing the frustrating delays so ingrained in the daily journey to work.

The community also benefits considerably from the increased mass transportation use that bus rapid transit will encourage. Possible reduced auto use can lead to improved air quality and reduced requirements for highway expansion, with consequent reduced transportation costs and right-of-way acquisition. Another by-product of the bus lane's operation is improved movement of emergency vehicles through the corridor.

PROJECT OPERATIONS

Traffic Operations and Controls

Detailed operating plans provide for lane changeover to and from the exclusive bus lane operation, police surveillance, and assistance to disabled vehicles. The lane is being operated on weekday mornings except when weather and traffic conditions make its use impracticable or unnecessary.

Under Part I of the project, approximately 80 lane directional signals were installed on overpasses and sign bridges along the westbound side of I-495 (Fig. 3). Placed over the center of each lane, these signals show either a green arrow pointing downward when the lane is open for traffic, or a red X to indicate that the lane is closed. The signals, which inform westbound motorists and eastbound buses of the prevailing operations, were activated as they became available in order to give motorists an opportunity to familiarize themselves with the new traffic control devices in advance of the actual bus lane operations.

In addition to the overhead lane signals, manually changeable signs and traffic posts are a vital part of the traffic control plan for the bus lane. Inconspicuous holes were drilled in the pavement for more than 350 cylindrical 1½-foot-high, bright yellow plastic traffic posts, which are placed at 40-foot intervals for the entire 2½-mile length of the bus lane when it is in operation. The traffic posts, which separate the eastbound bus lane from westbound traffic, are manually placed before the lane is activated for buses and then removed at the conclusion of the morning peak-period operation (Fig. 4). The Port Authority Police activate about 50 traffic signs, most of which are hinged and manually changeable to display different messages depending on whether the lane is operating or not (Fig. 5). New Jersey State Police assigned to the Turnpike are assisting in operating the lane along Turnpike access roadways.

Bus Passenger Flows

During 1971 some 206,050 buses, carrying about 8,654,000 passengers, used the exclusive bus lane. The average flow in the peak period (approximately 7:30 to 9:30 a.m.) was 818 buses, transporting 34,350 passengers, while the average flow in the 8 to 9 a.m. hour was 480 buses, carrying 21,100 passengers. Bus passenger flows are rounded estimates based on typical observed bus occupancies of 42 for the peak period and 44 for the 8 to 9 a.m. hour.

Railroad Strike

The I-495 exclusive bus lane performed perfectly during the May 17-18, 1971, railroad strike, handling the added loads easily and further demonstrating its present and future function as a high-capacity bus rapid transit link in the New Jersey-New York regional transportation system. Record numbers of buses and bus passengers were accommodated with remarkable ease and no delays, as noted by field observers and the news media. Following are some highlights of the bus lane operation during the strike:

1. Bus volumes surpassed by far all prior use, reaching an average of 573 buses during the 8 to 9 a.m. peak hour and 1,038 buses during an extended peak period. Record flows were achieved on May 18 with 597 peak-hour and 1,096 peak-period buses.
2. Bus passengers were estimated to have increased significantly during both the peak hour and peak period. Compared to an average day, during the rail strike the lane carried about 25,800 peak-hour passengers (versus 21,100 normal) and 47,800 in the peak period (versus an average 34,350).
3. Operations were very smooth, with not a single bus lane stoppage during the strike. Due to heavy flows of buses, the bus lane operation was extended each day an additional hour beyond normal shut-down time to about 10:30 a.m. Buses moved freely through the lane at all times, although bus volumes did drop off somewhat toward the end of the period. Even with this lower flow, Lincoln Tunnel police report that the bus lane was operated later because there was extremely heavy eastbound traffic con-

Figure 1. Exclusive bus lane on New Jersey approach to Lincoln Tunnel.

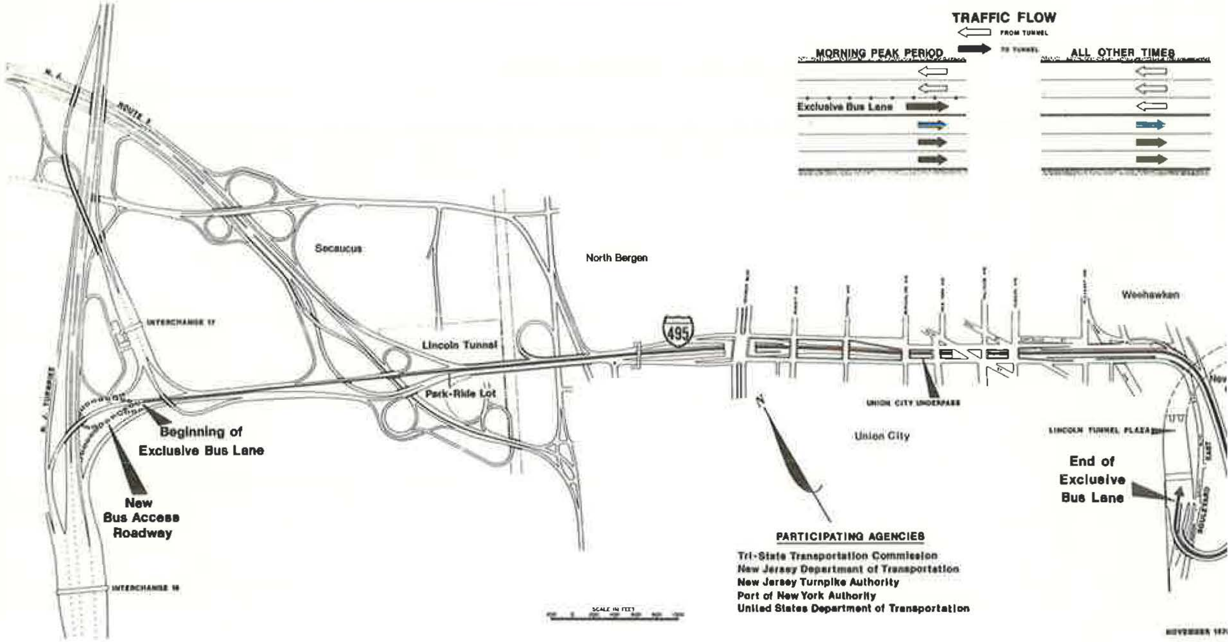


Figure 2. Bus access roadway at New Jersey Turnpike interchange; exclusive bus lane entrance at lower right. "Escape hatch" roadway at center allows off-route vehicles to enter regular eastbound flow.

Figure 3. Overhead lane directional signals and plastic traffic posts to separate exclusive bus lane from westbound flow.

Figure 4. Port Authority personnel in specially equipped vehicle inserting plastic traffic posts into pavement holes.

Figure 5. Police officer activating hinged, changeable bus lane guide sign.

gestion all morning, with delays of approximately ½ hour in the normal eastbound roadway.

4. Media coverage of the bus lane was generous and favorable. A highlight of the coverage was the local Channel 7 "Eyewitness News" on May 18 showing movies of morning peak traffic approaching the Lincoln Tunnel plaza, which included the bus lane, with commentary to the effect that, "The only thing moving into New York this morning was the express bus lane into the Lincoln Tunnel."

Bus Lane Stoppages

Exclusive bus lane stoppages caused by flat tires, brake problems, engine problems, and other factors occurred at the rate of less than three a month through 1971. This is an average, with three months (April, September, and October) having no recorded stoppages. Stoppage-handling procedures are working satisfactorily, with the typical incident lasting about 7 minutes.

This delay experience is certainly not unsatisfactory, particularly when compared with other mass-transit operations in the Tri-State Region. However, the Lincoln Tunnel operations staff is continuing to work with the bus companies to get their maintenance procedures improved.

Safety

There were four accidents involving exclusive bus lane operations in 1971, two of which involved minor personal injury. Accident statistics are not available yet from the Turnpike and state sections of I-495. The Port Authority has reported that during the first 6 months of 1971 there was no significant change in the overall accident records on the Lincoln Tunnel and its New York and New Jersey approaches.

SURVEYS

To evaluate the exclusive bus lane impact on traffic operations and transportation users, a comprehensive before-and-after survey program was developed, coordinated with the overall North Jersey/Mid-Manhattan Urban Corridor Study. This section summarizes the results of the survey program, highlighting the major findings and detailing the individual traffic and attitude surveys. Traffic surveys included volumes on I-495, Lincoln Tunnel, Lincoln Tunnel Park-Ride lot, and the exclusive bus lane; travel times on the exclusive bus lane, autos, buses, and trucks; vehicle occupancies for autos and buses; and terminal operation at the Port Authority Bus Terminal. Attitude surveys were conducted among bus passengers, bus drivers, bus company management, I-495 motorists both eastbound and westbound, and police. These surveys were supplemented with data from other sources, primarily regularly collected Port Authority data on use of the Lincoln Tunnel, the Port Authority Bus Terminal, and the Lincoln Tunnel Park-Ride lot.

Capacity

A comprehensive series of detailed traffic surveys conducted in April 1971 measured the impact of the exclusive bus lane on I-495 travel characteristics.

The presence of the exclusive bus lane has dramatically increased the traffic-carrying capacity of the substandard six-lane Union City Underpass section of I-495. Removal of eastbound buses to their own exclusive lane has increased morning peak-hour eastbound flow by 40 percent, from 3,287 vehicles (in three lanes) to 4,529 vehicles (in four lanes). Concurrent with this tremendous eastbound increase, the exclusive bus lane has had no adverse impact on westbound flow, as the same number of westbound vehicles was being handled before and after the lane became operational.

The peak-hour traffic composition of eastbound I-495 traffic has changed substantially, with the gaps caused by the removal of eastbound buses to their own lane filled primarily by passenger cars (2,324 before versus 3,227 after), with a doubling in the number of trucks (248 before versus 494 after).

The eastbound I-495 lane-by-lane classification also changed substantially due to the exclusive bus lane. Prior to the bus lane almost half the eastbound vehicles were carried in the single left median lane of the eastbound roadway. The creation of the bus lane has caused this lane's share of eastbound vehicles to drop sharply to 36 percent of its former load, although the lane is now actually carrying additional vehicles (1,523 versus 1,630). Even the right "truck lane", under the burden of about 50 percent trucks and tractor-trailers, has increased its peak-hour flow by about 70 percent (from 521 vehicles before to 884 vehicles after), due mainly to the influx of autos to that lane. While the bus lane has enabled the regular eastbound lanes to increase their vehicle-carrying ability, the bus lane still carries more than ten times the number of people carried in any of the three other eastbound lanes, at a much higher level of service.

Bus Volumes

Numerous exclusive bus lane traffic operating characteristics were obtained. The daily average lane volume has varied during 9 months of operation, ranging from a low of 724 buses per day in January to a peak in May of 852. Exclusive bus lane volumes have exhibited daily variation because of differing passenger demands on various weekdays, local traffic conditions, seasonal variations, and other reasons.

Data collected on bus volumes by 5-minute intervals at two exclusive bus lane locations yield the lane's hourly flow rates. The highest 5-minute counts at these two key points were 62 and 68 buses, which translate to hourly rates of 745 and 817 buses per hour respectively. Another survey examined bus flow in platoon groups; it indicates the lane's capacity to be substantially higher than 800 buses per hour.

The peaking characteristics of the bus lane traffic were also investigated, as given by the peak-hour factor (PHF). This is the ratio of the volume occurring during the peak hour to the maximum rate of flow during a given time period within the peak hour, usually a 5-minute period. The bus lane PHF is 0.70 to 0.76, reflecting moderate peaking. This can be contrasted with a PHF approaching 1.0 for the Lincoln Tunnel, where there is heavy, sustained flow and very little peaking during the morning peak hour.

It appears that the exclusive bus lane project has significantly altered the time distribution of morning eastbound Lincoln Tunnel traffic to an earlier peak while the total traffic has remained essentially unchanged. The total eastbound volume was essentially unchanged in the before-and-after periods (total traffic of 12,792 before versus 12,843 after), indicating that the exclusive bus lane project has not attracted increased traffic volumes to the Lincoln Tunnel during the morning peak.

Auto occupancy in the eastbound Lincoln Tunnel during the 7:30 to 9:30 a.m. period declined about 4 percent from 1.60 to 1.54 occupants per auto. During the 8 to 9 a.m. period, the time period of greatest bus lane benefits, the decrease in occupancy was almost 10 percent. This might indicate a shift of some auto riders in car pools to exclusive bus lane buses.

Figures for the first 7 months of 1971 indicate a marked increase in use of the Lincoln Tunnel park-ride lot. Reflecting increased use of the park-ride lot, a "before 9:00 a.m." category has shown a substantial 11.1 percent growth through the first 7 months of 1971. This increase in park-ride lot use is probably largely attributable to the exclusive bus lane, which has considerably improved operations in the shuttle-bus service from the lot to the Port Authority Bus Terminal.

Bus Patronage and Occupancy

A bus occupancy survey taken in April 1971 did not reveal clear-cut ridership changes due to the bus lane when compared with surveys in April and October 1970. However, a time-series analysis of data from past Port Authority bus passenger surveys shows a marked effect on patronage trends. It appears from this analysis that the exclusive bus lane had induced an additional 2,300 daily peak-period bus riders, representing a 6 percent increase in ridership, on the lane's bus runs.

Based on comparable spring survey data from 1968 through 1971, the bus lane has arrested a mild downward trend in the short-haul category of ridership on close-in bus companies while it has also spurred medium-haul patronage. Peak-period ridership on short-haul routes had been declining by 800 to 900 passengers per year until 1971, when it increased by 800, largely representing the exclusive bus lane's apparent inducement of 1,600 bus riders. Meanwhile, middle-range bus routes had been rising at an increasing rate in the past several years. With an expected increase during 1970-1971 of about 500 bus riders, there was in fact an increase of 1,200, indicating that about 700 were attracted by the exclusive bus lane.

Bus volumes on the short-haul routes increased less than their passenger volumes while medium-haul bus and passenger increases were about equal. This indicates that the medium-haul carriers reacted to the increase with increased schedules, whereas the short-haul increase was accomplished through higher loadings on existing scheduled buses.

Observed bus occupancy for routes using the bus lane was 42.2 passengers per bus during the 7 to 10 a.m. peak-period arrivals at the Port Authority Bus Terminal, while 44.1 passengers per bus traveled during the 8 to 9 a.m. peak hour.

Bus Travel Times

Eastbound bus travel times were obtained from two separate methods—ground observations and spot checks of bus riders. The ground observers scrutinized the average bus time savings in the immediate vicinity of the exclusive bus lane and the Lincoln Tunnel approaches; the rider survey recorded the effect of the bus lane on the overall journey to work.

Results from the ground observation surveys indicate that the exclusive bus lane saved the average bus about $7\frac{3}{4}$ minutes during the morning peak period, from the point where the bus approached the vicinity of the exclusive bus lane to the Lincoln Tunnel Plaza. During the 8:15 to 9:15 a.m. hour of peak congestion, the bus lane saved each bus an average of more than 10 minutes of travel time. These average time savings do not reflect larger traffic delays during shorter-term peaks or those occurring with some regularity on the normal inbound tunnel approach due to stoppages of various types. Savings by exclusive bus lane buses on these days can easily be on the order of a $\frac{1}{2}$ hour or more.

Interestingly, there is actually a time loss using the initial section of the bus lane from several approaches for several of the earlier time periods, because of the substantial "back-tracking" required from these approaches to gain access to the exclusive bus lane. However, in every time period from every approach, the time lost in gaining access to the exclusive bus lane was more than offset by the time saved on the total trip to the Tunnel Plaza, and thus there is always a positive overall time saving by buses using the exclusive bus lane.

The bus rider survey focused mainly on components of the total trip from home to the Port Authority Bus Terminal. Travel time data, before and after the bus lane, showed no perceptible changes on sections between home and the exclusive bus lane entrance and from Lincoln Tunnel Plaza to the bus terminal. The data did verify the significant travel time improvements produced in the exclusive bus lane section, resulting in a reduction in overall trip time.

The time the sampling of riders left their homes before and after the exclusive bus lane was also compared to determine if the bus travel-time saving allowed commuters to leave later. Of the 15 checked, 8 riders showed a tendency to leave home later whereas 7 riders either left home at the same time or slightly earlier. For those who did leave later, they were apparently satisfied that the reliability and time saving of the buses using the exclusive bus lane allow a 4- to 10-minute later start from their homes. Those leaving home at the same or slightly earlier times, perhaps constrained by limited bus schedules, also benefited from the exclusive bus lane and arrived consistently earlier at the Port Authority Bus Terminal.

Eastbound Auto and Truck Speeds

The exclusive bus lane, by removing a large volume of buses from the regular I-495 eastbound roadway, has significantly increased eastbound peak-period auto and truck speeds on the I-495 approach section through the New Jersey Turnpike-Route 3 merge and over the North Bergen Viaduct. However, this operating improvement abruptly ends for eastbound cars and buses beginning at the exit ramp for Kennedy Boulevard through the remaining 1.5-mile roadway to the Lincoln Tunnel Plaza, where slow-but-moving speeds are no different from speeds before the exclusive bus lane.

The Turnpike-Route 3 area, carrying slow (5-10 mph), heavily congested merging traffic prior to the institution of the bus lane, has been substantially freed of daily peak-period congestion with vehicular speeds now in the 30- to 40-mph range. Auto speeds from Route 3, at a 4-mph crawl into the merge area before the exclusive bus lane, have jumped to 40 mph. Motorists from both New Jersey Turnpike approaches have tripled their eastbound speed from about 10 mph to 30 mph. The combination of this merging traffic flowing over the ½-mile-long North Bergen Viaduct also shows a sizable increase from 10 up to 20 mph, with truck speeds slightly slower. These operating improvements over the I-495 approaches west of Kennedy Boulevard represent substantial savings in travel time for auto and truck traffic, especially for locally destined traffic using exits to US-1, US-9, and Kennedy Boulevard. The travel time improvements for eastbound autos and trucks end at the exit ramp to Kennedy Boulevard; thereafter, over the remaining approach to the tunnel, speeds remain essentially unchanged in the 10- to 20-mph range.

Westbound Vehicular Speed

In all I-495 sections surveyed, westbound traffic flowed with no congestion caused by the exclusive bus lane as indicated by speeds generally varying in the 30- to 40-mph range through the morning peak period. (There is a 35-mph speed limit along westbound I-495 when the left median lane is closed for the eastbound exclusive bus lane.) Although westbound speeds were undoubtedly substantially higher before the exclusive bus lane began (but were not recorded), the exclusive bus lane has resulted in westbound speeds that are only of minor time inconvenience in such a short roadway section.

Port Authority Bus Terminal Operations

The exclusive bus lane itself has had no perceptible effect on bus terminal operation. However, a modest change in bus unloading procedures, instituted concurrently with the bus lane implementation, has improved operations on the two commuter bus levels during the peak period. The new procedure, utilizing additional "load" berths for unloading, has appreciably lessened bus delay on the bus terminal approach ramps where, prior to the new procedure, there were 19 minutes of ramp delay during which 6 or more buses were observed queued on the ramps. After the new unload procedures were instituted, delay minutes were reduced about 85 percent from the 19 minutes of ramp delay to only 3 minutes, representing a substantial increase in the commuter unloading efficiency of the bus terminal during the morning peak period.

Attitude Surveys

A series of attitude surveys, undertaken as part of the I-495 exclusive bus lane project evaluation, obtained reactions and experiences of various groups involved in bus lane, Lincoln Tunnel, and Port Authority Bus Terminal operations. Groups surveyed (in May and June 1971) were the bus patrons, bus drivers, eastbound and westbound motorists, bus company management, and police.

Overall Reaction—The vast majority of all groups polled was extremely favorable toward the implementation and operation of the exclusive bus lane. Only a rather small number of westbound motorists, who gain least from the lane, expressed some reservations.

Bus Priority on Highways—All groups favored generally the introduction of special provisions for buses on highways, although eastbound and westbound motorists were far less inclined to this concept than the other groups surveyed.

Frequency of Trips—The proportion of bus patrons traveling four or more times a week increased substantially—from 82 percent to 92 percent—after the introduction of the exclusive lane. By contrast, the change in trip frequencies of westbound and eastbound motorists was less significant.

Safety and Relaxation of Trip—Some 88 percent of the bus drivers felt more relaxed and 75 percent felt safer while driving to Manhattan than before the exclusive bus lane was implemented. A majority of the eastbound and, surprisingly, a good many westbound motorists also felt that driving conditions had been improved. Almost all operating police felt that bus lane safety was adequate. Furthermore, the suggestions given by several officers for possible safety improvements have spurred operational and enforcement changes since the survey was conducted. In addition, the police observed no major change in accidents and violations on I-495.

Travel Time—All patron groups surveyed felt they save a goodly amount of time on their trips. The majority of bus patrons and bus drivers—54 percent in each group—indicated the exclusive bus lane saved them 10 to 19 minutes. Some 75 percent of the eastbound motorists also saved substantial time per trip. Surprisingly, more than one-third of the westbound motorists claimed their travel times have been shortened by the exclusive bus lane (although some 19 percent of these drivers did experience longer travel times). Police noted substantially improved traffic flow on the I-495 Lincoln Tunnel approaches.

Trip Reliability and Pleasantness—Practically all bus patrons (95 percent) said they experienced more reliable travel times, and only 1 percent indicated less reliable time. Some 86 percent indicated that their trips were more enjoyable, and the remaining 14 percent said that there was no change.

Travel Mode Changes—About 81 percent of the bus patrons indicated that they rode on the same bus route before and after the bus lane began operating; 7 percent said that they used another bus route to the Port Authority Bus Terminal before the exclusive bus lane. In addition, some 2 percent were patrons who previously traveled by bus to the George Washington Bridge (178th Street) bus station. These two bus groups together constitute nearly half the patrons who indicated some change in their travel modes. The second largest single group, almost 3 percent, did not travel to Manhattan prior to the exclusive bus lane. As for auto commuters, including those in car pools, they also accounted for almost 4 percent of those who switched. The remaining 3 percent were split between railroad (2 percent) and the PATH transit system (1 percent). Of those changing travel modes, 59 percent of the patrons gave the exclusive bus lane as their reason for changing. The remaining patrons indicated changes in location of residences or employment.

Travel Schedule—In spite of the significant travel-time savings attributed to the exclusive lane, three-fifths of the bus patrons responding to the attitude survey still continue to leave home at the same time. However, there were a large number of bus patrons (38 percent) who stated that they can now leave home at a later time.

Bus Patronage—A majority of bus-company managements reported small increases in patronage due to the exclusive bus lane. None of the several companies offering routes to both the midtown bus terminal and the uptown George Washington Bridge bus station reported any noticeable shift to exclusive bus lane routes to the terminal.

Bus Company Operations—Reductions in driver overtime costs were reported by three-quarters of the bus company managements due to the travel-time saving. A majority of bus-company managements indicated generally improved utilization of their equipment and also that their bus patrons and drivers are more satisfied and cooperative since the lane began operating.

PLAN FOR PERMANENT OPERATION

Based on the success of the first year of operations, preliminary engineering plans and a cost estimate for the completion of the permanent exclusive bus lane traffic control system have been prepared by Port Authority engineering staff with the guidance of the project technical committee. This "Part II" program includes the following elements:

1. Several additional installations of overhead lane-control directional signals to provide coverage in areas presently covered only by sign and traffic-post control;
2. Interconnection of all lane-control directional signals;

3. Replacement of the present manually operated, locally controlled changeable signs with electrically operated remote-controlled changeable-message signs;
4. Installation of a television camera in the Secausus interchange area, with monitors at a central control location;
5. Installation of central remote control for all changeable-message signs and signals in the Lincoln Tunnel Administration Building;
6. Installation of an automatic gate at the bus lane entrance;
7. Additions and revisions to the system of fixed-message signs based on operating experience; and
8. Provision of a permanent police booth for use of the police officer on duty at the bus lane entrance.

Numerous safety, service, and economic benefits will be gained with completion of the exclusive bus lane permanent traffic control called for in the Part II plan. Although several components are essential traffic control features for any reversible roadway operation, others are specifically tailored for this bus lane based on extensive operational experience. As the operation enters its second year, the participating agencies are in the process of reviewing possible financing and implementation of the Part II permanent traffic control plan.

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TRANSIT SYSTEM PLANNING: A MAN-COMPUTER INTERACTIVE GRAPHIC APPROACH

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A man-computer interactive graphic system for planning node-oriented (multiple-origin to single-destination) transit systems is presented. The system is implemented in a real-time computer environment with a cathode-ray tube. The user designs a transit system by specifying routes, park-and-ride lots, vehicle characteristics, frequencies, fares, and parking fees, and the computer immediately predicts and graphically displays the consequences of this design. The system enables a user to explore and assess a broad range of multiple-attribute alternatives in a short period of time, assists in the search for the best design by automatically generating efficient operating characteristics for given route layouts, makes trade-offs between competing objectives visually apparent, and allows testing of a solution's sensitivity to parametric variations of the model inputs. The paper describes the modal split/network equilibrium model on which the prediction process is based and then illustrates in an example the mechanics and capabilities of the man-computer interactive approach.

•TRANSPORTATION planning, and in particular the planning and design of urban transportation systems, is essentially a problem-solving process. It involves solving the very complex problem of finding the best technology, networks, routes, vehicles, and operating policies under certain physical, economic, and social constraints, where "best" usually refers to many objectives derived from multiple and often contradictory goals (1). This problem-solving process consists typically of cycles, which include five major steps:

1. Objectives are defined;
2. Possible alternative plans are generated;
3. The consequences of each plan are identified by means of some prediction mechanism;
4. These consequences are evaluated in the light of the objectives; and
5. If necessary, the objectives are reformulated.

These cycles are repeated, usually with an increasing degree of detail and specificity, until the "best" plan emerges.

In the past, most of the research efforts have been concentrated on the third step of the cycle, i.e., toward developing sophisticated mathematical models for predicting consequences of a plan, but little effort has been devoted to providing the urban analyst and decision-maker with adequate tools to assist him throughout the entire problem-solving process. Both the input and the output of today's mathematical models do not directly tie into the planning and problem-solving process, but they require digital coding of spatial problems and they necessitate the translation of voluminous computer printouts into reports, graphs, and maps. Moreover, the lengthy waiting for turn-around times interrupts the continuity of the process and often prohibits a great number of iterative cycles.

Sponsored by Committee on Transportation Systems Design.

Man-computer interactive graphic design is a technique for assisting a human throughout the entire planning process: It enables a planner or analyst to search out and evaluate a large number of alternative designs in a short period of time, it assists in the resolution of conflicting objectives, and it can help a policy-making body to reach compromises after a value-oriented discussion. This paper illustrates this technique by describing the Interactive Graphic Transit Design System (IGTDS), a tool for planning node-oriented park-and-ride transit systems developed at the University of Washington. Previous versions of IGTDS have been discussed earlier (2, 3).

THE INTERACTIVE GRAPHIC TRANSIT DESIGN SYSTEM

Node-Oriented Park-and-Ride Transit Systems

Node-oriented transit systems are defined as public or private transportation systems catering to trip desires that either originate at multiple locations and converge at one central destination (many to one) or originate at one central location and disperse to many locations (one to many). Node-oriented travel patterns are typically found in urban areas with large traffic attractors such as a central business district, a large educational facility, a compact industrial area, or important transportation transfer points such as airports, mass rapid transit stations, or railroad stations. Node-oriented park-and-ride transit systems offer a trip-maker the choice among three major modes: (a) walking to a transit stop and riding to the destination, (b) driving to a park-and-ride lot, parking, and riding transit, and (c) driving directly to the destination. We shall refer to these modes as the walk-and-ride mode, the park-and-ride mode, and the drive mode respectively. The components of a node-oriented park-and-ride system are shown in Figure 1.

Predicting the Consequences of Node-Oriented Transit System Designs

Inherent in IGTDS is a mathematical model that predicts the most likely consequences of a particular node-oriented transit system design, as illustrated in Figure 2. Design variables represent the options open to the designer and/or decision-maker relative to the design of node-oriented transit systems. It is obvious that the number and nature of these options depend largely on the specific setting of the problem: An option that may be open to the decision-maker in one case may be closed in another. (For example, for the design of a transit system oriented to an educational facility, the destination parking fee may be an important design variable, whereas the same variable may be out of the realm of the planner or decision-maker in the case of a CBD-oriented system.) IGTDS contains all those design variables that have important consequences for both the transit system in question and the community served. They are shown on the left side of Figure 2.

Transit system performance should be measured by assessing the quality of service provided in relation to the costs incurred. For transit systems the costs accrue to users in terms of fares or parking fees and possibly to the public at large in the case of a deficit. Quality of service can be measured in terms of accessibility. Also, since trip-makers have the choice between transit and non-transit modes, transit utilization (i.e., modal split and transit system loads) directly reflects the quality of service. The consequences listed on the right side of Figure 2 were felt to be the most important for evaluating a transit system design.

Predicting transit system utilization and system loads involves estimating how many among all the potential trip-makers are likely to use the modes available to them and then assigning the potential system patrons to these modes and system links. Thus, the performance prediction model is essentially a combined modal split and network assignment model.

The modal split model implemented in IGTDS is based on the logistic function (4, 5) of the form

$$W_{im} = \frac{\exp(-I_{im}c)}{\sum_j \exp(-I_{ij}c)} \qquad m = 1, 2, 3$$

where W_{im} is the share of mode m among trips from an origin i, I_{im} is the impedance between origin i and the destination via mode m, and c is the constant.

Furthermore, the model is based on the assumption that the average trip-maker travels on the shortest impedance path after a particular mode has been chosen. This can be expressed as

$$I_{im} = \underset{\{P_{im}\}}{\text{Min}} \left(\sum_{j \in P_{im}} d_j \right) + C_m$$

where d_j is the impedance of a link j, C_m is the initial impedance associated with mode m, P_{im} is a path from origin i to the destination via mode m, and $\{P_{im}\}$ is the set of all paths from origin i to the destination via mode m.

The impedance that trip-makers perceive as being associated with a particular trip component (link) is assumed to be a linear function of the amount of time or cost spent during that trip component, i.e.,

$$d_j = c_j \, x_j$$

where c_j is the impedance coefficient associated with the activity over link j, and x_j is the amount of time or cost spent over link j.

Algorithmically, the model adds to the physical network a set of virtual links denoting activities such as waiting or paying fares and fees and then builds shortest impedance path trees through the augmented network (3). An example of impedance paths is shown in Figure 3.

The transit trips generated by the modal split model are assigned on an all-or-nothing basis to the transit lines and parking lots that are incident to the respective shortest impedance paths. Three modes of assignment are provided, as follows:

1. Capacity-constrained assignment—The number and sizes of transit vehicles and parking lot sizes are fixed. If the load on a transit line exceeds the line's seating capacity, the impedance on that line is increased to the level associated with standing and the excess load is subjected to a further modal split/assignment cycle. If in a next step a line's standing capacity is exceeded, the line's frequency is set to zero and the excess load is again recycled. In a similar manner a parking lot is deleted when its load reaches its capacity.

2. Unconstrained Assignment I (Fig. 4, top)—The number of transit vehicles and sizes of parking lots are open. The number of vehicles on each line is calculated to meet the line load. Because the number of vehicles determines the average waiting time (function or frequency) and therefore, in turn, has an impact on modal split, the process must be reiterated. It is interesting to note that, unlike the case of iterative capacity-constrained highway traffic assignment, the level of service on a transit line increases with increasing load. The iteration nevertheless ends because it reaches the point where a marginal increase of volume is smaller than the capacity of one additional transit vehicle.

3. Unconstrained Assignment II (Fig. 4, bottom)—The number of vehicles is fixed, but the sizes of vehicles and parking lots are open. This case does not require an iterative assignment process.

Man-Computer Interactive Graphic Design

By using the prediction model described, IGTDS simulates the operation of a transit system that a user has characterized by selecting a set of options. Two characteristics make IGTDS unique and more powerful than the usual simulation systems available today and particularly suitable for the design and problem-solving process:

1. IGTDS is interactive. An on-line computer environment is provided where the user (i.e., the analyst) controls the computational process and gets an "immediate" response from the system to any input he makes (Fig. 5). This has three desirable consequences. First, he receives the results of a simulation very rapidly and is therefore able to generate and evaluate a large number of alternatives in a very short time.

Second, his thought process is not interrupted by waiting for hours or days for results. This means that less warm-up time is required, there is less forgetting between successive runs, and there will be "a tending toward better performance for highly exploratory and complex tasks"(6). Finally, IGTDS has the capability of greatly reducing the number of unsuccessful runs by editing the analyst's inputs immediately and pointing out errors and unfeasible ideas quickly and directly.

2. IGTDS is graphic. The user communicates with the computer graphically, verbally, and numerically via a cathode-ray tube (CRT) with a keyboard and a graphic input device ("joystick"). Since the user's problem is predominately spatial, graphic communication makes the conversion of graphic data to digital data the task of the machine. This not only eliminates a significant source of human errors but also relieves the analyst of a most tedious task.

SOLVING AN EXAMPLE PROBLEM: DESIGNING A PARK-AND-RIDE BUS TRANSIT SYSTEM FOR CBD-BOUND COMMUTERS OF AN URBAN CORRIDOR

The capabilities and mechanics of IGTDS are demonstrated in the following narration of a typical set of steps that would be followed in the process of planning a transit system in a hypothetical problem environment.

Let us assume that an urban corridor is experiencing severe peak-hour congestion problems, particularly on a multilane limited-access highway that traverses the corridor and links it to the central business district (CBD). Let us further assume that residential density, and thereby density of trip desires, is too low to warrant a high-capacity mass rapid transit link through the corridor. A short-term improvement in this corridor's transportation plight might be a CBD-oriented bus transit system that employs the corridor's freeway for fast linkage of the corridor and the CBD and uses parking lots for park-and-ride service in low-density areas as well as regular feeder bus lines in areas of higher density.

Before the interactive graphic design process can be started, five sets of data must be gathered and loaded into the system:

1. Network data—The street network must be coded in terms of nodes (i.e., intersections) and links. Each link must be annotated with an average automobile speed, walk speed, and transit speed. Again, an interactive graphic process is most suitable for building and editing a network file (7).
2. Demand data—The potential individual trip demands must be aggregated and located at the network node closest to their various actual origins and recorded in a demand file. In most instances these demand data are readily available from institutions located at the destination node in terms of employee or client's files. Such files invariably contain a person's address as the locational descriptor of his trip origin. Geocoding systems such as the U.S. Census Bureau's Admatch-Dime System (8, 9) or Seattle's Geobasys System (10) convert such addresses to coordinates, or even to network node numbers. The trip demands should be stratified into transit captives and non-captives because captives can be assigned to the walk-and-ride mode only.
3. Land value data—The approximate average values of land in the proximity of each node of the network are used for computing the costs of potential parking lots.
4. Transit vehicle data contain the characteristics and per-unit costs of all potential vehicle types that can be used in the design.
5. Calibration data contain the trip-maker behavioral parameters. They describe the relative perceptions of the trip-makers for the different components of a trip by each mode. These data are derived when the prediction model is calibrated. Methods for calibrating a multimode logit model have been discussed by Rassam et al. (5). The user can interactively manipulate the values of the calibration parameters for sensitivity analysis.

Let us now follow a user through the interactive process of designing a node-oriented park-and-ride transit system.

The user controls the interactive process by means of a "menu" from which he can select any of the 30 software modules available to him (Fig. 6). [Figures 6 through 17 are reproduced from slides taken directly from the cathode-ray tube. Although they are not of normal publication quality, the figures serve to illustrate the various steps described.] The modules fall into five classes: (a) data base display, (b) design input, (c) evaluation models, (d) consequence output, and (e) output data management. After the execution of a module, either the user can immediately proceed to the following module, or he can return to the menu and jump to any other module, or he can repeat the same module (if he made a mistake or changed his mind).

The user begins the interactive process by displaying his data base in the form of one or several maps (Fig. 7). The street network, demand pattern, and land-value pattern can be displayed individually or as overlays. The area displayed in our example represents an urban corridor approximately 10 miles long and 5 miles wide.

Next, the user specifies those characteristics at the CBD destination that will affect the impedance of those commuters who do not use the transit system. The inputs are shown in Figure 8.

Proceeding to the next module, the planner is again shown the network and, if he desires, the trip demand and/or land values. Following a query from the computer, the user designates the set of nodes at which he desires to locate parking lots by using the joystick (Fig. 9).

At the next module, the computer asks the user to specify the size of the lots at the locations selected (Fig. 10). Differences in the lot sizes may reflect the user's intuitive perception of the relative trip demand in the vicinity of the lot locations. This step can be skipped if the consequences are to be predicted on the basis of unconstrained assignment.

Next, the parking fees to be levied at the lots must be entered. Fees can be used to manipulate both the overall attractiveness of the park-and-ride mode and the relative attractiveness of individual lots, as well as for determining the revenues of parking-lot operation.

Continuing, the user must lay out the transit routes to serve the parking lots. He is shown the street network, the parking lot locations, and, if desired, the nodal demands. Routes are specified by pointing with the joystick to each node that is to become a transit stop, the computer automatically connecting sequential stops via the shortest path for transit (Fig. 11). The parking lots can be served at any place along a specific route, and more than one transit line can collect passengers at any given stop.

Once the routes are located, the user can select the number and/or types of vehicles that are to serve the various lines. To aid this selection, the routes with the transit stops and parking lots and, optionally, the trip demands are displayed (Fig. 12). In addition, a headway table is presented indicating the potential headways between vehicles for alternative numbers of vehicles operating on a line. The headway of a line has two impacts: It determines the average waiting time of trip-makers at bus stops and hence influences the attractiveness of individual transit lines, and it determines, together with the vehicle type (i.e., size), the capacity of a line, which should be at least in accordance with the capacity of parking lots that are served by a line. In addition, the vehicle type implies the comfort level of a line and hence influences the attractiveness of transit. If unconstrained assignment is to be used, only the numbers of vehicles or the vehicle types on each line must be specified.

The final input required before a configuration can be evaluated is the set of transit fares. Zonal or flat fares schedules may be specified. It is only necessary to indicate the fare at stops where a new fare zone begins—the fares at all other stops are displayed automatically. Again, transit fares have an impact on the attractiveness of transit in general and on the relative attractiveness of individual stops and lots as well as determining transit revenue.

At this point the user selects the mode of the prediction model (constrained or unconstrained). In our example the capacity-constrained mode has been chosen. After a computation time of 2 to 3 minutes the computer is ready to display the consequences of the design as selected by the user.

First, the user may examine the utilization and economics of the transit system as displayed in Figure 13. The "not served" column of the modal split summary indicates

Figure 1. Node-oriented park-and-ride transit system components.

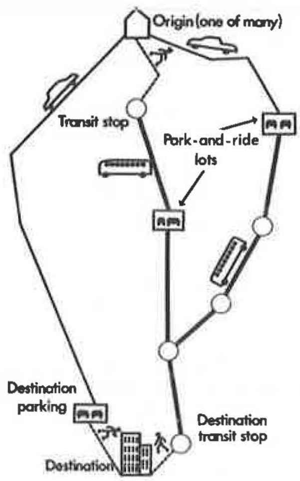


Figure 2. The IGTDS prediction model.

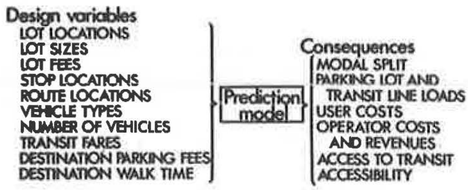


Figure 3. Example of impedance paths via walk-and-ride, park-and-ride, and drive modes.

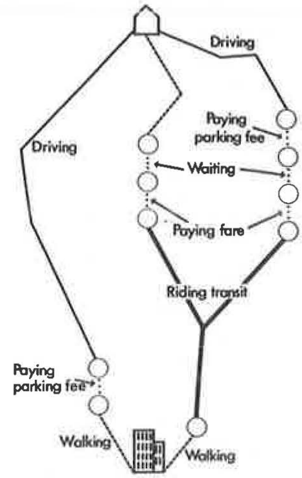


Figure 4. Unconstrained assignment models.

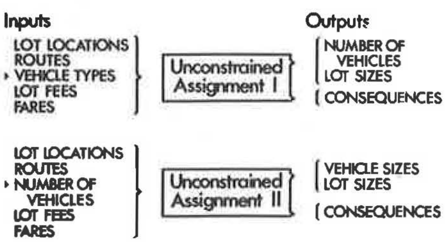


Figure 5. IGTDS computer environment.

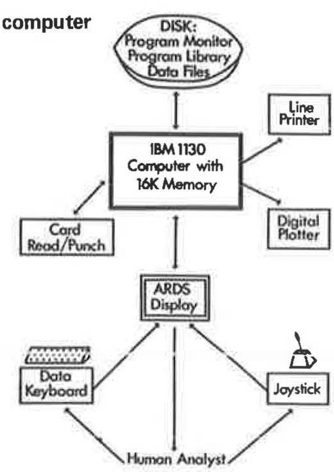
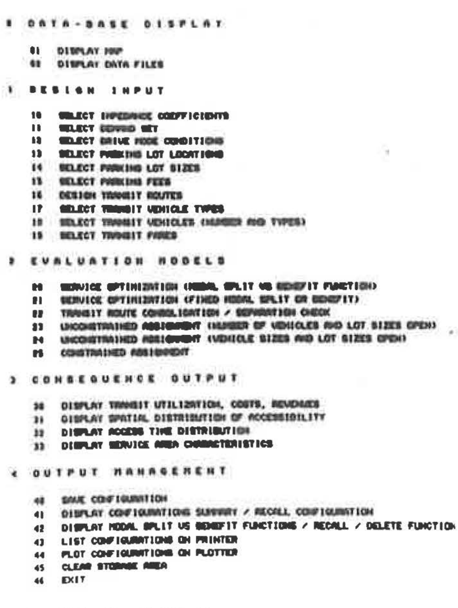


Figure 6. Selection of a module from the "menu".



0 DATA-BASE DISPLAY

01 DISPLAY MAP
02 DISPLAY DATA FILES

1 DESIGN INPUT

10 SELECT IMPEDANCE COEFFICIENTS
11 SELECT DEMAND SET
12 SELECT DRIVE MODE CONDITIONS
13 SELECT PARKING LOT LOCATIONS
14 SELECT PARKING LOT SIZES
15 SELECT PARKING FEES
16 DESIGN TRANSIT ROUTES
17 SELECT TRANSIT VEHICLE TYPES
18 SELECT TRANSIT VEHICLES (NUMBER AND TYPES)
19 SELECT TRANSIT FARES

2 EVALUATION MODELS

20 SERVICE OPTIMIZATION (MODAL SPLIT VS BENEFIT FUNCTION)
21 SERVICE OPTIMIZATION (FIXED MODAL SPLIT OR BENEFIT)
22 TRANSIT ROUTE CONSOLIDATION / SEPARATION CHECK
23 UNCONSTRAINED ASSIGNMENT (NUMBER OF VEHICLES AND LOT SIZES OPEN)
24 UNCONSTRAINED ASSIGNMENT (VEHICLE SIZES AND LOT SIZES OPEN)
25 CONSTRAINED ASSIGNMENT

3 CONSEQUENCE OUTPUT

30 DISPLAY TRANSIT UTILIZATION, COSTS, REVENUES
31 DISPLAY SPATIAL DISTRIBUTION OF ACCESSIBILITY
32 DISPLAY ACCESS TIME DISTRIBUTION
33 DISPLAY SERVICE AREA CHARACTERISTICS

4 OUTPUT MANAGEMENT

40 SAVE CONFIGURATION
41 DISPLAY CONFIGURATIONS SUMMARY / RECALL CONFIGURATION
42 DISPLAY MODAL SPLIT VS BENEFIT FUNCTIONS / RECALL / DELETE FUNCTION
43 LIST CONFIGURATIONS ON PRINTER
44 PLOT CONFIGURATIONS ON PLOTTER
45 CLEAR STORAGE AREA
46 EXIT

ENTER NUMBER OF DESIRED MODULE

Figure 7. Street network, demand pattern, and land-value pattern.

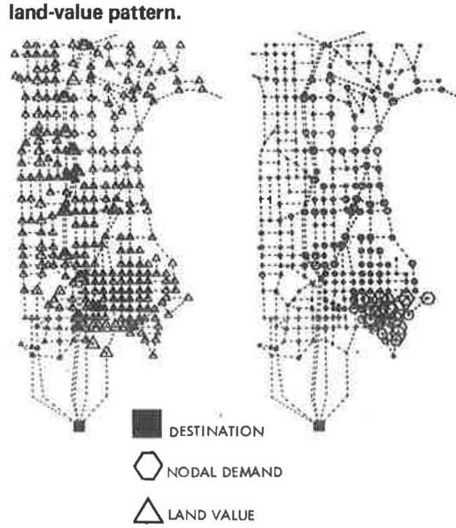


Figure 8. Selection of drive-mode constraints.

```
ENTER AVERAGE PARKING FEE AT DESTINATION (CENTS).
100
ENTER AVERAGE WALKING TIME FROM PARKING LOTS TO DESTINATION (MINUTES).
6
```

Figure 9. Selection of parking lot locations.

USE JOYSTICK TO LOCATE PARKING LOTS.

Figure 10. Selection of parking lot sizes.

TYPE LOT SIZES INTO TABLE.
LOT MAY BE REPEATED IF MODIFICATION DESIRED. TYPE 0 (ZERO) WHEN COMPLETED.

LOT NO.	NO. OF SPACES	DAILY LOT COSTS
1	800	243
2	300	91
0		
TOTAL	1100	334

Figure 11. Selection of transit routes.

USE JOYSTICK TO ENTER TRANSIT ROUTES.

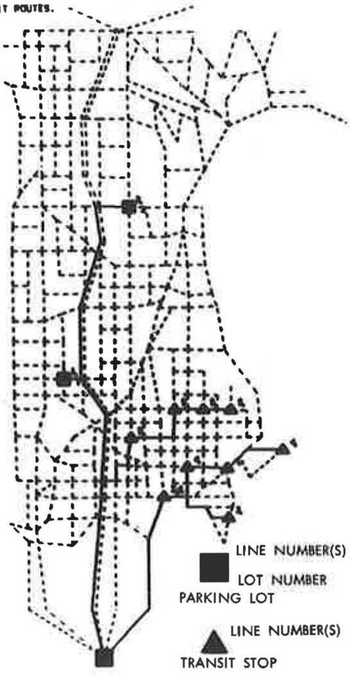


Figure 12. Selection of transit vehicles.

[illegible] HEADWAY TABLE (MINIMUM HEADWAYS IN MINUTES)

LINE	NUMBER OF VEHICLES 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	32	16	11	8	6	5	5	4	4	3	3	3	2	2	2
2	39	20	13	10	8	7	6	5	4	4	4	3	3	3	3
3	33	16	11	8	7	5	5	4	4	3	3	3	3	2	2
4	40	20	13	10	8	7	6	5	4	4	4	3	3	3	3
5	43	22	14	11	9	7	6	5	5	4	4	4	3	3	3

ENTER VEHICLE CHARACTERISTICS INTO TABLE.
LINE MAY BE REPEATED IF MODIFICATION DESIRED. TYPE 0 (ZERO) WHEN COMPLETED.

LINE	NO. OF VEHICLES	VEH. TYPE	VEH. SIZE SEATS	STANDS	VEH. COMFORT	DAILY LINE COSTS
1	8	6	40	22	2	720
2	9	3	35	15	2	675
3	5	1	19	0	1	270
4	6	1	19	0	1	324
5	7	1	19	0	1	378
TOTAL	35					2367

the percentage of trip-makers who are transit captives and do not receive adequate transit service. The detailed cost-revenue figures for transit lines and parking lots may be studied for subsequent elimination, relocation, or repricing of unprofitable lines and lots. In addition, lot loads and lot sizes may be compared for further adjustment of parking lot sizes. The annotated access volumes at each stop and lot may help subsequent elimination of "unpopular" stops. Care has to be taken, however, because low-access volumes may also stem from missing capacity of in-bound transit vehicles when they reach a stop.

The next two displays given by the computer (Fig. 14) show the spatial distributions of accessibility. They can be used to identify those areas where an improvement in service is most needed.

The distribution of service provided by the transit system may also be assessed in terms of the percentages of the trip-making population within certain ranges of access time to transit stops or parking lots (Fig. 15). For example, these displays might be used to check whether a sufficiently large portion of transit captives is within tolerable walking time from transit stops. The standard deviations of the access time distributions can be interpreted as a measure of the spatial equity of the system.

The final displays given by the computer show the service area characteristics for the walk-and-ride mode or, as in Figure 16, for the park-and-ride mode. In Figure 16, the service areas of the parking lots are defined by "trees" that show the paths on which people would drive to parking lots if they chose the park-and-ride mode. A locationally efficient solution may be characterized by the absence of backtracking paths and by service areas that are well balanced in size (see "demand" column of table) and average and maximum access times.

At any point during evaluation of the performance displays, the user can save his current configuration on the computer's disk, go back to any of the decision input modules, and re-enter modified design variables. He can also display a comparative summary of all the configurations that he has generated and saved, delete any of the saved configurations, recall a previously saved configuration for the purpose of subsequent modification, and obtain printed or digital plotter hard copies of any or all configurations.

ADDITIONAL SEARCH CAPABILITIES OF IGTDS

Initially, it was hoped that the interactive design process described would enable a user to find rapidly a large number of efficient solutions. (A solution is termed "efficient" if it cannot be dominated, i.e., if no improvements in total benefit can be made without a simultaneous decrease in total transit use.) Initial experience with IGTDS revealed, however, that unless the problem was stringently constrained the user was overwhelmed by the number of design variables and the astronomical number of possibilities they offer. Most users felt reasonably confident in making locational decisions (locating parking lots and designing routes), but they felt uneasy in the decisions as to level of service and pricing. It was, therefore, felt desirable to automate the search for efficient combinations of frequencies, fares, and parking fees.

The automated search process implemented in IGTDS contains two steps. In the first step the computer generates the trade-off function between transit use and operator benefit for a given route layout (Fig. 17). The process uses a partially inverted form of the modal split and unconstrained assignment model. In the second step the user specifies a point on the trade-off curve and thereby the combination of fares, number of vehicles, and lot sizes associated with that point. The user can immediately proceed to displaying the consequences, because they were already calculated when the curve was generated. The net computation time for the entire search process is approximately 3 minutes.

Choice of the "Best" Among Multiple-Attribute Alternatives

The combination of intuition and computer-assisted search should allow a user to find in a relatively short time a number of solutions that are acceptable with respect to his design criteria. However, having identified a number of acceptable solutions,

Figure 13. Presentation of modal split and cost/revenue figures.

MODAL SPLIT SUMMARY

PERCENTS	WALK+RIDE	PARK+RIDE	DRIVE	NOT SERVED
	14.6	12.0	71.0	.2

TRANSIT LINE SUMMARY

LINE	NO VEH	SEATS/VEH	STAND/VEH	COMFORT	HEADWAY	COST	REVENUE	BENEFIT
1	8	40	20	2	3.0	720	836	116
2	9	35	15	2	4.3	675	520	-155
3	5	19	0	1	6.9	270	68	-202
4	6	19	0	1	6.5	324	145	-179
5	7	19	0	1	8.1	378	124	-254
TOTAL	35					2367	1693	-674

PARKING LOT SUMMARY

LOT NO	LOT SIZE	LOT LOAD	LOT FEE	LOT FARE	COST	REVENUE	BENEFIT
1	800	732	0	50	243	0	-243
2	300	225	0	50	91	0	-91
TOTAL	1100	957			334	0	-334
TOTAL SYSTEM					2701	1693	-1008

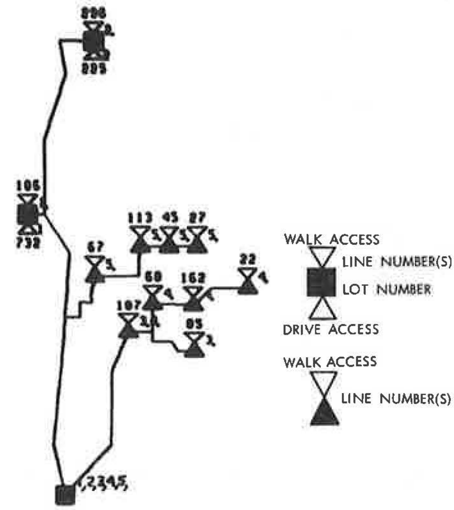
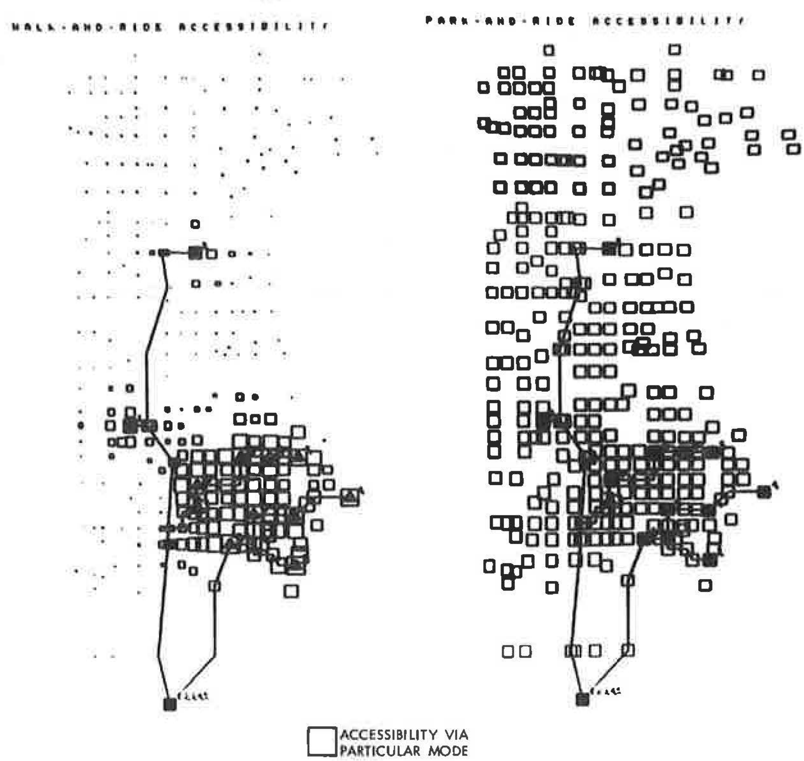


Figure 14. Spatial accessibility distribution.



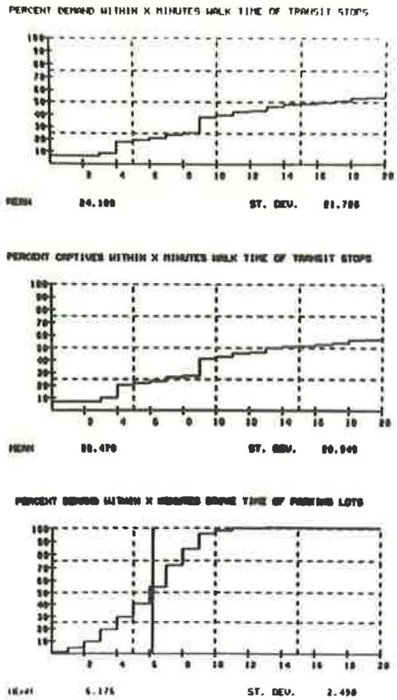


Figure 15. Distribution of access to the transit system.

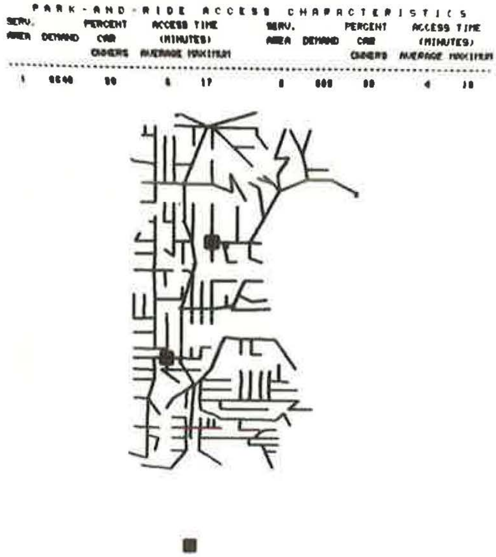


Figure 16. Service area characteristics for park-and-ride mode.

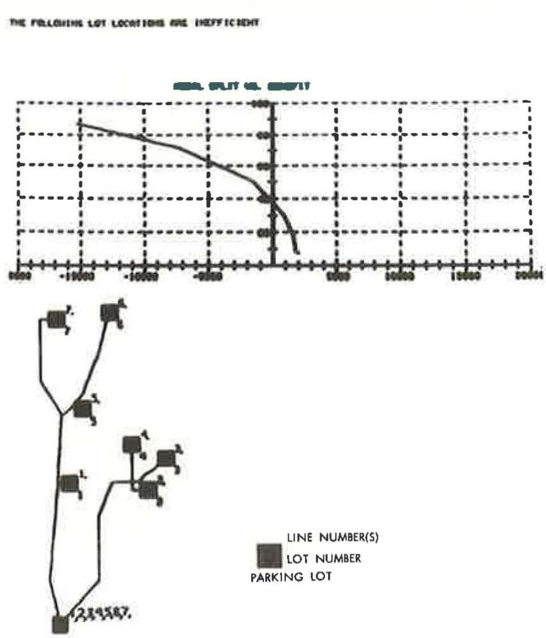


Figure 17. Configuration and associated trade-off function.

the user will still face the difficult task of selecting the "best" solution from them. Each acceptable alternative will achieve different levels of satisfying competing objectives such as maximum transit ridership, maximum operator benefit, minimum user costs, and minimum variation of accessibility. However, IGTDS makes apparent the extent to which certain pairs of goals are incompatible. The automated search process displays the trade-off function between transit use and operator benefit explicitly. In selecting a point of the curve of Figure 17, the user can apply a criterion of (a) a given profit or deficit level, (b) a given minimum transit use requirement, or (c) an objective function of the two performance measures. Additional trade-offs will become apparent when the values of other performance measures are compared in the summary tables. The knowledge of trade-offs allows the user-participants to identify compromises and to generate new alternatives in a framework of reformulated objectives and constraints.

Additional Choice Models

The interactive graphic approach is particularly well suited for computer-assisted decision-making among multiple-attribute alternatives. IGTDS does not yet contain specific choice models, but such models could be incorporated in the future. Computer assistance seems desirable for such decision-making methods as dominance, satisficing, maximin or maximax, lexicography, additive weighting, effectiveness index, nonmetric scaling, and others (11). Of particular interest are semantic scaling techniques for multiparticipant decision-making. Flack and Summers (12) have developed a promising prototype interactive graphic system for highlighting and resolving the differences in the value systems of two participants choosing among water resource system alternatives.

LIMITATIONS

IGTDS is currently limited to problems involving a network of up to 320 nodes and 1,280 one-way links. This limitation stems from the IBM 1130 memory capacity (16,000, 16-bit words) and disk size (½ million words). Also, larger problems would entail partitioning the network for display purposes (the ARDS display area is 6 × 8 inches). Implementation of IGTDS on a large third-generation computer would reduce net computation time by a factor of between five and ten.

Limited to many-to-one trip relationships, IGTDS cannot be directly applied to multidestination transit systems. However, urban transit systems can often be decomposed into node-oriented subsystems serving particular destinations and homogeneous clienteles and trip purposes. IGTDS can be used for designing such subsystems, although their superposition may require manual adjustments such as consolidating redundant routes and resolving inconsistent fares.

CONCLUSIONS

Decision-oriented transportation planning requires

> . . . more sophisticated tools of analysis to perceive individual and community preferences and formulate goals and program objectives in light of evolving technology and changing habits and values; to search for and generate alternative approaches to meet given objectives; to predict, evaluate and then rank the impacts of alternative proposals; and to give adequate recognition to the element of uncertainty in the design of decisions (13).

The man-computer interactive graphic design system presented in this paper comes very close to meeting the requirements quoted:

1. It enables the user to explore a wide range of alternatives, including "unusual" designs, and it helps him to find efficient solutions.
2. It allows a user to answer "what if" questions quickly. (It is foreseeable that interactive graphic systems with a wall-size display could be used to answer questions in public hearings, thereby enhancing a truly participatory planning process).

3. It does not require the formulation of a quantitative objective function at the outset of the design process but gives recognition to the fact that the true value systems of decision-makers emerge only when they are faced with hard trade-offs.

4. It allows the user to test the sensitivity of a solution with respect to certain model inputs such as travel demands and modal split model parameters.

5. Because it provides deep insight into the many interactions inherent in any transportation system, it is also a suitable educational and research tool.

To date, work on IGTDS has only been developmental. Future work will include controlled experimental use of IGTDS and, it is hoped, will lead to a proper assessment of the system's potentials for real-world problem-solving and research and educational use. Work is under way to calibrate the IGTDS prediction model and to apply it to a real-world problem. In addition, controlled experimental use of the system is expected to yield some evidence on the suitability of interactive graphic systems for solving transportation problems of various levels of complexity. Of particular interest is the identification of successful problem-solving strategies that can be implemented with computer heuristics and ultimately be used for creating an interactive system in which the computer learns from the user.

ACKNOWLEDGMENTS

This report was produced as part of a program of Research and Training in Urban Transportation sponsored by the Urban Mass Transportation Administration of the U.S. Department of Transportation. The results and views expressed are the independent products of university research and are not necessarily concurred in by the Urban Mass Transportation Administration or the U.S. Department of Transportation. The author thanks the members of the staff of the Urban Transportation Program at the University of Washington for their support, particularly Professor Jerry B. Schneider for his helpful comments and Mark Goldman, Claus D. Gehner, and Virginia R. Hetrick for their assistance.

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