TRANSPORTATION RESEARCH RECORD 626

Bus Service Planning

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1977

Transportation Research Record 626
Price $2.20
Edited for TRB by Dolores J. Breslaw

subject areas
53 traffic control and operations
84 urban transportation systems

Transportation Research Board publications are available by ordering directly from the board. They may also be obtained on a regular basis through organizational or individual supporting membership in the board; members or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Notice
The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The views expressed in this report are those of the authors and do not necessarily reflect the view of the committee, the Transportation Research Board, the National Academy of Sciences, or the sponsors of the project.

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Bus planning service.

(Transportation research record; 626)
Reports of the 56th annual meeting of the Transportation Research Board.
1. Motor bus lines–Congresses. 2. Transportation planning–Congresses. I. Title. II. Series.
HE7.H5 no. 626 [HE5606] 380.5'08s [388.4'1322] 77-20009
ISBN 0-309-02651-2

Sponsorship of the Papers in This Transportation Research Record

GROUP 1–TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
E. Wilson Campbell, New York State Department of Transportation, chairman

Public Transportation Section
Kenneth W. Heathington, University of Tennessee, chairman

Committee on Bus Transit Systems
Herbert S. Levinson, Wilbur Smith and Associates, chairman
Richard J. Anderson, J. J. Bakker, Alvin G. Basmadjian, John W. Bates, Eugene T. Canty, Tapan K. Datta, Robert B. Deuser, J. R. Doughty, James C. Echols, Curt M. Elmberg, Edward R. Fleischman, James L. Foley, Jr., Marvin C. Gersten, Ronald I. Hollis, Carol A. Keck, Henry M. Mayer, Neil Craig Miller, Donald A. Morin, Karen L. Paine, George W. Schoene, Franklin Spielberg, Vasant H. Surti, F. V. Webster, H. Donald White

GROUP 3–OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES
Adolf D. May, University of California, Berkeley, chairman

Committee on Maintenance and Operations Systems
Mathew J. Betz, Arizona State University, chairman
Richard D. Bauman, John B. Benson, Jr., Bertell C. Butler, Jr., Joseph L. Garner, William L. Grecco, John S. Jorgensen, Roy W. Jump, C. O. Leigh, Edward L. Miller, William G. Mortenson, William N. Records, Stephen N. Runkle, Gerald Saulnier, Gideon Schwartzbart, Ernst S. Valfer

W. Campbell Graeub and Adrian G. Clary, Transportation Research Board staff

Sponsorship is indicated by a footnote at the end of each report. The organizational units and officers and members are as of December 31, 1976.

Contents

Effect of Automatic Vehicle Monitoring Error on Transit Schedule Adherence Monitoring

P. Bruce, J. S. Ludwick, Jr., and G. F. Swetnam, Jr., MITRE Corporation

The timing accuracy required to support transit company use of an automatic vehicle monitoring system has been analyzed for the function of monitoring schedule adherence. Schedule deviation data from existing bus lines of the Southern California Rapid Transit District (a potential monitoring system user) were combined in a Monte Carlo analysis in which error distributions were chosen to limit the expected error behavior. Curves were obtained relating the percentage of false alarms and missed detections for each case. The monitoring system can be expected to perform satisfactorily with timing errors that meet a 95th percentile accuracy of ±15 s. However, allowance of an internal safety margin will be required to avoid an excessive number of false alarms. The size of the safety margin will depend on the actual error distribution.

Automatic vehicle monitoring (AVM) systems provide the locations of members of a fleet of vehicles to a central control point. AVM systems are usually used with communications links from the control point to the vehicles. Having location information and communications capability enables the dispatcher to improve the performance of the vehicle fleet. For instance, police cars or taxis can be dispatched more effectively and transit bus drivers can be advised when they are exceeding permissible schedule deviations.

Many such systems have been proposed and, during the past 20 years, a few experimental systems have been tested in which a variety of location technologies were involved (1). To determine accuracy limits the Urban Mass Transportation Administration (UMTA), in 1972, supported a series of tests of four of the most promising location techniques in Philadelphia. Although the results showed deficiencies (2), knowledge gained from the tests has led to further refinements and the development of techniques that promise improved accuracy. Consequently, several improved location subsystems are to be tested in Philadelphia. If one of the location techniques demonstrates adequate performance, this technique is to be incorporated in an AVM system in Los Angeles to demonstrate the potential of multiuser AVM (3).

The principal user of the Los Angeles system is to be the Southern California Rapid Transit District (SCRTD). SCRTD is to use the system to improve the schedule adherence of its bus fleet, to collect data on route running times, and to reduce the time required to respond to breakdowns, accidents, and other emergencies. Of the functions proposed for the system, schedule adherence monitoring and collection of running time data seem to have the greatest potential for operating cost savings. System requirements for schedule adherence monitoring are more restrictive than for running time data collection, and errors in schedule adherence monitoring may seriously cripple the system's utility to and acceptance by the transit company.

This paper analyzes the effect of anticipated AVM system error on schedule adherence monitoring. The analysis shows that, even with the highest anticipated accuracy, the system must incorporate a safety margin to reduce false schedule alarms to an acceptable value.

AVM AND THE SCHEDULE MONITORING PROCESS

The introduction of an AVM system is expected to change the transit company procedures and responsibilities for schedule adherence monitoring; this change complicates the analysis of the effect of error. Under present practices, approximately 20 mobile supervisors in radio-equipped cars observe 200 bus routes, note deviation from established schedules, and assist drivers with weather and traffic problems, breakdowns, accidents, or other disruptions of scheduled operation. In Los Angeles supervisors and drivers are in radio contact with a central dispatching point. When a driver has a problem, he or she calls the dispatcher, who may give the driver authority to deviate from a bus route or may direct a mobile supervisor to provide assistance.

The introduction of AVM will shift the primary responsibility for schedule adherence monitoring to the dispatcher although mobile supervisors will still be required for other functions. Dispatcher control should improve schedule adherence because there are so few supervisors now that only a fraction of the deviations are noted. The expanded responsibility of the dispatcher will require accurate data from the AVM system because schedule discrepancies are reflected on each driver's record. Drivers are expected to travel on or behind schedule; traveling ahead of schedule results in passing stops before passengers arrive. A driver who travels more than 1 min early is warned or disciplined. If a dispatcher sends warnings based on AVM-derived data and frequently finds that the bus was actually on time, he will lose faith in the system and schedule adherence responsibility will probably revert to supervisors. The problem is compounded by the fact that, unlike a mobile supervisor, the dispatcher cannot see local weather or traffic conditions that may suggest overlooking an individual schedule deviation; the dispatcher has only the AVM display and the radio to describe a situation. Thus, the proportion of false alarm deviation reports will be crucial in determining the usefulness of the AVM system.

Schedule deviation data obtained from the SCRTD were used to study the proportion of false alarms caused by AVM error. The data on schedule deviations were then combined in Monte Carlo analysis; the same assumed AVM error distributions were chosen to limit the expected error behavior. The analysis produced curves showing the percentage of false alarms and missed detections for the assumed AVM error distribution.

SIMULATION OF AVM ERROR

Schedule adherence monitoring is sensitive to the distribution function of the AVM location system error, but this function cannot be predicted in advance because the location technique has not been selected. Most of the error distributions of proposed AVM location systems appear to be normal except for humps on the tails that reflect irregularities in system operation. (That is, if the vehicle is actually at a given location, the distribution of many location measurements will approximate a normal distribution but with a disproportionate number of values at large distances from the mean. These values occur in pulse- or phase-ranging data as a result of multipath distortion and in LORAN data because of distortion of the grid by city structures. Perfectly exact systems also occasionally exhibit large errors when a map-matching routine incorrectly decides which street a vehicle is on.) These points are important because the tail of the distribution determines the incidence of schedule adherence false alarms.

To determine limiting values for acceptable error distributions, we analyzed each case for two assumed error distributions: normal and uniform. The normal distribution was chosen as a lower limit because of the theoretical and observed tendency of errors composed of a large number of independent error sources to approach the normal as a limiting case. The uniform distribution was chosen because it has a relatively large proportion of its error in the tails of its distribution and is almost certainly worse than any distribution that would be found in practice. The actual distribution of AVM error was expected to lie somewhere between these two limiting cases.

The assumed error distributions are shown in Figure 1. The 2σ normal distribution was set equal to the 95 percent error specification for four values: ±15 s, ±30 s, ±1 min, and ±2 min. The mean was assumed to be zero, since a nonzero mean can be compensated by the system. For a normally distributed random variable, less than 0.006 percent of the errors lie farther than ±4 standard deviations from the mean. This interval was defined as the range of the normal distribution for the purposes of this analysis.

To obtain an upper limit on error effect, a uniform distribution was assumed with a range equal to the defined range of the normal distribution. Thus, in the analysis of a specification that 95 percent of all errors be less than or equal to ±15 s, the standard deviation of the assumed distribution was set at 7.5 s, which yielded a 4σ range of ±30 s. The uniform distribution for comparison was subsequently defined by its range of ±30 s.

EFFECT OF AVM ERRORS ON DISPATCHER ACTION

The effect of AVM errors on the dispatcher's job was evaluated by a simulation model that combines assumed AVM error distributions with actual SCRTD schedule deviation data. The result is the expected number of schedule deviations and the portion of displayed schedule deviations that were false alarms caused by AVM error. Figure 2 shows the simulation process. The transit company data on schedule deviations are rounded to the nearest 0.5 min. To approximate data that would be collected by an actual system, the program adds to each data point a uniformly distributed random number. Next, a random number representing AVM error is chosen from the AVM error distribution and added to the deviation value. The program classifies the resulting event and proceeds to the next data point.

Model Rationale

SCRTD furnished schedule adherence data from lines 2, 3, 8, 26, and 92 tabulated on "Check of Time and Passengers" forms. These lines represent most of those that will be monitored by a typical dispatcher when AVM is installed. The data, which were collected on the street by schedule checkers, include the schedule time and actual departure time of all buses on a given day at given time points for each line. (Time points are locations along a route where a driver is responsible for maintaining specified schedule times. Time points are usually located at bus stops, and the time recorded for a driver at a time point is the time of departure. This allows a driver running ahead of schedule to return to schedule by waiting longer than otherwise necessary at a time point.) The deviations represent actual time minus schedule time. Therefore, buses ahead of schedule have negative values.

When AVM is installed, a typical dispatcher will control approximately 900 bus trips/d. Each bus trip will include an average of approximately 15 time points. Thus, a total of approximately 13 500 time point passages/dispatcher/d will occur. Although data were not available for all desired time points or for all desired bus lines, approximately 2200 time point passages were recorded. However, only the smallest of the desired lines are absent, and the larger lines have data from a number of time points. In fact, the data represent some time point data for 95 percent of all bus trips monitored by the typical dispatcher during a given day.

The simulation program reads the data, which have been rounded to the nearest 0.5 min, and adds a number from a uniform distribution with a mean of zero and a range of ±15 s to remove the effect of the data rounding. Thus, the resulting schedule deviation is assumed to be the actual one. A number is then chosen from one of the assumed AVM error distributions and is added to the actual schedule deviation to give a reported schedule deviation. The actual and reported times are then examined for inclusion in any of the following categories:

1. Bus early—actual schedule deviation more negative than -1 min;
2. Bus displayed early—reported schedule deviation more negative than -1 min;
3. False alarm early—actual schedule deviation more positive than -1 min but reported schedule deviation more negative than -1 min; and
4. Missed detection early—actual schedule deviation more negative than -1 min but reported schedule deviation more positive than or equal to -1 min.

A similar set of definitions applies for late times that have a limit of +5 min instead of -1 min.

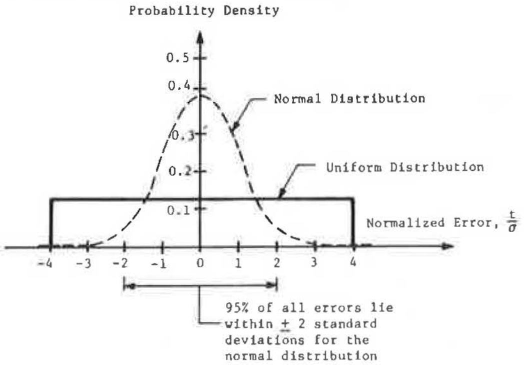
Separate tallies are kept for each hour; in addition, morning and afternoon peak hours and 24-h totals are accumulated. When all data points have been classified, measures of effectiveness are computed:

1. Ratio of false alarms early to buses displayed early, which indicates the fraction of the dispatcher's workload (warning drivers to speed up or slow down) that is unnecessary and
2. Ratio of missed detections early to buses early, which indicates the fraction of buses ahead of schedule that are not reported to the dispatcher.

The first measure of effectiveness pertains to driver and dispatcher confidence in the system and the second to passenger satisfaction. Since approximately one-sixth of the total daily number of time point passages were available, input data were replicated six times. Replication is preferable to multiplying the output tallies by six because the values chosen from the statistical distribution more closely approach the actual distribution.

Specifying a tolerable level for system errors (i.e., false alarms and missed detections) is very important. If the level is set too low, the cost of the resulting system may be unnecessarily high. However, if the level is set too high, the resulting system may be of little use to the transit company. False alarm errors have most impact on transit operations for two reasons. First, they require action from the dispatcher and, therefore, allow him less time to respond to real problems. Even a small percentage of false alarms might cause the dispatcher to lose confidence in the system. Second, bus drivers can be disciplined for being too far ahead of schedule. The false alarm rate must be very low to prevent unjust action from being taken against the drivers. Even if the AVM system output were not used for disciplinary purposes, a few false notifications by the dispatcher might convince the driver that the system really does not reflect the situation accurately and the driver might disregard the dispatcher's recommendations. Based on these considerations, this study assumes that the maximum tolerable level is an early false alarm rate of 1 percent.

Figure 1. Assumed error distributions.



The usefulness of the system to a transit company is based on the system's ability to detect buses that are running beyond the tolerance level. However, missed detections are not so serious as false alarms because missed detections do not result in actions being taken. A missed detection rate as high as 50 percent might be acceptable because few drivers would intentionally run ahead of schedule if the chance of being caught were equal to the chance of escaping detection.

Input Data

Figure 3 shows the distribution of 2223 schedule deviations collected by SCRTD. The mean is 1.10 min and the standard deviation is 2.03 min. Assuming that 50 percent of the data points at -1 min are actually more negative than -1, approximately 4 percent are early. A similar assumption for data points at +5 min implies that 5 percent are late. Although the schedule deviations were presented as accurate to the nearest 0.5 min, the shape of the histogram suggests that many measurements were rounded off to the minute. Also, considering the seriousness to the driver of being early or late and the schedule checkers' tendency to give the driver the benefit of the doubt, the bias is probably toward zero. If the

Figure 2. Simulation model for schedule adherence evaluation.

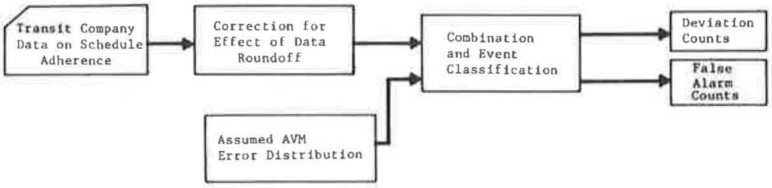
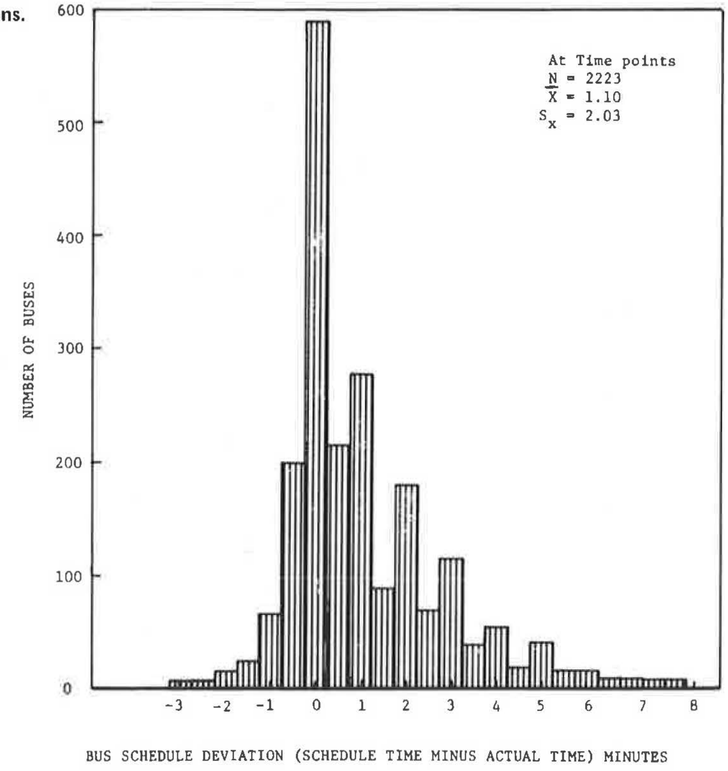


Figure 3. Bus schedule deviations.



number of buses both slightly ahead of a slightly behind schedule has been biased toward zero, then the true peak at zero is probably less pronounced than shown. However, even a smoothed version of the curve would not be normal because of the pronounced negative skew. Because penalties exist for being more than 1 min ahead of schedule, however, a skewed curve seems inevitable.

Results

The simulation results clearly show that a practical AVM system must apply a safety margin to reported deviations before displaying them if false alarms are to be kept acceptably low.

Figure 4 shows results of the simulation using 24-h totals. (The morning and afternoon peaks show curves with similar shapes.) Figure 4 displays data on missed detections and false alarms based on normal and uniform AVM error distributions with 4σ ranges from ±30 s to ±30 s to ±2 min. Figure 4 illustrates that an AVM system with errors of technologically attainable size cannot operate without a safety margin. For the best functioning vehicle location system, which has a normally distributed error and a 95th percentile performance of ±15 s (4σ range of ±0.5 min), the early false alarm rate is 9 percent. This fact means that about 1 bus in 11 that is displayed early is actually within tolerance. For uniformly distributed errors the false alarm rate is 24 percent.

Operation without a safety margin is unacceptable if one computes the hourly occurrence of early false alarms arising from the large volume of time point passages processed by the system. For a normally distributed error with 95th percentile performance of ±15 s, false alarms peak at about 10/h or 1 every 6 min. To sum-

Figure 4. System error rate as a function of AVM accuracy without safety margin.

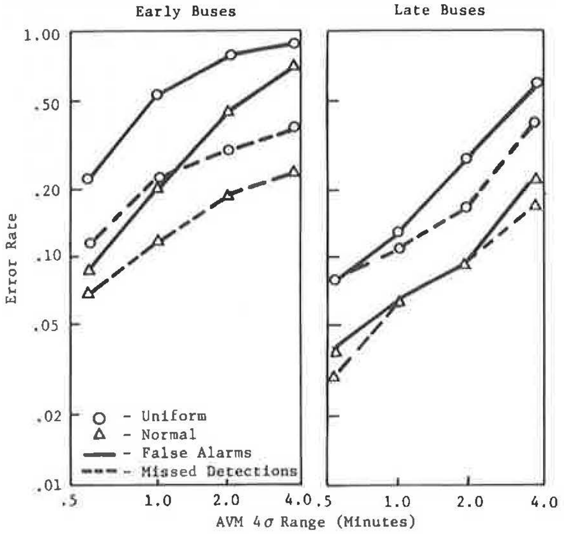


Figure 5. Redefined display threshold.

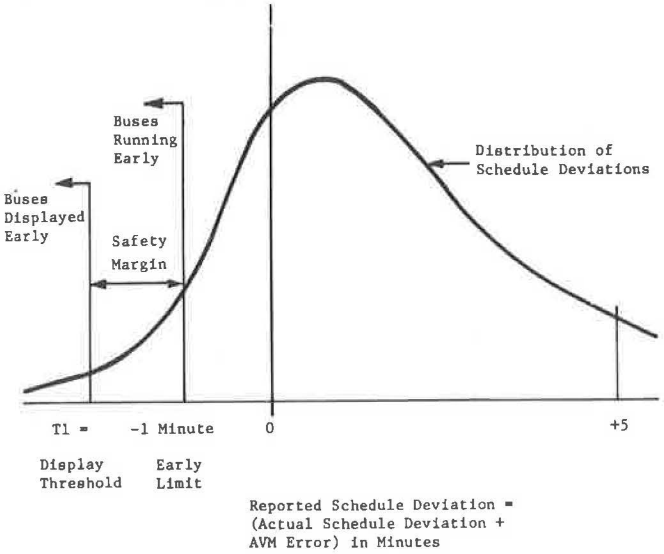


Figure 6. System error rate as a function of offset of out-of-tolerance threshold from -1 min.

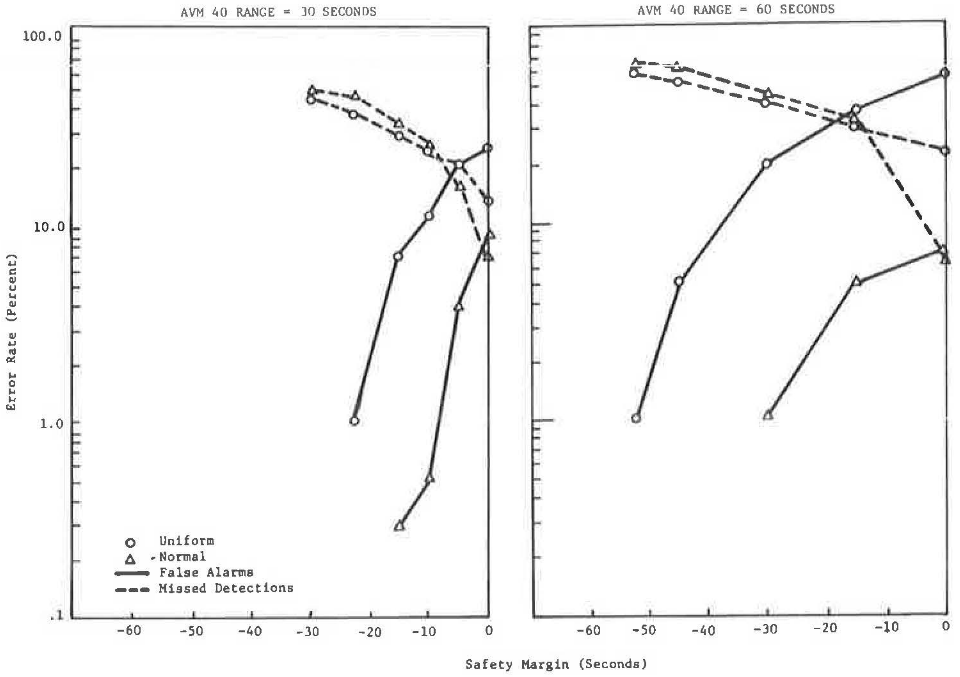
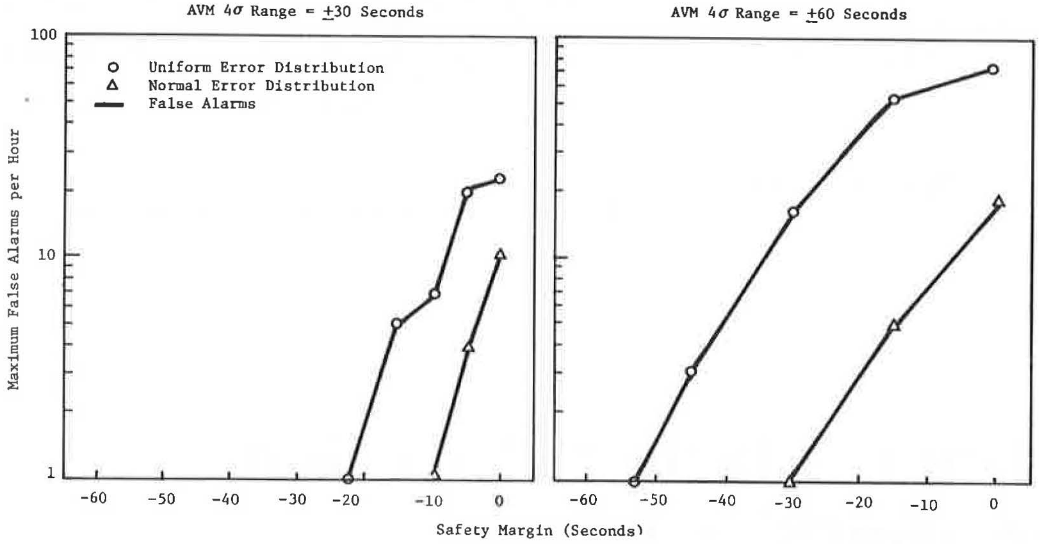


Figure 7. Effect of safety margin on maximum hourly early false alarm rate.



marize, the most important criteria—percentage of early false alarms and hourly early false alarm rate—are not close to being acceptable for the most accurate system unless a safety margin is used.

Allowing a safety margin before displaying an early bus involves a trade-off of improving false alarm accuracy while allowing more early buses to miss detection. This approach is illustrated in Figure 5. The reported schedule deviation data (i.e., actual schedule deviation plus AVM error) and the -1 min limit are shown. Some buses with deviations to the left of the limit are actually not out of tolerance but are displayed out of tolerance, which causes false alarms. Suppose we choose a new display threshold (T1) against which to display early buses. The farther to the left of -1 min the new display threshold is placed, the smaller the false alarm rate will be. That is, for a false alarm to occur, a displayed bus schedule deviation must now be more negative than T1 min, although the actual schedule is more positive than -1 min. More missed detections will now occur because no buses reported between T1 and -1 min are displayed as being out of tolerance. The farther to the left T1 is taken, the more early buses will be missed.

To evaluate the impact of the safety margin the simulation was run for various values of safety margin. Figure 6 shows the resultant false alarm and missed detection rates for the system with 4σ AVM accuracy of ±30 s, which corresponds to a 95th percentile error specification of ±15 s. Zero s margin gives the results shown in Figure 4; -30 s, however, eliminates all false alarms but allows nearly 50 percent of the early buses to go undetected. A -10 s offset results in a 0.5 percent false alarm rate for the normal distribution and a consequent 25 percent missed detection rate; however, the uniform distribution requires a -22.5 s offset to attain 1 percent false alarms and 35 percent missed detections. Figure 6 also shows the results of 4σ AVM accuracy of 60 s. The 1 percent false alarm thresholds for the normal and uniform distributions now require offsets of -30 and -52.5 s and resulting missed detections of 45 and 65 percent. Figure 7 shows how the safety margin affects the maximum hourly occurrence of false alarms for uniformly and normally distributed AVM error with 4σ ranges of ±30 and ±60 s.

Dispatcher Workload

If the simulated results are accurate, some screening may have to be applied to time point passage data to keep early buses displayed from overwhelming and distracting the dispatcher from other control tasks. Even when an accurate system with a well-functioning error distribution is assumed, the number of early buses appears very large. For example, for a normally distributed 4σ AVM error of ±30 s and a 10-s safety margin, the simulation predicts 70 early buses for the heaviest hour. This prediction is not extreme because the simulation predicts 70 and 66 early buses for the two next highest hours.

Making a firm prediction of the validity of this load estimate is difficult. As soon as dispatchers begin to call drivers of buses running ahead of schedule, distribution of schedule deviations can be expected to shift significantly. If the proportion of early buses drops, the load imposed on the dispatcher drops also.

Even so, screening raw reports of early buses seems advisable; in fact, screening raw reports for late buses also seems advisable. If a heavy rain or other traffic disruption begins to affect a number of lines, the dispatcher is not interested in a bus-by-bus tally of all bus drivers running behind schedule. This problem requires further study to select the best procedures for limiting schedule deviation reports to the dispatcher.

CONCLUSIONS

The analysis of adherence monitoring functions leads to the conclusion that a 95th percentile error specification of ±15 s should be adequate for schedule adherence monitoring. However, the system must allow a margin of time before notifying the dispatcher that a bus is running early. The size of the required margin should depend on the distribution function of the timing errors. The system might work with a 95th percentile error performance of ±30 s, but the larger errors require a wide time margin that allows up to 60 percent of actual early buses to escape detection. Therefore, a specification of ±15 s is recommended to support schedule adherence monitoring.

ACKNOWLEDGMENT

This work was supported by the Office of Research and Development of the Urban Mass Transportation Administration.

REFERENCES

1. W. C. Scales. Automatic Vehicle Monitoring Systems. MITRE Corp., McLean, Va., M75-9, Oct. 1974.
2. W. C. Scales. Urban Field Tests of Four Vehicle Location Techniques. MITRE Corp., McLean, Va., MTR-6397, April 1973.
3. D. J. Symes. Advanced Multi-User Area-Coverage Automatic Vehicle Monitoring Program. In IEEE, Transactions on Vehicular Technology, May 1977.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Transit Performance in the I-35W Urban Corridor Demonstration Project

Walter Cherwony, Lewis Polin, and Subhash Mundle, Simpson and Curtin, Philadelphia

The I-35W Minneapolis-St. Paul Urban Corridor Demonstration Project was designed to test (a) the effectiveness of expanding express bus route coverage and service frequency and (b) the potential of ramp metering to produce higher operating speeds. To evaluate expanding bus service and ramp metering of the I-35W project required an extensive data collection and monitoring program throughout the project. The results of this analysis clearly indicate the ability of both express bus service and ramp metering to substantially increase transit use. Further, we concluded that the freeway must have complete access control, both inbound and outbound, for ramp metering to produce high transit operating speeds. In addition, we found that express bus service exhibits a lower unit cost per kilometer than local service and, to the extent that ramp metering increases express bus-operating speeds, ramp metering produces further reductions in transit unit cost. The major conclusion of the I-35W project is that expanded bus service and ramp metering can provide a relatively low-cost technique to increase use of existing freeways and encourage diversion of travelers to environmentally desirable and energy-efficient modes of travel.

With growing awareness of limited funds to provide adequate urban-area transit, the U.S. Department of Transportation embarked on a program to identify and evaluate low-capital methods to expedite urban travel. This program consisted of about 12 Urban Corridor Demonstration Projects (UCDPs). The basic intention of the program was to focus on a particular corridor in an urban area and, through the use of low-capital techniques, increase both vehicle and person travel capacity. One such project and the topic of this paper was the I-35W UCDP in the Minneapolis-St. Paul metropolitan area. As indicated in Figure 1, the corridor extended from the Minneapolis central business district (CDB), south through densely developed residential areas of the inner city and through the outlying suburban communities that parallel I-35W. This corridor was selected because it accounts for a substantial degree of CBD-oriented travel. Furthermore, in recent years, the I-35W corridor has experienced an increased frequency and degree of congestion.

Two primary elements of the I-35W UCDP were the introduction of greatly expanded express bus service and the implementation of freeway ramp metering. The expansion of express bus service was accomplished by opening new routes and increasing frequency of express service. The ramp-metering concept includes surveillance of the roadway to compare traffic demand to available capacity. Based on relative balance of roadway supply and demand, the number of vehicles that may enter each ramp is controlled by a traffic signal; thus, access to the freeway is metered. The freeway always operates at a high level of service, assuring high-speed operation of public transit and other vehicles. In this project, transit vehicles were also given separate priority access ramps to further improve the quality and attractiveness of service.

An integral part of the demonstration project was the evaluation of each of the two major elements in satisfying certain transit objectives. For this reason, the evaluation was divided into the following three phases.

Phase	Period	Project Element
1	Fall 1972	Limited express bus service, no ramp metering
2	December 1972-Spring 1974	Full express bus service, no ramp metering
3	Spring 1974-December 1974	Full express bus service, ramp metering

Phases 1 and 2 represent the before and after condition of the installation of express bus service, and phases 2 and 3 represent the before and after situation for ramp metering. During each of the three phases, an extensive data collection effort was performed. The following objectives were established:

1. Provide more attractive transit service through increased express bus operating speeds;
2. Provide more attractive transit service through increased express bus dependability; and
3. Determine and evaluate transit operating characteristics such as patronage, revenue, and cost.

TRANSIT OPERATING SPEED

Service was made more attractive in the corridor by adding bus routes and increasing bus frequency during phase 2 and by ramp metering and giving priority freeway access to buses during phase 3.

The desirability of transit was assessed by travel time, which previous analyses had identified as a key determination in mode choice. On the basis of scheduled travel times between downtown Minneapolis and selected locations in the I-35W corridor via local and express routes, the implementation of express services produced substantial time savings in comparison to local bus service. In phase 1, when only nine downtown express routes were operated, travel time savings ranging from 25 to 50 percent were observed at selected locations. When the number of express routes in phase 2 was increased, travel-time savings were made available to a far larger portion of corridor residents. The magnitude of the travel-time savings offered by express service relative to local service is based on the proportion of line-haul operation (primarily route length) of I-35W.

Another factor that affects travel time is the speed of the transit vehicle. Transit routes can be divided into collection, line-haul, and distribution segments, and each one should be analyzed separately. The ramp metering of I-35W affected only the line-haul segment of the route. On the basis of operating speeds observed in all three phases, ramp metering reduced transit travel times on the freeway. However, reductions in travel time on many routes were offset by increased travel times on the collection and distribution segments of express lines. For this reason, we suggest that future transit improvement projects that use ramp metering consider the entire transit route, not only the line-haul segment on the freeway. In particular, priority treatment of buses should be provided on the surface streets leading to the freeway ramps as well as on the freeway and ramps. At several locations, buses were delayed in traffic queues. To remedy this situation, express bus lanes should be extended from the ramp to adjacent surface streets beyond any traffic congestion zones. Although not a part of the I-35W UCDP, reversible bus lanes were established by local agencies during phase 3. This special treatment of buses in the Minneapolis CBD significantly increased transit vehicle speeds on the distribution portion of inbound service and the collection portion of outbound service and thereby enhanced the attractiveness of the express service.

The ramp metering of I-35W and the priority access for buses produced substantially different speed results with respect to travel direction. The speeds during peak periods by direction with and without metering were as follows:

Direction	Without Metering (km/h)	With Metering (km/h)	Increase (%)
Northbound	65	80	23
Southbound	60	60	0

All ramps in the northbound direction were metered, and thus access leading to downtown Minneapolis was completely controlled. Because southbound vehicle access was not metered at all locations, the freeway operated at a lower level of service. Thus, ramp metering can only be effective in increasing transit operating speeds if all major access points to the freeway are controlled.

TRANSIT SERVICE DEPENDABILITY

Transit service dependability was based on the assumption that buses operating on the freeway without metering are subject to congestion that, in turn, results in poor schedule adherence. For this reason, any correlation between ramp metering and improved transit dependability is based on schedule-adherence performance attributable to late arrivals. Since on-time performance before ramp metering was characterized by early arrivals, regulating vehicle access on I-35W did not improve schedule adherence. Early arrivals and departures of transit vehicles were observed throughout the project on both local and express bus routes, which indicates that this problem is caused by factors outside the scope of this study (e.g., driver supervision and revised timetables that more accurately reflect actual traffic conditions). Apparently ramp metering cannot improve schedule adherence where buses tend to operate ahead of schedule; in fact, ramp metering may have a negative effect. However, on the basis of the increase in line-haul speeds and reduction in delay time, ramp metering appears to be able to substantially improve on-time performance when buses arrive late because of traffic congestion.

TRANSIT OPERATING CHARACTERISTICS

Improvements in transit system performance are ultimately measured by changes in patronage, revenue, cost, performance, and operating effectiveness. Because system operating results largely depend on local policies regarding fares and passenger loading, no numerical objectives were specified for such transit operating characteristics. In addition, the effects of exogenous factors are difficult to isolate and, therefore, an assessment of cause-and-effect relationships for the key elements of the I-35W UCDP was limited. Although no objectives were identified, several conclusions were reached regarding the following category of transit operating statistics.

Patronage

Establishing an extensive network of express bus routes produced a substantial gain in riders in the I-35W corridor throughout the three phases of the project. The large increase in express bus riders in phase 2 (Table 1) was accompanied by a modest decline in local patronage, which indicates some diversion of transit patrons from local service to the more desirable express bus routes. The gain on express service was more than sufficient to offset the decline in riders on local service. During phase 3 local patronage levels stabilized but express ridership continued to increase. These trends indicate that additional riders were former automobile users and possibly new tripmakers. A telephone survey conducted during the fall of 1974 indicated that 36 percent of the express transit users formerly drove but 10 percent never made the trip before. Although ridership changes between phases 1 and 2 can be attributed to the implementation of extensive express bus service, assigning passenger shifts between phases 2 and 3 to ramp metering is not possible since considerable service expansion was also undertaken in phase 3. However, the combined effect of improved express service in terms of increased route coverage, frequency, and higher transit speeds resulted in increased transit patronage.

Revenue

The trends described for patronage also apply to the generation of revenue in the corridor as given in Table 1. Of particular interest are the trends in average fare for express and local service during the three phases.

Phase	Express Fare (¢)	Local Fare (¢)
1	49	29
2	41	28
3	41	28

Figure 1. Study area of the I-35W Urban Corridor Demonstration Project.

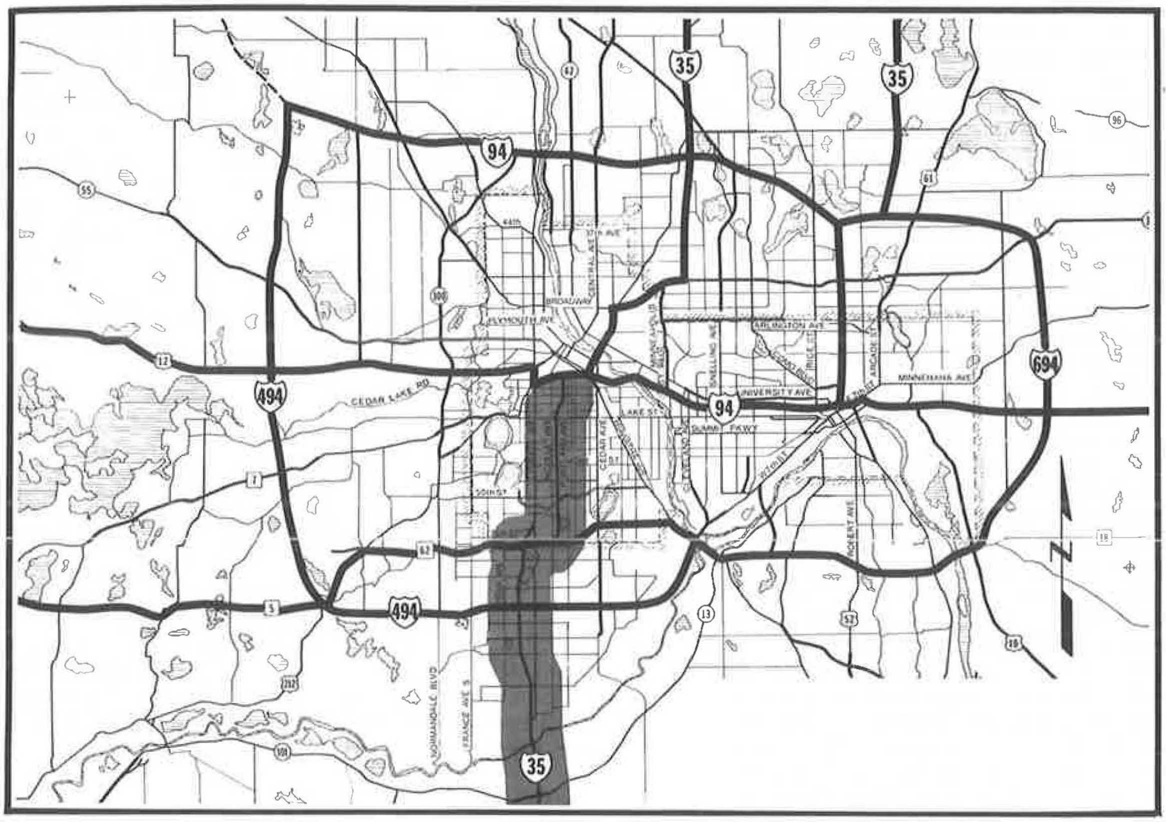


Table 1. Average weekday riders and revenue.

	Riders			Revenue ($)		
Phase	Express	Local	Total	Express	Local	Total
1	2100	22 300	24 400	1000	5400	6400
2	5400	20 800	26 200	2200	4900	7100
3	7100	20 400	27 500	2800	4800	7600

Express service exhibits higher average fares because express service is primarily used by long-distance, work-oriented riders. The initial decline in express service average fare in phase 2 resulted from the introduction of shorter express routes, many of which were not even in operation in phase 1. The local transit agency has a policy of relatively low fares on all bus service and particularly on the I-35W express routes on which the premium charge is only 5 cents regardless of trip length.

Operating Cost

Aggregate operating costs in the I-35W corridor were a manifestation of increased service levels and inflationary trends experienced throughout the 27-month study period. Given below are average weekday operating costs.

	Cost per Vehicle ($)		Cost per Vehicle-Kilometer ($)	
Phase	Express	Local	Express	Local
1	1900	6000	0.66	0.69
2	4500	6700	0.69	0.77
3	6800	7400	0.77	0.93

Based on cost per vehicle-kilometer, express service is less expensive to operate than local service, an indication of its higher operating speeds. Ramp metering encourages lower unit costs in direct proportion to the higher operating speeds on express routes produced by ramp metering. Speed-cost relationship is confirmed by the express service unit cost escalation of 17 percent (66 cents to 77 cents); the corresponding increase of local service was 35 percent (69 cents to 93 cents).

Performance

The I-35W UCDP clearly indicates that fare revenue for all service types is totally inadequate to cover operating costs. This disparity is especially true in the Minneapolis-St. Paul area where the local transit agency has adopted policies that maximize service to the public (e.g., the agency stabilized fares at relatively low levels) in spite of escalating costs. Also, decisions such as the one to purchase sufficient buses so that passengers would never have to stand have resulted in continued expansion of express service in route coverage; further, frequency in less productive transit service areas has produced higher cost/revenue ratios for all three phases. From the figures given below, we see that the cost/revenue ratio for local service is deteriorating 15 percent faster than that for express service.

Phase	Express ($)	Local ($)
1	1.86	1.12
2	2.15	1.36
3	2.47	1.54

This factor is attributable to the lower unit cost of express routes and the ability of this premium service to attract patrons. Changes in local fare policies such as premium charges for express service could substantially improve express service operating results.

Operating Effectiveness

Of particular interest in assessing transit system performance is the relationship between the demand for service and the service supplied by the system. Two widely recognized standards to determine relative performance were evaluated in this current analysis: passengers per vehicle-kilometer and passenger-kilometers per seat-kilometer. Considerable care should be exercised in making direct comparisons of express and local service because of the fundamental differences between the two forms of service. As indicated below, local service carries more passengers per vehicle-kilometer than express service.

Phase	Express	Local
1	0.73	2.11
2	0.79	2.00
3	0.76	2.11

This is not surprising since a high proportion of express service is composed of line-haul operation that neither discharges nor picks up passengers. Because of the decision to decrease local service in phase 3, and at the same time to expand express service in less productive transit service areas, passengers per vehicle-kilometer ratios can be somewhat misleading. The conclusion to be reached from the I-35W UCDP is that passengers per vehicle-kilometer for competing local service can be stabilized by appropriate reductions in service to match declining ridership. On the other hand, express service has the ability to attract new riders and thus increase passengers per vehicle-kilometer. The decline in express service between phases 2 and 3 reflects the acquisition of a private bus operator and the local decision to expand express coverage and frequency to enhance service in the corridor at the expense of operating effectiveness.

An apparent conclusion is that express service is accommodating a substantial proportion of the potential downtown transit travel market to such an extent that providing new or additional services in phase 3 has detrimentally impacted existing routes through the internal diversion of riders.

In terms of passenger-kilometers per seat-kilometer, express service maintains a superior rating over local service, as shown below.

Phase	Express	Local
1	0.444	0.548
Early 2	0.438	0.508
Late 2	0.637	0.546
3	0.583	0.546

The deterioration between phases 2 and 3 for express service and recovery for local routes reflects the local policy decision previously described.

CONCLUSIONS

Certain conclusions are directly applicable to travel corridors in other metropolitan areas; some conclusions are applicable only to local corridors. For example, conclusions relating to the impact of freeway metering on transit line-haul speeds are applicable to other urban areas; however, transit financial performance is more a function of local environment including policies relating to fares and negotiated labor agreements.

On the basis of the project results and analyses, the following conclusions appear appropriate.

1. Ramp metering can produce significant increases in transit line-haul operating speeds; however, access control to the freeway must be complete to ensure attainment of higher operating speeds.
2. Provisions such as contraflow lanes in downtown should be considered when ramp metering is instituted to ensure high-speed transit operation not only on the line-haul segments of express routes, but also on the collection and distribution segments as well.
3. On the basis of reduced incidences of traffic congestion and travel-time delays, ramp metering has the potential to improve transit schedule adherence.
4. The implementation of extensive express bus service and ramp metering can produce substantial increases in transit ridership.
5. Express bus service is less costly than local service because of higher operating speeds.
6. To the extent that operating speeds on express routes are increased by ramp metering, unit costs are lowered.
7. Although express bus service exhibits a higher cost/revenue ratio than local service throughout the project, this ratio deteriorates faster for local service because express bus service is operating at a lower unit cost and express buses are attracting new passengers.
8. In terms of route coverage and frequency of service, a point may be reached at which expansion of express bus services does not produce a corresponding increase in ridership (i.e., diminishing returns).
9. If existing facilities are used and relatively modest expenditures are made, expanded express bus service and ramp metering can provide increased mobility and encourage travel on environmentally desirable and energy-efficient modes of transportation.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

Transportation Planning for the 1980 Winter Olympic Games

Gerald S. Cohen, Richard D. Albertin, and Robert G. Knighton,
New York State Department of Transportation

Lake Placid, the site of the 1980 Winter Olympic Games, is a small community in the heart of the Adirondack Mountains of upstate New York, 160 km (100 miles) south of Montreal and 400 km (250 miles) north of New York City. The area has a permanent population of less than 3000, and lodging for guests in the immediate area is limited. However, an influx of more than 25 000 visitors is expected each day during the Olympic period.

Highway access to Lake Placid is limited to two routes: NY-86, which enters Lake Placid from both the northwest and northeast, and NY-73, which enters from the southeast. These roads are two-lane highways with numerous steep grades and sharp turns. Several stretches have low capacities and are potential areas for severe congestion under heavy traffic conditions. The problem, then, is to provide needed transportation for a large number of daily visitors over a low-capacity road network under possibly severe weather conditions.

This paper summarizes part of the transportation planning effort for the Olympics. Inventory data and standard demand techniques were used to develop peak-hour travel forecasts. Based on this analysis (and the limited funds available), the Olympic Transportation Committee proposes a bus circulation plan for Olympic visitors. This plan restricts automobile travel in the immediate area to official, resident, and other authorized use.

INITIAL PLANNING EFFORTS

The stated policy of the Lake Placid Olympic Organizing Committee is to organize the Olympics for the athletes and to return the games to a more traditional scale. This policy is being executed through four planning guidelines (1).

1. Plans must be sensitive to the environment and be prepared in consultation with local officials, environmentalists, and the Adirondack Park Agency (responsible for Adirondack Park within which Lake Placid is located).
2. No major highway or additional road capacity will be constructed exclusively for the games.
3. Known techniques will be used. The success of the Olympics is too critical to experiment with untested methods.
4. All permanent capital projects will be designed and constructed to satisfy future needs of the area.

Transportation planning responsibility was delegated by the Lake Placid Olympic Organizing Committee to the Olympic Transportation Committee. The Transportation Committee's reponsibilities include highway system analysis, public transportation coordination, traffic control, ice and snow removal, parking, and emergency services.

The first major task completed by the Transportation Committee was an inventory (2) of transportation-related facilities and services in the Olympic area. This inventory included items such as area population; overnight lodging accommodations; parking; freight handling and storage facilities; highway conditions and volume capacities; highway maintenance facilities and equipment; and airport, bus, and railroad facilities. This inventory highlighted major problems that should be analyzed in greater detail.

The next stage was to develop an estimate of the distribution of person trips by mode and direction of travel to the Olympics. These trip estimates were used to determine the highways leading to the Olympic area that would bear the greatest travel burden and to assess the approximate number and locations of peripheral parking sites that might be needed. Results indicate that about 50 percent of the visitors will use the south approach, the Adirondack Northway, and NY-73. Approximately 25 percent of the visitors will come from the north, and the remaining 25 percent will come from the west (4). If a policy of restricted ticket sales is implemented, approximately 30 000 person trips/d will be made to the Olympic area.

The New York State Department of Transportation was asked to develop a peak-hour forecast for the Olympics and to propose a feasible transportation system to handle these movements. The first step in designing a transportation system was to determine the peak hour of travel. The following assumptions were made:

1. A tentative schedule would be used,
2. A maximum of 10 000 people could enter or leave a site in an hour,
3. All events would be attended by a full-capacity crowd, and
4. The hour of maximum travel to or from the Olympic events would be the maximum travel period.

The Olympic events are expected to be held at four major locations (Figure 1). All of the skating events are to be held in Lake Placid Village. Intervale, 2.4 km (1.5 miles) south of the village, is to be the site for ski jumping. Mt. Van Hoevenberg, about 9.6 km (6 miles) south of the village, is to be the site for cross-country ski racing, biathalon, and bobsled and luge events. Whiteface Mountain Ski Center, the location of all downhill ski events, is about 12.8 km (8 miles) northeast of Lake Placid Village.

The procedure used to determine peak-hour volume was to add the number of trips made by people traveling to or from an event to the number of trips made by other people. The determination of event-generated trips could not be made merely by adding arrivals and departures from events because this procedure would double the number traveling directly from one event to another. Thus, a procedure was developed to correct for double counting.

To estimate the number of nonevent trips, we divided the people in the Olympic area into subgroups. These subgroups were permanent residents, guests of permanent residents, commercial lodgers, campers, and daily visitors. We determined the trip rates for each subgroup subjectively. We felt that daily visitors, having more places to go but fewer places to stay, would make the most trips; other visitors staying in the area

Figure 1. Locations of Olympic events.

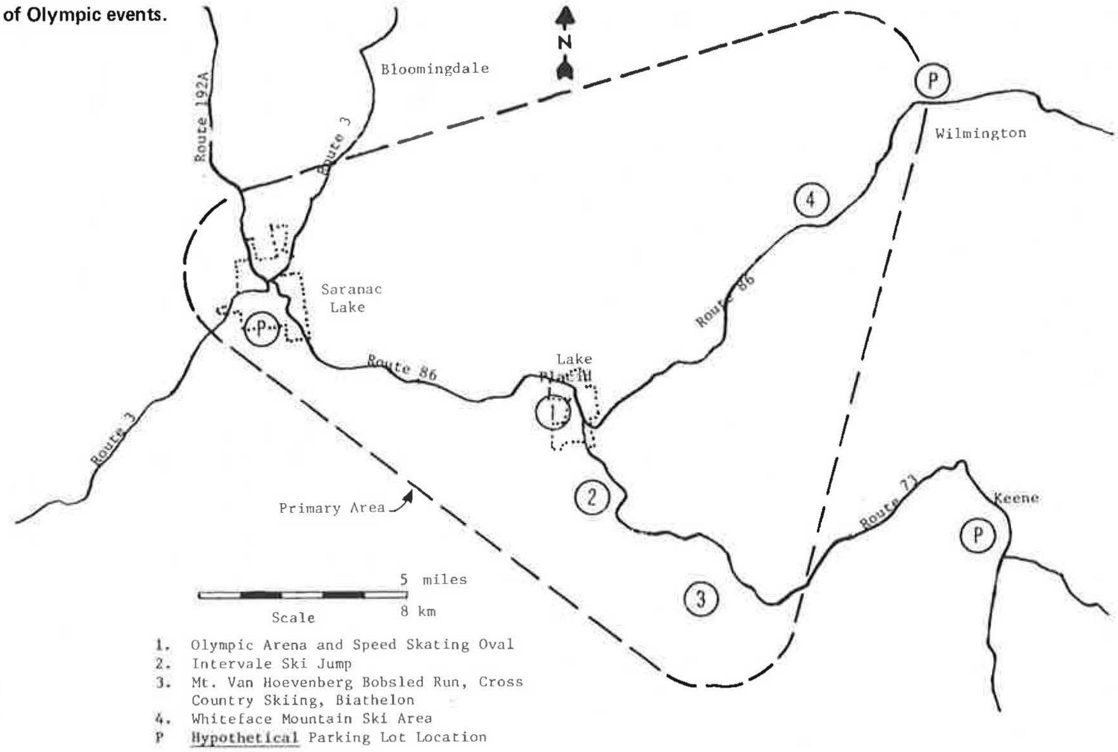
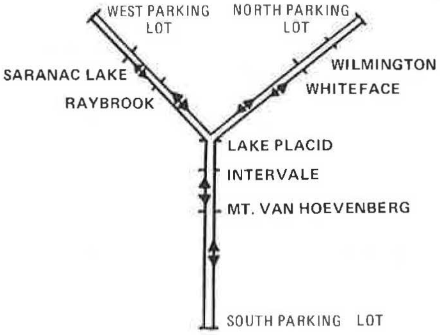


Figure 2. Double-directional bus service plan for primary area.



would make fewer trips; and permanent residents would make substantially fewer trips.

Total peak-hour travel (event and nonevent trips) was determined for the peak hour in each of five periods for every day of the Olympics. The peak hour will be Monday, February 18, between 3 and 4 p.m. During this period approximately 10 000 people will depart from the ski jump event at Intervale. In addition, many of the 8000 people who have attended hockey or figure skating events in the village of Lake Placid will also wish to travel to another event site, village, or parking lot. Nearly 24 000 trips will be made during the peak hour. To meet this demand will require 450 circulating buses. Use of automobiles must be limited to Olympic officials and service personnel. Parking lots will be provided on the edge of the primary area: southeast of Lake Placid Village on NY-73, near Saranac Lake Village west of Lake Placid on NY-86, and near the village of Wilmington also on NY-86 northeast of Lake Placid.

Once peak-hour travel was determined, a bus circulation system was designed to serve that peak travel. The design was based on the following assumptions (6):

1. Average bus occupancy will be 40 people;
2. Average bus trip will be 40 min;
3. Each bus will serve an average of 60 persons/h;
4. When trips are allocated to the parking lots, 50 percent of the trips will be to a proposed southern parking lot on NY-73 south of Mt. Van Hoevenberg and the remaining trips will be divided evenly between western and northern parking lots (based on previous analysis of direction of travel to the Olympics);
5. Of the 8000 persons departing from events held in Lake Placid during the peak hour, 2700 will remain at Lake Placid for at least 1 h, and these people will not require bus service in the peak hour; and
6. Of the people at a site where an event has just ended, 22.5 percent will wish to go to the parking lots.

Under these assumptions, a preliminary peak-hour bus system was developed that would offer the following types of service:

Type of Service	Number of Buses
From parking lot to event site	100
Express between event sites at event times	34
Local to site where event is beginning or ending	217

In addition, service for travelers who do not attend events will require 100 buses.

Each bus will make 60 trips/h; fifty will travel clockwise and 50 counterclockwise around the system (Figure 2). A counterclockwise bus, for example, will travel from the south parking lot to Mt. Van Hoevenberg, to the ski jump, to Lake Placid, to Whiteface Mountain, Wilmington, and to the north lot. The bus will return through Lake Placid to Saranac Lake and the west lot. Turning around, the bus will go to Lake Placid, the ski jump, Mt. Van Hoevenberg, and the south parking lot. These two routes should provide particularly good service for trips ending in Lake Placid. Buses will run on headways of 6 min in each direction so that a bus can pass a given location approximately every 3 min.

BUS VERSUS CAR AND SYSTEM CAPACITY

Peak-hour travel demand between Intervale and Lake Placid Village, the highest trip demand encountered on any link, will be about 10 000 person trips. An automobile occupancy of 3 persons and a bus occupancy of 40 persons would mean 3300 cars or 250 buses during the peak hour. Without restrictions, volumes of over 1000 cars/h could be expected to occur regularly on this and other routes. The limiting automobile capacities in one direction of the routes from Lake Placid to Intervale, Whiteface Mountain, and Saranac Lake respectively are 450, 450, and 560 vehicles/h in summer weather (2). Automobile demand three or four times greater than capacity and complicated further by the large number of pedestrians and adverse weather conditions would lead to an impossible traffic situation.

The person-carrying capacity of the highway network is a function of automobile capacity, proportion of buses in traffic, average vehicle occupancy, and terrain. The Highway Capacity Manual does not provide for cases in which there is an exceptionally high proportion of buses in the traffic stream (3). Therefore, we had to estimate road capacity. If buses are obtained that can maintain speed on hills and if buses maintain 80 percent or higher occupancy level, we believe that the roads are adequate for the bus system (although low system speed and high traffic density can be expected). Hence, adequacy of highway capacity to meet travel demand will be an important, perhaps critical, factor in designing an Olympic transportation system.

BUS LOADING FACILITY REQUIREMENTS

The ski jump site will have the greatest attendance capacity: 15 000 people at each event. Assuming that 1.5 h are needed for all these people to leave, approximately 10 000 people will get on or off the buses during peak 1-h periods. Based on available literature (5), 3 s/person are required to load a bus. Thus, a bus can be loaded in 2 min. Assuming an additional 1 min dead time each bus will require 3 min in a berth, and each berth will handle 20 buses/h. Since 10 000 people require 250 buses, about 13 loading and unloading points will be required. Similar estimates for other sites are given below.

Site	Peak-Hour Trips	Required Buses	Required Loading and Unloading Points
Ski jump	10 000	250	13
Mt. Van Hoevenberg	8 000	200	10
Whiteface	8 000	200	10
Lake Placid (stadium)	7 000	175	9

REFERENCES

1. C. G. Carlson and others. The Transportation Planning Process, First Report of Transportation Committee. Olympic Transportation Committee, Albany, March 1975.
2. C. E. Carlson, G. A. Stahler, and G. R. Perregaux. Transportation Inventory, XIII Winter Olympic Games, Lake Placid, 1980. Olympic Transportation Committee, Albany, Aug. 1975.
3. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
4. M. J. Vecchio and G. S. Cohen. Travel to the 1980 Winter Olympics in Lake Placid, New York: A Preliminary Analysis. Planning and Research Bureau, New York State Department of Transportation, Preliminary Research Rept. 96, Nov. 1975.
5. W. F. Hoey and H. S. Levinson. Bus Capacity Analysis. TRB, Transportation Research Record 546, 1975, pp. 30-43.
6. R. G. Knighton, G. S. Cohen, and R. D. Albertin. Travel Demand at the 1980 Winter Olympics: Estimation and Analysis. Planning and Research Bureau, New York State Department of Transportation, Preliminary Research Rept. 100, June 1976.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

An Aggregate Supply Model for Urban Bus Transit

Joel Horowitz, U.S. Environmental Protection Agency

The need to reduce air pollution, energy consumption, and traffic congestion caused by automobiles has stimulated widespread discussion of the feasibility and desirability of diverting large numbers of urban area automobile travelers to transit and car pools. Much of this discussion has been concerned with the problem of identifying measures that are effective in reducing the demand for automobile travel. The problem of characterizing transit systems that could carry a large fraction of current urban area automobile trips has received less attention than demand-related issues. Transit system characteristics that might affect the feasibility of diverting large numbers of automobile users to transit include the number of transit vehicles required, the geographical area served by the transit system, the relative travel times of transit and automobile trips, the relative costs of transit and automobile service, and the mode split that the transit system must achieve.

A possible reason for the relative neglect of these factors in the discussion of the feasibility of achieving large reductions in urban automobile traffic is the lack of a methodology that would enable aggregate characteristics of transit systems that may be quite different from current systems to be estimated relatively quickly and inexpensively for use in policy planning. Techniques like the Urban Transportation Planning System of the Urban Mass Transportation Administration tend to be too cumbersome, costly, and time consuming for use in policy planning. Simpler techniques frequently are used to compare the characteristics of alternative modes in a corridor (1, 2, 3, 4), but these techniques have not been generalized for application to an entire urban area. A model developed by the Rand Corporation (5, Appendix 4) does enable aggregate characteristics of regional transit systems to be estimated quickly and inexpensively. However, this model assumes a uniform distribution of trip ends over the transit service area and, hence, does not reflect the spatial structure of travel demand.

This paper describes a model that was developed to estimate aggregate characteristics of bus transit systems capable of carrying substantial fractions of person trips and, by implication, automobile trips in the Los Angeles area. The model can be applied to other cities and removes some of the previously described methodological difficulties. The model is based on a generalization of techniques that have been used in corridor-level comparisons of modal options (1, 2, 3, 4). The model is not intended to provide information useful in the detailed design and evaluation of transit systems. Rather, the model provides a relatively quick and inexpensive means of generating estimates of transit supply characteristics that can be used in forming preliminary assessments of the feasibility of proposals for reducing automobile travel in cities and in identifying options worthy of more detailed analysis.

STRUCTURE OF THE MODEL

The model (6) is based on traffic districts typically defined in urban transportation surveys. In the Los Angeles application of the model, 100 such districts were used. The districts were defined according to the Los Angeles Regional Transportation Study and have a median area of 64 km^2 (25 $miles^2$).

The demand for transit trips is developed from exogenously specified, district-level person trip tables and exogenously specified, transit mode-split factors. The trip tables give the number of person trips per hour between each pair of districts according to trip purpose and time of day. The mode-split factors give the fraction of trips of each purpose that will use transit if service is provided between their origin and destination districts. The mode-split factors do not represent projections of the demand for transit travel. Rather, they are parameters of the model that are used to establish supply-side relationships between transit mode split and other characteristics of the transit system.

A transit system that carries a substantial fraction of the trips in an urban area must serve suburban trips as well as trips oriented to the central business district. Consequently, the model is designed to estimate the characteristics of transit systems that serve trips whose origins and destinations are diverse and spread over a large geographical area. The model provides two types of transit service:

1. Interdistrict service provides limited-stop, line-haul service for trips whose origins and destinations are in different districts; and
2. Intradistrict service (a) carries trips whose origins and destinations are in the same district, (b) provides collection and distribution service for interdistrict trips, (c) enables trips with widespread and diverse origins and destinations to be served, and (d) enables the model to use the geographically aggregated travel data normally available in urban area transportation surveys. The intradistrict service design, however, does not permit the optimization of bus service in high-density corridors.

Bus service is provided in areas where the volume of person trips exceeds an exogenously specified threshold, and transit trips in these areas are assigned to bus routes on an idealized street network. Buses are assigned to the routes in sufficient quantities to both accommodate the demand for transit trips and achieve or exceed an exogenously specified minimum schedule frequency. Average transit travel time is computed from estimates of average walk and wait times, in-vehicle distances, and bus speeds. Average transit cost per trip is computed from estimates of the purchase prices of buses and auxiliary facilities (yards, shops, and stations) and from estimates of the relationship among bus-kilometers traveled, bus hours of operation, and bus operating cost. The average travel time and cost per trip that would be incurred if all transit trips were carried in automobiles also are computed. Through repeated runs of the model using different levels of transit mode split, threshold trip volume for providing bus service in an area, and minimum schedule frequency, relationships among total number of transit trips, transit service area, the transit mode split that must be achieved in the transit service area, transit schedule frequency, number of buses needed, average travel times, and average travel costs are developed.

APPLICATION OF THE MODEL TO LOS ANGELES

The Los Angeles application was based on travel data obtained from the Los Angeles Area Transportation Study. Transit service was provided during three periods of the day: morning peak (6 a.m. to 9 a.m.), afternoon peak (3 p.m. to 6 p.m.), and off peak (9 a.m. to 3 p.m. and 6 p.m. to 8 p.m.). Collectively, these three periods account for 88 percent of daily person trips in the Los Angeles area. No service was provided between 8 p.m. and 6 a.m.

The relationship among total transit trips, transit service area, mode split to transit in the transit service area, fleet size, minimum service frequency, average travel time, and average travel cost that was developed in the Los Angeles application is summarized in Table 1. Additional results of the model are presented in a previous study (6). In Table 1 the total number of transit trips is expressed as a percentage of total 6 a.m. to 8 p.m. person trips in the Los Angeles area. Transit service area is defined by the trip threshold for providing service on a potential bus route. Travel times and travel costs respectively are expressed as the difference between average transit travel times and costs per trip and the average times and costs per trip that would result if all transit trips took place in automobiles. Automobile travel times and costs per trip typically are in the ranges 17 to 19 min and 40 to 50 cents respectively, depending on the geographical coverage of the transit system. The transit mode splits in Table 1 are averages over all trip purposes and represent the mode splits that must be achieved in the transit service area if the indicated travel times, travel costs, and transit trip volumes are to be achieved. They are not projections of the mode splits that would

Table 1. Characteristics of Los Angeles transit options.

Daily 6 a.m. to 8 p.m Trips Using Transit (%)	Difference Between Avg Transit and Automobile Trip		Trip Threshold Volume[a]	Transit Mode Split Required in Service Area (%)	Number of Buses in Fleet	Min Service Frequency on Intradistrict Routes[b] (buses/h)
	Cost (¢)	Time (min)				
10	0	15	2350	61	3 500	16
10	0	20	2000	28	3 000	8
10	10	15	2200	48	5 000	17
20	0	15	2100	68	7 000	17
20	0	17	1700	45	9 500	11
20	0	20	1450	33	7 500	8
20	10	15	1950	55	8 500	19
30	0	15	1850	76	11 000	17
30	0	20	750	39	15 000	9
30	10	15	1675	63	13 000	21
50	0	15	1500	90	18 000	18
50	0	20	225	53	28 000	9
50	10	15	1250	77	23 000	24

[a] To provide service on a potential transit route.

[b] Min service frequency on interdistrict routes in 5 buses/h.

result from the implementation of the various options.

The Table 1 results show that carrying a substantial fraction of Los Angeles person trips on bus transit is possible at a cost per trip that is comparable to the cost of automobile travel and with average travel times that are within 15 to 20 min of automobile travel times. However, this requires bus fleets and transit mode splits that are quite large by current standards. The fleet and mode split requirements are further discussed below. Although not shown in Table 1, the difference between bus and automobile costs increases rapidly as the difference between bus and automobile travel times decreases from 15 min. Based on the bus service policies assumed in the model, bus travel times that exceed automobile travel times by less than roughly 12 min are not possible.

A fleet of 3000 to 5000 buses, depending on operating policies, is needed to carry 10 percent of 6 a.m. to 8 p.m. trips. To carry 20 percent of 6 a.m. to 8 p.m. trips, a fleet of 7000 to 9500 buses is needed. The current Los Angeles fleet has approximately 2500 buses and carries approximately 3 percent of daily trips.

High transit mode splits are needed to achieve the travel times and costs given in Table 1. When 10 percent of daily trips are carried by transit, 28 to 61 percent of the trips in the transit service area must use transit if an average transit travel time within 15 to 20 min of the average automobile travel time and a cost of transit travel comparable to the cost of automobile travel are to be achieved. The required mode split to transit increases as the fraction of daily trips using transit increases. All-day mode splits to transit that exceed 28 percent are found in some European cities. In the United States transit mode splits of 28 percent or more are usually experienced only during peak periods. Achieving the transit ridership levels and transit times shown in Table 1 with mode splits below the tabulated values would substantially increase the average cost of transit trips. For example, if the mode split to transit in the transit service area were 15 percent, then transit travel would be at least twice as costly as automobile travel, depending on transit operating policies.

The transit service described in Table 1 has a minimum schedule frequency on intradistrict routes of 8 to 24 buses/h, depending on ridership and operating policies. This minimum frequency range applies to suburban routes as well as central-area routes. Schedule frequencies equaling or exceeding these values are common in the central areas of U.S. cities, particularly during peak periods, but are not common in suburban areas.

CONCLUSIONS

The results presented here suggest that, to achieve the diversion of a large fraction of Los Angeles automobile travelers to bus transit, transit schedule frequencies and mode splits must be maintained systemwide and all day at levels that normally are experienced in U.S. cities only during peak periods and in central areas. Depending on the fraction of travelers that use transit, substantial increases in the bus fleet size may be needed.

The model on which these conclusions are based produces results that are qualitatively reasonable and not highly sensitive to the structural idealizations of the model (6). This fact suggests that the model is free of serious errors and instabilities. However, the model does have some significant limitations. One of its limitations is reliance on exogenously specified trip tables and mode-split factors. The implementation of policies to achieve high transit mode splits undoubtedly would change the magnitude and geographical distribution of travel demand as well as travelers' mode choices. The effects of such changes on transit system characteristics and the interactions between system characteristics and travel demand are not treated by the model and are not reflected in the results presented here.

Another limitation of the model is that it treats only one service concept: fixed-route, fixed-schedule service with separate collection-distribution and line-haul vehicles. Moreover, this service concept is evaluated by using district-level aggregate travel data. Other service concepts, such as various forms of paratransit and integrated service in high-density corridors, might be less costly or time consuming under some circumstances. Improvements in transit performance also might be achieved through the use of system designs that reflect subdistrict variations in the spatial distribution of trips.

A third limitation of the model is that it is static. Transportation changes of the magnitudes needed to divert large numbers of automobile travelers to transit will take many years to implement. During the implementation period, travel demand, supply of roadway facilities, and costs of travel by bus and automobile, among other factors, are likely to change in ways that depend, in part, on transportation policy. However, the model assumes that all factors influencing transportation system characteristics have fixed values. The effects of long-term changes in these factors caused by transportation policy or exogenous influences are not treated.

Despite these limitations, the model provides useful information on some of the transit supply implications of efforts to reduce automobile travel in cities. Specifically, the model gives estimates of fleet sizes and operating policies that would be needed to accommodate varying degrees of reduction in automobile travel. These estimates are important complements to the results of demand-side studies of the feasibility and desirability of policies to reduce automobile travel in cities.

ACKNOWLEDGMENT

I thank David Syskowski of the Environmental Protection Agency for his invaluable assistance in developing and operating the computer programs used in applying the model to Los Angeles. The views expressed in this paper are mine and are not necessarily endorsed by the Environmental Protection Agency.

REFERENCES

1. J. R. Meyer, J. F. Kain, and M. Wohl. The Urban Transportation Problem. Harvard Univ. Press, Cambridge, Mass., 1965.
2. J. H. Boyd, N. J. Asher, and E. S. Wetzler. Evaluation of Rail Rapid Transit and Express Bus Service in the Urban Commuter Market. Institute for Defense Analyses, Oct. 1973; U.S. Department of Transportation, Rept. DOT P 6520.1.
3. K. Bhatt. Comparative Analysis of Urban Transportation Costs. TRB, Transportation Research Record 559, 1976, pp. 101-116.
4. T. E. Keeler, L. A. Merewitz, and P. Fisher. The Full Costs of Urban Transport. Institute of Urban and Regional Development, Univ. of California, Berkeley, Monographs 19, 20, and 21, 1974-1975.
5. J. H. Bigelow, B. F. Goeller, and R. L. Petruschell. A Policy-Oriented Urban Transportation Model: The San Diego Version. Rand Corp., Rept. R-1366-SD, Dec. 1973; San Diego County Environmental Development Agency.
6. J. Horowitz. Transit Requirements for Achieving Large Reductions in Los Angeles Area Automobile Travel. U.S. Environmental Protection Agency, Rept. EPA/400-11/76-001, Nov. 1976.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Orlando Changes Direction: From Beltway to Busway

James W. Lee and David L. Grovdahl, East Central Florida Regional Planning Council, Winter Park
Marvin C. Gersten and Peter O. Sucher, Howard, Needles, Tammen and Bergendoff, New York

This paper reports on the long-range phase of an overall urban area transportation study in a three-county area centered on Orlando, Florida. The paper focuses on a major shift in perspective regarding solutions to future travel demand problems. Discussed are five transportation system alternatives with various combinations of automobile-oriented and transit-oriented systems and two major aspects of the study methodology: (a) the formulation of a land use sketch plan designed to be more compatible with a future transit system and (b) the development of a disutility modal-split model based on transit attitudes. Transportation system alternatives are defined, and the evaluation and public involvement processes that led to the selection of a preferred alternative plan are described. The implementation of the plan through a short-range transition period is described, and eight major conclusions and observations are given.

The Orlando urbanized area is in central Florida approximately 88 km (55 miles) from Daytona Beach on the east coast and 135 km (84 miles) from Tampa on the west coast. The area consists of approximately 4265 km^2 (1647 miles^2), includes Orange, Seminole, and Osceola counties, has a present population of 615 423, and an employment base of 249 900.

The area maintains a tourist economy encouraged by the presence of Walt Disney World, Sea World, and several other attractions and is slowly developing into a convention, financial, and governmental center. The Orlando Jetport, which has received international port status and the designation as a free-trade zone, has launched into a large-scale expansion plan involving a new $100 million terminal.

STUDY OBJECTIVES

This study was a part of the continuing Orlando Urban Area Transportation Study (OUATS) that began in 1965 under the guidelines of the Federal-Aid Highway Act. The purpose of the OUATS was to conduct the necessary analysis to permit development of a 1985 transportation plan that would meet both highway and mass transportation travel demands. The 1965 OUATS emphasized the improvement of the metropolitan highway system and placed little importance on transit.

Shortly after completion of the OUATS in 1968, tremendous growth began to occur in the Orlando urban area. This growth was initiated by such major developments as Walt Disney World, Sea World, the U.S. Naval Training Center, and Florida Technological University. Population grew almost 25 percent in 3 years, and Orlando became one of the fastest growing metropolitan areas in the country.

To accommodate these changing conditions, OUATS was revised in 1970 to develop a 1990 transportation plan. The initial result was another highway-oriented plan that included, as a carry-over idea from the initial 1965 OUATS, a metropolitan beltway (1). Mass transit was assumed to capture only 1 percent of the total trips in 1990, the same as it had done in 1970.

This beltway plan was questioned as to its assumption regarding future mass transportation, and the outcome was a proposal to conduct a long-range transit study. The primary objective of the long-range transit study was to reevaluate the traditional highway-oriented plan and investigate the potential for a significantly improved transit system to provide a more balanced and flexible solution to future travel demand in the booming Orlando urban area. Secondary objectives were to

1. Develop a land use plan that would be less dependent on construction of highways and thus discourage further urban sprawl;
2. Develop a transit demand forecasting model that could be easily updated for future planning purposes;
3. Test more than one alternative mass transit plan to assure both highway and transit supporters that all feasible solutions had been investigated;
4. Provide an estimate of future operating and capital costs and analyze all available funding sources, including fare-box revenues, for each of the transit systems tested;
5. Determine the feasibility, site selection, and cost estimates for a central downtown terminal and any required satellite terminals; and
6. Investigate the feasibility of relocating the Seaboard Coast Line Railroad for the purpose of using an exclusive existing transit right-of-way.

STUDY ALTERNATIVES

The 1970 OUATS update provided a strictly highway-oriented plan for 1990 that indicated minimal transit feasibility. The long-range transit study called for a more objective look at mass transit and assumed that no beltway would be built. Thus from these two alternatives the most optimistic highway and transit plans could be studied.

Shortly after work began on the long-range transit study, the decision was made to expand the study to include a middle approach to the undecided all-beltway or no-beltway predicament. Additional analysis was planned to investigate the future potential of transit and its effects in relieving highway congestion if only the eastern leg of the beltway were to be developed or if only the western leg were developed. After these four alternatives were agreed on, a final alternative was added: Because of the downward trend in economic conditions and resulting funding constraints, no improvements would be made to either the existing highway network or the transit system beyond those improvements already committed by the local, state, and federal governments. The five alternative transportation systems can be summarized as follows:

1. No beltway and high transit,
2. Full beltway and low transit,
3. East beltway and moderate transit,
4. West beltway and moderate transit, and
5. No beltway and modest transit.

STUDY METHODOLOGY

Land Use Sketch Plan

Because of the very low transit service levels and the sprawl pattern of land use development assumed in the 1990 projections, the daily travel demands of the region were foreseen as being met primarily by automobile on an extensive network of existing and proposed new highways. However, projections of revenues and costs indicated that only 60 percent of the required funds would be available to construct the recommended highway plan.

These factors led the East Central Florida Regional Planning Council (ECFRPC) to initiate a sketch-planning approach for the transit study to develop a more compact land use pattern envisioned to result in a transportation system less dependent on construction of additional highways (2). The sketch-planning process assembled a team of professionals familiar with the tricounty area to identify regional growth forces and constraints and to project development over the next 15 years. The team initially developed a map that embodied the consensus of opinions as to the direction of growth and development. Next, projections were made regarding the magnitude of growth expected in identified growth areas. All traffic zones in the urbanized area were divided into three categories.

1. No-growth zones were those zones that were completely developed by 1970 and unlikely to be redeveloped.
2. Residential growth zones were those zones that showed potential for additional development based on both land availability trends and accessibility.
3. Employment growth zones were those zones that showed potential for employment-oriented growth based on trends, available land, and conversion potential.

The additional population and employment anticipated between 1970 and 1990 were allocated on an individual zone basis to the designated growth zones. All other zones remained at 1970 levels. In general, zones adjacent to such major transportation routes as the I-4 corridor were assigned the population growth. Downtown Orlando was allocated the major employment growth.

Attitude Survey and Modal-Split Model

While the sketch land use plan was being prepared, the transit study work program, comprising seven major tasks, was initiated: literature review, survey research, model development, program development, input preparation, program processing, and long-range planning. The first four tasks were designed to obtain a regional modal-split forecasting procedure based on community attitudes and also to establish criteria for planning a regional transit system (3). The information obtained from the community attitude survey conducted as part of survey research included

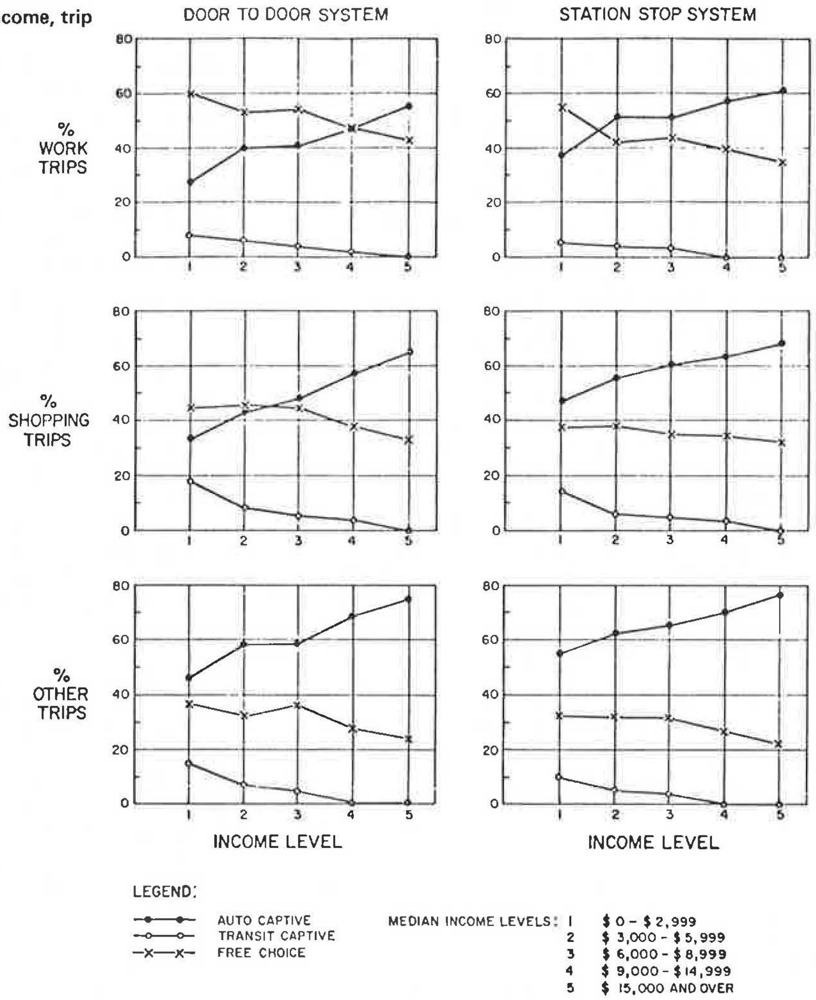
1. Attributes considered by Orlando area residents as important in satisfying their perceived acceptable transportation service;
2. Minimum levels of service necessary to generate significant patronage on a regional transit system;
3. Trip purposes for which the future public transit system would be used; and
4. Determination of automobile-captive, transit-captive, and free-choice ridership for different system alternatives, trip purposes, and income levels.

This determination of captive versus free-choice ridership permitted use of a universal free-choice modal split versus disutility difference model for forecasting future transit ridership and automobile person trips on alternative regional transportation systems (4). The captive and choice ridership data plots are shown in Figure 1.

The basic steps of the model performed by a computer program, written as a FORTRAN subroutine inserted into the UMODEL program of the Urban Transit Planning System (UTPS), are as follows:

1. Obtain mean income level of zone of origin;

Figure 1. Captive and choice ridership by income, trip purpose, and system.



2. Obtain total person trips in trip interchange pair;
3. Obtain percentage of automobile-captive, percentage of transit-captive, and percentage of free-choice riders for the particular system being tested, trip purpose, and income level;
4. Compute cost of time for this income level as 25 percent of wage rate per minute implied by annual income for the zone;
5. Obtain service levels for this trip pair from transit and highway networks, including travel running time, walking time, waiting time, transit fare, parking cost, and highway distance;
6. Compute disutility difference by using convenience weighting of 2.5:1, running time and cost weighting of 1.0:1, cost of time from step 4, service levels from step 5, and vehicle operating cost per kilometer;
7. Find the point of universal free-choice curve corresponding to disutility difference and read off percentage of transit usage of free-choice riders;
8. Multiply percentage of automobile-captive, transit-captive, and free-choice riders by total person trips to get number of person trips in each category;
9. Multiply number of free-choice person trips by percentage of transit users determined in step 7 to get number of free-choice transit person trips; and
10. Add free-choice and transit-captive person trips to get total transit trips for zone-to-zone interchange.

1990 Forecast

Zone-level land use, population, and employment forecasts based on the previously described sketch-planning process became the input to standard trip generation and distribution models developed in earlier studies by the Florida Department of Transportation. Individual trip purpose generation and distribution models were processed for home-based trips, work, personal business, social-recreational, shopping, and school trips, and for non-home-based trips. These purposes were compressed for modal-split forecasting into three categories as shown in Figure 1.

The attitude survey results permitted the stratification of captive and choice ridership percentages by two general system types: a door-to-door system with a high level of service and a fixed-corridor system with station stops. Overall ridership percentages (rounded off) for all income groups indicated that total potential ridership on a future transit system would be lower for the station-stop system that requires intermodal transfers than for the door-to-door system of regional express, arterial, and local bus routes at frequent route spacing.

At zero difference between transit and automobile, free-choice transit work trips on a door-to-door system would be 25.5 percent of the total work trips and 21 percent on the station-stop system. Addition of captive transit riders would result in a total transit work-trip ridership of 28.5 percent on the door-to-door system and 23 percent on the station-stop system. Similarly, for shopping trips, the percentages would be 25 percent transit trips on a door-to-door system and 21.5 percent on the station-stop system. The other-trip category showed nearly equal percentages for both systems.

For the operation of the modal-split model, transit and highway networks were designed, coded, and processed to obtain zone-to-zone system service characteristics for each transit-intensive regional transportation system alternative. The resulting 1990 daily travel forecasts indicated total 1990 average daily transit trips ranging from 6.3 percent to 7.9 percent of total daily person trips; the lower percentage was found on the rapid transit fixed-guideway system alternative. Corresponding average annual ridership estimates, based on an annualization factor of 294, ranged from 66.8 to 84.2 million passengers. By comparison, forecasts prepared for alternative 2, full beltway and low transit, and alternative 5, no beltway and modest transit, indicated about 1.0 percent of total daily person trips to be on the minimal transit systems, or about 10 million annual passengers. Transit ridership during the 1974-1975 study period on the existing Orange-Seminole-Osceola Transportation Authority transit system was 2.4 million passengers, or 1.0 percent of the urban area's person trips. The transit forecasting procedure indicated a potential increase of about 600 percent in modal split or a 35-fold increase in transit ridership during the 1975 to 1990 planning period if the present bus system is expanded to a regional system with maximum coverage and a high level of service. This expansion would require an increase in bus fleet size from the current 40 buses serving the study area population of approximately 615 000 to nearly 600 buses for an estimated 1990 population of 1 million.

LONG-RANGE PLANNING

Regional transit corridors were defined as links between major activity centers, special generators, high concentrations of employment, and multiple-unit housing. Projections for 1990 obtained by the ECFRPC sketch-planning procedure were used as the basis for identifying these major transit trip generating areas. Zones with at least 1000 employees or at least 100 multiple-unit dwellings were specifically noted. Within the resulting eight major travel corridors identified between these major activity areas, potential transit routes were selected by using, as much as possible, existing right-of-way. Any of several alternative long-haul transit vehicles could operate along these corridors, e.g., express buses on exclusive busways, rail rapid transit, and transit expressway vehicles.

Alternative Transit Systems

Several different levels and combinations of transit modes were considered to accommodate regional corridor transportation requirements. The following five alternatives were developed; however, budget constraints dictated that only alternatives 2 and 4 could be selected for detailed analysis:

1. Preferential treatment for buses on existing highway facilities,
2. Busway in the median of I-4 in the north-south travel corridor,
3. Capital-intensive regional busway system,
4. Fixed-guideway system (either light rail transit, transit expressway, or conventional rapid transit) in a north-south corridor and an east-west corridor, and
5. Regional fixed-guideway system served by a feeder bus system or other local circulation modes.

Alternative 2

Following the requirements of the Urban Mass Transportation Administration (UMTA) transit network coding system, express buses using the I-4 busway, buses using arterial streets, and local circulator and feeder systems were each assigned different mode numbers. This coding permitted each type of service to be designed and analyzed separately. Moreover, initial bus headways and maximum waiting times were selected on the basis of the community attitude survey findings, 15-min maximum for daytime peak periods.

Typical sections of the proposed I-4 median busway area were evaluated with a preliminary plan of the busway and an interchange modification at South Street in downtown Orlando. This improvement would provide access from I-4 north and south to the central business district (CBD) via the existing three left ramps and a new ramp from the south. These ramps, as well as the median lanes, would be designated for use only by buses and car pools during peak traffic periods. The lanes would be open for use by all traffic during other times.

Using projections of the 1990 volume of peak-hour buses and vehicular traffic volumes and applying guidelines developed in a recent NCHRP study (5), we determined that a 25-km (15-mile) section of I-4 would warrant this preferential roadway.

The preliminary cost estimate of this two-lane median roadway and CBD ramp modification was $23.1 million. Supporting facilities including a central transportation terminal, park-and-ride areas, and maintenance facilities were estimated at $22.8 million for a total cost for the busway of $1.86 million/km ($3.1 million/mile).

Using initial 1990 estimates of approximately 19 express routes feeding into the Orlando CBD and local and arterial service adding another 7 routes, all operating at 15-min intervals, we estimated that 104 buses would enter the downtown area during the peak hour. Scheduling these buses to circulate on local streets would increase traffic congestion, raise pollution levels, and generally detract from the image of the Orlando CBD. We concluded that the all-bus transit alternatives would require construction of a central bus terminal to which most CBD-bound express routes would go. Preferential ramps from the bus-car pool roadway and special contraflow lanes would be provided for direct bus access to the terminal. In addition to the downtown bus terminal, the plans provided for park-and-ride facilities, outlying terminal areas, and demand-responsive service.

This I-4 median busway alternative with its supporting facilities was essentially common to regional transportation system alternatives 1, 3, and 4: no-beltway, east-beltway, and west-beltway. Although express, arterial, and local bus routes varied, the 25-km (15-mile) busway and downtown terminal were found to be warranted for each.

Alternative 4

The fixed-guideway system included an 83-km (50-mile) north-south route linking Sanford in Seminole County to the Orlando CBD, Disney World, and Poinciana in Osceola County. Also included was a 28-km (17-mile) east-west route extending from the Pine Hills vicinity of western Orange County to the Orlando CBD, east to the Colonial Plaza-Herndon Field major shopping center area, and south to the Orlando Jetport at McCoy. Both routes would be served by feeder systems that would include local fixed-route buses, demand-responsive operations in residential areas, and bus or people-mover circulation systems at major activity centers.

Table 1. Preliminary cost estimates of three transit systems.

Corridor	Distance (km)	Rail Rapid Transit ($)	Transit Express-way ($)	Light Rail Transit ($)
North-south from Sanford to Orlando CBD in	32			
I-4 Median		7.02	2.46	2.04
Seaboard Coast Line Railroad right-of-way		7.86	3.00	2.58
North-south from Orlando CBD to Poinciana in I-4 median	48	6.78	2.34	1.92
East-west from Pine Hills to Orlando CBD in East-West Expressway median	9	9.60	3.78	3.90
East-west from Orlando CBD to jetport in McCoy	19	8.16	3.18	2.94

Notes: 1 km = 0.6 mile.
Values are in millions of dollars per kilometer.

Park-and-ride facilities at station stops would also be required.

Two potential alignments of the 33-km (20-mile) north-south corridor north of the Orlando CBD were considered. The first was in the median of I-4, and the second was within or parallel to the right-of-way (ROW) of the Seaboard Coast Line Railroad. South of the Orlando CBD one alignment, within the I-4 ROW, was assumed.

Initial requirements for alternative transit systems were based on preliminary station locations, maximum speed, headway and dwell times, and varying ridership assumptions. Final requirements were based on computer network assignments. Preliminary cost estimates were then prepared for three types of fixed-guideway transit systems: rail rapid transit, light rail transit, and transit expressway. These estimates were based on available unit cost information (6, 7) for the three systems, escalated to 1975 dollars, and applied to estimates of physical facility requirements including structures, track and trackbed, communications, power, stations, and maintenance plan. The resulting cost estimates (excluding rolling stock) are summarized in Table 1.

As indicated, both the light rail transit and transit expressway systems were similar in average construction costs, in the range of \$2.04 million to \$3.0 million/km (\$3.4 million to \$5.0 million/mile). The conventional rail rapid transit system was nearly three times as costly as the light rail system. In the northerly section of the north-south corridor, the Seaboard Coast Line Railroad alignment was more costly for all three transit systems. These higher costs combined with the many operational problems envisioned for joint use of the active Seaboard Coast Line Railroad ROW alignment north of the Orlando CBD eliminated this alternative corridor alignment from further consideration.

PLAN EVALUATION

To analyze the proposed regional system alternatives required that a set of evaluation criteria be formulated that could be applied equally to each system alternative. Three major categories of evaluation were established: economic costs, travel service, and environmental impact. Sufficient criteria were defined to enable local officials responsible for selecting the final alternative to base their decisions on accurate, detailed estimates of impact.

For each of the five transportation alternatives estimates of the measurement items were prepared by using results of the transit and highway network assignments, recent bid prices on transit and highway projects, Florida Department of Transportation (DOT) environmental computer programs, data on transit and automobile operating costs and travel time values, and a handbook assembled by UMTA listing characteristics of various transportation systems (8).

Summary of Data

Evaluation of the resulting cost and impact estimates indicated that no one alternative could be identified as significantly superior in all categories. Alternative 5 displayed a marked advantage because it was about one-third as costly as the other alternatives. This advantage substantially decreased, however, when the significantly greater vehicle operating costs, travel time costs, and accident costs of alternative 5 were taken into consideration. At the other end of the scale alternatives 2, 3, and 4, each of which featured some type of beltway facility, were all in an approximate 1 percent cost of each other.

Alternative 5 ranked last in travel service. The other four alternatives were all within 4 percentage points of one another in providing good highway travel service (as measured by a level of service C or better). Of these four alternatives, the transit systems developed for alternatives 1, 3, and 4 were similar in that each provided high areawide coverage, good service frequency, and comparable estimated annual patronage of over 80 million passengers.

Environmental impact results were scattered. Alternative 5 had the highest energy consumption and air pollution figures because of its inability to satisfy travel demand, which in turn created lengthy travel time delays. Again alternatives 1, 3, and 4 were quite similar in providing the lowest energy consumption and air pollution figures. However, when the criteria of the effect on water quality and community disruption were examined, alternatives 2, 3, and 4 had the greatest adverse effect. This conclusion was reached because of the facility's proximity to major water recharge and surface runoff areas and also because of the relatively high numbers of families and businesses that the facility displaced.

No clear-cut overall advantages were displayed by any one alternative.

Evaluation Process

An extensive public involvement process was used to explain the data results to the area's citizens and to provide for the feedback of their comments, criticisms, and suggestions. Initial interest in the study results was generated by a series of newspaper articles and news releases followed by a public seminar. This approach brought forth several of the previously hidden influence groups in the area and served to further publicize the decision-making process. The seminar was immediately followed on successive nights by public hearings, one each in Orange, Seminole, and Osceola counties. At these public hearings, a polarization of support for particular alternatives became evident as the groups evaluated the data results in terms of their own interests. For example, the environmental issues were sensitive to such groups as the Sierra Club and the League of Women Voters, who perceived alternative 1 as best fulfilling the goals of energy conservation and control of air and water pollution. Other groups in the western part of the Orlando urban area supported alternative 4 because of the economic development advantages that it promised for the outlying municipalities on the west side. Citizens from comparatively rural Osceola County, on the south and southeast side of the Orlando urban area, believed that travel service was of primary importance and generally supported alternative 2. Since each of the alternatives best fulfilled the goals of only one interest group, the problem became the determination of the alternative that best fulfilled the overall goals of the whole region.

A key factor that emerged in the decision-making stage was the flexibility of a particular system alternative. Concern was expressed repeatedly over the unpredictability of future gasoline prices, availability of fuel, federal and state funding programs, and so forth. Nevertheless, committee members felt that action of some type was preferable to the relative inaction of alternative 1. The Transportation Technical and Citizen Advisory committees ranked alternatives 1 and 3 as their top two choices although in different order. The issue was settled when the Transportation Policy Committee, as the decision-making body of the OUATS, selected alternative 1 as the official 1990 plan.

PLAN IMPLEMENTATION

Development of a realistic staging strategy for implementation of a long-range plan was an important objective in this study. Consequently, a transition period (from 1976 to 1981) was established to define those short-range improvements to the existing system that will evolve into the adopted long-range plan.

The capital improvement program for the transition period will consist of 135 buses, 50 of which are either in service or in the process of being acquired. An expanded downtown terminal will require 24 berths; satellite park-and-ride lots, transfer sites, and terminals will be developed. The existing garage-maintenance facility will be expanded by more than 50 percent of its present size, and additional miscellaneous equipment and shelters will be purchased. For this entire improvement program, a total of $9.9 million and $9.4 million will be required for capital and operating costs respectively between 1976 and 1981, based on current estimates escalated to account for anticipated price increases over the 5-year period.

The table below gives state and local matching dollars required to receive federal funds.

Costs	Federal	State	Local	Total
Capital				
Section 5	4 182 000	522 750	522 750	5 227 500
Section 3	3 738 000	467 250	467 250	4 672 500
Subtotal	7 920 000	990 000	990 000	9 900 000
Operating				
Section 5	4 718 000		4 718 000	9 436 000
Total	12 638 000	990 000	5 708 000	19 336 000

As indicated, the Florida DOT will have to match approximately $1.0 million and the Orlando urban area will have to raise $5.7 million. Present local commitments fall short of the required match; only $2.9 million can be committed to the total $5.7 million required, which will leave a deficit of approximately $2.8 million to be raised locally. To implement the program in this time period, a strong local commitment to regional transit improvements will be required, both to ensure availability of maximum matching funds under section 5 of the National Mass Transportation Assistance Act of 1974 and to generate justification for the allocation of additional capital assistance funds under section 3.

The similar transition period for highway improvements requires $222 million, and only $88 million is available in federal, state, and local roadway funds.

Possible sources of local funds are available to support transportation improvements in the tricounty region. The requirement of state legislative action restricts the local counties from using most of these sources, except for gas and ad valorem taxes. Recently the state has recommended that local governmental bodies increase gasoline taxes by 1 cent (9). This tax would provide an estimated annual minimum $4.2 million.

CONCLUSIONS AND OBSERVATIONS

1. The decision to adopt a transportation plan without a beltway represented a major shift in thinking in the Orlando urban area from the 1973 support of the beltway. Furthermore, this decision was viewed by citizens, planners, and policy officials as a zoning decision away from sprawl and toward a more compact land development pattern. This point was perfectly summed up by the following statement from the local Seminole County, Florida, League of Women Voters.

> We view roads as development tools which can wisely be used to plan the growth of a community. Construction of a beltline and the concurrent development that would accompany it would put an unnecessary strain on already overburdened taxpayers and local governments to provide essential services.

2. Certain major events transpired during the study that may have affected its outcome. Initially, the energy crises of 1974 emphasized the uncertainty of future motor fuel prices and supplies. This uncertainty caused many officials to feel that inadequate energy conservation programs plus minimal commitment toward mass transit could severely limit the capacity of the area to prosper should another fuel shortage hit the country. Consequently, these officials favored alternative 1 as the most flexible approach to solving future transportation problems without jeopardizing the area's prosperity. Another major event that supported emphasis toward transit was the National Mass Transportation Assistance Act of 1974. This act appropriated approximately $7.8 million for the Orlando urban area through 1980. The availability of these funds and the threat of returning several million dollars to the federal government because of a lack of local matching funds may have been a contributing factor in supporting the chosen alternative. Furthermore, the shortage of highway construction funds did not help the highway interests in their effort to support the beltway alternative.

3. The large financial transportation costs estimated for the selected alternative suggest either that the local area make a stronger commitment toward achieving a slower growth rate or that area officials make a stronger commitment toward financing the required transportation improvements.

4. The area has continued to experience serious problems in financing its local toll roads. During its first year of operation, the East-West Expressway through downtown Orlando suffered an operating deficit of over $2 million that had to be subsidized by Orange

County road funds, and almost 60 percent of the county's major road funding source for that year was depleted. The heavy losses did not support any of those alternatives that included the beltway.

5. The decision reached definitely indicated support of a strong central business district in Orlando and the need for an improved downtown transit terminal.

6. The I-4 bus and car-pool roadway, although not specifically evaluated for percentage of car pools, is expected to accommodate car pools as well as express buses. Also, the benefit of existing ROW in the I-4 busway concept left open the future possibility of a fixed-guideway system should the densities in the area ever warrant it.

7. The Orlando urban area, similar to other tourist areas, is attempting to solve resident and tourist travel demand with the same system, a difficult if not impossible task. Travel characteristics of tourists are different from those of residents and are sometimes hard to quantify, especially when international markets are involved. We suggest that this problem be further explored by UMTA.

8. Finally, we observed that the adopted plan did not offer the rural areas much transit or highway facilities. This lack was an important flaw in the selected alternative and caused many of the rural areas to support the beltway alternative because they had no other choice.

REFERENCES

1. Orlando Urban Area Transportation Study: 1970 Update, Summary. Wilbur Smith and Associates, Dec. 1973.
2. Land Use Alternatives: Orlando Urban Area Transit Study. East Central Florida Regional Planning Council, June 1973.
3. L. M. Levinson and M. C. Gersten. Transportation Attitude Survey for Modal Split Forecasting as Part of Long-Range Transit Planning. TRB, Transportation Research Record 508, 1974, pp. 13-22.
4. R. H. Pratt. A Utilitarian Theory of Travel Mode Choice. HRB, Highway Research Record 322, 1970, pp. 40-53.
5. H. S. Levinson, C. L. Adams, and W. F. Hoey. Bus Use of Highways, Planning and Design Guidelines. NCHRP, Rept. 155, 1975.
6. Transit Expressway Report. Port Authority of Allegheny County, Penn., Feb. 1967.
7. G. R. Beetle. Light Rail Transit Construction Costs. TRB, Special Rept. 161, June 1975, pp. 115-121.
8. Characteristics of Urban Transportation Systems, A Handbook for Transportation Planners. U.S. Department of Transportation, May 1974.
9. C. Mackey and others. Report of the Governor's Advisory Committee on Transportation. Advisory Committee on Transportation, Tallahassee, Fla., Jan. 1976.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Increasing the People-Moving Capability of Shirley Highway

James T. McQueen, Urban Mass Transportation Administration
Robert Waksman, Transportation Systems Center, U.S. Department of Transportation

Because of the dramatic increase in construction costs of rail rapid transit in recent years, the exclusive highway right-of-way for high-occupancy vehicles has emerged as a possible cost-effective alternative for transporting peak-period commuters through congested corridors. The Shirley Highway busway in northern Virginia offered the first such exclusive right-of-way when its first section was opened to buses in 1969. The busway was opened to car pools of four or more riders in December 1973 and became the principal element of the Urban Mass Transportation Administration's Shirley Highway express-bus-on-freeway project, which was conducted for 1 year until December 1974. Priority treatment accorded buses and car pools resulted in a substantial improvement in the corridor's people-moving capability during peak hours. In addition, considerable travel-time savings were realized by all commuters using Shirley Highway. This paper discusses (a) increases in the people-moving capability of Shirley Highway and (b) the reasons for the increases. The increases in the people-moving capability of Shirley Highway can be attributed to increases in commuter use of buses and car pools. Particular attention was given to bus users to determine why a large number of automobile users—many with upper-middle incomes from homes with several automobiles—switched to bus and why some bus users switched to automobiles (driving alone or car pooling).

Because construction costs of rail rapid transit facilities have risen dramatically in recent years, finding less costly means of effectively transporting large numbers of travelers through congested corridors has become necessary. One alternative includes use of exclusive right-of-way lanes for high-occupancy vehicles. Although usually referred to as "busway," many (if not a majority of) exclusive rights-of-way permit use by car pools containing some minimum number of occupants.

In 1969, the first section of the Shirley Highway busway—two reversible lanes in the median of Shirley Highway (I-95)—was opened to buses. This busway, the first in the United States, became the principal element of the Urban Mass Transportation Administration (UMTA) Shirley Highway express-bus-on-freeway project that began April 1971 and ended December 1974. The project provided express-bus service between a portion of northern Virginia and Washington, D.C., shown in Figure 1, and included the following major elements:

1. Two 18-km (11-mile) reversible lanes in the median of the Shirley Highway plus bus-priority lanes in downtown Washington;
2. The addition of 90 new, special-feature buses with new schedules on new, more direct routes; and
3. The coordination of residential fringe parking facilities with express-bus service.

In December 1973 an important new dimension was added to the project when car pools with four or more occupants were permitted to use the busway.

The principal goal of the project was to demonstrate that such priority operations could lead to an improvement in the people-moving capability of a corridor's transportation facilities. People-moving capability is evaluated in terms of both the magnitude of people moved and the effectiveness with which they are moved.

This paper examines the increases in people movement during peak periods on Shirley Highway over the time span of the project as well as the service perceptions of the commuters. The paper includes an estimate of the increase that can be properly attributed to the project and a determination of factors that might have led to the increase. Although these results apply to the Shirley Highway corridor, the experience should be useful to transportation planners in design and implementation of similar efforts.

The Shirley Highway is an eight-lane freeway with two three-lane directional roadways separated by the two-lane reversible express roadway. During the time span of this demonstration project, Shirley Highway was burdened by a major construction program. As the construction program progressed, the capacity of the freeway increased; as the capacity increased, automobile traffic increased. Between April 1970 and November 1974, total morning peak-period person trips (observed between 6:30 and 9:00 a.m.) on Shirley Highway increased from approximately 17 000 to 37 000.

An indication of the increase in people-moving capability attributable to the project can be determined by an analysis of commuter travel on the reversible lanes. Changes in people-moving capability are assessed in terms of project-stimulated changes in

1. The number of person trips per hour carried by the transportation system,
2. The effectiveness of people movement as represented by commuter use of high-occupancy vehicles, and
3. Travel time of commuters using Shirley Highway.

INCREASED PERSON TRIPS PER LANE ON SHIRLEY HIGHWAY

The number of person trips per lane stimulated by the project is estimated as the difference between person trips per lane counted during the hour when the highest number of person trips was counted on the main roadway and on the reversible lanes. Trends in person trips during peak hours are shown in Figure 2. These trends indicate that, between 1971 and 1974, person trips during the peak hour averaged 6100 on the reversible lanes and 2300 on the main roadway.

Thus, the project increased the person trips on Shirley Highway by more than 3500. In calculating person trips during the peak hour, the busway was considered to have been a single-lane facility before May 23, 1973, when eight lanes of highway were completed to a point about 1.6 km (1 mile) south of the Potomac River. Prior to that time, even though the southern part of the busway had two lanes of completed reversible roadway, flow through the northern part of the region narrowed to a single temporary lane. After May 23, 1973, the busway was considered a two-lane facility in the calculations.

As shown in Figure 2, the change in the number of busway lanes from one to two on May 23 reduced the computed person trips per lane by one-half. Car pools of four or more persons, which began using the busway in December 1973, were responsible for the sharp increase in person trips per busway lane during 1974. Regardless of whether the busway was considered a one-lane or two-lane facility, the rate of peak-hour person trips was always much greater than that of the main roadway.

Increase in Bus Ridership and Car Pooling

Between April 1971 and November 1974, peak-period bus ridership (one-way) on the Shirley Highway express-bus routes increased from approximately 5000 to about 16 000. As indicated in Figure 3, bus ridership on other corridor bus routes declined only approximately 1000 during this period. We therefore concluded that more than 10 000 commuters who used the express-bus service were new to the corridor-area system.

This dramatic increase in bus ridership led to a 30 to 41 percent increase in the bus share of the corridor commuter market. An examination of trends in passengers per bus (Figure 4) indicates that the increases in ridership and bus market share were achieved efficiently; i.e., express service averaged 45 passengers/bus. Moreover, Figure 4 suggests that bus ridership might have been even higher had not the limited supply of buses acted as a constraint. Although the bus service was continually expanded, the busway buses always operated at, or above, seating capacity.

Increases in commuter car pooling also increased the highway's people-moving capability. Approximately 4600 car poolers (1050 automobiles) used the reversible lanes each peak period during November 1974 (1 year after they were opened to car pools with four or more riders). These car pools resulted in increases in automobile-occupancy rates both in the corridor area and on Shirley Highway.

Reductions in Line-Haul Travel Times on Shirley Highway

The reversible lanes for buses and car pools have increased the magnitude of people moving on Shirley Highway. The question that arises is whether this priority treatment has affected quality of service. To examine level of service with and without the priority treatment, a computer simulation model was used to estimate the travel times for buses, car pools using the busway, and other automobile users (5). The model estimated these travel times both under the 1974 bus and car-pool priority operations and under those conditions that could have been expected had all lanes (including the reversible lanes) been open to all vehicles. For these calculations, existing conditions under priority operations in 1974 were assumed to be those observed in June 1974 during the morning peak period when 45 percent of the person trips on the Shirley Highway were by bus and automobile occupancy was 1.49. The assumption made was that the total number of peak-period person trips and the total number of bus passengers on Shirley Highway were the same as they would have been had there been no project: that is, 18 500 peak-period person trips, 5000 bus passengers, and automobile occupancy of 1.44.

Travel-time savings were estimated for a 2-km (1.3-mile) length of highway between Glebe Road and Washington Boulevard exits for which data were available. The results showed that the 1974 priority operations for buses and car pools of four or more persons saved over 1400 total person-h daily during the morning peak when compared with travel times under expected mixed traffic conditions on all lanes without the project. A savings of 1400 person-h approximately equals the total time spent on that highway length by all commuters under existing priority conditions. The time savings represents more than a 3-min saving for each bus rider and car-pool user on the busway plus nearly a 2-min saving for each person traveling by automobile on the main roadway. This large daily time savings still underestimates the benefits of the priority lanes because the time savings refers only to the 2-km (1.3-mile) section (between Glebe Road and Washington Boulevard exits) and also does not include the afternoon peak period. Thus, the model clearly suggests that this priority operation for buses and car pools saved considerable amounts of time not only for bus and car-pool users on the busway, but also for automobile users on the main roadway.

FACTORS CONTRIBUTING TO INCREASE IN BUS AND CAR-POOL USE AMONG CORRIDOR COMMUTERS

Before the busway project, commuter use of buses and car pools had been steadily declining. A major objective of this paper is to identify the reasons for the reversal of this decline.

Figure 1. Location of Shirley Highway busway.

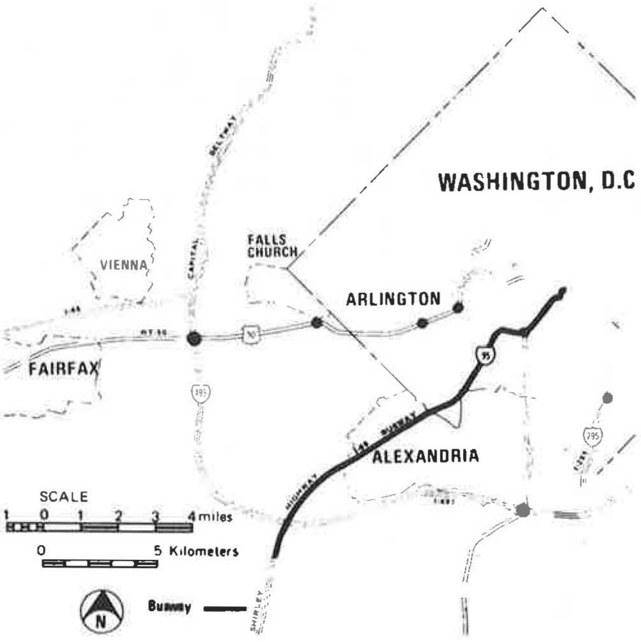


Figure 2. Inbound person trips per lane on busway between 7:00 and 8:00 a.m.

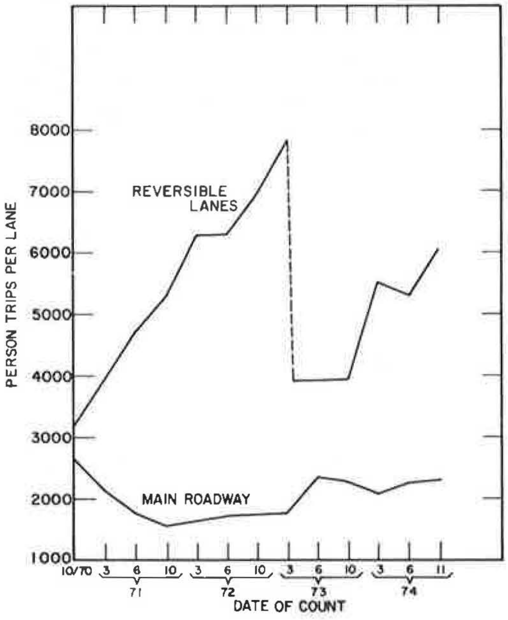


Figure 3. Inbound bus and automobile person trips on Shirley Highway and other corridor roadways between 6:30 and 9:00 a.m.

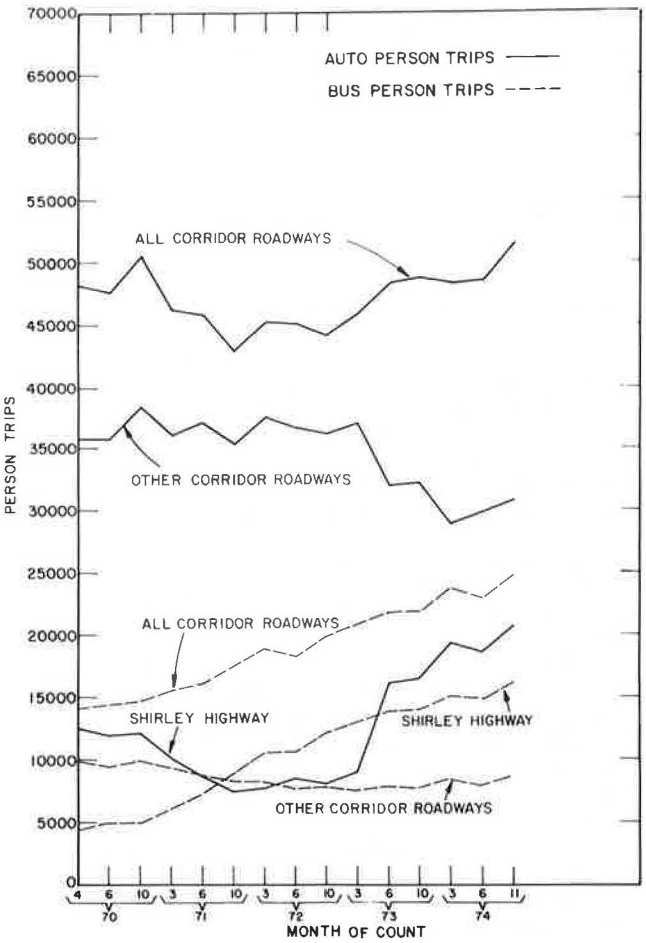


Figure 4. Number of inbound passengers per bus between 6:30 and 9:00 a.m.

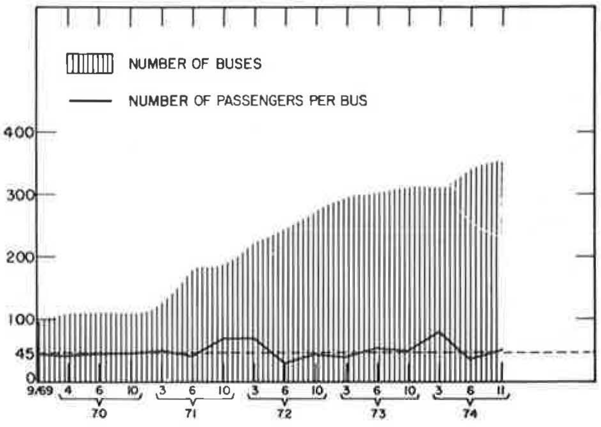


Table 1. Selected demographic characteristics of Shirley Highway commuters in 1974.

Characteristic	Busway Bus Passenger (%)	 Car Pooler (%)	Drivers Alone[a] (%)
Household income, $			
<5000	0	0	0
5000 to 15 000	21	7	23
15 000 to 30 000	61	61	45
>30 000	18	32	32
Age, years			
<21	3	1	1
21 to 39	59	46	47
40 to 65	37	53	51
>65	0	0	1
Sex			
Male	62	85	73
Female	38	15	27
Automobile ownership			
0	5	1	0
1	51	30	35
2	37	56	55
3	6	11	9
4	1	2	1

[a] Includes motorists from other corridor arterials.

Corridor-Commuter Surveys

The most recent data on corridor commuters and their modal-choice decisions are provided by surveys conducted during the fall of 1974. The surveys involved different procedures for bus and automobile commuters. For the bus survey, request-return questionnaires were distributed by bus drivers to a sample of passengers on peak-period buses. The automobile survey procedure was more involved. A sample of license plates of automobiles crossing the corridor screen line was recorded, and request-return questionnaires were sent to the owners of automobiles that were registered in Arlington and Fairfax counties.

A 30 percent sample of busway buses resulted in a sampling rate of 34 percent. A 20 percent sample of nonbusway automobiles was attempted. Because of the speeds of the automobiles as they passed the observation stations, this is about the maximum sampling rate. However, the actual sampling rate was 13 percent for drivers alone and 15 percent for car poolers because of observation and recording errors and automobiles with non-Virginia license plates. A 100 percent sample of busway car poolers was attempted, but the actual sample rate was 66 percent, again, because of automobiles registered out of state and observation and recording errors.

Survey-response rates ranged from 45 to 64 percent. Commuters who benefited directly from the busway had the highest response rates. Two short studies were conducted to investigate potential bias due to survey nonrespondents. These investigations, one for the bus survey and the other for the automobile drivers, indicated little statistical difference between respondents and nonrespondents (based on chi-square tests at the 5 percent level). Thus, we concluded that the responding commuters represented a random sample of corridor commuters.

The fall 1974 commuter survey data, given in Table 1, provides the following summary of a corridor commuter. The person came from a family that owned two automobiles, had an annual income between $15 000 and $30 000, and was a male between 21 and 39 years of age. Bus passengers were the youngest and least affluent, were predominantly females, and owned fewer automobiles; busway car poolers were the most affluent, were predominantly male, and owned the most automobiles. The average number of automobiles owned per household was 1.47 for busway bus passengers, 1.83 for busway car poolers, and 1.76 for drivers alone.

Modal-Choice Decisions Involving Bus

After the entire Shirley Highway busway was opened in April 1971 and service was expanded on routes using the busway, daily peak-period patronage on busway buses increased from less than 5000 in October 1970 to 16 000 in November 1974, an increase of nearly 92 percent or 14 700 transit trips from the beginning of the project in April 1971. During the same time period, daily peak-period patronage declined slightly on nonbusway buses from 10 000 to 9000.

Modal-choice decisions of busway bus riders were examined to determine the reasons for this large increase in ridership. Approximately 20 percent of these busway bus riders indicated that they had no alternative to the bus because they did not have an automobile for commuting. These riders are referred to as captive riders and are not included in the examinations of modal choice.

A majority of the noncaptive (choice) busway bus riders had previously commuted by automobile. The table below gives a summary of the responses of the choice bus riders to the survey question: Before you began using this bus, how did you actually commute from home to work? Sixty percent of the choice busway bus riders formerly used automobile transportation. (Of these commuters who had the same trip prior to using bus, 79 percent formerly used automobile transportation.)

Prior Mode	Percent
Did not make this trip, that is, previously resided or worked elsewhere and	
Used automobile	30
Used bus	23
Used other	4
Drove alone	19
Was an alternate driver in a car pool	5
Drove in a car pool	3
Was a passenger in a car pool	3
Used another bus	8
Other	5

To determine why such a large number of bus riders in the area had switched from automobile, responses to the following survey question were examined: If prior to riding this bus you commuted regularly by automobile, why did you switch to bus? As indicated in the table below, "discomfort of driving" was given most often as the reason for switching from automobile. About 28 percent of the busway bus riders indicated that bus operations were the reason for switching, and 26 percent of the busway riders indicated that an income-related feature was the reason.

Reason	Percent	Reason	Percent
Automobile not available	13	Bus faster	2
Automobile too expensive	3	Bus more reliable	2
Parking too expensive	10	Bus express	8
Reduced effect of traffic congestion on bus	20	Time on bus usable	2
Discomfort of driving	34	Other	6

Just as automobile commuters switched to bus, some bus users switched to automobile. A summary is given below of the responses to the question, If you do not now regularly commute from home to work by bus, why not? In the tabulation, A drivers are those drivers alone who had tried regularly commuting by bus in the Shirley Highway corridor since 1970 and B drivers are those drivers alone who had not done so. The reason given most often is ranked first, and ties are assigned the same ranks.

	A Drivers		B Drivers	
Reason	Percent	Rank	Percent	Rate
Loss of flexibility in working hours	35	3	48	1
Bus takes too long	42	1	40	2
Too much time spent waiting at bus stops	42	1	32	3
Need automobile during workday	29	5	30	4
Bus unreliable	30	4	14	8
Too much walking necessary	20	7	22	5
Bus too expensive	19	8	16	7
No seats available on bus	22	6	8	9
Bus not available	7	9	17	6
No personal privacy	6	10	8	9

The percentages were estimated from survey forms that had "other" checked and a reason specified afterwards. No significant differences were noted in the reasons given for not commuting by bus between those persons who had tried commuting by bus since 1970 and those who had not. Significantly, an analysis of the residences of the diverted bus riders revealed that at least two-thirds lived in areas served by nonbusway routes that provided much slower service than busway routes.

A special category of busway bus riders were those who did not make the same trip prior to using their present bus. These were commuters who began riding the bus after a change in job or residence location. An analysis of their responses revealed that such changes appeared to be a factor in the decisions of many automobile commuters to switch to bus. Responses of current automobile users and of the bus users who formerly had commuted by automobile were compared for the questions: When was the last time you changed your place of residence? and When was the last time you changed your place of work? The automobile users who switched to bus had more recent changes in employment and residence locations then the current automobile users. This switching was further supported by chi-square tests that showed the differences to be significant at the 5 percent level. This analysis indicates that many commuters used a job or residence change to experiment with commuting by bus and suggests that areas of high mobility (such as Washington, D.C.) are also areas of potentially good transit markets.

Modal-Choice Decisions Involving Car Pools

After a long period of decline, late in 1973, car pooling in the Shirley Highway corridor began to increase. Of the car poolers surveyed during October 1974, more than 40 percent began car pooling during 1974. In addition, 37 percent of the car-pool drivers stated that their car pools had increased in size during the energy crisis of the winter of 1973-1974 and after the opening of the busway to car poolers of four or more persons in December 1973.

To gain insight into the reasons for this increase, an examination was made of responses to the survey question that asked car-pool drivers and passengers to identify the importance of several factors to their decisions to join or form their present car pool. Four choices were provided for each factor: very important, moderately important, unimportant or didn't consider it, and not applicable. Tabulated below is a summary of the very important responses. The factor cited most often is ranked first and ties are assigned the same rank. Among both car-pool drivers and passengers, availability of Shirley Highway express lanes for car-pool usage, reduction in commuting cost, special parking privileges, and convenient work locations of other car-pool members were the factors most often reported as "very important."

	Drivers		Passengers	
Factor	Percent	Rank	Percent	Rank
Reduction in commuting cost	71	1	62	2
Special parking privileges	70	2	61	3
Convenient work location of other car-pool members	65	4	59	4
Reduction in gasoline use	53	5	53	5
Availability of Shirley Highway express lanes for car-pool use	69	3	72	1
Reduced stress and frustration in commuting	42	6	46	6
Concern for energy and air-pollution problems	26	7	26	8
Reduced use of an automobile or making the purchase of an automobile unnecessary	21	8	28	7
Availability of good bus service as a backup	15	9	26	8
Characteristics of other car-pool members	12	11	18	10
Comfort of vehicles used by car pool	13	10	13	11
Loss of flexibility in working hours	8	12	7	12
Additional trip time resulting from passenger pickup and discharge	4	15	4	15
Availability of car-pool locator services	5	13	6	13
Additional risk to personal safety	3	17	5	14
Loss of personal privacy	5	13	2	17
Additional automobile insurance required	4	15	3	16

Since there was a sharp increase in car pooling during 1974, the car-pooling factors discussed in the previous paragraph were examined separately for persons who began car pooling during that year and for those who began car pooling earlier. In both groups, the same factors—reduction in commuting cost, special parking privileges, and convenient work locations of other car-pool members—were most often reported as very important.

The availability of Shirley Highway express lanes to car pools was the factor most often cited as very important by busway car poolers who joined their present car pool during 1974. In addition, the express lane factor was ranked fourth in importance by busway car poolers who joined their present car pool before January 1974. Although this ranking was probably an attempt by respondents to ensure that the busway would remain open to car pools, the ranking is also an indication of the importance attached to the busway by car poolers who had established car pools prior to the opening of the busway to them.

An examination of the surveyed transit trips of car poolers and their previous trips by automobile revealed some of the benefits car poolers enjoyed. One was employer-providing parking. Prior to joining their present car pool, approximately 50 percent of the former automobile commuters used employer-provided parking; for their present car pools, this figure rose to 70 percent. Another benefit was travel-time savings; more than 60 percent of busway car poolers reported a door-to-door travel time lower than that of their previous transit trip.

Although a majority of the choice car poolers had commuted by automobile prior to joining their present car pools, a substantial percentage had formerly used the bus. The following table summarizes responses of choice car poolers to the survey question: Before you began using this car pool how did you usually commute from home to work?

Prior Mode	Car-Pool Drivers (%)	Car-Pool Passengers (%)
Did not make this trip, that is, previously resided or worked elsewhere and		
Used automobile	22	18
Used bus	9	9
Used other	1	2
Drove alone	23	16
Was an alternate driver in a car pool	23	20
Drove in a car pool	3	2
Was a passenger in a car pool	4	4
Used bus	12	24
Other	3	5

Former bus users accounted for about 25 percent of all corridor car poolers and about 30 percent of busway car poolers. Significantly, the residences of over 90 percent of the busway car poolers were located in the service area of the busway bus operation. Thus, the busway car-pool operation was in competition with busway bus service, and many of the former bus commuters in these car pools had probably switched from the high-quality express-bus service of the project. Of those who switched from the express-bus service to car pools that used the reversible lanes, approximately 80 percent reported car pooling took less travel time.

As bus riders diverted to driving alone, so did some car poolers switch to driving alone. To investigate why those persons who drove alone and who tried commuting to work by car pool had returned to their automobiles and why the remaining persons who drove alone never car pooled, responses to the following survey question were examined: If you do not now regularly commute from home to work by car pool, why not? The responses are summarized below. A drivers are those who had tried regularly commuting by car pool in the Shirley Highway corridor since December 1973, and B drivers are those who had not.

Reason	A Drivers		B Drivers	
	Percent	Rank	Percent	Rank
Loss of flexibility in working hours	71	1	67	1
Inability to locate others willing to car pool	34	2	21	4
Need automobile during workday	32	3	26	2
Too much time required to pick up and discharge car-pool passengers	9	4	22	3
No personal privacy in car pool	0	7	10	5
Too much automobile insurance required	7	5	4	7
Too much risk to personal safety	5	6	5	6

No significant differences are apparent in the reasons given for not commuting by car pool between those persons who had commuted by car pool in the corridor since December 1973 and those who had not.

CONCLUSIONS

1. This project demonstrated that priority treatment for a comprehensive high-quality bus service and for car pools can lead to a substantial increase in the people-moving capability of a major freeway. Peak-hour person trips per lane of the reversible lanes exceeded those of the main roadway by more than 3500 because many motorists switched to either express-bus service or car pools of four or more members, which could use the reversible lanes.

2. Most of the increase in person trips per hour on the reversible lanes was due to increases in bus ridership. During the time span of the project, daily peak-period, one-way bus trips on the new express-bus service increased by almost 12 000 (from 4200 in April 1971 to 16 000 in November 1974).

3. Many motorists with upper-middle incomes from homes with several automobiles switched to the improved bus service. Faced with expensive parking and frustrating congested roadways, motorists switched to the express-bus operation that provided (a) travel times shorter than preproject travel times by bus, (b) improvements in the reliability of bus service, and (c) expansions in the coverage and frequency of the bus service.

4. Priority treatment on highway facilities and in the assignment of special parking privileges stimulated substantial increases in car pooling. These two incentives plus gasoline shortages during the winter of 1973-1974 were found to be principal reasons for the increase in corridor car pooling. Car-pool locator services and concern for air-pollution problems were not found to be influential to car pooling. Loss of flexibility was found to be the greatest obstacle to car pooling.

5. Most of the increase in car pooling and automobile occupancy can be attributed to motorists; however, former bus users made up approximately 25 percent of the surveyed car poolers. Of commuters diverted to car pooling by the availability of the busway to car pools, nearly one-third had formerly commuted by bus. A large majority of these former bus riders resided in the service area of busway bus routes.

6. The project, which gives priority treatment to buses and car pools of four or more members, resulted in reductions in travel time for all commuters using Shirley Highway, i.e., for those on the main roadway as well as for those on the reversible lanes. Thus, the project not only increased the people-moving capability of Shirley Highway but also improved the level of service for all commuters using the freeway.

ACKNOWLEDGMENTS

This study was part of the evaluation of the Shirley Highway Express Bus-on-Freeway Demonstration project, a 4-year effort of the National Bureau of Standards funded by the Urban Mass Transportation Administration. The final report (3) presents the overall results of this evaluation. Ronald Fisher and James Bautz of the Urban Mass Transportation Administration and Ralph Schofer of the National Bureau of Standards provided overall direction and encouragement for the study. Gerald Miller, Dave Levinsohn, and Carol Harrison assisted in the collection and analysis of travel volume and survey data. Richard Yates and Elaine Bunten helped in the development of the survey questionnaires.

REFERENCES

1. R. J. Fisher. Shirley Highway Express Bus-on-Freeway Demonstration Project. HRB, Highway Research Record 415, 1972, pp. 25-37.
2. J. T. McQueen and G. K. Miller. The Shirley Highway Express Bus-on-Freeway Demonstration Project: A Study of Park-and-Riding. National Bureau of Standards, Interim Rept. 6, April 1975; Urban Mass Transportation Administration, U.S. Department of Transportation.
3. J. T. McQueen, D. Levinsohn, R. Waksman, and G. K. Miller. The Evaluation of the Shirley Highway Express Bus-on-Freeway Demonstration Project. National Bureau of Standards, Final Rept., Aug. 1975; Urban Mass Transportation Administration, U.S. Department of Transportation.

4. A Computer Simulation Model for Evaluating Priority Operations on Freeways. Institute of Transportation Engineering, Univ. of California, Berkeley, 1973; Federal Highway Administration, U.S. Department of Transportation.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

Modal-Choice Analysis of an Exclusive Bus and Car-Pool Lane

R. K. Mufti, L. S. Golfin, and C. D. Dougherty, Delaware Valley Regional Planning Commission, Philadelphia, Pennsylvania

Since the Delaware Valley Regional Planning Commission (DVRPC) adopted its 1985 regional transportation plan in 1969, changes in attitudes and conditions have impeded the implementation of that plan. Neighborhoods have become resistant to major new highway construction. Citizens and legislative bodies have demanded that environmental impacts of plans and projects be fully assessed. Escalated construction costs have made the building of all of the facilities shown on the 1985 plan impossible. Federal ambient air quality standards have required that automobile emissions be reduced. Energy shortages have necessitated complete reevaluation of transportation policies.

Of significant impact to the Delaware Valley region are recent revised regulations of the U.S. Environmental Protection Agency (EPA) concerning air quality and regulations of the U.S. Department of Transportation concerning transportation planning and programming. In 1975 the New Jersey Department of Transportation requested the DVRPC to provide an analysis of modal choice in the US-30, I-676, and Lindenwold High-Speed Line corridor (Pennsauken Township-Camden City). This analysis was part of an assessment of the impact of implementing an exclusive bus and car-pool lane through that corridor. This request was in accordance with the federally mandated New Jersey Transportation Control Plan (NJTCP) that states that each appropriate governmental entity shall establish bus and car-pool lanes on designated traffic flow corridors. One of these designated corridors is the Admiral Wilson Boulevard, a section of US-30 between the Ben Franklin Bridge Plaza and the Camden Airport Circle.

In addition to the NJTCP, EPA also promulgated the Pennsylvania transportation control plan. A section of this plan requires all governmental and public agencies to take the necessary actions to establish a peak-period exclusive bus lane over the Ben Franklin Bridge (US-30) going into Philadelphia in the morning and returning to New Jersey in the evening.

The combination of the two requirements delineates a facility, approximately 6.5 km (4 miles), that during the peak periods would serve primarily those people who reside in South Jersey and work in the Philadelphia central business district (CBD).

The corridor is currently served by the Port Authority Transit Corporation's (PATCO) Lindenwold High-Speed Line, numerous bus routes operated by Transport of New Jersey (TNJ), and four major arterial highways that converge at the Camden Airport Circle. The TNJ bus routes include local service to the city of Camden, feeder service to the PATCO line stations, and express and local service to the Philadelphia CBD.

DELINEATION OF POTENTIAL BUS AND CAR-POOL MARKET

Because the exclusive bus and car-pool lane was nonexistent at the time of this study, its market area was not defined. If a market is to develop, however, it must draw on the users of existing facilities (in the short range), i.e., the high-speed line, existing bus routes, and the highway network. Therefore, the subarea's total travel demand and the interdependence of that demand and the facilities currently offered must be understood before a potential market area for a bus and car-pool lane can be delineated.

The approach for market-area delineation was to overlay maps of the market areas of the existing prime facilities in the study area to form a composite market area. The market area served by the high-speed line was derived from automobile license plate surveys conducted at the train stations by the University of Pennsylvania. The highway network market area was derived by a select-link analysis of the Ben Franklin Bridge and the Admiral Wilson Boulevard. The commuter bus market area was assumed to be the coverage areas of those routes that traverse the general area and provide service to Philadelphia. The resultant composite market area was then modified to conform to DVRPC data collection district boundaries. The Pennsylvania portion was limited to the districts of the Philadelphia CBD because all buses using the facility would be destined for only that area and because the density of destinations there provides the greatest likelihood for car pooling.

Travel-demand matrices were constructed for the market area for the project year 1976. This task involved refining previously derived modal trip tables to agree with current corridor passenger and vehicle flows, demographic data, and employment data. The trip tables were further refined to reflect peak-period travel demand.

MODAL-CHOICE MODELING

In modeling the effect of implementing an exclusive bus and car-pool lane on modal choice in the study corridor, a binary-choice logit model was used. The general form of the model is

$$P_i = V_i \Big/ \sum_{j=1}^{m} V_j$$

where

V_i = EXP [aAPH + b TIME + c (COST/INC) + d],
Pi = probability of choosing mode i,
APH = number of automobiles per household,
TIME = total travel time by mode i,
COST = total travel cost by mode i,
INC = dummy variable for household income,
i, j = different modes 1, 2, . . ., m, and
a, b, c, d = calibration factors.

A tested and calibrated binary-choice formulation (two modes in competition) of the above model was available for the Shirley Highway busway in the Washington, D.C., area.

Values of the independent variables for each interchange (New Jersey district to Philadelphia CBD) were calculated on the basis of existing travel parameters as follows:

1. Automobiles per household and income—1970 census aggregated to transportation analysis districts (values for 1976 assumed equal);
2. Total travel time by mode—based on probable route selection, average peak-period link speeds, and nonnetwork times; and
3. Total travel cost by mode—based on fares, operating cost per kilometer, applicable tolls, and parking charges.

MODEL REPLICATION (QUASI-CALIBRATION) PROCEDURE

When a generally applicable model is transferred from one region to another, some revision might be necessary: The variable coefficients might vary slightly because of regional peculiarities, the methods of measuring the absolute values of the independent or dependent variables might vary, and the choice context might be more or less complex.

To ascertain how well the transferred model could replicate the existing modal percentages, a preliminary set of input data based on existing conditions was used in the model run. As guidelines, existing modal shares were developed at the corridor level. Adjustments were then made until the model satisfactorily replicated the guidelines at the corridor level. The adjustments were made to the values of non-line-haul variables of each interchange by mode. These adjustments affected the terminal times for access and egress, the parking time for automobile, the weighted frequency of service penalty for bus, the change of mode time for the high-speed line, and the pickup time penalty for car pooling. In effect, the results were modifications to the model coefficients. The modifications may be interpreted as proxies for the variation between regions and the introduction of a more complex choice context. However, no such outright claims are made.

MULTIMODAL SOLUTION OF BINARY-CHOICE MODEL

Because the model is one of binary choice, only partial results are derived if each mode is modeled separately. However, four modes (automobile, car pool, bus, and high-speed line) can be related with three binary pairings and a relationship of the modes to some absolute total demand. A simultaneous solution was derived. The following five mode pairs were analyzed: high-speed line versus automobile, high-speed line versus bus, high-speed line versus car pool, automobile versus bus, and car pool versus automobile. The other two mode pairs acted as checks and provided insight into particular shifts in mode choice.

MODAL-CHOICE MODELING OF EXCLUSIVE LANES

Two alternative configurations of exclusive bus and car-pool lanes were analyzed: (a) an exclusive bus and car-pool lane preempted from the non-peak-flow direction traffic lanes (contraflow) and (b) an exclusive bus and car-pool lane preempted from the peak-flow direction traffic lanes.

The contraflow configuration improves existing conditions by providing higher speeds for buses and qualified car pools (three or more passengers) through use of an additional exclusive lane on the boulevard. The contraflow configuration also marginally increases traffic speed in the four remaining lanes through a reduction in the number of vehicles demanding space on those lanes.

The peak-flow configuration similarly provides higher speeds for buses and qualified car pools through use of an exclusive lane on the boulevard. However, because the exclusive lane has been preempted from one of the four peak-flow lanes this exclusive lane necessarily increases traffic density and lowers traffic speed on the remaining three peak-flow lanes.

Between the Ben Franklin Bridge Plaza and the Philadelphia CBD, the bridge has seven lanes, one of which is always kept empty to separate directional traffic. For maximum flow the Ben Franklin Bridge provides four lanes in the peak direction and two lanes in the contraflow direction. Within this framework, the bridges' four peak-flow lanes become three peak-flow lanes and one exclusive bus and car-pool lane when either configuration is being used. Existing bridge traffic speed must, therefore, marginally decrease because of decreased capacity.

Obviously, the differences between present conditions and the alternative configurations must result in changes in modal travel time. The travel times by each mode for each interchange were calculated and, with all other variables held constant, the model was rerun for each of the modal pairings for each alternative case.

ANALYSIS OF MODAL SHIFTS

The model indicated that there were diversions from automobile to bus, from automobile to car pool, from automobile to high-speed line, and even from high-speed line to bus and car pool.

The results of applying the model indicate that the implementation of an exclusive bus and car-pool lane would yield nearly identical exclusive lane use (approximately 10 500 person trips in the morning peak period) whether the lane were contraflow or peak flow. This yield represents an approximate 13 percent increase in bus plus car-pool demand.

Although the high-speed line now carries slightly over 51 percent of the market, implementation of either exclusive bus and car-pool lane alternative would only drop the high-speed line's share to 50 percent.

The analysis shows that the automobile mode would suffer the greatest intrusion on its market share (2.3 percent and 3.2 percent for the contraflow and peak-flow alternatives respectively). The corresponding losses for the high-speed line would be 2.1 percent and 1.3 percent respectively.

Figure 1. Marginal shifts in modal demands.

ALTERNATIVE	AUTO	BUS/CARPOOL	HIGH-SPEED LINE
CONTRA-FLOW	(651) → 651 Net Loss	→ 1,240 ← 1,240 Net Gain	← (589) 589 Net Loss
PEAK-FLOW	(239) → (675) → 914 Net Loss	→ 1,264 ← 1,264 Net Gain	→ 239 ← (589) 350 Net Loss

Although these net modal gains and losses are of primary interest to this study, isolating the various intermodal marginal shifts that resulted in these net changes is also important. Figure 1 reveals that the high-speed line loses an equal number of persons to the exclusive lane under either alternative. The automobile mode also loses nearly an equal number of persons to the exclusive lane under either alternative. The major difference between the two alternatives is that the peak-flow alternative causes an additional loss of 239 persons from automobile to high-speed line. This additional marginal shift is a direct result of the decreased vehicle capacity on the boulevard.

This study indicates that a car pool is the least significant travel mode in the corridor. Even the implementation of an exclusive bus and car-pool lane on a congested, but vital, arterial highway seems to have little real effect on boosting the market sharing of car pooling.

CONCLUSIONS

1. The implementation of an exclusive bus and car-pool lane on Admiral Wilson Boulevard and on the Ben Franklin Bridge would yield nearly identical use whether the lane is contraflow or peak flow.
2. If an exclusive lane is implemented, regardless of its configuration, it could result in a reduction of 1 to 2 percent of the Lindenwold High-Speed Line share of the total market.
3. Excluding car pooling, the automobile is the least significant mode in the market and would sustain the greatest intrusion into its share of the market (2.3 to 3.2 percent).
4. Implementation of an exclusive lane in the peak-flow direction would result in a loss of nearly three times as many riders from automobile as from high-speed line. The contraflow lane would result in a loss of almost equal numbers from both automobile and high-speed line.
5. The peak-flow alternative would cause a 40 percent greater shift from automobile than would occur in the contraflow alternative. However, this additional loss would be attracted to the high-speed line rather than to the exclusive bus and car-pool lane.
6. Car pool would be the least significant mode in the market area. The implementation of an exclusive lane might have little real effect in improving the market share of this mode.

ACKNOWLEDGMENT

This paper was financed, in part, by the Federal Highway Administration and the Urban Mass Transportation Administration, U.S. Department of Transportation, and the New Jersey Department of Transportation. The views expressed are ours and do not necessarily reflect the views or policies of the sponsors.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

Simulation of a Bus-Priority Lane

R. J. Salter, University of Bradford, England
A. A. Memon, Mehran University, Pakistan

The use of bus-priority measures to increase to optimum highway flow of passengers, as opposed to highway flow of vehicles, is being applied in many developed countries. A review of the application of bus-priority measures has been made in the United States by the National Cooperative Highway Research Program (1) and in the United Kingdom by the Transport and Road Research Laboratory (2). This paper describes a simulation model of bus priority developed at the University of Bradford, England.

To assist the peak-hour tidal traffic flow into and out of the city of Bradford, West Yorkshire, England, a bus-only lane has been established on a section of the A-65 Bradford to Keighley highway.

The section of the Bradford to Keighley highway studied is a two-way, four-lane highway 1.1 km (0.7 mile) long and has three signal-controlled junctions. The highway carries bus flows in excess of 50 buses/h inbound in the morning peak period and in excess of 60 buses/h outbound in the evening peak period.

SIMULATION MODELS

In an investigation into the overall travel effects of this bus-priority scheme, two digital computer simulation models have been developed. The first simulates inbound traffic flow on the highway in the morning peak hour under normal nonpriority conditions; the second simulates traffic flow when bus-priority lanes are in operation.

In the nonpriority model the rules of operation of the model assign vehicles traveling straight ahead to the in-

Figure 1. Distributions of non-bus-vehicle travel times with and without priority scheme.

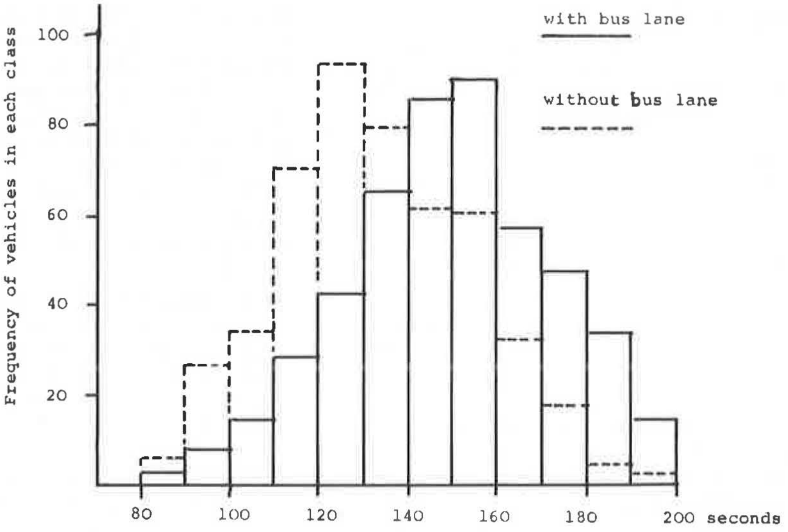
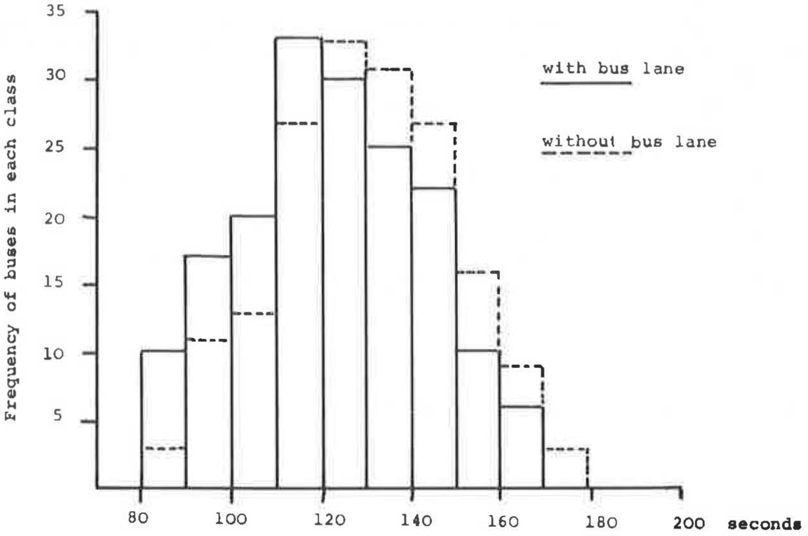


Figure 2. Distribution of bus travel times with and without priority scheme.



side lane of the two traffic-signal-approach lanes and vehicles turning right (left rule of the road) or traveling straight ahead to the outer lane. In the priority model, nonbus vehicles traveling straight ahead or turning right are confined to the outer lane and only buses travel on the inner lane. Vehicles turning left are not considered in the models because the number of these vehicles in the traffic flow is small.

At the traffic-signal approach, the bus-priority lane terminates 60 m (196.8 ft) from the stop line to allow vehicles traveling straight ahead to bypass vehicles turning right, which are prevented from completing their traffic movement by opposing vehicles, and also to allow the use of the full approach width to all vehicle types.

Observations of traffic flow on the highway were carried out to determine the characteristics of the speed and headway distributions. We noted that the displaced negative exponential distribution was an adequate description of the cumulative headway distribution on the highway and that the normal distribution described the observed velocity distribution.

A microscopic Monte Carlo simulation model was used that assigned each vehicle entering the section of the highway under study to a lane and to a vehicle type. A vehicle-following procedure was used; the performance of the vehicle following was determined from a consideration of the characteristics of the vehicle leading. The system was scanned at a uniform time increment of 0.5 s and commenced with the scanning of the vehicle nearest to the exit of the section under study. A vehicle assigned to a lane at the entry of the section was not allowed to change lanes or to overtake vehicles in its own lane. All vehicles were assumed to have similar characteristics.

1. Minimum space between vehicles in a queuing condition was 7 m (23 ft).
2. Maximum speed was 14 m/s (45.9 ft/s).
3. Acceleration and deceleration rates were 1.5 m/s^2 (4.9 ft/s^2) and 2 m/s^2 (6.6 ft/s^2) respectively.

The use of similar operating characteristics for buses and nonbus vehicles in congested flow conditions was justified by field observations. No provision was made for the time lost when passengers get on or get off buses because this time was considered to be similar for both non-bus-priority and bus-priority conditions. The traffic signals along the route operated on a fixed-time basis without coordination because real-life conditions were represented.

To validate the operation of the simulation model, we made a comparison between the delays at the signal-controlled intersections along the route given by the models and those delays obtained by using the expression derived by Webster (3). Close agreement between simulated and calculated delays was noted.

EFFECT OF BUS PRIORITY ON TRAVEL TIMES

A comparison was made between the travel times of buses and nonbus vehicles by running the priority and nonpriority models under identical traffic flows and signal settings. Figure 1 shows the variation in the distribution of nonbus travel times with and without the bus-priority schemes in operation when total vehicular flow was 1100 vehicles/h and the proportion of bus to nonbus vehicles was 20 percent. Because nonbus traffic is confined to a single lane under bus-priority conditions, there is an increase in journey time and a decrease in overall speed for nonbus vehicles compared to nonpriority conditions. These changes in journey times were caused by the interaction of vehicles throughout the length of the simulated section rather than by increases in delay at the junction alone. Similar distributions of journey times for buses are shown in Figure 2, on which journey time is a decrease in mean journey time from 129.9 to 122.6 s under bus-priority conditions.

The small changes in travel times due to the introduction of the bus-priority scheme are caused by the inelasticity of speed. The simulated flow was within the range of 600 to 1400 vehicles/h in one direction. At lower traffic volumes there is no justification for affording priority to buses, and at higher traffic volumes

Figure 3. Travel time and flow relationship for buses in priority lane, non-bus vehicles under priority conditions, and all vehicles under non-priority conditions.

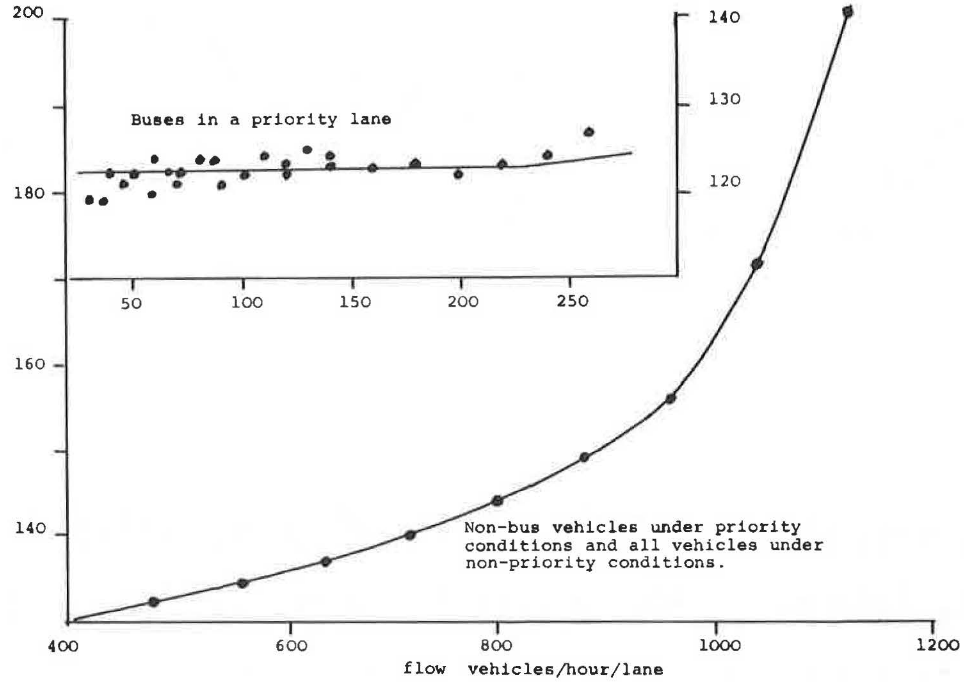
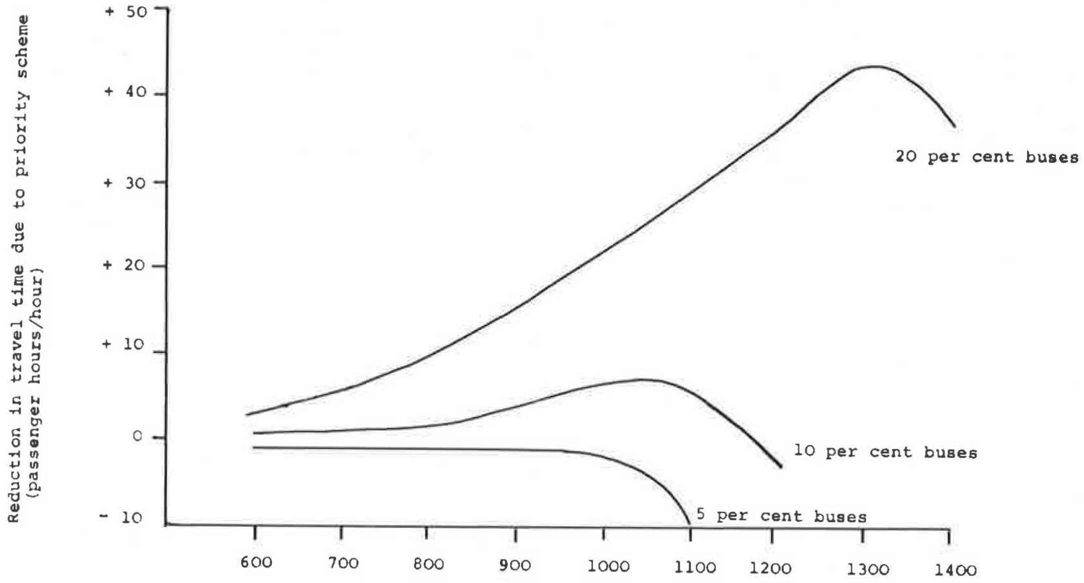


Figure 4. Reductions in passenger travel time due to priority scheme.



the signal-controlled intersections have inadequate capacity to pass the traffic.

Speed and flow relationships for bus and nonbus traffic under priority and nonpriority conditions obtained by the use of the simulation model are shown in Figure 3. Figure 3 shows that (a) for a wide range of bus flows the travel time on the simulated section of highway may be regarded as constant with no interaction between vehicles and (b) for nonbus vehicles interaction occurs as the traffic volume increases because there is a marked increase in travel time as the traffic flow increases beyond 1000 vehicles/lane/h.

CONCLUSIONS

Use of these two speed and flow relationships allows overall passenger travel time savings to be calculated for various proportions of buses in the traffic flow as illustrated in Figure 4, in which we assumed a bus occupancy of 50 persons and a nonbus vehicle occupancy of 1.5 persons. When only 5 percent of the traffic is buses, the installation of a bus-priority scheme results in increases in passenger journey time at the traffic volumes studied. When the proportion of buses in the traffic flow is 10 percent, then the saving in passenger delay reaches a maximum at a total traffic flow of approximately 1050 vehicles/h. As would be expected when there is a high proportion of buses in the flow, then substantial reductions in passenger journey time can be expected; at a 20 percent proportion, a maximum saving of 43 passenger·h/h is reached when 1300 vehicles/h enter the section.

Since the introduction of the bus-priority scheme, field observations have verified, as far as possible, the validity of the model. The highway under consideration has, however, pronounced peaking characteristics, and the recent establishment of signal-controlled, pedestrian-crossing facilities has prevented the determination of comprehensive speed-flow relationships. Observations have shown, however, that the travel times of buses in the priority lane are in the region of 120 to 130 s when the flow is 50 to 60 buses/h. Travel times of nonbus vehicles are very variable, as would be expected, at flows producing such low levels of service.

REFERENCES

1. H. S. Levinson, W. F. Hoey, D. B. Sanders, and F. H. Wynn. Bus Use of Highways: State of the Art. NCHRP, Rept. 143, 1973.
2. Bus Priority. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. 570, 1973.
3. F. V. Webster. Traffic Signals. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Technical Paper 56, 1966.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

Evaluation of Bus-Priority Strategies on Northwest Seventh Avenue in Miami

Joseph A. Wattleworth, Kenneth G. Courage, and Charles E. Wallace, Transportation Research Center, University of Florida

A 3½-year demonstration project was established in Miami in 1973 to develop more efficient people-moving capabilities in the I-95 and Northwest Seventh Avenue corridor that extends 16 km (10 miles) from the Golden Glades Interchange in north Dade County to Miami to the south. The basic transit concept was to provide fast, directional, line-haul, peak-period service by express buses that operated between a major residential area and four specific areas of major employment along Northwest Seventh Avenue (US-441), a major arterial street.

A park-and-ride facility located in the Golden Glades Interchange contained a bus terminal and a 967-space parking lot to accommodate the park-and-ride patrons. Some of the express buses were used to provide feeder route service in the residential market area. Provisions were made for kiss-and-ride and local bus interchanges. In addition, some car pools were formed and used the facility.

Various combinations of the following three bus-priority treatments were evaluated:

1. A reversible, exclusive bus lane;
2. A traffic signal preemption system that allowed express-bus drivers to preempt traffic signals to give themselves the green signal; and
3. A coordinated signal system designed to favor the movement of express buses in the peak-period direction.

Combinations of the three priority treatments were examined in the following five evaluation stages:

1. Stage 0—before condition, no priority treatment;
2. Stage 1—bus preemption of traffic signals, buses in mixed mode;
3. Stage 2—bus preemption of traffic signals, buses in reserved bus lane;
4. Stage 3—signal progression, buses in reserved bus lane; and
5. Stage 4—signal progression with bus preemption of traffic signals, buses in reserved lane.

The express-bus service was named the Orange Streaker and was operated by the Metropolitan Dade County Transit Agency (MTA). The bus-priority treatments were evaluated by considering their effects on bus operations, traffic signal performance, traffic stream, and transit operations (1).

EFFECT OF BUS-PRIORITY TREATMENTS ON BUS OPERATIONS

All priority treatments were successful in reducing bus travel times and delay on the 16-km (10-mile) line-haul route equipped with the systems. The provision of a preemption capability (in mixed-mode operation) reduced the average travel time (during both morning and evening peak periods) by 22.5 percent from a before condition of 28.0 min. Adding the reserved lane resulted in the best overall travel times experienced in the project. The average travel time was 19.5 min, a 30.4 percent reduction. When signal progression was substituted for preemption, the travel time increased slightly to 20.9 min or 25.4 percent less than during stage 0. The combination of all priority treatments (stage 4) was only slightly better than treatments in stage 3 because average travel time was 20.6 min, only 26.4 percent lower than that in stage 0. These improvements were reflected proportionately in vehicle delay and other travel-related measures.

The improved bus travel was more pronounced in the evening peak period. For example, the improvement of stage 2 over stage 0 was 20.4 min versus 29.7 min, but all travel times were somewhat higher in the evening peak period. The greater the traffic congestion was, the greater were the improvements.

There were three distinct geometric sections on Northwest Seventh Avenue. In a five-lane section the bus travel times increased between stage 1 and stage 2 (i.e., when the exclusive bus lane was added) in the evening peak period. In this five-lane section the bus lane was converted from the center left-turn lane and all left turns were prohibited, but the turning restrictions were widely violated. These violations point out a strong need for adequate enforcement of traffic regulations when bus-priority treatments are used and suggest that, unless a high degree of motorist cooperation can be anticipated, the benefits of bus-priority measures may not fully materialize.

In addition, two of the three bus-priority treatments produced an improvement in schedule adherence (i.e., arrival time of buses at the terminal compared to scheduled time); the combination of all three treatments produced the same improvement. The one treatment that demonstrated a lower degree of schedule adherence was the signal-preemption treatment. Drawing strong conclusions based on this observation is difficult; however, we may hypothesize that, because the preemption equipment allows the driver to proceed through the signal system at any desired speed, a greater variation in arrival times may be anticipated. Additional research would be required to support this theory.

EFFECT OF BUS-PRIORITY TREATMENTS ON TRAFFIC SIGNAL PERFORMANCE

Several observations were made from field studies of the traffic signal operations. Buses were able to clear the preempted intersection in nearly all cases within the maximum allowable preemption time of 120 s, and the bus-preemption signal produced a stable contact with the detection equipment at the intersection. No false preemption was evident during the off-peak period when buses were not operating, nor was there any indication of erratic preemption signals transmitted from the buses.

Slightly longer phase lengths were observed during cycles in which buses arrived. No differences from the normal timing were apparent on cycles immediately following bus departures. This lack of differences suggests that the disruption due to bus preemption is a short-lived phenomenon. More significant, the system control parameters (isolated versus interconnected, pretimed versus semiactuated, and so forth) exerted a more pronounced effect on the measures of effectiveness than did the bus-priority functions. Coordinated operation resulted in a vastly superior quality of progressive movement for through traffic, and semiactuated operation tended to favor the arterial route slightly, relative to pretimed operation.

The combination of coordination and signal preemption produced no evidence of incompatibility between these two functions. This conclusion applies only to the type of control system that was studied, i.e., central coordination of a system of traffic-actuated controllers. Other control equipment such as electromechanical, pretimed controllers may have led to different conclusions because of hardware constraints that create a greater potential for disruption of progression.

Bus-priority treatment required approximately twice the normal number of repair and maintenance calls to the 37 intersections; however, the result of 36.5 percent of these calls was that no problem was found and of the problems found only 10.5 percent related to the systems. This low percentage of problems suggests that such systems can be expected to increase the maintenance workload slightly, but public misunderstanding of the proper operation (particularly preemption) will result in a high incidence of nuisance calls.

EFFECT OF BUS-PRIORITY TREATMENTS ON TRAFFIC STREAM

Automobile travel time studies conducted along the bus route indicated that the average travel time decreased between successive stages until stage 3 (exclusive bus lane plus signal progression). During this stage automobile travel times were minimized; automobile travel times were increased when the bus-preemption feature was reactivated. The initiation of the bus-priority features actually reduced automobile travel time by almost 7 min (22.4 percent between stage 0 and stage 3).

Aerial photographic studies were conducted to determine the effect of the priority treatments on intersection delay at the signalized intersections on Northwest Seventh Avenue and on the cross streets (morning peak-period only). These data supported the results of the automobile travel time studies. Stage 3 was the best operational stage with relation to the Northwest Seventh Avenue traffic stream. In general, initiation of bus-priority treatments had little, if any, adverse effect on the traffic stream; considerable evidence showed that bus-priority treatments actually improved automobile movement in the traffic stream.

Perhaps the most significant measure of the effectiveness of bus-priority treatment on the traffic stream is the relative importance of the bus and automobile in moving people in the arterial. Generally, the Orange Streaker dramatically improved the people-moving capacity of the artery. Some variations between priority-treatment stages were apparent, but we felt that external factors such as construction on I-95 and changing demand had more influence on traffic stream than the priority treatment did. The Orange Streaker increased the total number of people moved by about 26.8 percent in the morning peak period even though the buses were only 2 percent of the traffic stream. This movement translated to an increase in equivalent automobiles of about 460 vehicles (28.3 percent).

One adverse outcome of the priority strategies concerned bus accidents. The bus accident rate was substantially higher on Northwest Seventh Avenue during the stages that included a reserved lane. Most of the bus accidents involved automobiles making illegal left turns; e.g., 72 percent of the bus accidents happened because buses were cut off by automobiles, and 22 percent of the bus accidents were caused when buses were sideswiped by automobiles—all illegal maneuvers by automobiles. Thus, illegal use of the exclusive lane by automobiles was the major source of bus accidents.

EVALUATION OF THE TRANSIT SERVICE

One of the most important measures of the effectiveness of the transit service is patronage. Total ridership increased from approximately 1050 passengers/d at the beginning of the project to approximately 1450. The net ridership increase during the project was 37.3 percent, which represents an annual increase of 20.3 percent. In the same time period, MTA total ridership increased by 14.6 percent; therefore growth of Orange Streaker ridership was greater than overall growth of transit ridership in the Miami area. Except for a few months at the beginning of the Orange Streaker service, the average load factor was slightly over 60 percent.

Another indicator is the percentage of tripmakers using the transit service. In this analysis only persons making project trips (i.e., from the Orange Streaker market area to its service areas) were considered. Trips on the Orange Streaker averaged 17 percent of the trips during the demonstration project (with a high of 19.4 percent) compared to 5.1 percent for comparable routes that existed prior to the Orange Streaker service.

To assess public reaction three surveys were conducted.

1. An on-board survey was conducted of all bus riders.
2. A handout, mail-back survey was conducted of car poolers forming at the park-and-ride facility.
3. A telephone home-interview survey was conducted of the general public in the market area.

One of the most interesting findings of the bus survey was that most of the Orange Streaker passengers were choice riders. Almost three-fourths of the passengers had an automobile available to them but chose to ride the bus. Of the passengers who made the same trip before the Orange Streaker service, 55.6 percent made the trip in a single-occupant vehicle. Another 18 percent had previously made the trip in multiple-occupant vehicles, and 25.4 percent had ridden another bus. Thus, the Orange Streaker service did replace a large number of automobiles in the traffic stream. The passengers were generally favorable toward the service (93.8 percent gave it a positive rating and only 2.6 percent gave it a negative rating).

Most of the nonusers of the service cited bus-service-related reasons for not using the service: 32 percent cited inconvenience of bus routes, 25 percent cited schedule difficulties, 8 percent cited preference for automobile, and 5 percent cited bus travel time. The attitude toward transit service, therefore, appeared to be positive among the nonusers, and apparently a high percentage of the nonusers would use a transit system if it serviced them more directly.

The Golden Glades park-and-ride facility provided the opportunity for intermodal transfers. Parking lot use was approximately 440 vehicles near the end of stage 1, and car-pool formation was estimated to be between 30 and 40/d. The relatively low car-pool formation was not too surprising since car pooling was not stressed in this stage and other locations were more accessible.

Approximately two-thirds of the vehicles that entered the lot parked there (i.e., park-and-ride vehicles). About 26 percent of the entering vehicles were kiss-and-ride vehicles and 7 percent were car-pool vehicles. A study of the access modes used by express-bus passengers indicated that approximately 25 percent of the bus passengers used the feeder-bus service to reach the bus terminal, approximately 55 percent used the park-and-ride mode, and approximately 20 percent used the kiss-and-ride mode.

We concluded that the park-and-ride facility was an important element of the express-bus service. We estimated that if the park-and-ride and kiss-and-ride capabilities had not been provided, approximately 60 percent of the express-bus passengers would have been lost to the automobile.

Another important measure of effectiveness is the economic viability of transit operations. We determined that the total cost of operating the Orange Streaker service in the Northwest Seventh Avenue stages of the project was $903 698 ($1.70/passenger); revenues, however, accounted for only $320 836 ($0.60/passenger). This deficit resulted in a total deficit of $1.10/passenger (or $2.20/passenger/d). There were five primary reasons for this deficit.

1. Costs attributed to vehicle-hours represented 53 percent of the total cost, primarily because of drivers' wages and related expense items. Because the express service was strictly a peak-period service and drivers had to be paid a minimum of 8 h/d, an extremely high percentage of non-revenue-producing hours resulted (63 percent of the total).
2. A relatively large number of buses were only able to make one revenue trip since the service was offered only in the peak period. The average number of trips per bus was less than 1.5 trips/peak period. Costs due to these vehicles (which relate to expenses of yards, garage facilities, and administrative overhead) amounted to 30.4 percent of the total cost.
3. The peak-period, unidirectional nature of the express service produced a high percentage of deadhead travel. Over 46 percent of the Orange Streaker bus travel was nonrevenue producing; the comparable figure for MTA systemwide, however, was 13.3 percent. This variable contributed 14.5 percent of the total cost and relates to fuel, lubrication, and maintenance costs.
4. The Orange Streaker service included some feeder routes in the market area. These routes returned only 10.5 percent of their cost, although the line-haul portion returned 39.1 percent of its cost.
5. Service to each of the four employment areas was investigated, and we found that the downtown and Civic Center routes were the most productive and collected about 41 percent of their costs. The airport employment area was less productive, returning 36 percent of its cost; but the airport terminal and Coral Gables route was extremely inefficient, returning only 11.9 percent of its cost.

In summary, the extremely high-quality service and low-fare structure, coupled with some relatively inefficient routes (airport area and the feeder segments), produced costs that greatly exceeded the collected fares.

CONCLUSIONS

1. The project was successful in demonstrating that express buses can be given priority treatment on urban arterial streets and cause little or no adverse effect on

the general traffic stream. Indeed, positive benefits can accrue to the automobile traffic.

2. A park-and-ride express-bus combination that provides a high level of service can attract automobile riders although such high-level service is extremely expensive for the public to support. This observation suggests that a service oriented to a relatively small market requires a carefully established fare and route structure to ensure that revenues offset a realistic portion of the operational costs.
3. Increases in bus accidents appear to be a problem when a reversible exclusive center bus lane is used.
4. The bus-preemption system did not appear to have an adverse effect on traffic signal operation but did increase the required service calls.
5. The new bus service and the bus-priority treatment greatly increased the number of persons moved on Northwest Seventh Avenue. Between 20 and 30 percent of the persons moved on Northwest Seventh Avenue were moved by bus although buses constituted less than 2 percent of the traffic stream.
6. The park-and-ride facility was an essential element of the transit service, and a majority of the bus passengers would have been lost to the automobile if the facility had not been provided.

ACKNOWLEDGMENTS

We wish to express our gratitude to the sponsors of this research project: the Urban Mass Transportation Administration, the Federal Highway Administration, the Florida Department of Transportation, and the Metropolitan Dade County Transit Agency and Department of Traffic and Transportation. The direct support and participation of these agencies were invaluable to the success of this research. We are also indebted to the many graduate assistants, administrative staff members, and student assistants who collected and reduced the tremendous quantity of data. The opinions, findings, and conclusions expressed in this report are ours and do not necessarily reflect the views of the sponsors.

REFERENCE

1. J. A. Wattleworth and others. I-95/NW 7th Avenue Bus/Car Pool Systems Demonstration Project Evaluation Phase I. Florida Department of Transportation, Transportation Research Center Technical Repts. 20-1 through 20-10, 1977; Urban Mass Transportation Administration.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Where Express Buses Work

Jeffrey M. Zupan and Boris Pushkarev, Regional Plan Association, New York

Densities of residential areas and sizes of central business districts necessary to generate sufficient demand to support express buses for given frequencies of service at a reasonable cost are estimated. Two types of express-bus operations are considered. In the first case, patrons are picked up by buses circulating in a residential area before the bus travels express to the central business district. In the second, commuters arrive by automobile at a park-and-ride lot before continuing their trips by express bus. We found that, for express-bus operations with pedestrian access, a cost of 6 cents/passenger·km (10 cents/passenger-mile) is attainable for only a narrow range of residential densities and only to rather large central business districts. If 12 cents/passenger·km (20 cents/passenger-mile) is an acceptable cost standard, a wider range of supporting conditions is possible. Express-bus operations that provide park-and-ride facilities are more broadly applicable at the 6 cents/passenger·km (10 cents/passenger-mile) standard. Residential densities as low as 7 dwelling units/hm^2 (3 dwelling units/acre) and central business districts of moderate size can in some cases support express-bus service. These findings match reasonably well with empirical data from 11 express-bus operations in two Connecticut cities. The achievement of more express-bus operations is possible by higher residential densities over a larger area and by growth of central business districts in medium- to large-sized cities.

This paper is part of a larger study to determine the land use densities suitable for a variety of public transit modes and service levels. The express bus is only one of eight modes considered. The measure of demand for public transit in an urban setting and the cost of supplying the service to meet that demand, developed as part of this effort, will not be fully described here. Nevertheless, outlining the relevant variables involved is necessary before the focus of this paper—matching demand and supply for express-bus service—is discussed.

A set of models was created that estimate the number of public-transit trips from a residential area to a nonresidential concentration or cluster. One model estimates the total number of trips between two places; the other model divides those trips into trips by transit and trips by automobile. The models further record the distinction between work trips and nonwork trips and the distinction between travel to CBDs or spread highway-oriented clusters.

The model developed to estimate total trips between a residential area and a nonresidential cluster shows that such trips are a direct function of the size of the nonresidential cluster measured by square meters (square feet) of nonresidential floor space, the number of workers (for work trips) and number of people (for nonwork trips) in the residential area, and an inverse function of the distance between the residential and nonresidential areas. Since the model was calibrated with data from the New York urban region, the competing influence of Manhattan as an attractor of trips is also accounted for.

The modal-choice model distinguishes among travelers with zero, one, or two or more automobiles available in their households. Automobile ownership is shown to be a function of residential density, income, transit service available, and number of drivers in the household. Bus frequency, proximity of rapid transit, availability of commuter-rail service and, most important, the size and character of the nonresidential cluster are significant parts of the model. A complete description of all the models is published in another report (1).

The cost of express-bus operations to meet the transit demand is found by estimating the vehicle-hours necessary to meet that demand in a particular urban setting. Vehicle-hour calculations are based on round-trip distance (including the usually empty return run) and speed. Speed, in turn, depends mostly on how much of the run is on freeways and how much is on congested streets.

The vehicle-hours must be related to passenger boardings within the entire collection area of the route. That area may be quite small if passengers walk to the bus or very large if passengers arrive by automobiles. The proportion of passengers who arrive by automobiles may range from 10 to 90 percent or more, depending on whether the express-bus service is from residential streets or from commuter parking lots.

Two types of collection areas are examined:

1. The bus circulates 15 min through the neighborhood or 5.2-km^2 (2-mile^2) collection area to ensure that every resident is within 0.37 km (0.25 mile) of a bus stop before the bus makes the express run to a CBD, and
2. Most riders drive or are driven from a 52-km^2 (20-mile^2) tributary area to a single location from which the bus makes the express run.

For both types of areas, a cost of \$15/bus·h and a 4 and 4-h split-shift labor agreement were assumed. Thus daily cost is \$120/bus. We assumed that the trips are exclusively trips to work and that they take place only during a 2-h period inbound and a 2-h period outbound.

The purpose of the illustrative calculations (Tables 1 and 2) is to find out what minimum residential densities in the collection areas will provide sufficient passenger volume to keep costs per passenger-kilometer (passenger-mile) within predetermined limits. This is done for three assumed operating speeds—56, 40, and 23 km/h (35, 25, and 15 mph); three peak-hour service frequencies—5, 10, and 30 buses in 2 h; four downtown sizes—4.7, 3.3, 1.9, and 0.9 km^2 (50, 35, 20, and 10 million ft^2 of nonresidential floor space; four distances between the beginning of the express run and the downtown—8, 16, 24, and 32 km (5, 10, 15, and 20 miles); and two limits of cost—6 and 12 cents/passenger·km (10 and 20 cents/passenger-mile). The 6 cents/passenger·km (10 cents/passenger-mile) rate appears to be in scale with many existing express-bus operations as well as rail operations with which the express bus may be competing. The 12 cents/passenger·km (20 cents/passenger-mile) rate is in scale with local bus operations that express buses might replace on particular routes. Many densities are unlikely to occur in the given situations even over a 5.2-km^2 (2-mile^2) collection area, on the average, given empirically encountered density gradients. This observation is even more true in the case of collection areas as large as 32 km^2 (20 miles^2) where average densities are likely to be quite low. In Tables 1 and 2 density ranges that are likely to exist are boxed in.

Table 1 deals with a 5.2-km^2 (2-mile^2) pedestrian collection area. A cost of 6 cents/passenger·km (10 cents/passenger-mile) or less can only support a frequency of five buses during the peak-hour period, a CBD of 4.7 million m^2 (50 million ft^2), 40 to 56-km/h (25 to 35-mph) speeds at a distance of 16 km (10 miles), and densities in the 30 to 35-dwelling unit (du)/m^2 (12 to 14-du/acre) range. However, if costs of 12 cents/passenger·km (20 cents/passenger-mile) are acceptable—which converts to a cost per passenger of \$2 at 16 km (10 miles), \$3 at 24 km (15 miles), and so on—then there is a somewhat wider variety of situations that can support express buses with pedestrian collection, as shown by the boxed data in Table 1. There are no reasonable densities that can support a service of 30 express buses during the peak period from a 5.2-km^2 (2-mile^2) collection area.

Although under some circumstances express-bus operations with local collection are possible, these cases are largely confined to a narrow range. At 6 cents/passenger·km (10 cents/passenger-mile), a 24 to 32-km (15 to 20-mile) run to a CBD of 4.7 km^2 (50 million ft^2) requires average speeds of at least 40 km/h (25 mph) and rather high residential densities of 30 to 34 du/hm^2 (12 to 14 du/acre). For lower residential densities, a still larger CBD size would be needed to attain the same trips per square kilometer. Nonresidential clusters of over 4.7 km^2 (50 million ft^2) are mostly found in urban areas of over one million people, which suggests that our hypothetical express-bus service remains confined to very large cities if this service is dependent on pedestrian access. In fact, the major existing walk-to-express-bus services are located in the Washington, D.C., area, in New York City, and in New Jersey where commuters to New York City live.

An express-bus service of the park-and-ride variety is applicable more broadly, as Table 2 indicates. However, the larger collection area of 52 km^2 (20 miles^2) is less likely to have the average densities that may be encountered in a 5.2-km^2 (2-mile^2) area. Therefore, the range of realistic densities for the collection areas is narrowed a great deal, as evident from the boxed data in Table 2.

If a cost of 12 cents/passenger·km (20 cents/passenger-mile) is acceptable, express-bus service with a park-and-ride facility can cover a still wider range of conditions, including a slower speed of 24 km/h (15 mph) and higher service frequencies.

Summarizing, park-and-ride express-bus services generally can provide low and medium-service frequencies (about 10 buses in a 2-h period or less) to CBDs larger than approximately 1.9 km^2 (20 million ft^2) for distances of approximately 24 km (15 miles) from residential areas with densities as low as 5 du/hm^2 (2 du/acre). However, although park-and-ride express-bus service is broadly applicable to medium-sized cities, park-and-ride express-bus service becomes more difficult for CBDs of less than 1.9 km^2 (20 million ft^2).

The firmness of these conclusions must be tempered by once again calling attention to some of the key assumptions. We assumed that the cost of the bus operation was \$15/h. In the New York region the actual costs vary from approximately \$13 to over \$21/h. If costs lower than \$15 are assumed, the range of possible express-bus operations widens. In addition, the demand model cannot estimate peculiar or special situations. If a particular residential area has an unusually high orientation to a CBD, residential densities lower than those shown might support express-bus operations.

The conclusions above are meant to be illustrative. The intention is not to lay down a hard-and-fast rule; e.g., 10 du/km^2 is appropriate in a given situation, and therefore bars from consideration areas with 8 du/hm^2. Instead, the intention is clearly to caution planners from accepting 8 du/hm^2 as absolute and certainly to be wary when the method indicates 4 du/m^2.

Analytical conclusions to empirical observations are useful. Table 3 gives some characteristics of express-bus routes instituted in 1973-75 to serve the CBDs of two medium-sized cities—Hartford and New Haven, Connecticut. (These data, for 1975, were provided by the Connecticut Department of Transportation.) All of these routes operate from park-and-ride lots, either existing church-owned parking lots or newly constructed commuter lots. The suburban routes operate mostly over a distance of 8 to 19 km (5 to 12 miles) and two 27-km (17-mile) routes go essentially beyond the suburbs to neighboring urban areas. The demand densities were available only at town-level aggregation (large in Connecticut) and range from 5 to 60

Table 1. Minimum residential densities that provide sufficient passenger volume to keep costs within predetermined limits for express-bus service with local collection.

Cost per Passenger-Kilometer (¢)	Buses During 2-h Peak	Distance From CBD (km)	Line-Haul Speed (km/h)	Residential Density (dwelling units/hm^2) by Downtown Floor Space			
				4.7 km^2	3.3 km^2	1.9 km^2	0.9 km^2
6	5	8	56	—[a]	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		16	56	29.7	46.9	—[a]	—[a]
			40	34.6	59.3	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		24	56	44.5	—[a]	—[a]	—[a]
			40	61.8	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		32	56	66.7	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
	10	8	56	—[a]	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		16	56	59.3	74.1	—[a]	—[a]
			40	69.2	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		24	56	—[a]	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		32	56	—[a]	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
	30	—	—	—[a]	—[a]	—[a]	—[a]
12	5	8	56	12.4	14.8	19.8	46.9
			40	12.4	14.8	24.7	54.4
			24	14.9	17.3	32.1	66.7
		16	56	14.9	19.8	37.1	—[a]
			40	17.3	24.7	44.5	—[a]
			24	24.7	34.6	64.2	—[a]
		24	56	19.8	32.1	69.2	—[a]
			40	27.2	39.5	—[a]	—[a]
			24	37.0	61.8	—[a]	—[a]
12	5	32	56	34.6	56.8	—[a]	—[a]
			40	44.5	69.2	—[a]	—[a]
			24	66.7	—[a]	—[a]	—[a]
	10	8	56	17.3	22.2	34.6	74.1
			40	19.8	27.2	46.9	—[a]
			24	24.7	34.6	64.2	—[a]
		16	56	24.7	37.1	69.2	—[a]
			40	32.1	49.4	—[a]	—[a]
			24	46.9	66.7	—[a]	—[a]
		24	56	39.5	61.8	—[a]	—[a]
			40	54.4	—[a]	—[a]	—[a]
			24	71.7	—[a]	—[a]	—[a]
		32	56	71.7	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
	30	8	56	54.4	66.7	—[a]	—[a]
			40	59.3	69.2	—[a]	—[a]
			24	71.7	—[a]	—[a]	—[a]
		16	56	—[a]	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		24	56	—[a]	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		32	56	—[a]	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]

Note: 1 km = 0.6 mile; 1 m^2 = 10.8 ft^2.

[a] Either more than 7413 dwelling units/hm^2 are required or supplying the service at the stated cost per passenger-kilometer is impossible at any residential density.

Table 2. Minimum residential densities that provide sufficient passenger volume to keep costs within predetermined limits for express-bus service with park-and-ride lots.

Cost per Passenger-Kilometer (¢)	Buses During 2-h Peak	Distance From CBD (km)	Line-Haul Speed (km/h)	Residential Density (dwelling units/hm^2) by Downtown Floor Space			
				4.7 km^2	3.3 km^2	1.9 km^2	0.9 km^2
6	5	8	56	4.9	4.9	7.4	12.4
			40	4.9	4.9	7.4	12.4
			24	—[a]	—[a]	—[a]	—[a]
		16	56	7.4	7.4	12.4	32.1
			40	7.4	9.9	12.4	39.5
			24	—[a]	—[a]	—[a]	—[a]
		24	56	9.9	9.9	17.3	74.1
			40	9.9	12.4	24.7	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		32	56	9.9	14.8	32.1	—[a]
			40	12.4	17.3	49.4	—[a]
			24	—[a]	—[a]	—[a]	—[a]
	10	8	56	7.4	7.4	9.9	19.8
			40	9.9	9.9	12.4	24.7
			24	—[a]	—[a]	—[a]	—[a]
		16	56	9.9	12.4	17.3	56.8
			40	12.4	12.4	19.8	74.1
			24	—[a]	—[a]	—[a]	—[a]
		24	56	12.4	14.9	24.7	—[a]
			40	12.4	17.3	34.6	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		32	56	17.3	24.7	71.7	—[a]
			40	19.8	37.1	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
	30	8	56	12.4	14.8	19.8	—[a]
			40	12.4	17.3	29.7	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		16	56	17.3	22.2	56.8	—[a]
			40	19.8	32.1	74.1	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		24	56	29.7	51.9	—[a]	—[a]
			40	29.7	66.7	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
		32	56	56.9	—[a]	—[a]	—[a]
			40	—[a]	—[a]	—[a]	—[a]
			24	—[a]	—[a]	—[a]	—[a]
12	5	8	56	4.9	4.9	4.9	7.4
			40	4.9	4.9	4.9	9.9
			24	4.9	4.9	4.9	12.4
		16	56	4.9	4.9	7.4	12.4
			40	4.9	4.9	9.9	17.3
			24	7.4	7.4	12.4	29.7
		24	56	4.9	7.4	12.4	37.1
			40	7.4	7.4	12.4	46.9
			24	9.9	9.9	17.3	74.1
		32	56	7.4	9.9	14.8	69.2
			40	9.9	9.9	17.3	—[a]
			24	12.4	14.8	29.7	—[a]
	10	8	56	4.9	4.9	7.4	12.4
			40	4.9	4.9	7.4	12.4
			24	4.9	4.9	7.4	14.8
		16	56	4.9	7.4	9.9	24.7
			40	4.9	7.4	12.4	32.1
			24	7.4	9.9	14.9	56.8
		24	56	7.4	9.9	14.9	61.8
			40	9.9	12.4	19.8	—[a]
			24	12.4	14.8	34.6	—[a]
		32	56	12.4	12.4	27.2	—[a]
			40	12.4	17.3	39.5	—[a]
			24	17.3	27.2	74.1	—[a]
	30	8	56	7.4	9.9	12.4	22.2
			40	9.9	9.9	14.8	29.7
			24	12.4	12.4	17.3	42.0
		16	56	9.9	12.4	19.8	74.1
			40	12.4	14.8	29.7	—[a]
			24	14.9	22.2	51.9	—[a]
		24	56	14.9	17.3	42.0	—[a]
			40	17.3	27.1	74.1	—[a]
			24	29.6	61.8	—[a]	—[a]
		32	56	22.2	37.1	—[a]	—[a]
			40	32.1	59.3	—[a]	—[a]
			24	59.3	—[a]	—[a]	—[a]

Note: 1 km = 0.6 mile; 1 m^2 = 10.8 ft^2.

[a] Either more than 7413 dwelling units/hm^2 are required or supplying the service at the stated cost per passenger-kilometer is impossible at any residential density.

Table 3. Characteristics, daily use, and services of express-bus operations to two medium-sized cities.

Origin of Trip	Passengers	Bus-Hours	Service Period (h)	Buses Assigned to Route		Runs	Running Time (min)	Distance (km)	Scheduled Speed (km/h)	Trips per Square Kilometer[a]	Avg Passengers per Bus-Hour	Bus-Hours per Assigned Bus
				Morning	Evening							
To Hartford[b]												
Manchester	1064	24.15	2.0	5	7	14	20	13	39	8.8	44.0	4.0
West Hartford	783	19.02	2.0	4	5	13	20	8	24	6.9	40.2	4.2
Enfield	709	23.43	1.6	7	7	9	30	28	55	4.1	30.3	3.3
Avon	526	27.50	1.5	5	7	7	35	19	32	4.3	20.8	4.6
Glastonbury	328	13.50	1.5	4	4	7	25	11	27	1.2	24.3	3.3
Middletown	255	11.40	1.2	3	3	4	30	28	55	1.2	22.4	3.8
Simsbury	244	11.00	1.3	5	4	4	30	19	39	1.4	22.2	2.4
Newington	204	11.40	1.5	3	3	6	20	16	48	3.0	17.9	3.8
Total	4113	139.22									29.5	
To New Haven[c]												
Bradford	447	14.42	2.0	3	3	9	15	11	45	4.0	31.0	4.8
Milford	98	10.00	1.5	2	2	4	25	16	39	0.8	9.8	5.0
Total	545	24.42									22.3	

Notes: Data for passengers and bus-hours are for two directions; other data are for one direction.
$1\ km^2 = 0.4\ mile^2$; 1 km = 0.6 mile; $1\ m^2 = 10.8\ ft^2$.

[a] Arbitrarily calculated over gross land area of each municipality, which ranges from 34.2 to 133.9 km^2; actual tributary area not known.
[b] Urbanized area population 465 000; CBD office floor space 0.69 km^2; nonresidential floor space in cluster over 3.25 km^2.
[c] Urbanized area population 348 000; CBD office floor space 0.33 km^2; nonresidential floor space in cluster 2.47 km^2.

daily trips/km^2 (2 to 23 daily trips/$mile^2$). The average scheduled speed varies from 24 to 55 km/h (15 to 34 mph); higher speeds generally occur in corridors that have freeways. Although the service period does not exceed 2 h in each direction, there are 4 to 14 departures. The productivity varies greatly from route to route but averages 28.4 passengers/vehicle·h, and the fare in May 1975 averaged $0.44/passenger for a trip just under 16 km (10 miles). How much of the cost this fare covered is not clear. On the Hartford bus system in general, the operating cost was $14.20/bus·h. However, this average cost cannot be applied to the express-bus routes that have below-average vehicle use. As evident from Table 3, buses assigned to the service operated only about 4 h/d. Whether these buses could be used elsewhere during off-peak hours is questionable though the labor agreement did permit 4-h split shifts for bus drivers.

More generally, Hartford, which has a downtown nonresidential concentration in excess of 3.3 km^2 (35 million ft^2), about one-third of which is in the CBD proper, supports a flourishing number of express-bus services; perhaps the two most heavily used close-in routes operate at a profit.

By contrast, New Haven, which has a concentration of 2.4 km^2 (26 million ft^2), supports only one reasonably used route; the other route carries fewer than 100 people/d or only 10 passengers/bus·h. Express-bus patronage may well be more a function of CBD office floor space than of total CBD floor space in a more broadly defined cluster. The CBD office floor space is 0.7 km^2 (7.4 million ft^2) in Hartford, plus additional large office buildings outside the CBD proper; in New Haven, however, the floor space is 0.3 km^2 (3.6 million ft^2). Furthermore, a heavy commuter market to the north of New Haven's downtown is not exploited by commuter buses because of the lack of convenient freeway access. Nevertheless, the Connecticut data seem to support the proposition that a downtown cluster size on the order of 2 km^2 (20 million ft^2) may represent the lower limit of park-and-ride express-bus feasibility, at least if the frequency is five buses during the peak period.

From a land-use-policy perspective, the achievement of more widespread express-bus operations is possible by higher residential densities over a larger area and by the growth of the downtowns in medium- to large-sized cities.

ACKNOWLEDGMENTS

The underlying work for this paper was accomplished as part of a study, Urban Densities for Public Transportation, prepared under contract with the Tri-State Regional Planning Commission, funded by a grant from the Urban Mass Transportation Administration, U.S. Department of Transportation, and by matching grants from the Ford Foundation and the Rockefeller Foundation.

REFERENCE

1. B. Pushkarev and J. M. Zupan. Public Transportation and Land Use Policy. Indiana Univ. Press, Bloomington, 1977.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

Planning and Designing Bus-Transit Garages

Rick Kuner, New Alternatives, Inc.

How large should a bus garage be? How many square meters are needed to accommodate the different functions that must be contained in the building and on the site? Answering questions of future design size with certainty cannot be done. Uncertainty arises because of the potential impact of public policies regarding car or van pools, preferential treatment for buses, parking fees, potential fuel shortages, type and amount of transit service provided, population in the service area, and availability of funds. The best way to deal with these uncertainties is to test the implications of different sets of conditions.

The purpose of this paper is to describe a computer-based model, developed by the author, that deals with questions of transit-garage size under different future conditions. The model is quick, is inexpensive to use, and has been applied to existing and proposed bus-transit garages in five cities where the bus fleets are small to medium sized.

Bus garages have five major functional areas or elements: general offices, operations area, repair area, vehicle storage (cold-weather indoor, warm-weather outdoor, or both), and an outside area. The linkages among these elements are shown in Figure 1. Three types of circulation are essential to the proper functioning of the facility. Buses need quick access from the street to the returned-bus reservoir and easy access to the street to start a revenue run. Within the site, buses must be able to circulate through the fueling-cleaning-washing line every night and then to the repair bays or bus-storage area. One report (4) found that half of the service-cycle time was consumed by moving the buses from the returned-bus reservoir through the fueling-cleaning-washing line to the storage or repair area. Employees should be able to circulate quickly between general offices, operations area, and repair area; hostlers should be able to proceed from one bus to another quickly. Employee and visitor vehicles should have easy access to parking areas. The importance of an efficient layout increases as the size of the fleet increases (4).

MODEL FUNCTION

The problem-solving technique inherent in the model is sensitivity analysis, a procedure employed because of uncertainty about the actual value of a parameter under analysis. The major input parameter is the estimated future bus-fleet size. Although the exact number of buses needed in the future is seldom known, the planner will want to know how sensitive allocation of garage and site space is to changes in bus-fleet size. The procedure in sensitivity analysis is to change the value of the parameter in question (bus-fleet size) and to examine the extent to which the changes affect the results of the analysis (garage and site space allocation).

The model user identifies the different bus-fleet sizes to be tested and specifies whether buses are to be stored indoors or outdoors. The model uses these input data and a series of precoded assumptions and guidelines (Table 1) to generate an architectural space program for each element of the garage and site.

MODEL OUTPUT

The output report produced by the computer program is shown in Figure 2. Test results of any four bus-fleet sizes (between 10 and 150) can be given in one report. The results of the model can be used to draw curves showing the effects of bus-fleet size on facility size.

QUESTIONS THAT THE MODEL HELPS TO ANSWER

How adequate is the space in the present garage? In Flint, Michigan, a fleet of 40 buses was stored in a building of 5357 m^2 (57 600 ft^2); the model, however, indicated a need for only 3142 m^2 (33 800 ft^2) (2). In Sioux City, Iowa, a 30-bus fleet was housed in a building twice as large as needed; the transit board dealt with the excess space by leasing it to a trucking company (3). In Duluth, Minnesota, the working areas in a bus-transit garage were too large and the storage areas were too small (1). The fleet contained 88 buses; 63 were stored in the area designed for bus storage, and the remaining 25 had to be stored in the repair shop, body shop, and cleaning-washing area.

How large a site is needed for the present bus fleet? This question is answered in the final rows of the computer report (Figure 2) that show total site area required.

How large a building and site might be needed in the future? This question is directly related to staging. Given a projected need for increased service, a large bus fleet, and the uncertainties of when the need will occur, the transit agency should acquire a larger site than needed initially, build a core facility, and have the facility designed so that additions can be made easily when the need arises. The model is ideally suited to deal with this question because of the range of bus-fleet sizes that can be tested.

How should space be allocated in a new garage? The model generates a preliminary architectural space program that can be used in discussing future needs with interested agencies. The model does not produce a final space program, but it does provide a useful start.

How much can the size of the building be reduced by storing buses outdoors instead of indoors? In warm climates, indoor bus-storage areas need only be heated to 2 to 4°C (35.6 to 39.2°F). The model provides for an option to specify either indoor or outdoor storage. Bus storage can amount to a significant portion of the building, but this space is the cheapest space per unit to build.

LIMITATIONS OF THE MODEL

1. The model is a planning tool and not a substitute for architects and engineers. The model extends the capabilities of technical personnel, but does not replace them. In all applications to date, the model has been used as an aid in making fundamental decisions concerning need for a new garage and concerning best site location. These decisions have been made prior to contracting with architects and engineers.
2. The model does not account for inefficiencies of

sites with unusual shape, topography, or subsoil conditions.

3. The precoded assumptions and guidelines built into the model are limited to fleet sizes of 10 to 150 buses. The model could be modified to deal with larger fleet sizes, but the applications so far have not required this capability. The model also assumes that the garage will be the single transit maintenance garage and general administrative offices for the transit system.

4. The model is limited because assumptions that are valid in some cases are applied to all cases.

ACKNOWLEDGMENTS

I wish to acknowledge the technical assistance received from Robert Brown and C. Raymond Kary of the W. C.

Figure 1. Linkages among major elements of a proposed facility in Sioux City, Iowa.

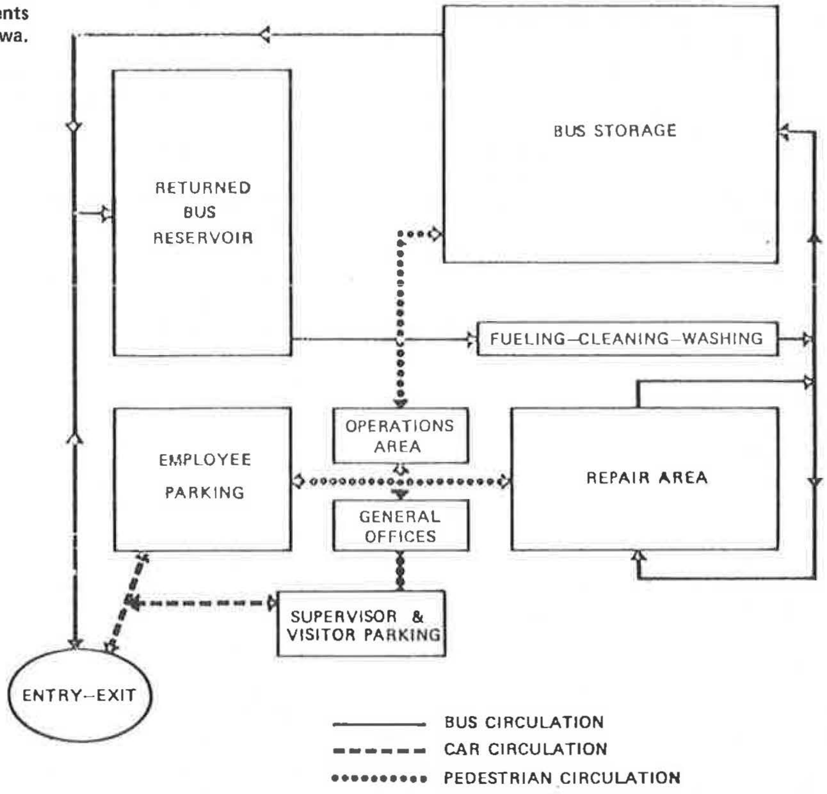


Table 1. Major assumptions of the model.

Facility Element	Size (m^2)	Miscellaneous
General offices		
Private offices	11.2 to 15.6	Private office
Transportation supervisor	0 or 13.4	In small systems, dispatcher
Maintenance supervisor	0 or 13.4	In small systems, foreman
Office manager	0 or 11.2	In small systems, receptionist or secretary
Counting room	4.7 minimum	Space for a work table, file cabinets, and fare boxes
Interior circulation	15 percent of subtotal	
Operations area		
Dispatcher	11.2	Private office
Operator's day room	18.6 minimum	
Interior circulation	10 percent of subtotal	
Repair area		
Foreman	11.2	Private office
Repair bays	69.8/bay	One 20-bus bay plus 1 bay for increments of 10 or more buses
Machine and electrical	18.6 minimum	
Tire repair and storage		Two sets (winter and summer)
Paint and body area	237/bay	One 50-bus bay plus 1 bay for increments of 25 or more buses
Fueling-cleaning-washing	298 minimum (93 for a second fuel island and cleaner)	Wraparound washer (a second fuel island and cleaner when the fleet reaches 100 buses)
Contingency	10 percent of subtotal	
Vehicle storage		
Bus parking	39.1/bus	Indoor or outdoor
Circulation	15 percent of subtotal	
Outside area		
Parking	32.6 to 37.2/space	Employee, supervisor, and visitor parking
Returned bus reservoir	39.1/bus	
Contingency	10 percent of subtotal	

Note: 1 m^2 = 10.8 ft^2.

Figure 2. Model output of a hypothetical office-bus maintenance facility.

```
-----------------------------------------------------------------------------------
FUNCTIONAL AREAS            FACILITY SIZE (SQUARE FEET) AT DIFFERENT BUS FLEET SIZES

                                30 BUSES       40 BUSES       88 BUSES      130 BUSES
-----------------------------------------------------------------------------------

A. GENERAL OFFICES

    GENERAL MANAGER.............     168            168            168            168
    TRANSPORTATION SUPERVISOR...       0              0            144            144
    MAINTENANCE SUPERVISOR......       0              0            144            144
    OFFICE MANAGER..............       0              0            120            120
    VISITORS....................      24             32             64             80
    SECRETARIES AND CLERKS......       0            144            288            432
    RECEPTIONIST-SECRETARY......      72             72             72             72
    CONFERENCE ROOM.............     150            150            176            260
    WORK SPACE..................      60             80            176            260
    OFFICE STORAGE..............      88            108            204            288
    COUNTING ROOM...............      80             90            138            180
    VAULT CART STORAGE..........      11             15             31             45
    MALE REST ROOM..............      35             35             44             65
    FEMALE REST ROOM............      35             35             44             65

                   SUBTOTAL.....     723            929           1813           2323

    INTERIOR CIRCULATION........     108            139            272            348

      TOTAL-GENERAL OFFICES.....     831           1068           2085           2671

B. OPERATIONS AREA

    DISPATCHER..................     120            120            120            120
    OPERATORS DAY ROOM..........     500            600           1080           1500
    MALE LOCKER ROOM............     120            180            468            720
    FEMALE LOCKER ROOM..........      60             90            234            360
    MALE REST ROOM..............      90            120            264            390
    FEMALE REST ROOM............      60             80            176            260

                   SUBTOTAL.....     950           1190           2342           3350

    INTERIOR CIRCULATION........      95            119            234            335

      TOTAL-OPERATIONS AREA.....    1045           1309           2576           3685

C. REPAIR AREA

    FOREMAN.....................     120            120            120            120
    REPAIR BAYS.................    1500           1500           3000           5250
    MACHINE AND ELECTRICAL AREA.    1400           1400           3720           5400
    TIRE REPAIR AND STORAGE.....     140            180            372            540
    PAINT AND BODY AREA.........    2550           2550           3300           4050
    FUELING-CLEANING-WASHING....    3200           3200           3200           4200
    STOCKROOM...................     300            400            880           1300
    BOILER ROOM.................     600            700           1180           1600
    LOCKER ROOM.................      50             60            108            150
    MALE REST ROOM..............      40             40             58            100
    FEMALE REST ROOM............      20             20             29             50

                   SUBTOTAL.....    9920          10570          15967          22760

    CONTINGENCY.................     992           1057           1597           2276

           TOTAL-REPAIR AREA.....  10912          11627          17564          25036

D. VEHICLE STORAGE
    BUS PARKING.................   12600          16800          36960          54600
    AUXILIARY VEHICLES..........     400            400           1200           2400
                   SUBTOTAL.....   13000          17200          38160          57000

    CIRCULATION.................    1950           2580           5724           8550

      TOTAL-VEHICLE STORAGE.....   14950          19780          43884          65550

E. OUTSIDE AREA
    SUPERVISOR PARKING..........    4000           5200          11600          17200
    EMPLOYEE PARKING............   15750          19250          36050          50750
    RETURNED BUS RESERVOIR......    4200           5460          12180          18060
    CIRCULATION.................    2395           2991           5983           8601
    WALKWAYS....................    1007           1209           2286           3314
    LANDSCAPING.................    2007           2209           3286           4314
                   SUBTOTAL.....   29359          36319          71385         102239
    CONTINGENCY.................    2936           3632           7139          10224

         TOTAL-OUTSIDE AREA.....   32295          39951          78524         112463

TOTAL-BUILDING AREA.............   27738          33784          66109          96942
TOTAL-SITE AREA (SF)............   60033          73735         144633         209405
TOTAL-SITE AREA (ACRES).........     1.4            1.7            3.3            4.8
```

Gilman Division of Barton-Aschman Associates, Inc. Their long years of transit experience and expertise were invaluable in developing the assumptions and guidelines coded into the model. However, any errors in fact or in judgment are my sole responsibility.

REFERENCES

1. Analysis of Bus Maintenance and Storage Facilities: Duluth Transit Authority, Duluth, Minnesota. Barton-Aschman Associates, Inc., Evanston, Ill.; Head of

the Lakes Council of Governments, Duluth, Minn., Jan. 1975.
2. The Proposed MTA Office-Bus Maintenance Facility. Barton-Aschman Associates, Inc., Evanston, Ill.; Mass Transportation Authority of Flint, Mich., March 1974.
3. A New Transit Garage for Sioux City, Iowa: A Feasibility Study. Barton-Aschman Associates, Inc., Evanston, Ill.; city of Sioux City, Iowa, March 1975.
4. V. S. Thurlow, J. A. Bachman, and C. D. Lovett. Bus Maintenance Facilities: A Transit Management Handbook. MITRE Corp., McLean, Va.; Office of Transit Management, Urban Mass Transportation Administration, Nov. 1975.

Publication of this paper sponsored by Committee on Maintenance and Operations Systems.