similar results could be found in other suburban parts of the transit system, even more significant fuel cost savings could be obtained. Restructuring the routes and service in developed areas such as the inner city and the middle city may not yield similar levels of savings because of various constraints such as heavy automobile congestion and the difficulty of moving routes that have been in place for 40 years or longer. Nevertheless, an examination of an inner city area should be conducted to determine how much energy might be saved by a more efficient route and schedule design. From this study it may be concluded that suburban areas appear to be good locations for obtaining substantial energy savings payoffs through restructuring the routes and service level of an existing system.

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Montgomery County, Pennsylvania, Turnpike Express Bus Study

THABET ZAKARIA, W. THOMAS WALKER, and PANAGIOTIS P. SALPEAS

ABSTRACT

A summary of the methodology, analysis, evaluation, and findings of a bus study that was conducted to assess the feasibility of park-and-ride and express bus service within the Pennsylvania Turnpike corridor is presented. Some of the fastest developing commercial and industrial areas in the Philadelphia metropolitan area are within this corridor, including many high-technology industries. A special traffic demand estimation method, which requires a special coding procedure and uses an existing traffic assignment model, was developed. This demand estimation technique reduces the computer cost of simulation, allows the use of the regional modal split and transit assignment models without recalibration, and produces accurate transit ridership estimates within the detailed study area for the routes under study. The evaluation of the promising express bus alternatives for the Pennsylvania Turnpike indicated that the subsidy for circumferential express bus routes is rather large because the patronage is generally small, even for growing and congested circumferential urban corridors.

The Pennsylvania Turnpike and US-202 Expressway describe a circumferential transportation corridor through Philadelphia's northern and western suburbs. The corridor includes a 31.4-mile segment of the turnpike between Valley Forge (Exit 24) and the Delaware Valley (Exit 29) interchanges and an 18-mile segment of US-202 Expressway from Valley Forge to the Town of West Chester, Pennsylvania. Some of the fastest developing commercial and industrial areas within the Delaware Valley region are adjacent to these two expressways. These areas include many high-technology industries, which are attracted by the access to national markets provided by the turnpike (see Figure 1) and the availability of large tracts of inexpensive land for commercial development. This growth in employment, coupled with suburban residential development, has increased traffic congestion and consequently decreased the level of

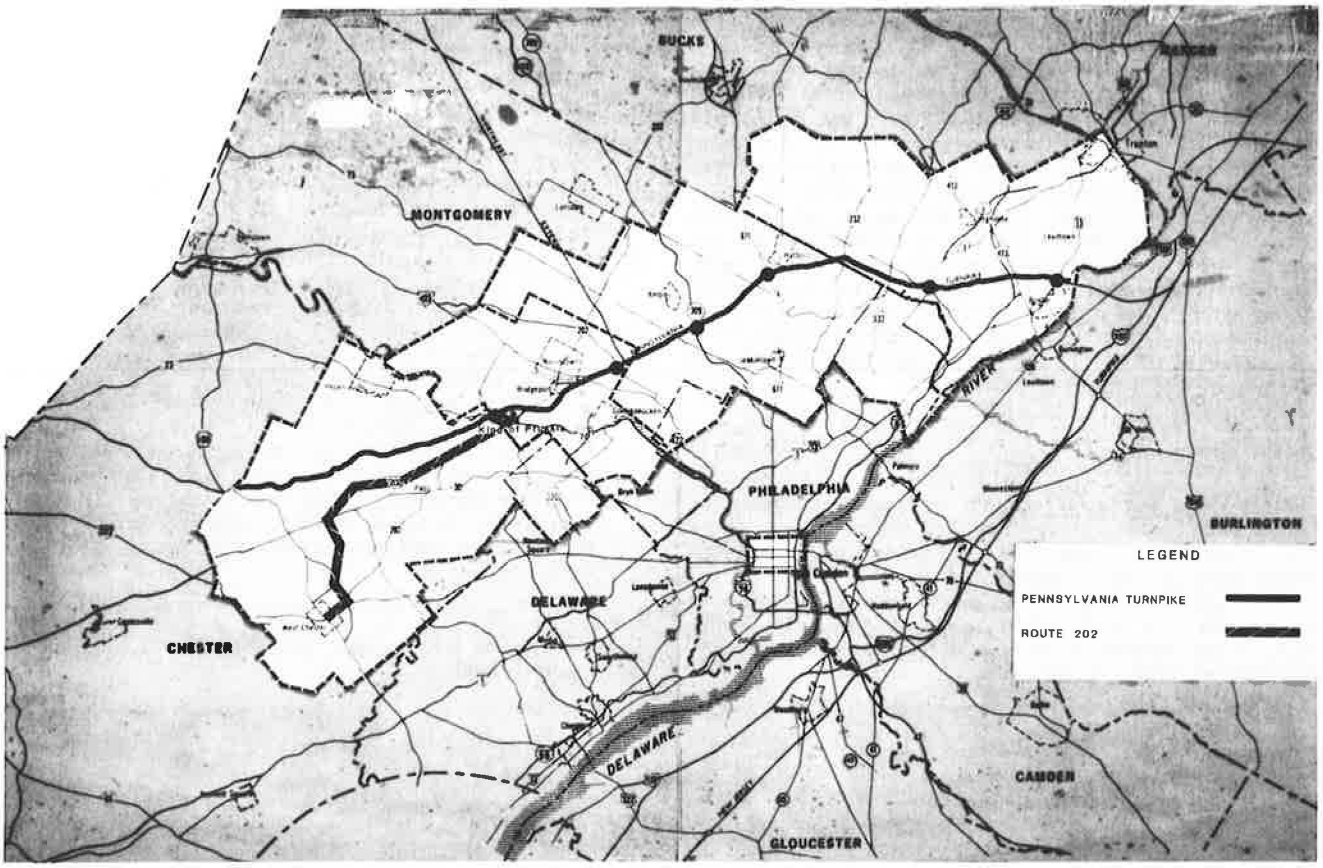

FIGURE 1 Pennsylvania Turnpike corridor planning superdistricts.

service provided by the turnpike and its surrounding road network.

A summary is presented of the methodology, analysis, evaluation, and findings of an express bus study conducted to assess the feasibility of park-and-ride and express bus service within this corridor, and to recommend an appropriate level of public transportation service. This bus service is needed to provide present and projected turnpike automobile travelers with an alternate mode of travel in order to reduce traffic congestion on the turnpike and to provide access to the employment and shopping activities within the corridor for people without access to an automobile. Guidance for the study and a review of the results were provided by a steering committee made up of representatives of Montgomery, Bucks, and Chester counties and the Southeastern Pennsylvania Transportation Authority (SEPTA), the Pennsylvania Turnpike Commission, and the Delaware Valley Regional Planning Commission (DVRPC).

CORRIDOR DEFINITION AND DATA REQUIREMENTS

In planning for new bus services, it is necessary to make an initial delineation of the area to be served by the proposed bus routes. A natural corridor is formed by an area 5 miles on either side of US-202 Expressway and the Pennsylvania Turnpike. This corridor is shown in Figure 1. The 5-mile bandwidth was chosen because previous studies had shown that the maximum trip length to park-and-ride lots would be less than 5 miles (1).

Four categories of data are required for developing and analyzing express bus service alternatives in the corridor:

1. Land uses,
2. Demographics and employment,
3. Travel characteristics, and
4. Existing transportation facilities.

Travel impact analysis requires that the data be collected for small districts (census tracts). It is also convenient to aggregate these small districts to larger superdistricts so that the amount of information can be reduced to a more manageable level. For this reason the 256 census tracts within the study area were aggregated to the four superdistricts shown in Figure 1.

Land Uses

Public transit service requires high concentrations of land-use activities in order to generate travel volumes of sufficient magnitude to make the transit routes economically viable. This land-use survey suggests the magnitude of bus services that can be supported and the location of high-density developments that may be served.

The Pennsylvania Turnpike corridor is intensively developed, particularly in the vicinity of the turnpike interchanges. All types of development--high and low density, residential, commercial, cultural, educational, medical, and industrial--are found within the corridor.

Demographic and Employment Data

Although the land-use survey is useful for locating areas of high development, more specific information about the nature of these developments is needed before precise estimates of patronage on the new bus routes can be made. Thus, estimates of demographic and employment data for small zones (census tracts for this study) must be provided. These variables include population; number of households; automobile ownership rates; and retail, commercial, industrial, and total employment.

The most recent detailed estimates for the demographic and employment variables (until 1980 Census information becomes available) were prepared for 1977 by DVRPC staff as part of the year 2000 planning process (2). These data were used for this study.

In summary, more than 1.1 million persons (22.1 percent of the regional population) live within the study corridor. Similarly, 21.1 percent of the region's households, 22.3 percent of employed residents, 25.8 percent of automobiles owned (and only 7.5 percent of households without automobiles) are located in the Pennsylvania Turnpike study area. This is a significant portion of the regional population; moreover, households within the corridor are characterized by greater than average automobile ownership, which provides them with greater automobile access for their daily travel needs.

A total of 436,322 jobs is located in the corridor. Manufacturing employment accounts for 23.3 percent of the total employment in the study area, retail 20.4 percent, and service 19.2 percent. This large concentration of employment tends to create severe traffic congestion during peak periods, particularly in the vicinity of major interchanges between freeways and arterials. Projections indicate that this corridor will grow at a high rate in population and employment (3).

Travel Patterns

Existing travel patterns for the turnpike corridor were summarized from the 1977 simulated trip tables produced as part of the year 2000 planning process. These trip tables are based on the 1977 population and employment estimates (2).

Most person-trips associated with the corridor begin and end in the corridor. Work travel is somewhat less concentrated: about 50 percent of corridor work-trip origins have their trip destinations within the corridor. About one trip in five is work related; 80 percent of travel is for shopping, personal business, and other nonwork purposes.

Overall, just over 2.4 percent of daily person-trips originating within the corridor use public transit. More than one-third of these transit trips are destined for the Philadelphia central business district, which has the highest percentage of trips made by transit of any destination of corridor travel. Only 1 percent of the person-trips that have both origin and destination within the corridor use public transit service. There are about 2 million daily automobile trips within the corridor; some of them may be diverted to public transit if a good level of transit service is provided.

Existing Transportation Facilities

The turnpike corridor originally developed as a series of commuter rail corridors radially oriented toward Philadelphia and, to a lesser extent, around Norristown. This radial orientation resulted in highway and public transit networks that are also focused on Philadelphia. Few transportation facilities are provided for cross-corridor movements, except for the turnpike--a facility constructed primarily for long-distance interstate travel.

Commuter Rail Facilities

Nine commuter rail lines cross the turnpike corridor and can be used for turnpike bus alternatives in two ways: rail stations near the turnpike interchanges can provide parking for park-and-ride bus operations, and the rail system can provide connecting transit service for riders whose trips are, in part, radial. Reduced fare transfers between bus and rail facilities are available at many suburban stations.

Bus Facilities

Only one interchange totally lacks peak-hour bus service. All other interchanges are served by at least two peak-hour bus routes. Like the commuter rail lines in the corridor, these bus routes provide primarily radial service oriented to Philadelphia. At present, there is no bus route that provides service on or parallel to the turnpike.

Highway Facilities

The turnpike corridor contains many miles of freeways and high- and low-type arterial roads. However, poor provision is made for east-west vehicular movement across Montgomery County. The only major east-west road in the central portion of the turnpike corridor is the turnpike itself.

Turnpike traffic within the study area has been stable since 1977. The greatest link volume--48,000 vehicles per day--occurs between the Norristown interchange and the Northeast Extension junction. A large portion of turnpike travel has both its origin and its destination within the corridor. The maximum toll for turnpike travel within the corridor is $1.15 (for travel from the Valley Forge interchange to the Delaware River Bridge interchange). The minimum toll charge is $0.30 for one interchange movement.

Parking Facilities

All turnpike interchanges have park-and-ride lots available near the interchange. Shopping centers, industrial parks, and rail stations afford excellent parking facilities for park-and-ride operations.

DEVELOPMENT OF BUS ROUTE ALTERNATIVES

Three items were considered in the development of viable alternative bus routes for the corridor. These include potential locations for park-and-ride lots and routing for distribution loops; bus route configuration and service characteristics; and operating characteristics including headways, travel times, fares, and operating costs.

Potential Bus Service Areas

The land-use inventory identified high-density concentrations of commercial and residential development in the vicinity of the turnpike and US-202 Expressway interchanges that may be served by an express bus. In defining the park-and-ride lot and passenger distribution loops in these areas, provision for transfer to existing radial transit routes was made wherever possible.

Express Bus Service Patterns

Five types of express bus service operation were considered. They were line-haul on the turnpike and US-202 Expressway with buses routed through each distribution loop in series, line-haul with transfer to a distribution loop shuttle bus at each freeway interchange, line-haul with transfer to existing transit routes at the freeway interchanges, and binary service (direct service between the parking lot and distribution loop with the route terminating on completion of the distribution loop). Two variations of binary service were considered: independent service with each route scheduled separately, and transfer service with arrivals and departures at and from the parking lots timed to allow trips not directly served with binary service to be made through convenient transfers.

The operating characteristics of each of these modes of operation were evaluated in terms of area coverage, directness of travel, transfers, convenience and delay, service quality, network clarity and image, and operating cost and complexity.

Generally, line-haul services have good area coverage but lack service quality or efficiency and ease of operation, or both. Binary service patterns generally offer high-quality service but lack area coverage unless many routes are operated at a high operating cost.

These operating characteristics were reviewed by the policy steering committee. The line-haul service patterns were rejected because they did not offer sufficient quality to be acceptable to travelers within the corridor. Line-haul bus and shuttle service was also rejected because of excessive operational complexity and cost. All possible binary service patterns were to be considered further and evaluated so that promising routes could be identified for possible implementation.

Binary Service Bus Route Operating Characteristics

In this bus service, the express bus is accessible to all available travel modes at the park-and-ride lot. Bus patrons can park their cars and ride the bus, or they can transfer from other modes such as rail and bus. People who live within walking distance may walk to the express bus.

At the destination, however, the express bus should become a distribution vehicle or local bus that takes the passengers to their destinations. Thus, there is no need for transferring passengers to another travel mode at the destination. About 20 min would be the time required to take passengers to their destinations at each of the turnpike interchanges, except for the King of Prussia area where the bus distribution time is estimated to be 30 min.

The express bus should be operated at headways of 20 min in the peak hours and 60 min in the off-peak. With regard to the regional fare structure, SEPTA proposed a $0.75 base fare with $0.30 zone charges. Zones are usually 5.5 miles long.

TRAVEL DEMAND ESTIMATION

The binary express bus route structure defined previously resulted in 110 potential bus routes. This large number of express bus routes required a special adaptation of the DVRPC regional travel forecasting process because 110 simulation runs with the traditional simulation procedures would have resulted in excessive computer costs.

Focused Express Bus Simulation Process

The travel forecasting process used to estimate the ridership on potential turnpike express buses is shown in Figure 2. The focused simulation has several characteristics that make it desirable for use in this study (4).

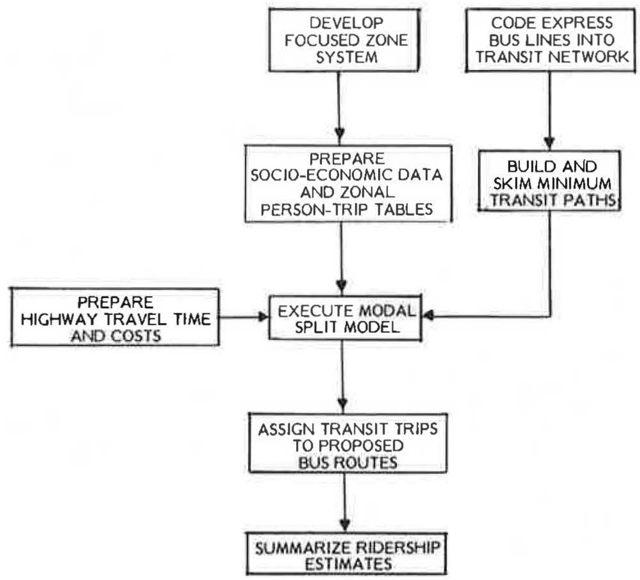

FIGURE 2 Focused express bus simulation process.

Coding the Public Transit Network

The preparation of the turnpike study network required three steps:

1. Focus the network by reducing network detail outside of the study area,
2. Update the network to include all regularly scheduled existing transit service within the corridor, and
3. Code the alternative binary turnpike bus services into the network.

At the place of origin, express bus access links were coded for all approach methods including park and ride, kiss and ride, and bus and rail. Walk approach was also coded from all centroids within 0.5 mile of the park-and-ride lot. All zones within a 3-mile radius of the park-and-ride lot in each service area were connected to the park-and-ride lot via automobile approach. An average speed of 14 mph was used to calculate the travel time needed to traverse the over-the-road distance between the zone of origin and the park-and-ride lot. An automobile operating cost of $0.22 per mile was assumed.

At the destination, a distribution loop was constructed to give potential riders direct access to their destinations. This loop was coded as follows:

1. A distribution loop time of 20 min was assumed for all service areas except Valley Forge, which was allocated 30 min for this loop;
2. This travel time was converted to a travel distance by assuming an average bus speed of 12 mph;
3. The location of employment centers within

each service area was determined and a bus loop was constructed to service these employers within the maximum travel times and distances given previously;

4. Walk approach links were coded to give direct connections between the bus distribution loop and the zones containing employment; and

5. Service headways and the fare structure noted previously were coded into the network.

As mentioned before, a special network coding procedure was devised that allowed the estimation of the patronage resulting from all 110 bus alternatives in a single run of the network generation, modal split, and transit assignment submodels. This specialized express bus coding procedure took advantage of the requirement that each express bus alternative stops only at the park-and-ride lot to pick up passengers and as necessary on the distribution loop to discharge passengers. No intermediate stops are made at service areas between the origin and destination service area. This special characteristic of the route allows the network coding to be broken into three distinct subelements (see Figure 3)--a trunk segment connecting all service areas (20-min headway service) and two satellite approach segments that connect the trunk with the park-and-ride lots and satellite distribution loops.

Because no waiting time or fare was assessed for a transfer between the satellite and the trunk segments, the total travel time and fare between origin and destination through this composite route is exactly what would be expressed by a home-to-work or home-to-nonwork trip using a direct express bus service between the park-and-ride lot and the distribution loop. The projected one-way travel volume on each proposed bus alternative is the appropriate cell in the internode volume matrix on the trunkline. This volume should be doubled to produce an estimate of total daily bus route ridership making that movement in both directions.

Modal Split Model

The modal split model operates on each person-trip interchange in the trip table (5). The model calculates a percentage of each interchange to be allocated to transit, with the residual being highway trips. In general, the better the transit service (as measured by time and cost) relative to highway travel, the higher the percentage allocated to transit. Trip purpose, transit submode, and automobile ownership are also considered in defining this relationship. The ridership loss that would be caused by combining binary routes with timed transfer or through intermediate distribution loop routing can be easily calculated by a pivot point process based on modal split model elasticities (6,7).

The DVRPC model assigns public transportation trips to the facilities that provide the best service (measured by time and cost) from the origin to the destination of the trip. During the assignment process, a transit submode (bus or rail) is selected and transit trips are "unlinked" into the assigned boardings.

Estimated Turnpike Bus Patronage

Table 1 gives the estimated ridership for each of the 110 potential bus routes evaluated as part of this analysis. Each entry in this matrix represents the average weekday ridership that would use a bus operated in a binary fashion. This ridership was taken from the intermode volume matrix of the trunkline.

An inspection of bus route patronage shows that 63 of the 110 proposed routes generate extremely low ridership (fewer than 10 trips). Of the 47 remaining buses, 31 have insignificant estimated bus ridership ranging from 11 to 30 daily trips.

The ridership estimates produced by this fore-

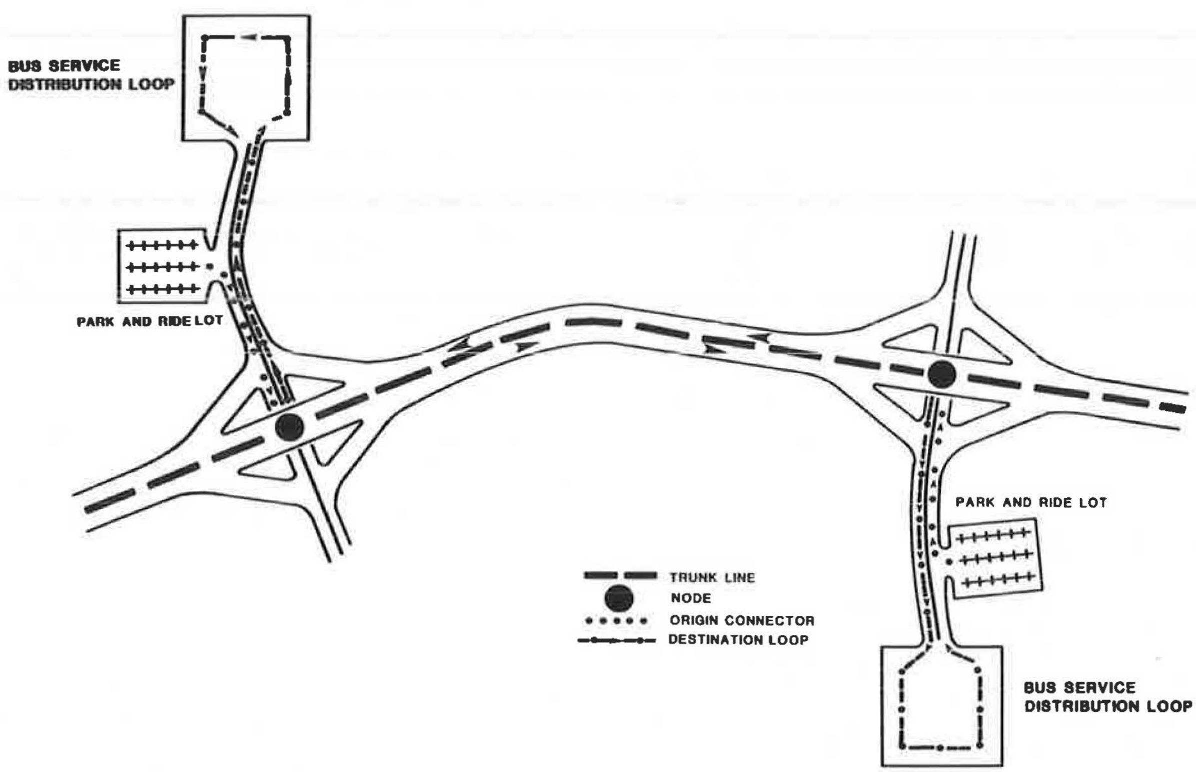

FIGURE 3 Binary coding of potential express bus routes.

TABLE 1 Estimated Daily Bus Ridership

Origin (Parking Area)	Destination (Distribution Loop): Oxford Valley Mall (1)	Levittown Railroad Station (2)	Neshaminy Mall Interchange (3)	Willow Grove Interchange (4)	Fort Washington Interchange (5)	Norristown Interchange (6)	Valley Forge Interchange (7)	Valley Forge Music Fair Area (8)	Paoli Railroad Station (9)	Exton Mall (10)	W. Chester Railroad Station (11)
Oxford Valley Mall (1)		*	16	*	*	16	*	*	*	*	*
Levittown Railroad Station (2)	*		*	12	*	12	*	*	*	*	*
Neshaminy Mall (3)	30	*		16	14	26	*	*	*	*	*
Willow Grove Interchange (Exit 27) (4)	*	16	20		68	80	*	*	14	*	20
Fort Washington Interchange (Exit 26) (5)	12	*	12	30		140	20	*	16	*	32
Norristown Interchange (Exit 25) (6)	16	*	*	24	120		34	14	22	*	20
Valley Forge (Exit 24) (7)	30	*	*	*	*	*		*	14	*	44
Valley Forge Music Fair Area (8)	*	*	*	*	*	18	24		*	*	18
Paoli Railroad Station (9)	28	*	*	*	38	42	46	*		*	38
Exton Mall (10)	*	*	*	*	*	12	48	*	*		*
W. Chester Railroad Station (11)	*	*	*	*	20	38	278	16	98	*	

Note: Each entry of this matrix represents the sum of passenger trips from the Park and Ride lot to the destination and the return trip. The ridership in this table is representative of the average weekday volumes that would occur on direct express bus service between the Park and Ride lot and the distribution loop via US-202 and/or the Pennsylvania Tkp.

*Less than 10 trips

casting method seem to be reasonable on the basis of three available data items: (a) an employment survey identifying the place of work for Bucks County residents and their mode of travel, (b) traffic counts and patterns on the turnpike, and (c) the percentage of transit trips for work trips by the U.S. Census Bureau and DVRPC regional simulation. A comparison of the estimated patronage with these data indicated that the error of forecasting is small, and the results are acceptable for all planning purposes. The 1977 calibration results for focused transit assignment indicated that the percent RMS error is about 15 percent for station and park-and-ride volumes (8).

Peak and Off-Peak Distribution of Bus Ridership

To determine the peak and off-peak distribution of turnpike express bus ridership, current ridership counts by hour were examined for existing suburban circumferential bus routes. On the average, about 46 percent of the daily rides on these routes occur during peak hours and 54 percent during the midday. On this basis, it was expected that about one-half of the turnpike bus ridership would occur during peak periods.

EVALATUION OF EXPRESS BUS ROUTES

The evaluation of alternative express bus services should consider both the direct and indirect costs and the benefits associated with this type of bus service. These benefits and costs can be grouped into three general categories--those accruing to transit operators, users, and nonusers.

Transit Operator Costs and Revenues

The evaluation criteria considered by the transit operator are principally financial. That is, the operating ratio (revenue to cost) should be commensurate with the subsidy policies applied to other existing bus lines.

Bus Operating Costs

For the purpose of calculating operating costs, representative schedules were developed for each of the four most promising bus routes shown in Figure 4.

The daily operating costs for these routes vary from $1,211 per weekday for the West Chester-Valley Forge service to $533 per weekday for the Willow

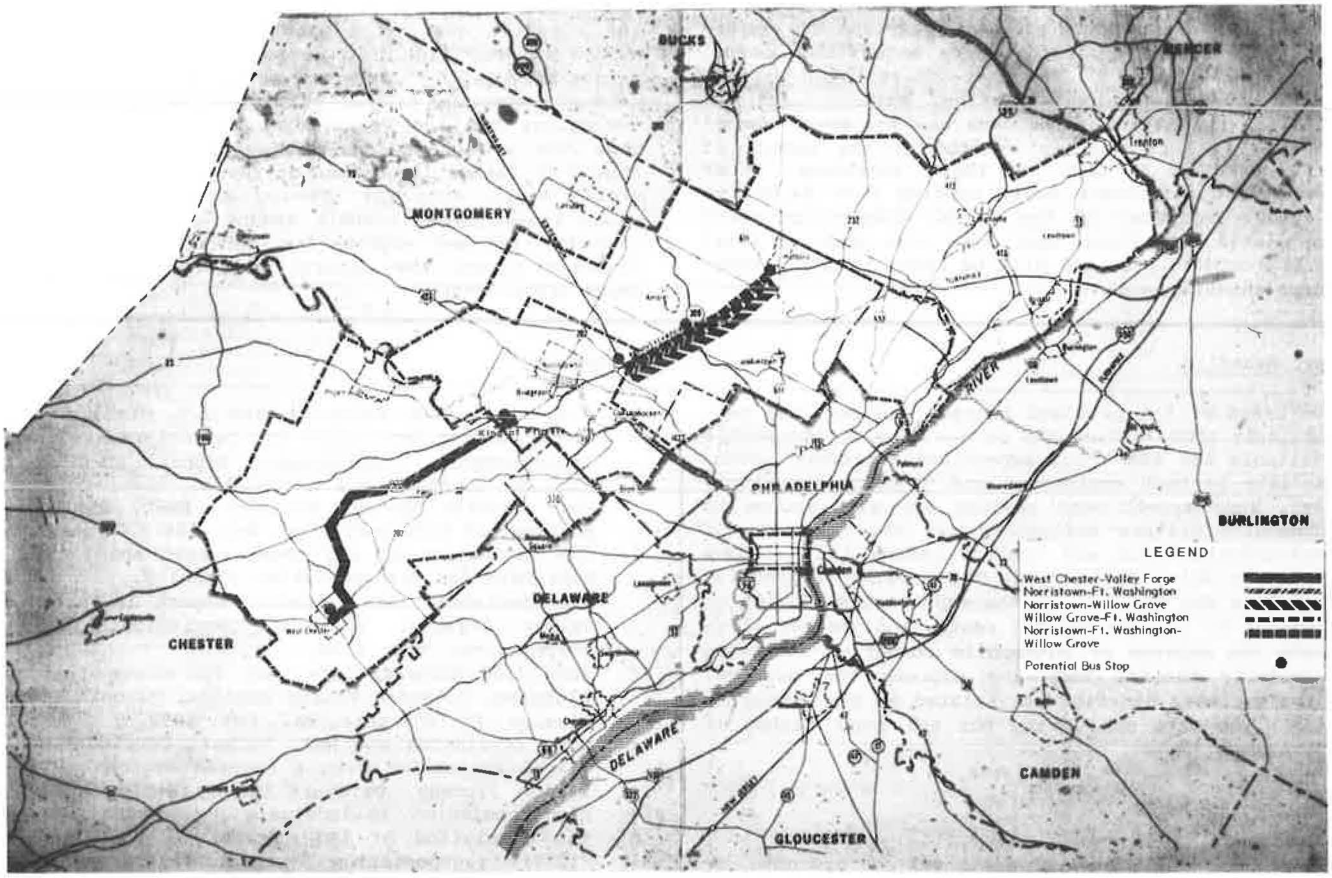

FIGURE 4 Pennsylvania Turnpike corridor potential express bus routes.

Grove-Fort Washington service. The major factor accounting for this difference is route length.

The West Chester-Valley Forge service generates the most revenue ($440 per weekday) reflecting the route length and sizable patronage; and the Willow Grove-Fort Washington service shows the least revenue ($75 per weekday).

The annualized revenue, operating cost, and operating ratio for each promising bus route are given in Table 2. The most promising route in terms of projected operating ratio is the West Chester-Valley Forge service, with a 0.36 operating ratio. Reflecting the relatively high potential ridership generated by this route, the West Chester-Valley Forge service also requires the largest annual subsidy.

The proposed West Chester-Valley Forge and composite Norristown-Fort Washington-Willow Grove routes both have operating ratios greater than 0.3, the minimum level used by SEPTA to consider operating a suburban bus route.

TABLE 2 Operating Ratios for Promising Turnpike Corridor Bus Routes

Route	Annual Fare Box Revenue ($)	Annual Operating Cost ($)	Annual Subsidy ($)	Operating Ratio
West Chester-Valley Forge	114,400	314,860	200,760	0.36
Norristown-Fort Washington	50,700	218,920	168,220	0.23
Norristown-Willow Grove	28,600	161,200	132,600	0.18
Willow Grove-Fort Washington	19,500	138,580	119,080	0.14
Norristown-Fort Washington-Willow Grove	84,500	272,480	187,980	0.31

Note: An annualization factor of 260 was used to convert average weekday estimates to annual estimates. The operating cost was estimated using a unit cost of $1.05 per bus-mile and $9.91 per bus-hour.

Capital Costs and Other Operating Costs

The promising turnpike bus routes have other costs besides the cost of operating the proposed bus service. These costs fall into two categories: the cost of acquiring the buses needed for the proposed service and the cost of implementing and maintaining the park-and-ride lots associated with these services. Table 3 gives the capital cost required to provide the buses for the four most promising express bus alternatives. It should be noted that the existing SEPTA bus fleet may be used to operate all or part of these proposed bus routes by using surplus buses or shifting surplus service from existing routes.

TABLE 3 Vehicle Capital Costs for Promising Turnpike Bus Routes

Route	Vehicle Requirements	Total Capital Cost (1982 dollars)
West Chester-Valley Forge	5	800,000
Norristown-Fort Washington	4	640,000
Norristown-Willow Grove	3	480,000
Willow Grove-Fort Washington	3	480,000
Norristown-Fort Washington-Willow Grove	5	800,000

Note: These vehicle requirements may be substantially reduced by using existing surplus buses in the SEPTA fleet or by shifting surplus service from existing routes.

Capital and operating costs for each of the park-and-ride lots served by promising express bus alternatives, excluding parking space acquisition costs, were also calculated. The park-and-ride lot capital cost includes signing, lighting, marking, and bus shelters needed to accommodate the projected number of riders. This cost is related to the number of cars expected to park at these locations. These costs were relatively small ranging from $4,000 to $17,000. Estimates of the annual maintenance costs associated with these lots were also made. A total of approximately $9,900 will be spent in lot maintenance annually.

User Benefits

The users of the proposed express bus service, particularly those riders who do not have an automobile available for the trip, experience increased accessibility to both employment and shopping opportunities. Some travel cost savings may also accrue to automobile drivers and passengers who make use of park-and-ride lots and thereby reduce the distance that they drive their cars. Those former automobile travelers who can walk to the express bus service or transfer to it from another route, and thereby eliminate the expense of automobile commuting entirely, especially benefit from the express bus service. Clearly, these benefits are related to the number of riders who make use of the bus and their method of approaching it.

Nonuser Benefits

The benefits of the express bus service are not limited to the riders of this service. Clearly, nonusers of the service also benefit. These benefits to society take the form of reductions in air pollutant emissions, energy savings, and reduced highway congestion. In general, these bus routes will not have significant impact on traffic congestion, pollution emission, or gasoline consumption. All reductions in these indicators are less than 1 percent of existing levels.

It is clear from this evaluation that the most promising bus routes for implementation are West Chester-Valley Forge express bus via US-202 Expressway and Norristown-Fort Washington-Willow Grove bus via the turnpike.

Before implementation, however, these routes should be further studied as part of the ongoing detailed transit studies concerning the operation and integration of these routes with the existing transit system, which has been changed slightly since the completion of this study.

CONCLUSIONS

A special traffic demand estimation method, which requires a special coding procedure and uses the existing regional travel demand model, was developed. The travel demand forecasting method reduces the computer cost of simulation and produces accurate transit ridership estimates for the transit routes selected for study and evaluation.

The evaluation of the promising express bus alternatives for the Pennsylvania Turnpike indicated that the subsidy for circumferential express bus routes is rather large because the patronage is generally small, even for growing and congested suburban areas. Heavy transit demand that justifies a park-and-ride and express bus service is generally oriented toward the central business district in large urban areas.

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