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FOREWORD

The four papers in this RECORD describe bus transit strategies and evaluation techniques used to compare alternative public transport systems.

Miller, Goodwin, Hoffman, and Holton compare, for varying passenger capacity on hypothetical new routes, costs of bus-on-busways with train rapid transit. Operating and maintenance costs for near-future bus systems or train systems are presented. The paper also makes a prognosis of future developments in train and bus technology that will enhance the quality of service and afford some possibility of cost reduction.

The Lindenwold Rail Line and the Shirley Busway, two of the most modern transit services in the country, are the subjects of a paper by Vuchic and Stanger. Their research uses the two systems for a comprehensive comparative study of bus and rail technology and types of operations. The authors conclude from their study that there is considerable latent potential for transit in cities, including the low-density automobile-oriented suburbs.

Eriksen and Beimborn present an analysis of alternative transit distribution systems in central or downtown areas. They report on the test of 20 alternatives through the use of a model that simulates the operation of buses as they travel through a downtown area. Alternatives include preferential and exclusive bus treatments, bus-actuated signals, and various operational improvements. Research findings indicate that transit operation in central cities can be substantially improved by the use of certain strategies that the authors outline.

The economics of a hypothetical enhanced bus transit system for a middle-sized city are described by Fichter. The enhanced bus transit system conceived for the study would provide frequent day-and-night local service on a fine-meshed route grid in the city with 10 buses per hour from dawn till late evening. Fichter reports on tests made comparing total expense of service with revenue at several assumed patronage levels. He suggests that appealing public transit is likely to require subsidy, but no new technological breakthrough is required for his concept to provide superior public transit service within a few years.

COST COMPARISON OF BUSWAY AND RAILWAY RAPID TRANSIT

D. R. Miller, B. C. Goodwin, G. A. Hoffman, and W. H. T. Holden,
Daniel, Mann, Johnson, and Mendenhall, Inc., Los Angeles

Costs of bus-on-busways and train rapid transit systems were compared at varying passenger capacities on hypothetical new routes using both current and future vehicle equipment. The calculations indicated that fast transit service could currently be provided at comparable costs by either buses or trains at about 2,000 to 5,000 passengers per peak hour, based on equipment and facilities of recent design. Improved or enlarged designs of current bus and transit equipment tend to shift the bus-train equivalence or crossover region another 1,000 or 2,000 passengers per hour and to somewhat reduce the modal differences in costs between bus and train below that capacity. Above these capacities, rail systems provide lower total costs. The study concluded with a prognosis of future developments in transit and bus technology that will enhance the quality of service while affording some possibilities for cost reduction.

•THE TRANSPORTATION planning process requires the selection of a specific mode of transportation in each link of the regional system. The modal options available to the planner include rail rapid transit, automobiles, and buses. The buses may operate in several configurations, including mixed traffic on streets, mixed traffic on freeways, or operation on grade-separated exclusive busways. The economics of the modal choice are at best somewhat obscure; therefore, the purpose of this paper is to analyze further some of the cost parameters affecting the choice options and to search for general guidelines that may help in preliminary studies.

In the past, the choices available to the planner were limited to automobiles, rapid transit, or slow service buses in mixed traffic. More recently, experience has been extended to bus operation on freeways, the mode termed "freeway flyer" in the Los Angeles area. Bus operation using a lane in the Lincoln Tunnel of the New York Port Authority and the use of exclusive lanes on Shirley Highway in the Virginia suburbs of Washington, D.C., have raised the question of an intermediate mode; this mode might be less in cost than the traditional form of rail rapid transit and provide more rapid service than the conventional bus mixed with other automotive traffic. Also requiring consideration by planners are the rail systems referred to as "limited tramways." In these systems, rail cars are operated in trains or single units on an exclusive right-of-way, which may not be fully grade-separated, as in Boston's MBTA Riverside Line. Indeed, this issue of new busways or rail rapid transit became a substantial one in the first Atlanta rapid transit system proposals, where busways were suggested by the local bus company as an alternate mode to the proposed rail rapid transit plan (1). The resulting controversy required a number of special studies for resolution, in which the authors' firm participated in the evaluation of busway costs; this activity, therefore, stimulated our interest in the subject of comparing busway and rail rapid transit costs (2).

The availability in Los Angeles of a wide median in the San Bernardino Freeway and the loss of the 1968 rapid transit bond issue resulted in the conversion of the San Bernardino corridor to an exclusive busway, now under construction. Allowance has

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been made for conversion there to a full rapid transit system when funding and patronage permit or demand such a change. The busway is being built in part with 90 percent Federal Highway Administration financing, and it is interesting to note the reversionary clauses and design criteria modifications required as a result of such participation. However, the basic question remains: Given a free choice, under what circumstances will a busway be more economical than rail rapid transit?

DEFINITIONS AND ASSUMPTIONS

Our inquiry necessitated certain assumptions and definitions. First, it was assumed that a line transit peak-hour demand of less than 3,000 passengers per hour can be accommodated by a "freeway flyer" type of operation, utilizing buses in mixed traffic on a freeway. Otherwise, we adopted the following definitions:

Rapid Busway—This mode utilizes manually driven motor buses operating on a grade-separated and exclusive roadway.

Rapid Transit—This mode utilizes vehicles capable of operation in trains when required and guided by means external to the vehicle on a grade-separated and exclusive right-of-way.

The rapid busway is currently based on the use of internally powered and steered vehicles, whereas the rapid transit vehicle is externally guided and powered from a contact line. The rapid busway vehicle might also be externally powered from a contact line and might also be provided with positive external mechanical guidance, as discussed later. Such systems are not currently in use in the United States, although they have been proposed and test prototypes are now being demonstrated. Most existing rapid transit systems use steel wheels on steel rails, except for a few using elastomer or rubber tires. Since tires lack the lateral guidance of the flanged wheel on the steel rail, these systems employ additional guide wheels. It is possible that air-cushioned or magnetically levitated cars may be utilized in the future instead of wheels, as discussed later.

For the pusposes of this paper, it will be assumed that the current bus is of the high-performance diesel type and that the rapid transit system employs steel wheels on steel rails. These are the systems for which detailed cost reports are readily available; the sources used were the 1970-1971 fiscal year reports of the New York City Transit Authority (3) and the 1969-1970 report of the San Francisco Municipal Railway (4). These sources provide sufficient detail to permit disaggregation into components that represent fixed costs and those that are dependent only on volume of operation. The latter costs, expressed in cost per vehicle-mile, are in turn separated into those that are dependent only on miles operated and those for which the cost per vehicle-mile is directly proportional to the inverse speed, or slowness, expressed in minutes per mile. The Interstate Commerce Commission or American Transit Commission cost accounting systems do not make this separation in their reported functional accounts.

While discussing transit assumptions, it is well to consider the source of funding for rapid busways. In the past, the differences in federal funding of highways that are available for busways (90 percent) and for rail transit (less than 67 percent) have resulted in some decisions for busways simply because better funding was available. It now appears that federal policy in regard to aid to transportation is changing and that the federal share will be about the same for both rail transit and busways.

Another aspect of federal participation in transit funding will require exploration at the planning state: Federal policy limits federal participation to capital costs and discourages federal aid for operating costs. Although this policy may change soon, its present impact in withholding operating subsidies makes a capital-intensive system (rail transit) more attractive to operating agencies than a labor-intensive system (busways).

In making a comparison of costs, it is then necessary to define the agency by which costs are incurred. In this study it is assumed that decisions and funding responsibility are placed on the local public agency. The data will be presented in such a way that any changes in these assumptions as to allocation of costs to the local agency and the federal government can easily be reevaluated from the cost comparison matrix.

METHODOLOGY OF COST ANALYSIS OF TRANSIT SYSTEMS

Our earlier analyses of transit system costs, both capital and operating, indicate that these appear to fall into three cost classes—fixed, mileage-variable, and speed-variable—as follows:

CAPITAL COSTS	OPERATING COSTS
Fixed Costs	
Ways and structures, including stations. Power distribution. Signals, control, and communication.	Maintenance of structures, buildings, and stations. Station operations, including fare collection. Operation of interlockers. Cleaning, sanding, and removal of snow from way. Maintenance of power system, except contact lines.
Mileage-Variable Costs Independent of Speed	
None.	Maintenance of traveled way. Maintenance of equipment. Maintenance of contact line. Power or fuel. Injuries and damages.
Mileage-Variable Costs Varying Inversely With Operating Speed	
Vehicle fleet, including spares.	Vehicle operating personnel, wages, salaries. Cleaning and servicing vehicles. Yard and shop costs, proportional to number of vehicles.

The reason underlying these cost allocations will become obvious in most cases. The number of vehicles to operate a line L miles in length, with an operating slowness of s_3 minutes per mile (this includes terminal time) at a headway h, is $N_v = 2Ls_3/h$. (Headway h is in minutes at peak hours.) For example, a local bus line 10 miles long with a peak-hour schedule slowness of $s_2 = 5.6$ minutes per mile, as determined from actual timetables, will experience s_3 approximately equal to $1.1s_2$, or 6.2 minutes per mile. If peak-hour headway is 3 minutes, then $N_v = 124/3$, or at least 42 buses. Shop margin or spare vehicles will be 10 percent or more, 5 in this case, so that a total of 47 buses would be assigned to this line. Thus, the number of vehicles is proportional to slowness of operation.

Vehicle servicing is required whenever a vehicle is in use; therefore, this cost factor is also speed-dependent and mileage-invariant. It is not possible to equate costs per bus-mile with costs per car-mile of a rapid transit car while comparing operating costs. Since bus designs are well standardized (about 8.5 feet wide and 40 feet long), the range in seating capacity of a typical bus is from 50 to 53, and the maximum load is 75 passengers. The rapid transit car of the 60-foot New York type can seat only 50 (R-32 BMT type) but has a practical load capacity of 220, whereas a design that provides more seats at the expense of standing room might seat as many as 100. Because of this variability in design, we have used relative area as the basis of comparison. The bus area is 340 square feet; the R-32 car, 600 square feet. On this area ratio basis, then we equate the car to 600/340, or 1.77 buses.

At the present time, a larger car is being adopted for use by most rapid transit systems except where loading gauge limits make it impossible. These larger cars were pioneered by the Toronto Transit Commission; typical dimensions are a 75-foot length and a 10.5-foot width, for an area of 787.5 square feet. Such cars may be considered equivalent to 2.32 buses. These cars actually seat 80 to 84 but can be designed for as many as 120 seats. In this paper, the New York City Transit Authority (NYCTA) costs are based on the 60-foot car, since the R-44 and R-46 75-foot types were not yet in service during the last accounting period. It is not possible to express fixed costs on the basis of cost per vehicle-mile, since surface bus operation involves negligible fixed costs.

However, it can be seen that the fixed-cost items listed earlier will apply to rapid busway as well as to rail rapid transit. We have used the costs per route-mile as the unit on which comparisons are made. These then are combined with the operating costs of a mileage-only or a mileage- and speed-variable type by multiplying the cost per vehicle-mile by the vehicle-miles per route-mile annually. This figure can then be added to the fixed-cost items to obtain a total cost per route-mile of the transit mode being considered. Vehicle-miles per route-mile are actually the number of vehicles passing a fixed point in both directions during one year. This number is dimensionless and independent of speed of operation. It is directly proportional to the utilization of equipment—total revenue vehicle-hours divided by the number of vehicles required for peak-hour operation (omitting spares), times 8,760. If vehicles were operated at a headway of h minutes for an entire year, then M_1 is the number past a fixed point in both directions in one year and would be twice 525,600/h, where 525,600 is the ratio of minutes per year. However, in any actual operation, the number operated would only be a fraction of this amount, and it can be seen that this fraction is the utilization-of-equipment factor just described. The symbol "p" is used here for this utilization factor.

The parameter M_1 is directly proportional to the number of passengers carried in a peak hour. While a 40-foot bus has a capacity of 75, it has been shown that one cannot rely on a 100 percent fill due to the random fluctuations in the arrival of passengers (5). The efficiency of fill has been taken at 80 percent in the present study. Since $75 \times 0.80 = 60$, we will use the value of 60 for the average number of passengers per bus at peak hours. Therefore, if there are P passengers per hour, a fleet of P/60 buses per hour will be needed to carry this load. At a headway of h minutes, there will be 60/h buses per hour, so that $h = 3{,}600/P$. For 40-foot bus operation, $M_1 = 100P$ if utilization is 0.35, a value in the normal range for high-density transit operation. Denoting by C_m the cost per bus-mile and by C_f the fixed costs per route-mile gives the formula for the total cost per route-mile for the operation under consideration, C_1, to be

$$C_1 = C_f + 100\ PC_m$$

for a rapid busway system using 40-foot buses.

SYSTEM COSTS FOR CURRENT EQUIPMENT

Values for Busway Operation

The cost per bus-mile is available from NYCTA and San Francisco Municipal Railway (SFMR) data. New York data are averaged for each of four divisions, while in the San Francisco report one finds line-by-line cost and performance data for 40 lines. The statistical base is thus larger, and the results from the data are of greater reliability than from other operations. By linear regression of the data, it has been found that

$$C_m = 0.71s_3 + 0.616$$

where C_m is the cost in dollars per bus-mile at an operating slowness of s_3. It can be shown by the methods of Haas and Holden (6) that s_3 is approximately 2 minutes per mile for a line with stations at 1-mile intervals, a maximum speed of 60 mph, initial acceleration of 3 mphps, 20-second station delay or dwell time, and s_3 equal to 110 percent of schedule slowness. Hence, $C_m = \$0.958$ per bus-mile.

Assumed Capital Costs for Busway

Two types of construction have been considered: (a) at grade in a freeway median and (b) elevated structure over such a median or other right-of-way. In either case, the traveled way consists of three 12-foot lanes; the outer ones are the operating lanes while the central one is a paved median emergency or disabled bus space. A narrow strip at each side should added to the total width of 36 feet to keep the fences or side-walls on the elevated structure clear of the lanes. The "ways and facilities" cost data are based on a recent detailed construction study of transit and busways in major metropolitan areas in the midwestern and western United States and provided the C_f figures for the busway system.

Capital cost for buses is based on an acquisition cost of $45,000 and a 15-year life, making depreciation $3,000 annually; interest on the investment per bus is $2,250 annually. The number of buses required per route-mile is $2s_3/h$. The value of h for 2,500 passengers per hour is 2,500/60, which will be taken as 42 buses per hour, or $h = 1.41$ minutes. With $s_3 = 2$ and 2.83 buses required per route-mile at this level of operation, the busway costs were calculated as given in Table 1.

Values for Rapid Transit Operation

The rapid transit capital costs consist of right-of-way, structures and trackwork, car fleet, and station costs and were based on current cost estimates for systems planned for U.S. cities. It should be noted that, unlike trolley coach and streetcar systems, rapid transit is normally operated with multicar trains. However, on some low-volume lines at off-peak hours, 1-car trains may be used. In general, rapid transit operating costs per car-mile are a function of train length because the size of the train crew is invariant with train length. If C_p is the cost per train-mile for trainmen (e.g., motorman and conductor in NYCTA operation or train attendants only on the Lindenwold, London's Victoria Line, or BART), this cost is a mileage- and speed-variable cost, so that $C_p = Ks_3$. For other speed-variable items, which depend on number of cars, the car-mile at a stated slowness is adequate. If there are N cars in a train, then the cost per car-mile can be expressed as

$$C_a = K_1 s_3 + Ks_3/N + B$$

When 1-car trains are operated, it is usual for this to be a 1-man operation. When 2 or more cars are used, K will be 1.85 times the value for 1-car trains, or less, depending on labor contract provisions, if conductors are used. The first term in the above equation is rather small and is actually independent of miles operated, since it is derived from the cost of maintaining yards and shops. It is most convenient for the purposes of this paper to add it to the annual charges per car. Since this item added a mere $208 annually to the costs per car, the annual cost per car for depreciation was raised from $6,500 to $6,700.

The relation between peak-hour passengers and car-miles per route-mile has been shown to be 100 times peak-hour passengers and equals the bus-miles per route-mile. We are considering here the use of a 60-foot car and, on the basis of area ratios, car-miles per route-mile annually are 56.7 times the number of passengers at peak hour. To avoid excessive headways at light loads, however, we must use smaller or larger trains than the NYCTA average, which is 8.50. As a result, Table 2 gives the costs calculated per car-mile as affected by train size for $s_3 = 1.94$ minutes per mile. Combining these figures with the car-miles per route-mile for various peak-hour loads gives the total transit costs in Table 3.

The results of these comparative cost calculations are shown in Figure 1 on the basis of route-miles and in Figure 2 on the basis of seat-miles, should "seated-only" service be contemplated. Note that the costs of the two modes are approximately equivalent—on a route-mile basis—in the range of 2,000 to 5,000 passengers per hour. On a per-seat-per-mile basis, the conventional bus is consistently costlier than rail.

These costs, based on NYCTA rapid transit, but calculated at a higher speed because of doubled station intervals, do not represent the minimum that is possible by taking advantage of several advances. One is the use of longer cars, such as the R-44, since

Table 1. Cost per route-mile of busway.

Passengers Per Peak Hour	Annual Bus-Miles Per Route-Mile	Buses Per Route-Mile	Direct Operating Costs	Bus Capital Costs		Total Costs[a]	
				Interest	Depreciation	At Grade	Elevated
2,500	250,000	2.83	$ 240,000	$ 6,400	$ 8,500	$ 383,800	$ 881,900
5,000	500,000	5.66	480,000	12,800	17,000	638,700	1,137,000
7,500	750,000	8.49	720,000	19,200	25,000	893,000	1,391,000
10,000	1,000,000	11.32	960,000	25,600	34,000	1,148,500	1,646,600
15,000	1,500,000	17.98	1,440,000	38,400	50,000	1,657,300	2,155,400
20,000	2,000,000	22.64	1,920,000	51,200	68,000	2,168,000	2,666,000

[a]At-grade cost includes $128,900 and elevated includes $627,000 fixed costs for construction.

Table 2. Car-mile costs for variously constituted trains.

Cars Per Train	Cost Per Car-Mile
2	$1.488
4	1.086
6	0.951
8	0.884

Figure 1. Total costs of transportation service over a route-mile of busway and rail transit using current equipment.

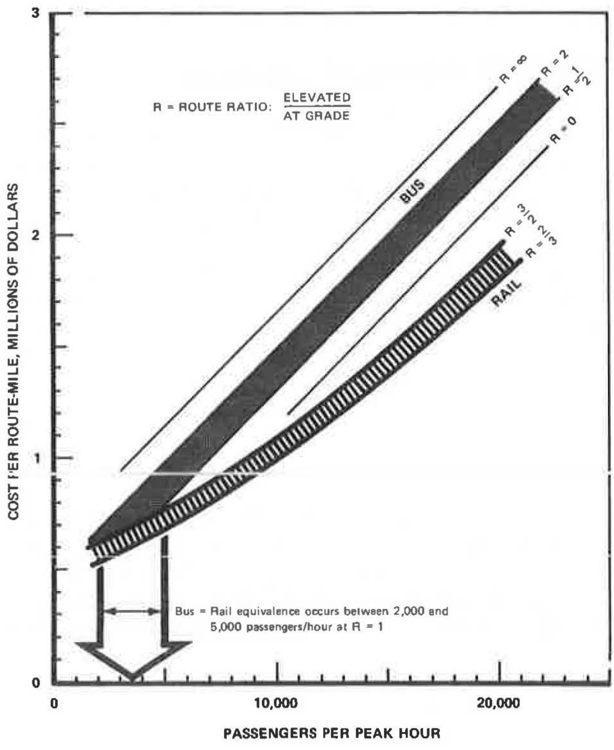


Table 3. Total costs of transit versus peak-hour capacity.

Peak-Hour Passengers	Trains and Headway		Annual Car-Miles Per Route-Mile	Cars Per Route-Mile	Operating Costs	Total Costs	
	Cars	Minutes				At Grade	Elevated
2,500	2	5	157,200	1.54	$ 233,900	$ 360,500	$ 848,000
5,000	4	5	314,400	3.88	341,400	544,800	954,400
7,500	6	5	471,600	4.62	448,500	572,200	992,200
10,000	8	5	628,800	6.16	555,900	823,000	1,253,000
15,000	8	3.5	943,200	8.08	833,700	1,143,200	1,752,000
20,000	8	2.5	1,257,600	12.32	1,112,000	1,551,500	2,160,000

these cars cannot be made to weigh more than the weight of the older R types considered, and power cost will not change. However, car-miles per route-mile annually per peak-hour passenger will be lowered to 80 percent of the value used in the previous estimates. The average train will be reduced to 6.8 cars, but costs for train crews will be the same; therefore, the cost per car-mile for this item is increased. Mileage-variable maintenance costs are reduced to 80 percent of the values for the 60-foot cars.

Substantial reductions in the cost of mileage-variable equipment maintenance may be expected from improved control systems using electronic power devices. The chopper should lead to a major cost reduction as compared to the now-obsolete camshaft controller, while the further advance of the use of squirrel-cage induction motors to replace the high-cost and high-maintenance dc motor can lead to equal or even greater savings.

Use of regenerative braking systems greatly reduces heat liberated in tunnels and can reduce power consumption if other trains can be relied on to absorb regenerated energy.

By way of summary and conclusion, these calculations indicated that fast transit service could be currently provided at comparable costs by either bus or transit trains at about 2,000 to 5,000 passengers per peak hour, based on equipment and facilities of recent design.

FUTURE DEVELOPMENTS IN TRANSIT AND BUS SERVICE

Current rail transit and bus/busway systems were compared up to this point of the study on the basis of their costs for providing urban mass transportation. Future developments in these modes of transportation are now discussed from their cost-reduction aspects and potentials.

For bus systems, the possibilities are good for employing an articulated vehicle (with a heat engine at first and electrically powered at a later date) for exclusive use on the busway. Such articulated buses have demonstrated in Europe the capability of accommodating 75 seats in a 60-foot length and providing rapid service if confined to roadways with ample curves—such as busways of current U.S. design. This potential is contingent on initiation of a domestic program of research, development, testing, and operation of fleets of 60-foot buses.

The "long" bus, relegated to busway travel only, was evaluated to offer an increase of almost 50 percent in the volume capacity of a fast-link trunk bus line, at only minor cost increases in tractive power, labor, and vehicle fleet acquisition. These cost variations were calculated for a hypothetical 60-foot bus fleet and are shown in Figure 3. The slight rightward shift in this plot of the bus-transit equivalence point—to about 4,000 seated passengers per hour for $R = 0.5$—should be interpreted with great caution: The crossover point is extremely sensitive to the cost assumptions of future operational experience with unrealized conceptual equipment. The possibility of the 60-foot bus-on-busway-only opens avenues for savings and environmental benefits. Wayside electrification can be provided at a later time, allowing a gradual introduction of electric buses, if so desired, and providing a smooth transition from a conventional-engine bus fleet to a mix and eventually to an all-electric fleet.

Figure 3 also shows the costs of a novel transit car development that could drive costs down: a hypothetical air-cushioned transit vehicle that our studies indicate to be slightly more economical than the current rail cars. The sequence of savings afforded by supporting a transit car by an air cushion rather than by wheels is given in Table 4 and ends with 2 percent systems fixed-cost savings potential. Although small, this savings from introduction of new transit technology is particularly worthwhile, since it also brings the many other well-documented advantages of ATVs in public appeal, convenience, quietness, and ride qualities. Operating cost savings have not been evaluated but promise to be significant.

Buses and trains will undoubtedly experience further technical developments in the more distant future, leading to increased value of service; for example, one can predict magnetic levitation of trains or the advent of dual-mode buses. The latter offer some intriguing possibilities for reducing time-of-travel costs and lowering the suburban environmental impacts of buses by enhancing their cleanliness, quietness, and unobtrusiveness to higher levels.

Battery-operated buses can be designed with modern traction components (7) such that, while on the busway, the power pickup (Fig. 4) delivers propulsion energy to the

Figure 2. Cost of seated transportation service with current equipment. This hypothetical example is based on a 75-foot transit car having 80 seats and a 40-foot bus with 51 seats. The upper and lower bounds on the bus lines represent two-thirds and one-third of the busway being of elevated construction and the remainder on grade.

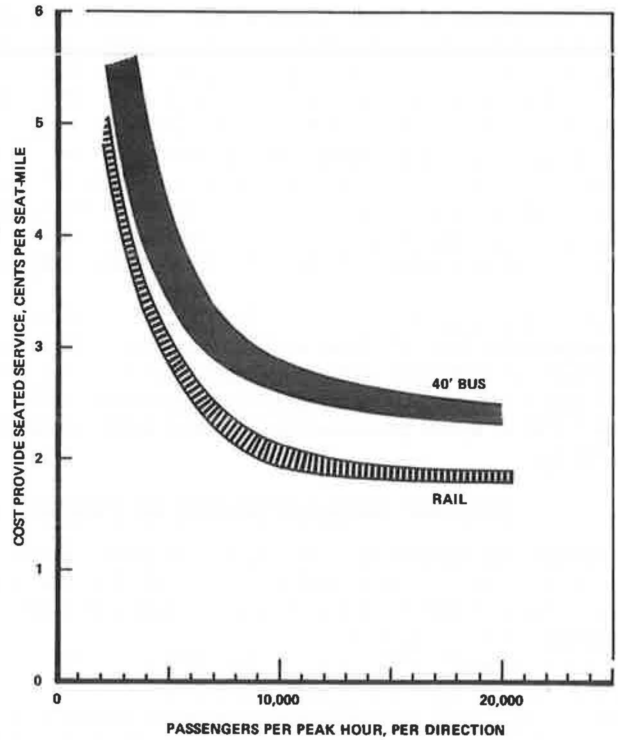


Figure 3. Cost to provide seated service with near-future equipment.

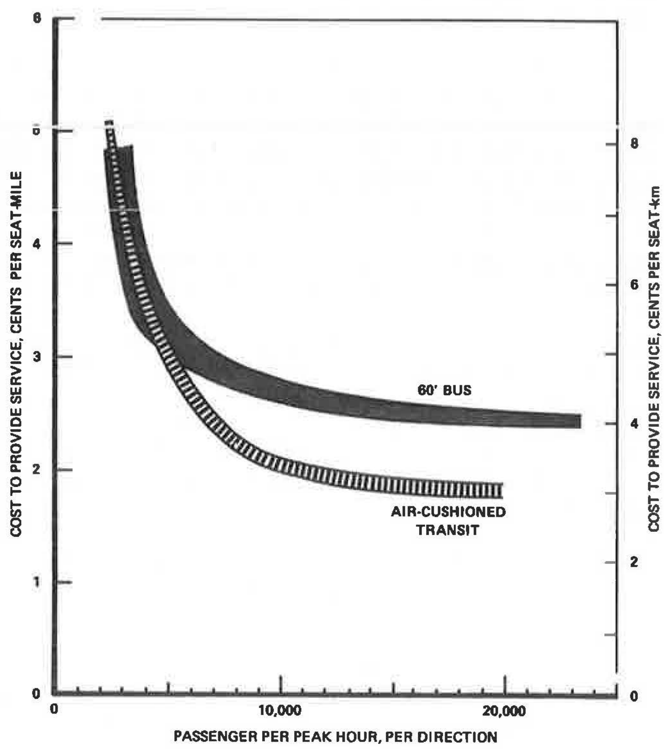


Table 4. Economic effects of rail-car conversion to air-cushion suspension.

Cause	Effect	Reduction Effected (percent)
Conversion from wheels to air cushion	Cuts suspension components' weight in half	50
Halving of suspension subsystem	Eliminates one-tenth of laden-vehicle mass	10
Vehicle mass reduction by one-tenth	Lowered critical structures' load and design criteria related to gross weight of vehicles, intensity, and distribution of vehicle dynamic loads	6
Lessened loading conditions on structures	Lower cost of guideways	4
Guideway cost reduction	Decrease in transit system fixed costs	2

Note: It was also calculated that the elimination of wear on wheels and guideways reduces the maintenance costs by an amount comparable to the increase in operating costs due to the air-cushion pumping power.

Figure 4. Possible design evolution from current heat-engine bus to an electric bus with both batteries and external power pickup.

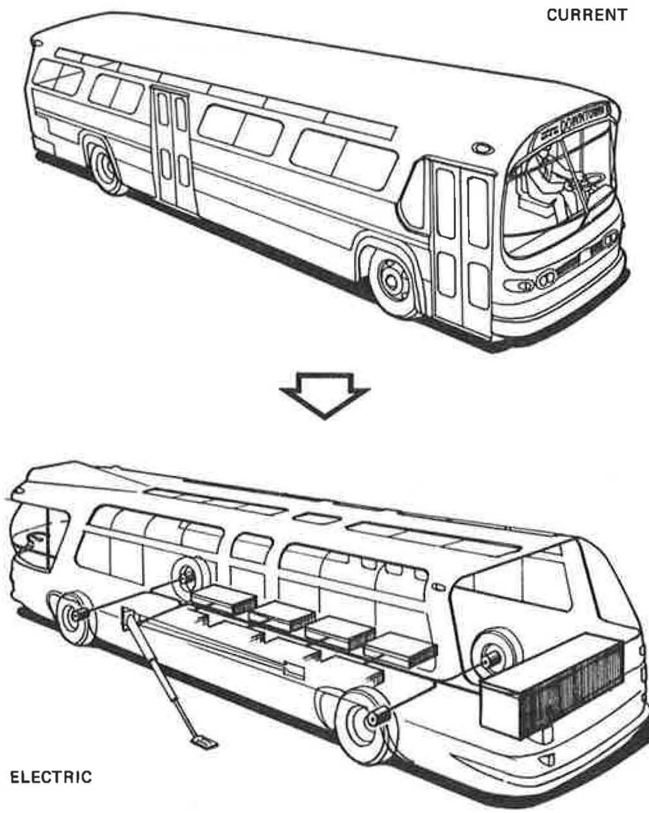
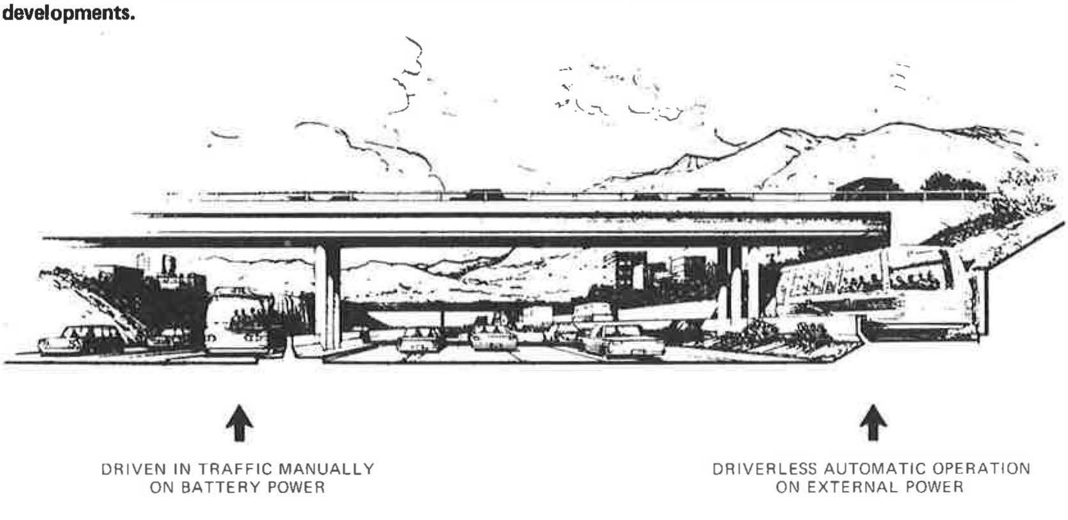


Figure 5. Dual-mode bus in freeway and on automated guideway: an illustrative example of possible future developments.



traction motors at the same time that it furnishes recharging energy into the partially depleted batteries. When the bus travels off the busway to either collect or distribute passengers, the power arm is retracted and propulsion energy comes from pure battery sources.

Time savings are possible in routings without the annoyances and delays of transfers from fast-link to feeder modes when the same electric bus performs the fast-transit-link (on external power) and the FTL feeder function (on battery power). On the other hand, this feature may be countered by the experience in low-density suburbs—e.g., Cleveland and Lindenwold—where about half of the passengers reach stations by automobile.

The cost-saving developmental stage beyond the battery/external power electric bus could be fully automatic operation on the busway. A newly designed automated busway can be made considerably narrower than a conventional busway. Its dimensions could be so reduced that it may be installed in marginal-use corridor land, and now may be called a bus guideway (Fig. 5). The partially automated bus would be boarded by a driver at stations where the vehicle exits the bus-guideway to go on its off-link routes on battery power.

In conclusion, this section of the study indicated that in the future enlarged designs of current bus and improvements in transit equipment tend to shift the bus-train equivalence or crossover region another 1,000 or 2,000 passengers per hour and somewhat reduce the modal differences in costs between bus and transit below that capacity.

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DISCUSSION

Thomas B. Deen, Alan M. Voorhees and Associates, Inc.

This paper represents a third effort to compare costs of bus and rail transit systems using a generalized cost approach. The first effort of this nature (8) came out in 1965, and it concluded that busway systems were cheaper than rail systems up to a one-way peak-hour passenger volume of 50,000 per hour (for medium-density situations), while rail transit systems were less expensive at volumes above that. The present paper concludes that equal costs occur at volumes of 2,000 to 5,000 per hour, with rail systems being cheaper at passenger volumes above that level. The difference in the conclusions between the two papers approximates 1,000 percent. I confess to some measure of satisfaction that my paper, presented to the Highway Research Board in 1969, found the bus-rail equal cost point at about 12,000 per hour (2), somewhere between the extremes of the other two papers.

One thing all of the papers agree on: As passenger volumes climb, rail gets relatively cheaper compared to bus. Unfortunately, the conclusion that equality occurs at somewhere between 4,000 and 40,000 passengers per hour is not much help, since virtually every transit corridor considered for any kind of special right-of-way transit service in the United States falls somewhere in that range.

Clearly the key to the difference among the papers lies in the assumptions used in the cost calculation and in whether equitable assumptions are used with respect to the two modes. Rail transit costs are better understood than busways since there are many rail transit systems in operation throughout the United States. Thus, we find the bigger differences in assumptions on the busway side of the ledger. However, out of the numerous assumptions required for such an analysis, only a few can be examined in this critique.

The first difference among the papers can readily be seen in the assumption about the dimensions of the busway itself. Wohl (8) assumed that only 2 lanes were required for a busway, that non-CBD loading could take place on the local streets, and only ramps were required for transfer of buses between the busway and the local street system. Thus, only modest stations were required. Deen also assumed that 2-lane busways were adequate but that stations similar to the rail system were required for an adequate comparison. In this latest paper, the assumption is made that an adequate busway must consist of at least 3 lanes, 2 for running and a center lane to provide median separation for opposing traffic and for a refuge lane in case of breakdown. Stations similar to rail stations were also assumed, although these are not diagrammed and the bases for them are not clear. The question is, Which paper is right? How many lanes are required for a busway? The fact is, no one knows. Proponents of 3- or even 4-lane busways argue that safety requirements necessitate some space (if not a physical barrier) between opposing bus loads and that a continuous breakdown lane is required. It is further argued that bus drivers would become fatigued at high speeds on 2-lane roadways. On the other hand, proponents of 2-lane busways argue that 2-lane roadways without median separation are used throughout the nation with vehicular volumes much higher than called for on most busway systems, without professional drivers and without apparent excessive fatigue. Thirty thousand passengers per hour are carried through the Lincoln Tunnel in New York City each weekday morning without breakdown lanes, and this bus flow is mixed with other automobile traffic. The recently constructed Los Angeles busway was designed in a freeway median without special breakdown lanes or median separation (breakdown lanes in this case were provided by sharing the shoulders of the adjacent freeway). Could breakdowns be handled by an occasional bay and disabled buses be pushed to such points for repair or appropriate action? Rail rapid transit cars are also subject to breakdowns and are pushed as dead cars by the rest of the train until they can be removed; the present paper assumes that 1-car trains can be operated with no refuge "track" to handle disabled vehicles, and why not? It is not clear that equitable assumptions have been used here. Clearly, research is needed to clarify the facts in this cloudy area.

Methods of operation of busways are another point of difference among the papers. Wohl assumed a loop type of operation that results in very few empty seat-miles in the heavy direction of traffic movement. Deen and this paper assumed that buses are operating like rail transit, with all buses stopping at each station (Deen admits that this assumption may somewhat bias the analysis against the busway). The present paper uses a number of assumptions that appear to give an overestimate of busway operating costs. Perhaps the use of the New York City Transit Authority or San Francisco Muni operating cost data or the unusual method of estimating costs could be the reason. In any case, the final results provide some bus operating cost estimates that appear to be extravagant. For example, the paper uses a unit cost of $0.96 per bus-mile while assuming the bus is operating at 30 miles per hour. The product of these two figures is almost $29.00 per bus-hour, not including depreciation or amortization of either the busway itself or the vehicle. This is more than double the bus-hour operating costs found in typical bus properties. Since drivers' wages make up at least half the typical bus operating costs, it is difficult to see how this cost could be accurate unless busway drivers get premium wages vastly in excess of anything known at present.

Finally, Miller computes rail operating costs for low-volume situations by assuming 1-car rail trains. However, the question of reducing rail operating costs by reducing train consists in the off-peak period is fairly controversial in the industry. Toronto, for example, chooses to run its 6-car trains all day, including off-peak periods, since costs for decoupling and switching of cars are, in its judgment, greater than the savings to be had from reduced power and maintenance costs. Further, most rail transit properties purchase cars that can only be operated at a minimum of 2-car trains, since the savings in the equipment by reducing the number of cars required with controls, etc., is significant. Thus, one must question whether rail systems can demonstrate as much efficiency at low volumes as is implied in this paper.

One must also question whether the service level is the same at low volumes when comparing the two modes. With low-volume situations (say 5,000 passengers per hour) only about 800 passengers per hour will be moving during most non-peak hours. This volume would require rail cars operating at about 10-minute headways. However, buses—being smaller—would be required to run at about 6-minute headways. I think 6-minute headways are significantly better than 10-minute headways, so even if costs are somewhat higher for buses the cost comparison is not a comparison of equal service levels. If the decision were made to go for a 6-minute headway for the rail system as a matter of policy, the costs would be much higher for rail. Using the analysis in the present paper, costs per rail-car-mile at low volume are about $1.50 per car-mile, whereas bus costs are only $0.96 per car-mile. It is this off-peak operation that gives busway systems favorable cost characteristics even when low volumes are involved. It is not clear that the present analysis, which devotes itself exclusively to peak-hour problems, adequately accounts for the bus off-peak savings.

In summary, we need more such papers. This paper offers a new method of looking at the problem. Perhaps we will learn the final truth only after a number of busway systems are in operation.

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AUTHORS' CLOSURE

Deen's discussion is a welcome addition to the growing body of knowledge on the relative merits of buses and trains. His thesis is that the bus-rail cost equivalence point can fall between wide extremes that depend on the method of calculation. To reach a better definition of this equivalence value, we recently compared the two modes of bus and rail for a specific route on a railroad right-of-way in an urban region and found the crossover to be at 12,000 passengers per hour. This level was for current-technology vehicles, whereas advanced-technology buses and trains indicated a higher equivalence point. Thus our latest calculations seem to agree with Deen's values in his discussion.

Deen appropriately raises the question as to which paper is more descriptive of the facilities required for buses. Our latest studies describe facilities such as bus lanes, turn-offs, and CBD stations in terms of their geometries and costs, with these parameters varied with system patronage capacities ranging from 2,000 to over 16,000 passengers per hour.

In conclusion, we are grateful to Deen for his thoughtful commentary and thank him for highlighting many of the topics of additional research that need yet to be explored. We all seem to agree that many unresolved questions are still to be studied before a better understanding of the trade-offs between equal-service bus/busways and train/rail modes is achieved.

LINDENWOLD RAIL LINE AND SHIRLEY BUSWAY: A COMPARISON

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Comparisons of different transit modes have seldom given sufficient attention to service parameters. Rather, costs were compared for modes that optimally provide different types of operations. This study utilizes 2 existing systems for a comprehensive comparative study of bus and rail technologies and their different types of operations. It differs from previous studies in 2 respects: First, it performs the analysis on 2 actual systems and thus does not utilize any hypothetical assumptions. Second, it includes more system characteristics than any of the previous studies. The Lindenwold "Hi-Speed Line" offers all-day, high-frequency, reliable service among its 12 stations; it depends heavily (80 percent) on access by automobile. The Shirley Busway provides mostly peak-hour service on very many lines with different routings, but with a lower frequency and reliability than Lindenwold; it relies mostly (84 percent) on access by walking. Lindenwold required very high investment and was completed as one project; its revenues exceed operating costs by a significant amount. The line is extremely well operated and managed. Shirley was introduced with considerably lower investment, but it requires at least a 3 to 5 times higher labor force per passenger than Lindenwold. Its revenues closely cover the operating costs. Lindenwold attracts a 70 percent higher ridership than Shirley. Shirley can be improved by the introduction of all-day high-frequency service on some of its routes. The main deficiency of the busway concept will remain street operation in the CBD. Both systems are very successful. Their attraction of new riders proves that there is a considerable latent demand for transit, even in low-density auto-oriented suburban areas, and an underutilized potential of modern bus and rail modes.

•THE NEED for provision of high-type transit service on predominantly or entirely separated rights-of-way has been recognized throughout the world as imperative for modern transportation in large and medium-sized cities. The optimal domains of rail rapid transit, light rail, and different bus operations are often misunderstood, and their definition requires additional analysis.

Yet, comparison of different modes of transportation is quite a complex problem, and the tendency of past studies has been either to simplify it to a consideration of only a few or even one parameter (usually cost) or to use a theoretical model that in most cases does not represent reality in some important aspects. Both simplifications result in incorrect conclusions.

Two recently introduced transit systems, the Lindenwold Rail Rapid Transit Line between the New Jersey suburbs and Philadelphia's city center and the Shirley Highway Express Bus Lines between the Virginia suburbs and Washington's city center (for convenience the 2 systems will be referred to as Lindenwold Line and Shirley Busway) are so similar in the service they are intended to provide that they represent an excellent real case for a comparison of bus and rail modes.

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PREVIOUS STUDIES

A number of studies have compared urban transportation modes or technologies. Several typical ones will be discussed and evaluated here.

Leibbrand, in a study for Frankfurt, Germany (9), analyzed 4 different modes: rapid transit, light rail, Alweg monorail above ground, and Alweg in tunnels. Although similar networks were assumed for each technology, each system was adapted somewhat on the basis of its own characteristics and given conditions. The analysis was rather comprehensive; the only criticism might be that quantitative items, and particularly cost, had a very dominant role in the evaluation.

De Leuw, Cather and Company (5) recently performed for Manchester, England, a comprehensive comparative study of rail rapid transit, Safege, Alweg, and Westinghouse Expressway for a proposed rapid transit line. The different technologies were evaluated with respect to the state of their development and the technical characteristics of vehicles and guideway. However, service characteristics were only briefly mentioned, and great emphasis was placed on environmental aspects. The relative weight given to these aspects as well as cost might be questioned.

Deen and James (4) used a theoretical model to make a comparison of bus and rail modes for line-haul service in Atlanta. The authors emphasize that "it was essential to ensure equal service for bus and rail systems being compared". This approach is, however, conceptually incorrect. A hypothetical vehicle design used for the bus without realistic associated costs and the little attention given important service parameters made the comparison unrealistically favorable for the bus. The authors recognized these shortcomings and placed considerable emphasis on the analysis of influence of change in conditions on relative advantages of each mode.

Fehr (6, 7) recently completed for the Boston Transportation Planning Review a study of 9 alternative modes and/or types of operations for outer sections of a rapid transit line. The inherent differences of each mode were respected and the value of higher speed was suitably acknowledged. A deficiency of the study was that qualitative facts were virtually disregarded and cost was again the overriding concern.

One study (1) used a hypothetical model for comparisons of private automobile, bus, and rail. Assumptions were made stipulating service parameters to match as much as possible those of the private automobile. This does an injustice to the public transportation modes, particularly since system aspects (i.e., reliability, capacity, space limitations, environmental impacts) were disregarded. The evaluation of the modes was based exclusively on cost.

Another study (2) presented the most comprehensive conceptual framework for comparison of modes. The study gave an excellent theoretical basis, although the suggested methodology was not brought to an operational form.

It is not known whether any comprehensive study has been undertaken to compare modes on the basis of real systems already in operation. However, it can be concluded that studies comparing different modes suffer from some of the following deficiencies:

1. The models used are incorrect when they force identical types of operation on modes that inherently operate optimally in different ways.
2. The models used are not comprehensive enough; many factors important in real life are "assumed away".
3. Many important parameters are not given adequate consideration, and dominant, often exclusive, weight is given to cost.
4. One of the basic objectives of public transportation systems—to transport the maximum number of passengers—is disregarded.

LINDENWOLD RAIL LINE AND SHIRLEY BUSWAY

The Lindenwold Line (Fig. 1) was constructed between 1966 and 1969. Utilizing existing subway tunnels in downtown Philadelphia and Camden, the line extends on a private right-of-way southeasterly to Lindenwold, New Jersey. The line serves a total of 12 stations 24 hours a day. No bus feeders were provided until recently, and the line relied for access predominantly on the private automobile from the relatively low-density areas it serves. On October 28, 1972, bus routes paralleling the line were converted to feeder routes.

The first 5-mile section of the Shirley reversible-lane busway in the center of Interstate 95 (the Henry G. Shirley Memorial Highway) south of Washington, D.C., was opened in 1969 (Fig. 2). By April 1971 a temporary busway was completed for the remaining 4 miles to the center span of the 14th Street Bridge. Subsequent improvements were achieved by construction of a bus ramp in Springfield, Virginia (11 miles from the Potomac), and reserved bus lanes in downtown Washington. At present the Shirley Busway consists of a number of bus lines that operate on various routes through the Virginia suburbs and then enter the exclusive lanes on Shirley Highway. No stations are provided along the way; in downtown Washington the lines split into 3 groups. At times other than peak periods most of the lines do not operate; a few operate on local streets.

By far the largest user of the busway is AB&W Transit Company, with approximately 84 percent of the bus trips. The remaining trips are composed of WV&M Transit Company, Trailways, Greyhound, charter, and Armed Forces buses. The regular AB&W fleet has been augmented by the use of 76 modern, specially designed buses purchased by the Northern Virginia Transit Commission (NVTC).

PURPOSE AND SCOPE OF THIS STUDY

The basic characteristics of the Lindenwold Line and Shirley Busway, given in Table 1, clearly show the great similarity between them. Both systems serve, with the exception of the city of Camden, relatively low-density, middle- to high-income, auto-oriented suburban residential areas. Both have highly peaked demands.

The Lindenwold Line competes against relatively fast driving conditions but with bridge tolls and expensive parking in the CBD. Shirley Highway at present has very poor driving conditions on automobile lanes, but a considerable amount of parking in the city is provided free or at a nominal charge by government agencies.

The basic operational characteristics of both systems are given in Table 2. Both systems represent in many respects the latest in technology and operations of the 2 modes. Lindenwold Line, with its high automation, high speed (maximum 75 mph), extensive parking facilities at stations, and competent management, represents the latest in rail rapid transit. Shirley Busway lines, operating in good part on an exclusive right-of-way but utilizing the capability of buses to branch out in suburbs to different lines and operating on reserved bus lanes downtown, represent what is often defined as the optimal bus semi-rapid transit system. Consequently, Lindenwold Line and Shirley Busway represent the best real case anywhere in the country for comparing the two modes with respect to their effectiveness in providing modern transit service. The purpose of this study is to make such a comparison on a comprehensive basis.

The study data have been obtained from many sources, but mostly from the managements of the Lindenwold Line and several agencies in charge of operations utilizing the Shirley Busway. Because of the complexity of the busway system and multiplicity of parties involved, some data desired for the Shirley Busway either do not exist or could not be obtained, especially for the relatively small number of buses not operated by AB&W that also use the busway facilities.

COMPARATIVE ANALYSIS

There is no standard, generally adopted theoretical method for the comparison of different modes of transportation. To ensure a systematic and comprehensive review of all characteristics, requirements with respect to the systems have been classified by "interested parties"—passengers, operator, and community:

Passenger	Operator	Community
Availability	Area coverage	Quality of service
Speed (travel time)	Frequency	System impact
Reliability	Speed	Passenger attraction
User cost	Reliability	
Comfort	Cost	
Convenience	Capacity	
Safety and security	Safety and security	
	Side effects	
	Passenger attraction	

Figure 1. Philadelphia: The Lindenwold Rail Line.

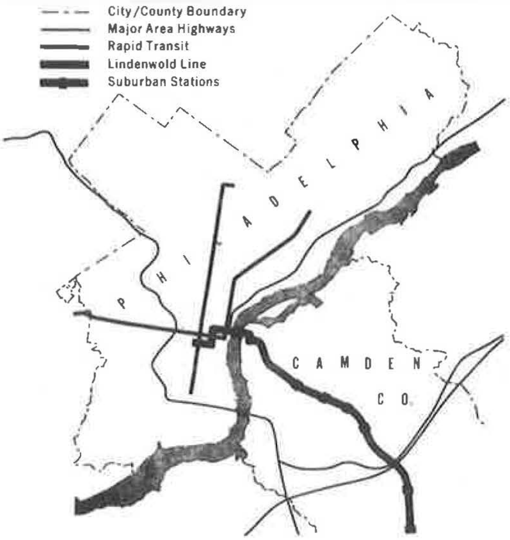


Figure 2. Washington, D.C.: The Shirley Busway.

Table 1. Basic system characteristics.

Characteristics	Lindenwold Line	Shirley Busway
Location	From southern New Jersey northwest into central Philadelphia	From northern Virginia northeast into central Washington
Types of lines	Radial via bridge to CBD	Dispersed, then radial via bridge to three central employment areas
Type of service		
Line-haul	Rail	Bus on buswav
Access modes (percent)		
Feeder transit	9	0
Park-and-ride	37	8
Kiss-and-ride	43	8
Walk	11	84
Percent changing vehicles	89	16
Downtown distribution	4 stations, discount on transfer to rapid or surface transit	Stops along 15 blocks, possible transfer to surface transit
Primary service area (square miles)	130	95
1970 population (est.)	442,000	356,000
1970 population density (est. persons per square mile)	3,400	3,750
Average cars per household	1.3	1.5
Employment centers served (1975 jobs)	Central Philadelphia (380,000) Camden, New Jersey (45,000)	Central Washington (400,000) Crystal City (40,000) Pentagon (20,000)
Opening Date	February 1969	September 1969

Each requirement will be defined and then both systems will be examined with respect to it. Reliability, safety and security, and passenger attraction are discussed only once to avoid duplication. A concluding table is given in which the findings of evaluation are summarized. The discussion is based on this table, i.e., on the evaluation of the different requirements. No effort is made to give relative values to the parameters in a quantitative way, nor is an attempt made to find an overall quantitative measure for each of the 2 systems. Rather, it is considered more valuable that the reader have a clear overview of the 2 systems with respect to each requirement so that he can judge its relative significance for the specific situations he wishes to analyze.

ANALYSIS OF PARAMETERS: PASSENGER

Availability

Availability to the passenger, without which the population cannot use a transit system, has 2 facets: locational—closeness to the system's terminal—and temporal—frequency of service. For good availability, users must have both close terminals and high frequency of service. Because of cost constraints, trade-offs between the two must be made. At one extreme is a dense network with low frequency; such a system is not available for long intervals of time. At the other extreme is frequent service to few points; users far from terminals do not have the service unless they use feeders. Availability for the 2 systems is shown schematically in Figure 3.

Lindenwold—The Lindenwold system has a line-haul service with few outlying stations and a short distribution segment within the center city of Philadelphia. Area coverage is now provided by walking, bus, and automobile. However, bus feeder service carries only 9 percent of the total, so that area coverage in the suburbs is still predominantly provided by the automobile—kiss-and-ride, 43 percent; park-and-ride, 37 percent. Walking and bicycling combined amount to 11 percent. At present 8,800 parking spaces are available (Lindenwold Station alone has 2,202 spaces, of which 1,070 are free and 1,132 require a 25-cent fee during the morning peak). Parking at some stations is still inadequate. For persons beyond walking distance who do not have automobiles, availability is limited to bus service, which is often unsatisfactory. The feeder bus system consists of 20 routes during off-peak hours, 13 during the peaks (the line does not have capacity to accept riders from all routes). Frequencies are generally low.

The line-haul portion of the system offers a high frequency of service—headways are 10 minutes or less between 5:20 a.m. and midnight, with hourly owl service afterwards, except on Sundays, when headways are 10 to 15 minutes.

Downtown distribution is not fully satisfactory because the stations are located 2 to 4 blocks away from the main employment centers and shopping areas, i.e., at a moderate walking distance. Reduced fares are provided for transfers to several SEPTA lines, including the 2 subway lines.

Shirley—AB&W Transit Company operates 9 major routes using the Shirley Busway for the line-haul portion. Each of these routes in turn represents a family of collection and distribution route options that branch out over a large area. The purpose is to increase area coverage, but it does so at the expense of frequency of service. An example will show the character of Shirley Busway services. During the 2 peak periods Route No. 7 carries 5,761 passengers—29.7 percent of the busway's AB&W peak-period total—and has a total of 48 routings. (Figures are based on October 10, 1972, summary totals, which showed 19,413 peak-period AB&W riders entering south of the Mixing Bowl.) One-half the schedule for this line is reproduced in Figure 4. Many of the subroutes operate during 1 peak period only; thus, 21 subroutes of Route No. 7 have a total of only 12 departures during the morning peak period. Average morning peak headways for the large subroutes are between 11.3 and 18 minutes. Other routes are similar in nature. There are no stations along the busway.

Each bus follows 1 of 3 routings within the central city, serving a set of stops along 2 to 3 miles of local streets before terminating at 1 of 3 terminals.

The splitting of routes is so excessive that frequency on most of them is highly unsatisfactory (once per day in some cases). In off-peak hours and on weekends only a small number of lines even operate, and some of them run on local streets, thus offering a different, much lower level of service. Park-and-ride and kiss-and-ride are used by only 16 percent of passengers, who utilize 3 designated park-and-ride facilities with a total capacity of 480 spaces; the remaining cars are parked on suburban streets and other areas about which there is no information. Consequently, the availability of service is excellent for persons who live within walking distance of the lines and travel at the times a bus for their desired destination is scheduled. For those traveling at other times or to other terminals and for those residing beyond walking distance of a line, availability is inadequate; a relatively small group of these use automobiles for access to bus lines.

Comparison—The Lindenwold Line, in combination with private automobiles and buses as feeders, offers a considerably higher availability than the Shirley Busway (required transfers are a factor in speed and convenience, not availability).

Speed (Travel Time)

The total door-to-door travel time is composed of 5 parts: access, waiting, transfer, travel, and departure times. Relative weights of these time intervals vary since passengers perceive them differently. Therefore, based on various studies reported in the literature, a factor of 2.5 is used in this study for waiting and transfer times to obtain perceived travel times.

Lindenwold—For the commuter residing 3 miles beyond the Lindenwold station, approximately 47 minutes are required for the morning peak-hour drive to the Philadelphia CBD, including parking. The same journey using the Lindenwold park-and-ride or kiss-and-ride facilities requires 35 actual minutes, or 42 perceived minutes.

Shirley—Because the uncongested busway allows its users a full view of the auto congestion they are bypassing, perceived travel times are shorter than actual times. The latter are for most users from 10 to 30 minutes below comparable automobile times. The greatest saving is made for commuters living south of Seminary Road. Much of the present automobile congestion on Shirley Highway is caused by construction works. After their completion the advantage of buses may be somewhat diminished.

Comparison—The absolute travel speed on the Lindenwold Line is considerably higher than on the Shirley Busway; however, the latter is superior to the former in relative speed with respect to the competing automobile travel for most peak-hour trips.

Reliability

Reliability is expressed by schedule adherence. The variance from scheduled travel times may result from traffic delays, vehicle breakdowns, or adverse weather conditions. It depends mostly on the control that exists over the system. By far the most significant factor for reliability is operation on private rights-of-way.

Lindenwold—In 1971, 99.15 percent of all trains ran less than 5 minutes late, including all weather, mechanical failure, and other delay causes. So far in 1972 the percentage figure has fallen to about 97 percent, as a result of extra passenger loads placed on the line during a 9-week bus strike, with subsequent operating delays. The line has never been seriously affected by adverse weather.

Shirley—Surveys performed on 4 different days during 1971-1972 showed that at the last bus stop in the Washington CBD, of the total 363 observed buses, 22 percent arrived before scheduled times, 32 percent were more than 6 minutes late, and only 46 percent arrived on scheduled times or up to 6 minutes later.

On several occasions of inclement weather, when transit service is most essential, major breakdowns of service on the Shirley Lines occurred. Many passengers remained stranded at stops without information that service was cancelled.

Comparison—The Lindenwold Line is clearly far superior to the Shirley Busway with respect to reliability.

User Cost

Transit fare is the most significant portion of transportation costs, but other out-of-pocket costs are also included, particularly by commuters. In a broader sense cost of access by automobile and even its fixed costs (if the auto is owned for that purpose) should also be considered.

Lindenwold—Fares are graduated, ranging from 35 to 75 cents. Transfer to SEPTA lines in Philadelphia is given at a 50 percent discount (2 rides for 35 cents). For commuter parking close to the stations the fee is 25 cents (16 percent of all riders pay it); at off-peak hours all parking is free. The fare for bus feeders and the line is the same as it was for direct bus travel to the city. The alternative of traveling by car is in most cases higher, however, since the auto driver must pay a bridge toll (60 cents or 35 cents for commuters) and a parking fee in the Philadelphia CBD of approximately $1.75 per day.

Shirley—For short trips the fare is 50 cents and for those past the Beltway, 80 cents. Transferring among AB&W buses is free, but transferring to DC Transit in Washington allows a discount of only 5 cents. Driving by car has only parking as the out-of-pocket cost, and for many downtown employees free parking is provided.

Comparison—Lindenwold fares, particularly if transfer in the city is included, are lower. If costs of owning and operating an automobile for access are included, Shirley requires on the average a somewhat lower total cost since residential collection is included and fewer of its users must own an automobile.

Comfort

Comfort encompasses many factors. Paramount are the availability of a seat and the quality of ride (affecting user's ability to read and write). The physical comfort of the seat, geometry of the entrances and exits, width of aisles, presence of air-conditioning, jerk and noise levels, image of patrons relative to user's self-image, and degree of privacy offered all enter in.

Lindenwold—In half of the 16 trains from 7:12 to 8:37 a.m. (surveyed in June 1971), seated capacity was exceeded before the Ferry Avenue station. From there to the 8th and Market station, load factors are now often about 1.4. Beyond the latter station, seats once again become available. The time spent standing is between 9 and 13 minutes. Off-peak seating is, naturally, always ample.

The seats themselves are wide, high-backed, and comfortably cushioned. Interiors of the cars are plush, air-conditioned, clean, and well-lighted, affording the opportunity for reading. Vehicle acceleration is smooth and rapid, with high-speed operation equally smooth. Coupled with a visibly private guideway, the system generates a high level of psychological comfort.

Shirley—Riding in buses is considerably less comfortable than in rail vehicles because of the greater sway and vibrations and less space in the vehicle. An average of less than 10 percent of NVTC bus patrons must stand during the morning peak period (regular buses show a better, if still overloaded, record). Because average trip time on these buses is roughly 30 minutes, standing becomes a serious annoyance. Seventy percent of the regular AB&W buses are air-conditioned. The 76 NVTC buses offer greater comfort, wide seats, pleasing visual image, and more leg room. Operating characteristics, unfortunately, are comparable to older buses. With 57 percent of choice riders and an average user annual household income of $16,400 (October 1971), the self-image of the user should be good.

Comparison—An analysis indicates that on the Lindenwold Line 32 persons stand a total of 320 minutes per car-trip during the peak hour for an average of 2.96 minutes per passenger. On Shirley NVTC service 5 persons stand a total of 150 minutes per bus, an average of 2.89 minutes per passenger. The conditions are considered comparable. Based on the considerable advantage of modern rail vehicles over buses in riding qualities and larger space per person, it is concluded that the Lindenwold Line is superior in comfort.

Convenience

While comfort is related to the vehicle, convenience refers to the overall system. Lack of transferring is a great convenience, as are good off-peak service, clear system information, well-designed and protected waiting facilities, and sufficient, close parking (if required). By nature, discussion of conveniences is predominantly qualitative.

Lindenwold—The Lindenwold Line requires for 89 percent of its passengers a transfer from access modes. However, parking around stations means a great convenience to the users. Off-peak riders are provided with free close-in parking. The option of fare-integrated bus feeders is also a convenience. Stations are pleasing and offer good weather protection, rest rooms, automatic fare collection, and other conveniences. Information about the service is clear, simple, and available. In fact, the conveniences offered the commuter are excellent with the exception of the transfer annoyance inherent in most trips on rail commuter service.

Shirley—Besides shorter travel times, the main attraction of the Shirley service is considered to be the lack of transferring or the possibility for many passengers to walk to the stops. However, in common with most bus networks, the Shirley system bus stops generally have no weather protection, security arrangements, route information, or seating. In fact, even the AB&W management has no clear idea of where all its stops are. The published schedules are extremely complex and unclear (Fig. 4). The sketch of routings is unintelligible. In short, although lack of transferring represents a major asset, the Shirley service provides very low user convenience.

Comparison—The wider range of access mode options, simplicity of the system, clarity of information, and positive system amenities of Lindenwold outweigh the only convenience in which Shirley is superior—lack of transfers.

Safety and Security

Safety includes 2 areas: absence of accidents and protection from crime.

Lindenwold—Like all modern rail systems, the Lindenwold Line has redundant automatic safety devices, which ensure extremely high operating safety. The system's security arrangements include 24-hour closed-circuit television monitoring of all stations using 20 television screens coupled to a public address system and a police force that guards the station areas and late-night trains. These arrangements have produced a high security record and good public image.

Shirley—Operation on an exclusive busway increases bus safety, although it remains only as good as manual control allows. According to limited data, the Shirley service has shown a very high level of operational safety. Off-peak and night security for the waiting user is in some areas a serious problem.

Comparison—In both safety and security the Lindenwold Line is excellent, the Shirley Busway offers good safety, but the security of the system has a low image.

ANALYSIS OF PARAMETERS: OPERATOR

Area Coverage

With respect solely to network extensiveness, the Shirley Busway provides in outlying areas superior coverage (kiss-and-ride and park-and-ride). Although Lindenwold now has bus feeders and its facilities for access by automobile are superior, it is considered that Shirley has an advantage in this respect.

Area coverage in the CBD is adequate (but not excellent) for both systems: Lindenwold has 4 stations with numerous entrance points and easy transfer to supplementary distribution by rapid transit; Shirley has distribution along some 15 blocks (each line follows one of the 3 main distribution routings), but inconvenient transfer to other bus lines. The two are therefore comparable.

Comparison—In overall evaluation Shirley has an edge in area coverage over Lindenwold.

Frequency

As discussed under availability, frequency on the Lindenwold Line is excellent, as it is for access by car or walking. Most of the Shirley routes have very poor frequency and variable headways. It is often believed that, for commuters, frequency is not important. In reality, however, there are no residential areas in which 1, 2, or 3 departures during the whole 2-hour peak period would be convenient for all potential users. Short, regular headways are desirable for all passengers. This characteristic is probably the most serious deficiency of the Shirley Busway. Consequently, Lindenwold is clearly superior in this feature.

Speed

The operator is particularly concerned with high operating speeds on the lines, since they affect his fleet size, labor costs, fuel, maintenance, and—above all—attraction of passengers. Several speeds are used in transit systems analysis, including (a) travel speed, the one-way average speed of a vehicle including stops, and (b) paytime speed, the average speed based on the driver's paid time.

Comparison: The average speeds shown in the following table clearly indicate that the Lindenwold Line is much faster; this is one of the major factors for its operating efficiency:

Speed	Lindenwold	AB&W	NVTC
Travel	38.7	15.8	18.6
Paytime	24.2	11.3	13.5

Cost

Although cost has often been given an unjustifiably high relative weight (even used as a single evaluation criterion for different systems), it remains the single most important factor to the operator. In this analysis three aspects of costs are discussed: investment, operating cost, and revenue. Investment cost analysis is, however, very cursory since it depends so heavily on local conditions; the general value of results of such an analysis would be quite limited.

Lindenwold—The total investment for the line, including rolling stock, amounted to $94 million. This cost is, however, considerably lower than it would have been for construction of the whole facility because the existing tunnels and bridge were utilized. New investments are being planned for the purchase of additional vehicles, lengthening of platforms, expansion of park-and-ride facilities, etc. All investments have been borne by the Delaware River Port Authority.

Operating costs (not including depreciation) amounted to $4,756,407 in 1971 while the revenues totaled $4,749,635. Thus the operating deficit amounted to $6,772. Since the line carried 9,414,329 passengers, its operating costs, as well as revenues, were $0.50 per passenger and $0.06 per passenger-mile. Revenues for the line now exceed losses at an approximate rate of $1 million per year.

PATCO employs 242 persons, and thus the line carries an average of 171 daily passengers per employee. Computations for the presently planned addition of 20 cars show that 37 new employees will be needed. Based on the present car utilization rate, marginal productivity for this expansion will be 284 passengers per employee.

Shirley—It is impossible to determine even approximate investment costs of the Shirley Busway. One estimate (3) places the cost at $7.57 million for the "temporary" Busway project. There are no estimates for such costs as right-of-way, longer structures, additional ramps, etc. Another cost that cannot be determined is that of reserved lanes in the city. Total actual cost of this project would obviously be several times higher than the quoted amount. All direct investments for the project were provided by the federal government (UMTA).

Operating costs for the 76 NVTC buses were $138,493 in October 1972, while revenues amounted to $142,540, or a 2.9 percent profit. In addition, a "diversion cost" allowance collected by AB&W from UMTA for the revenue loss to the NVTC buses amounted to $37,288 in October 1972. Thus, for October 1972, per-passenger operating cost for NVTC service averaged $0.68 while revenues averaged $0.70 per passenger.

Very conservative estimates are that Shirley has at least 455 employees (administration not included). With its present ridership its labor productivity is 52 daily passengers per employee. To accommodate the same additional volume as 20 Lindenwold cars, Shirley would require an additional 114 buses and 196 employees. Under the same assumptions productivity would not change.

Comparison—It is extremely difficult to compare capital costs of the two systems; however, it is rather obvious that Lindenwold required an appreciably higher investment.

With respect to operating costs and revenues Lindenwold has better results (Table 2). Present productivity of its employees is 3.3 times higher than that of Shirley. For an incremental capacity increase of 20 rail cars (10,500 daily passengers) this ratio would increase to 5.4 in favor of Lindenwold. The high operating cost of Shirley buses is also caused by highly peaked use and very high dead mileage.

Capacity

Two different capacities can be critical for a system: line-haul capacity and terminal capacity. The latter is smaller in all cases except when vehicles from a line-haul section branch out into several terminals.

Lindenwold—Total line capacity can be conservatively estimated at 9,750 persons per hour. Present daily peak hourly volume is 8,000 persons, and some trains during intervals shorter than 1 hour are crowded. However, neither line-haul nor terminal capacity has been approached; fleet size is the bottleneck. With an additional 55 vehicles, capacity would be increased by 80 percent; lengthening of platforms, which would involve substantial works only at the terminal station, could increase it by an additional 30 percent.

Shirley—Counts indicate that approximately 100 buses (6,500 seats and standing spaces) cross the 14th Street Bridge during the peak hour and continue on the reserved lanes in the streets. They carry an estimated volume of 5,400 passengers. While the line-haul operation on the busway is far below capacity, the capacity of the terminals has almost been reached; congestion causes frequent delays and irregularities. Thus, although the fleet capacity is insufficient, the fleet could not be substantially increased without adding new terminals and street routings.

Comparison—Both systems are limited in capacity by their current fleet sizes, but Lindenwold carries 48 percent more persons per hour than Shirley. Reserve capacity of Lindenwold with fleet increase is about 80 percent, whereas Shirley could not use a major fleet increase without extension of reserved lanes and provision of new terminals. Lindenwold is clearly superior.

Side Effects

System effects on the non-users and the environment for which the operator is responsible include such physical impacts as aesthetics, noise, and air pollution.

Lindenwold—The tunnel and bridge sections have no impact; the elevated structure is aesthetically satisfactory. Noise levels are low and air pollution is nonexistent. However, although many underpasses are provided, the line has a certain dividing effect on the area.

Shirley—Busway and buses in streets are aesthetically satisfactory. Noise and air pollution by buses are considerably improved on the latest models, but they still create problems, particularly in the streets.

Comparison—Shirley buses produce more negative side effects than does the Lindenwold Line.

Passenger Attraction

The number of passengers a transit line carries is the most important single indicator of its success and its role in urban transportation. The attraction is obviously a function of the type and quality of service, but there is also an additional factor, probably best described as "system image", which can be very important. This image is difficult to define, but it is influenced by the simplicity of the system, reliability of service, frequency, and regularity as well as physical characteristics of facilities.

Lindenwold—The Lindenwold Line carries on weekdays an average of 41,500 trips. Excluding the influence of the 1972 bus strike, when trips increased to 50,000, the ridership has been steadily increasing. A certain number of persons have tried the line but did not stay with it when park-and-ride facilities were overcrowded. Each expansion of these facilities has captured some of the latent demand. Additional non-auto-owners have been attracted by bus feeders.

Shirley—Average weekday ridership is now about 20,300 AB&W passengers plus approximately 4,000 passengers from smaller carriers. Patronage is increasing steadily on most lines. Although this number far exceeds the projections for the project, it is known that considerable latent demand is not attracted because of the inadequate information and extreme complexity of the service, low frequency, and, above all, insufficient number of buses. Estimates are that because of these deficiencies several thousand persons tried the service but did not stay with it.

Comparison—Lindenwold Line has shown a considerably better passenger attraction than Shirley Busway.

ANALYSIS OF PARAMETERS: COMMUNITY

Quality of Service

Overall quality of service from the community's point of view is difficult to evaluate for single facilities. Most of its individual components have been discussed earlier, and therefore the quality of service as such will not be included in the summary comparison.

System Impact

Two major items are included in the discussion of system impact: first, the impact of the transit system on other modes and, second, its long-range impact on land use, city form, etc.

Lindenwold—A survey reported by Vigrass (10) indicated that 40 percent of the line's patrons were previously auto drivers. Since capacity of park-and-ride facilities has been doubled, the percentage could only have increased. If one conservatively assumes that only 37 percent would be using automobiles, that would amount to 7,600 trips per direction per day, or 3,040 during 1 peak hour, when levels of service are extremely sensitive to volumes. In addition to the benefits to other auto users created by this flow reduction, some 7,000 to 8,000 parking spaces are now at outlying stations rather than in high-density central areas of Philadelphia (where 1 space costs $4,000) and Camden. The only negative impact is felt in some areas around the stations (particularly Haddonfield) where traffic congestion has increased considerably in the station vicinity.

Impact on city form can be expected to stimulate strengthening of suburban centers around the stations and vitality of the Philadelphia CBD; both impacts are desirable.

Shirley—The analysis of impact of Shirley Lines is even more complex because of current construction work that impedes traffic. An analysis similar to that for Lindenwold indicates that only approximately 2,000 car trips per day have been diverted to buses. The benefits in terms of traffic volume and parking demand decrease are similar to those for Lindenwold, although at a smaller scale since the number of riders is substantially lower. Because of the extreme dispersal of lines in the suburbs, no impact in terms of formation of subcenters in those areas is expected with the present type of service.

Comparison—With respect to impact on traffic congestion, parking in the CBD, and urban form, Lindenwold is considerably better. On feeder sections Shirley creates less congestion. In total, Lindenwold is better, although impacts of both systems are very positive.

SUMMARY OF COMPARATIVE ANALYSIS

For an easy overview of the foregoing comparison of the 2 systems, their evaluation with respect to each characteristic is described in Table 3 by 1 of 5 terms: very good, good, fair, poor, and very poor. It is emphasized that this evaluation is made with respect to the desirable feature of individual system characteristics. Thus, "very poor" for cost implies that the system cost is very high. Clearly, this type of evaluation is subjective in absolute terms, but its simplicity makes it helpful in comparing the two systems.

Table 2. Operational characteristics and system use.

Characteristics	Lindenwold Line	Shirley Busway All Services	Shirley Busway NVTC Only
Weekday hours of operation	19 + 5[a]	6 + 12[a]	6 + 4[a]
Daily trips			
Weekdays	288	789	203
Saturdays	230	200	0
Sundays	156	83	0
Average travel speeds (mph)			
Line-haul	47	35	35
Suburban collection	25 (auto)	N. A.	13 (bus)
Downtown distribution	24	12	12
Overall (typical)	30	N. A.	20
Average speed on competing highway (mph)	12-30	10-20	
Number of vehicles	75	265 (est.)	76
Peak-hour seated and standing passengers per vehicle	76 + 32	49 + 5	47 + 5
Average peak-hour floor area per passenger (square feet)	6.3	5.3	5.7
Vehicle-miles per weekday	13,746	N. A.	8,494
Miles per vehicle per day	183	N. A.	112
Number of passengers per weekday	41,500	24,300	9,270
Average trip length on the system (est. miles)	8.5	N. A.	12.7
Passenger-miles per weekday	353,000	N. A.	118,000
Passenger-miles per vehicle-mile	25.7	N. A.	12.2
Fare (cents)	35-75	40-80	40-80
Revenue per passenger (dollar)	0.57	N. A.	0.70
Operating cost per passenger (dollar)	0.51	N. A.	0.68[b]
Revenue per passenger-mile (dollar)	0.067	N. A.	0.055
Cost per passenger-mile (dollar)	0.060	N. A.	0.053[b]

N.A. = not available.

[a]Hours with very low frequencies. [b]Includes weekly fee but not diversion cost.

Figure 3. Availability of service: Routes and daily frequencies.

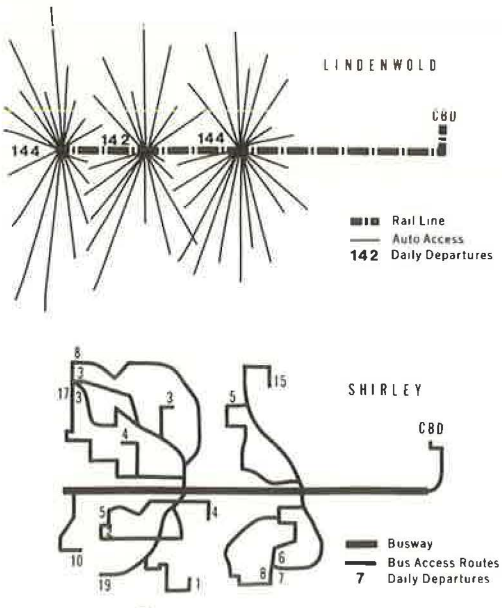


Table 3. Summary of comparative analysis.

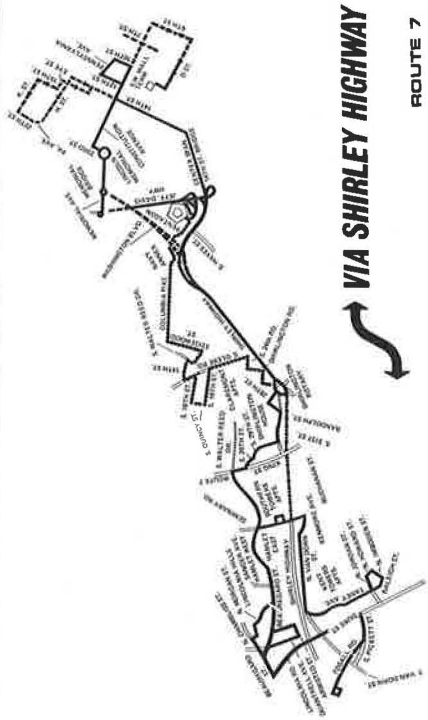
Requirement	Lindenwold	Shirley	Higher Rated System
Passenger			
Availability	Good	Poor	Lindenwold
Speed (travel time):			
Absolute	Very good	Good	Lindenwold
Relative to auto	Good	Very good	Shirley
Reliability	Very good	Poor	Lindenwold
User cost	Good	Very good	Shirley
Comfort	Good	Poor	Lindenwold
Convenience	Good	Fair	Lindenwold
Safety and security	Very good	Good	Lindenwold
Operator			
Area coverage	Good	Very good	Shirley
Frequency	Very good	Very poor	Lindenwold
Speed	Very good	Poor	Lindenwold
Cost: investment	Very poor	Fair	Shirley
Cost: operating	Good	Fair	Lindenwold
Capacity	Good	Poor	Lindenwold
Side effects	Good	Fair	Lindenwold
Passenger attraction	Very good	Good	Lindenwold
Community			
System impact	Very good	Good	Lindenwold

Figure 4. Shirley Route No. 7: Eastbound schedule and route map.

LINCOLNIA–WASHINGTON LINE
EASTBOUND

	ROUTE NO.	SYMBOL	SOUTHPORT APTS.	ORLEANS VILLAGE	DUKE & BEAUREGARD	KENT TOWERS	SHIRLEY DUKE	MORGAN & BEAUREGARD	SOUTHERN TOWERS	BUSWAY AT SEM. RD.	28TH & KING STS.	SHIRLINGTON	BUSWAY AT SHIRLINGTON	PENTAGON	VA. END OF BRIDGE	14TH & CONST. AVE.	WASHINGTON TERMINAL	S.W. MALL TERMINAL	FARRAGUT SQUARE *
A.M.	7D	M	...	...	...	...	...	(Claremont 6:10)			6:13	6:19	6:20	6:25	6:30	6:36	6:38	...	...
	7P		6:00	...	6:10	6:12	...	6:16	6:23	...	6:28	6:36	6:38	6:44	(6:49 Crystal City)			...	...
	7F	M	6:11	...	6:21	6:23	...	6:27	6:34	...	6:39	6:47	6:49	6:55	7:00	7:08	...	7:14	...
	7P		6:19	...	6:29	6:31	...	6:35	6:42	...	6:47	6:55	6:57	7:03	(7:08 Crystal City)			...	...
	7M	H-EX	6:27	...	6:37	...	...	6:40	6:47	6:50	...	...	...	...	6:55	...	...	7:11	...
	7G	H-EX	...	6:35	6:38	...	...	6:42	...	6:51	...	...	...	...	7:00	7:06	...	...	7:15
	7P		6:29	...	6:39	6:41	...	6:46	6:53	...	6:58	7:06	7:08	7:14	...	...	...	...	...
	7E		...	...	...	...	...	(Claremont 6:48)			6:53	7:01	7:03	...	7:09	7:15	...	...	7:24
	7X	M-EX	6:33	...	6:43	6:45	...	6:50	6:57	7:00	...	...	...	...	7:10	7:19	...	7:29	...
	7G	H-EX	...	6:50	6:53	...	...	6:57	...	7:06	...	...	...	...	7:15	7:21	...	...	7:30
	7N		...	...	...	...	...	...	7:01	...	7:06	7:14	7:16	7:22	(7:27 Navy Annex)			...	...
	7E		...	...	...	...	...	...	7:02	...	7:07	7:15	7:17	...	7:23	7:29	...	...	7:39
	7E	M-EX	...	...	...	...	...	(Claremont 7:03)			7:08	7:16	7:18	...	7:25	7:34	...	7:44	...
	7N		6:42	...	6:54	6:56	...	7:01	...	...	7:11	7:19	7:21	(7:27 Navy)	(7:32 Pent.)			...	...
	7Y	SF	...	...	...	...	...	(Claremont 7:13)			7:18	...	7:33	7:39	(7:48 Yds. & Dks.)			...	...
	7X	H-EX	...	...	...	6:57	...	7:02	7:09	7:12	...	...	...	...	7:21	7:27	...	...	7:36
	7P	EX	6:45	...	6:57	6:59	...	7:04	7:11	7:14	...	...	...	7:23	(7:28 Crystal City)			...	...
	7W	M-EX	6:52	...	7:04	...	...	7:08	7:15	7:18	...	...	...	...	7:28	7:37	...	7:47	...
	7M	H-EX	6:54	...	7:06	...	...	7:10	7:17	7:20	...	...	...	...	7:30	...	...	7:41	...
	7G	H-EX	...	7:05	7:08	...	...	7:12	...	7:21	...	...	...	...	7:30	7:36	...	...	7:45
	7W	H-EX	6:58	...	7:08	...	...	7:12	7:18	7:22	...	...	...	...	7:31	7:37	...	...	7:46
	7E	H	...	...	...	...	...	(Claremont 7:17)			7:22	7:30	7:32	...	7:38	7:44	...	...	7:53
	7E	M-EX	...	...	...	...	...	...	7:20	...	7:25	7:33	7:35	...	7:42	7:51	...	8:01	...
	7P	EX	6:55	...	7:07	7:09	...	7:14	7:21	7:24	...	...	...	7:33	(7:38 Crystal City)			...	...
	7P		...	...	...	...	...	...	7:25	...	7:30	7:38	7:40	7:46	...	...	...	...	...
	7W	H-EX	...	...	7:14	...	...	7:18	7:25	7:28	...	...	...	...	7:37	7:43	...	...	7:52
	7E		...	...	...	...	...	...	7:25	...	7:30	7:38	7:40	...	7:46	7:52	...	...	8:01
	7X	M-EX	...	...	...	7:15	...	7:20	7:27	7:30	...	...	...	...	7:40	7:49	...	7:59	...
	7G	M-EX	...	7:15	7:18	...	...	7:22	...	7:31	...	...	...	...	7:40	7:49	...	...	7:55
	7W	H-EX	7:10	...	7:22	...	...	7:26	7:33	7:36	...	...	...	...	7:45	7:51	...	...	8:00
	7G	H-EX	...	7:25	7:28	...	...	7:32	...	7:41	...	...	...	...	7:50	7:56	...	...	8:05
	7E	H	...	...	...	...	...	(Claremont 7:30)			7:35	7:43	7:45	...	7:51	7:57	...	...	8:06
	7E	H	...	...	...	...	...	...	7:32	...	7:37	7:45	7:47	...	7:53	7:59	...	...	8:08
	7P		7:10	...	7:22	7:24	...	7:29	7:36	...	7:41	7:49	7:51	7:57	(8:02 Crystal City)			...	...
	7W	M-EX	7:15	...	7:27	...	...	7:31	7:38	7:41	...	...	...	...	7:51	8:00	...	8:10	...
	7E	M-EX	...	...	...	...	...	...	7:40	...	7:45	7:53	7:55	...	8:02	8:11	...	8:21	...
	7P	EX	...	...	7:29	...	...	7:33	7:40	7:43	...	...	...	7:52	(7:57 Crystal City)			...	...
	7X	H-EX	...	...	...	7:27	...	7:32	7:39	7:42	...	...	...	...	7:51	7:57	...	...	8:06
	7W	H-EX	...	...	7:34	...	...	7:38	7:45	7:48	...	...	...	...	7:57	8:03	...	...	8:12
	7P	EX	...	...	7:32	7:34	...	7:38	7:46	7:49	...	...	...	7:58	(8:03 Crystal City)			...	...
	7M	H-EX	7:24	...	7:36	...	...	7:40	7:47	7:50	...	...	...	...	7:59	...	...	8:11	...
	7E	H	...	...	...	...	...	(Claremont 7:43)			7:48	7:56	7:58	...	8:04	8:10	...	...	8:19
	7P	EX	7:26	...	7:38	7:40	...	7:45	7:52	7:55	...	...	...	8:04	(8:09 Crystal City)			...	...
	7P		...	...	...	...	...	...	7:48	...	7:53	8:01	8:03	8:09	(8:14 Crystal City)			...	...
	7G	H-EX	...	7:35	7:38	...	...	7:42	...	7:51	...	...	...	...	8:00	8:06	...	...	8:15
	7W	H-EX	7:28	...	7:40	...	...	7:44	7:51	7:54	...	...	...	...	8:03	8:09	...	...	8:18
	7X	M-EX	...	...	...	7:37	...	7:42	7:49	7:52	...	...	...	...	8:02	8:11	...	8:21	...
	7E	M-EX	...	...	...	...	...	...	7:51	...	7:56	8:04	8:06	...	8:12	8:21	...	8:31	...
	7X	M-EX	...	...	...	7:43	...	7:48	7:55	7:58	...	...	...	...	8:08	8:17	...	...	8:27
	7W	EX	...	...	7:45	...	...	7:49	7:56	7:59	...	...	...	...	8:08	8:14	...	...	8:23
	7E		...	...	...	...	...	...	7:53	...	7:58	8:06	8:08	...	8:14	8:20	...	...	8:29
	7W	M-EX	7:36	...	7:48	...	...	7:52	7:59	8:02	...	...	...	...	8:12	8:21	...	8:31	...
	7E		...	...	...	...	...	...	8:00	...	8:05	8:13	8:15	...	8:21	8:27	...	...	8:36
	7X	H-EX	...	...	...	7:50	...	7:55	8:02	8:05	...	...	...	...	8:14	8:20	...	...	8:29
	7G	H-EX	...	7:45	7:48	...	...	7:52	...	8:01	...	...	...	...	8:10	8:16	...	...	8:25
	7E	M-EX	...	...	...	...	...	(Claremont 7:55)			8:00	8:09	8:10	...	8:17	8:26	...	8:38	...
	7S	SF-P	...	...	...	...	...	(Claremont 7:58)			8:03	8:20	8:22	8:28	...	...	...	...	...
	7E	H	...	...	...	...	...	...	8:08	...	8:13	8:21	8:23	...	8:29	8:35	...	...	8:44
	7X	H-EX	...	...	...	7:54	...	7:59	8:06	8:09	...	...	...	...	8:18	8:24	...	...	8:33
	7G	H-EX	...	7:55	7:58	...	...	8:02	...	8:11	...	...	...	...	8:20	8:26	...	...	8:35
	7X	M-EX	...	...	...	7:59	...	8:04	8:11	8:14	...	...	...	...	8:24	8:32	...	8:40	...
	7W	M-EX	7:49	...	8:01	...	...	8:05	8:12	8:15	...	...	...	...	8:25	8:33	...	8:41	...
	7X	M-EX	...	...	...	8:04	...	8:09	8:16	8:19	...	...	...	...	8:29	8:37	...	8:45	...
	7G	H-EX	...	8:05	8:08	...	...	8:12	...	8:21	...	...	...	...	8:30	8:36	...	...	8:45
	7E	M-EX	...	...	...	...	...	(Claremont 8:16)			8:21	8:29	8:31	...	8:35	8:46	...	8:54	...
	7G	H-EX	...	8:15	8:18	...	...	8:22	...	8:31	...	...	...	...	8:40	8:46	...	...	8:55
	7B		...	...	...	8:16	...	8:21	...	...	8:30	8:38	8:40	8:48	8:50	8:56	...	...	9:05
	7G	EX	...	8:22	8:25	...	...	8:29	...	8:33	...	...	...	...	8:47	8:53	...	...	9:02
	7G	EX	...	8:32	8:35	...	...	8:39	...	8:48	...	...	...	...	8:57	9:03	...	...	9:12
	7A		8:30	...	8:38	...	...	8:41	...	...	8:49	8:55	...	9:02	9:06	9:13	...	9:21	...
	7G	H-EX	...	8:50	8:53	...	...	8:57	...	9:06	...	...	...	...	9:15	9:21	...	...	9:30
	7F		...	...	...	8:55	...	9:00	9:05	...	9:09	9:15	...	9:22	9:26	9:33	9:35	...	...
	7B		...	...	...	9:16	...	9:21	...	...	9:29	9:35	...	9:42	9:46	9:53	9:55	...	...
	7A		9:30	...	9:38	...	...	9:41	...	...	9:49	9:55	...	10:02	10:06	10:13	10:15	...	...
	7C		...	...	...	...	9:55	...	10:05	...	10:09	10:15	...	10:22	10:26	10:33	10:35	...	...
	7B		...	...	...	10:16	...	10:21	...	...	10:29	10:35	...	10:42	10:46	10:53	10:55	...	...
	7A		10:30	...	10:38	...	...	10:41	...	...	10:49	10:55	...	11:02	11:06	11:13	11:15	...	...
	7C		...	...	...	...	10:55	...	11:05	...	11:09	11:15	...	11:22	11:26	11:33	11:35	...	...
	7B		...	...	...	11:16	...	11:21	...	...	11:29	11:35	...	11:42	11:45	11:53	11:55	...	...
	7A		11:30	...	11:38	...	...	11:41	...	...	11:49	11:55	...	12:02	12:06	12:13	12:15	...	...
P.M.	7C		...	...	...	...	11:55	...	12:05	...	12:09	12:15	...	12:22	12:26	12:33	12:35	...	...
	7B		...	...	...	12:16	...	12:21	...	...	12:29	12:35	...	12:42	12:46	12:53	12:55	...	...
	7A		12:30	...	12:38	...	...	12:41	...	...	12:49	12:55	...	1:02	1:06	1:13	1:15	...	...
	7C		...	...	...	...	12:55	...	1:05	...	1:09	1:15	...	1:22	1:26	1:33	1:35	...	...
	7B		...	...	...	1:16	...	1:21	...	...	1:29	1:35	...	1:42	1:46	1:53	1:55	...	...
	7A		1:30	...	1:38	...	...	1:41	...	...	1:49	1:55	...	2:02	2:06	2:13	2:15	...	...
	7C		...	...	...	...	1:55	...	2:05	...	2:09	2:15	...	2:22	2:26	2:33	2:35	...	...
	7B		...	...	...	2:16	...	2:21	...	...	2:29	2:35	...	2:42	2:46	2:53	2:55	...	...
	7A		2:30	...	2:38	...	...	2:41	...	...	2:49	2:56	...	3:02	3:06	3:13	3:15	...	...
	7C		...	...	...	...	2:55	...	3:05	...	3:09	3:15	...	3:22	3:26	3:33	3:35	...	...
	7B		...	...	...	3:16	...	3:21	...	...	3:29	3:35	...	3:42	3:46	3:53	3:55	...	...
	7A	L	3:33	...	3:41	...	...	3:44	...	...	3:52	3:59	...	...	4:07	4:17	...	4:25	...
	7C	L	...	...	...	...	...	...	4:00	...	4:05	4:11	...	...	4:20	4:29	...	4:38	...
	7B	L	...	...	...	4:13	...	4:24	...	...	4:32	4:38	...	...	4:47	4:56	...	5:05	...
	7F		...	...	...	...	...	...	...	...	...	...	...	4:49	4:54	5:03	...	5:12	...
	7A	L	4:30	...	4:38	...	...	4:41	...	...	4:49	4:55	...	...	5:04	5:13	...	5:22	...
	7A		...	...	...	...	...	...	...	...	...	...	(23rd & Const. 5:22)			5:28	...	5:37	...
	7F		...	...	...	4:55	...	5:00	...	...	5:09	5:15	...	5:22	5:26	5:35	...	5:44	...
	7B		...	...	...	5:16	...	5:21	...	...	5:29	5:35	...	5:42	5:46	5:55	5:57	...	...
	7A		5:31	...	5:39	...	...	5:42	...	...	5:50	5:56	...	...	6:03	6:10	6:12	...	...
	7F		5:47	...	5:55	5:57	...	6:02	6:07	...	6:11	6:17	...	6:24	6:28	6:35	6:37	...	...
	7A		6:10	...	6:18	...	...	6:21	...	...	6:29	6:34	...	...	6:41	6:48	6:50	...	...
	7F		6:35	...	6:43	6:45	...	6.49	6:53	...	6:57	7:02	...	7:09	7:13	7:20	7:22	...	...
	7Q		...	...	...	...	7:06	...	7:15	...	7:19	7:24	(Navy 7:39)		7:44	7:51	7:53	...	...
	7F		7:35	...	7:43	7:45	...	7:49	7:53	...	7:57	8:02	...	8:09	8:13	8:20	8:22	...	...
	7Q		...	...	...	...	8:06	...	8:15	...	8:19	8:24	(Navy 8:39)		8:44	8:51	8:53	...	...
	7F		8:35	...	8:43	8:45	...	8:49	8:53	...	8:57	9:02	...	9:07	9:13	9:20	9:22	...	...
	7Q		...	...	...	...	9:06	...	9:15	...	9:19	9:24	(Navy 9:39)		9:44	9:51	9:53	...	...
	7F		9:35	...	9:43	9:45	...	9:49	9:53	...	9:57	10:02	...	10:07	10:13	10:20	10:22	...	...
	7Q		...	...	...	...	10:06	...	10:15	...	10:19	10:24	(Navy 10:39)		10:44	10:51	10:53	...	...
	7F		10:35	...	10:43	10:45	...	10:49	10:53	...	10:57	11:02	...	11:07	11:13	11:20	11:22	...	...
	7Q		...	...	...	...	11:06	...	11:16	...	11:19	11:24	(Navy 11:39)		11:44	11:51	11:53	...	...

* Arrive Time 20th & Eye St. Terminal



CONCLUSIONS AND DISCUSSION

Comparison of the Systems

The Lindenwold Line and Shirley Busway serve similar areas and should play virtually identical roles, namely, to connect suburbs with the centers of large cities. However, they differ drastically in the type of service they offer and the results they achieve. The major differences in their services are as follows:

1. Lindenwold, conceived as a system competitive with the auto, provides all-day service. Shirley, conceived as a relief service for high-volume auto movement, provides competitive service mostly during peak hours.
2. Lindenwold provides intensive service—very high frequency at few stations; Shirley's service is extensive—many collection points with low frequencies.
3. Lindenwold, being a rail system, has a very high investment and low operating cost and offers a very high quality of service. Shirley buses require a lower investment and higher operating cost and provide lower service characteristics.
4. Lindenwold relies heavily on auto access (average access distance is 3.2 miles); Shirley relies mostly on walking (84 percent of riders).
5. Lindenwold attracts reasonably good off-peak riding as well as those commuters who would return at different times; such users cannot conveniently use most of the Shirley routes.
6. Lindenwold carries 41,500 weekday trips and operates at capacity during the peaks. With additional cars its capacity could be increased by more than 100 percent. Shirley also operates at capacity, serving 24,300 weekday trips. Its capacity cannot be substantially increased with additional vehicles without decreased speed and reliability of service in the CBD.

Evaluation of Concepts and Modes

The interesting and very important fact is that the two systems, serving similar areas and travel markets, attract different numbers of passengers: Lindenwold carries some 70 percent more daily riders than Shirley. Three factors may be the causes of this advantage:

1. Lindenwold offers all-day service. The reason for this is found in the characteristic of the modes: A single rail line can be operated economically with a much higher frequency than can an extensive network of bus routes.
2. Lindenwold is much simpler to use. This is partly caused by operational deficiencies (e.g., inexcusably complicated information) and partly by the concept: An extensive network is more complicated to use than a single line.
3. Lindenwold offers a considerably higher quality of service. Most of these advantages are related to modal characteristics of rail and bus.

In comparing busway system with rail rapid transit it is concluded that the 2 modes are not fully substitutable: Each has a different optimal domain. The bus mode generally has a lower investment because it does not require an exclusive right-of-way over the entire length of its lines. On the other hand, rail rapid transit has operating cost advantages, mostly because its labor requirement is one-third to one-fifth that of bus service (this ratio increases with passenger volumes). Buses are physically easier to implement but represent a system that is much more difficult to manage and control than rail. Not being physically independent, buses are subject to the influences of many highway authorities, townships, traffic police units, and often several bus company managements.

By utilizing the ability of buses to travel on any highway and street, it is possible to provide an extensive network of routes that permit users to walk to the stops and have a no-transfer ride into the city. However, if this branching out is done to an extreme (Shirley has 127 routing permutations), quality of service seriously suffers. The route layout and quality of service are often more important factors than system costs, since they seriously affect system attractiveness. The systems studied clearly illustrate this point. It is obvious that transferring, objectionable by itself, can be more than offset by such service aspects as high reliability, frequency, simplicity, and riding comfort (this corroborates the experiences of other cities such as Hamburg). Rail provides these qualities as well as high capacity.

Shirley can be modified to overcome some of these deficiencies by higher frequency and simplicity of service. A major drawback will, however, remain street running in the center city. Bringing an exclusive busway to city streets defeats many advantages of the whole system. To be a high-quality system, a busway must be led into exclusive transit areas in the city center, such as the Lincoln Tunnel-Port Authority Terminal in New York City.

The light rail concept—partially separated rail lines in the suburbs proceeding into tunnels in the city center—falls between the busway and rapid transit concepts and has been very successfully developed in many European cities (11). Light rail requires a considerably smaller investment than rapid transit, offers a quality of service higher than buses, and allows tunnel operation in the city center. It can be incrementally upgraded into a fully controlled system. The system is particularly suited to medium-sized cities.

Needed Improvements to Lindenwold and Shirley

Lindenwold urgently needs to increase its rolling stock, extend the line outward to intercept more of its present and potential riders, and construct additional stations and expanded park-and-rail facilities. These improvements are planned but not yet financed. Eventually, the line should be extended through central Philadelphia and connected with another radial line.

Shirley also badly needs vehicles, but only with considerable improvement of terminal and street operations in central Washington (traffic engineering techniques, enforcement of reserved lane, etc.). However, the most beneficial improvement would be consolidation of suburban routes into fewer and higher frequency lines with adequate information and more hours of high-type operation using the busway. It is specifically suggested that several stations be constructed with ample park-and-ride and kiss-and-ride facilities and with guaranteed all-day service with headways not longer than 10 minutes, and that simple, clear information about the service be provided. This proposal is in line with a similar 1971 DOT recommendation that efforts be made to attract more park-and-ride and kiss-and-ride users to the Shirley Busway. Unless opening of the Metro (subway) line has a major influence on the character of the Shirley system, consideration should also be given to the introduction of articulated buses with considerably greater capacity. These buses are available and are widely used in many European cities.

Some Additional Observations

The relative advantages of one system over the other should not obscure the overall absolute value of either of them. There is a strong consensus among system users and professionals alike that both Lindenwold and Shirley are extremely successful. The fact that both systems attract so many passengers from heavily auto-oriented low-density areas proves that transit need not be an inferior, supplementary mode of transportation: Both systems already carry during peak hours more than 50 percent of all passengers in the corridors in which they operate. A large latent demand for transit has been demonstrated in both cases.

It is absurd that these new systems that have attracted so many new choice riders do not have the funds to provide adequate capacities while numerous parking facilities in centers of both cities are heavily subsidized. It is also a paradox that both systems are basically individual projects rather than parts of major modern transit networks. This clearly shows the need for creation of a much better defined urban transportation policy (including transit, highways, parking, etc.) than our cities now have.

An interesting finding is that the introduction of the Lindenwold Line has resulted in both an increased use of private automobiles as part of the work trip and decreased use of the auto in the center city. Finally, Lindenwold and Shirley show that standard transit modes, bus and rail, are capable of attracting many new riders if they are adequately financed, modern, and well-operated.

In closing, it is pointed out that despite the limitations of this study (complexity of the systems, incomplete data, current changes) it has shown that transportation systems must be analyzed on a comprehensive basis: Qualitative aspects such as comfort, reliability, and information cannot be ignored, even though their evaluation must be partly subjective. Conclusions of this study are relevant to planning of new transit systems, particularly bus and rail modes.

ACKNOWLEDGMENTS

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EFFECTIVENESS OF ALTERNATIVE DOWNTOWN AREA BUS DISTRIBUTION SYSTEMS

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An analysis is made of alternative bus transit distribution systems in central or downtown areas. This is done through the use of a model that simulates the operation of buses as they travel through a downtown area, stopping at signalized intersections and at designated stations to take on passengers. Variables such as bus headways, passenger arrival rates, and passenger boarding times are treated stochastically in the event-advanced simulation. A total of 20 alternatives were tested with the simulation. The alternatives included preferential bus treatments, such as exclusive streets for buses, grade-separated busways, and bus-actuated signals, and facility improvements in the form of skip-stop operations, bus loading bays at stations, and improved boarding and fare-collection methods. The results indicate that transit operations in central areas can be substantially improved by the use of preferential bus treatments and facility improvements. Reductions of bus operating times to less than half of those of conventional operations were found.

•IN RECENT years, the U.S. Department of Transportation has placed major emphasis on the movement of people, rather than vehicles, on urban freeways and streets. Policies have been developed to encourage the use of buses in preference to individual automobiles. This, of course, is particularly desirable in urban areas, where the competition for street space is high and where congestion is part of the everyday scene. Some typical forms of preferential bus treatments include exclusive bus roadways, exclusive bus lanes, and bus-actuated traffic signals. These enable buses to bypass areas of traffic congestion and thereby reduce travel times.

Exclusive lanes or streets for buses should carry traffic volumes comparable with other lanes and streets to demonstrate sufficient utilization of such facilities within a short period of time after implementation. If not, the demand for private driver use of the exclusive bus lanes and streets will mount, and decision-makers eventually will have to yield to public demand. This would, of course, jeopardize some of the very basic goals of express-bus mass transit—namely, reducing travel times and encouraging drivers to leave their cars at home.

In addition to making mass transit more attractive by increasing the operating speed, reduced travel times also increase the economic efficiency of transit operation. A reduction in delays would make the transit driver more productive, and the number of transit vehicles could be reduced without any loss in level of service.

This paper describes the development of a technique for evaluating the efficiency of alternative mass transit distribution systems and quantifying the time savings that can be expected from the installation of preferential bus treatments and bus facility improvements in central areas. A major portion of the research involved the structuring of a computer model that simulates the flow of buses through a central area and then using the model to test the efficiency of alternative improvements on a specific case study. The model was used to evaluate alternatives and select viable treatments for

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improving central area transit operations. This information indicates to the transportation planner what improvements would be needed in order to maintain an adequate level of service and what changes might be considered necessary to meet future demands.

MODEL FORMULATION

In formulating the model, the primary objective was to provide a realistic representation of the operational behavior of buses as they travel through a central area during the peak hour. In order to simulate the alternative systems, it was necessary to identify the components of a central area bus distribution system (as discussed later) and to make basic assumptions about their operating characteristics based on historical and observed data. Stochastic variables such as bus headways, pedestrian arrival rates, and passenger boarding times were also required and were generated randomly according to appropriate statistical distributions.

A flow chart of the model is shown in Figure 1. The simulation, which is event-advanced, computes and reports the delays and travel times as the vehicles pass through a downtown area, stopping at signalized intersections and stations as determined by the input characteristics of the alternative system to be tested. The model proceeds through the simulation of a bus arriving at an intersection and performing all necessary operations for the next block of the route. These operations may include stopping for a signal, stopping to board passengers, and waiting in a queue behind other buses. The bus then moves to the next intersection and through the route until all operations are performed. The next bus then proceeds through the route, and the simulation proceeds until all buses have passed through the route.

By changing the variables representing the performance characteristics of the various components of the system, the model is able to compare alternatives and to indicate the consequences that can be expected from various facility improvements. The simulation program is flexible enough to accommodate any alternative presently under consideration, along with any alternative that might be included at a later date. Because it was impossible to predict exactly which alternatives would be explored in the near future, it was essential that flexibility and provision for rapid, simple modifications be built into the model.

The model was constructed in a 2-phase procedure. The initial phase produced a general model to test the more basic assumptions that were made about the systems and to verify that the model recognized all travel times and delays and assigned buses and passengers to their proper destinations. The second phase of the model building comprised the development of the submodels containing stochastic representations used during the simulation runs and the inclusion of these into the general model. The end product was a simulation model capable of testing a broad range of alternative distribution systems in a reasonably realistic manner. Further details on the nature of the model can be found elsewhere (1).

DEVELOPMENT OF ALTERNATIVES

Definition of System Components and Options

In order to simulate the flow of transit vehicles during a peak hour in a central city area, it is necessary to identify the various common components of each of the alternative systems. For each of the system components, such as the right-of-way on which the vehicles run, there are 2 or more possible options that could be used, such as exclusive lanes, exclusive streets, or exclusive right-of-way on elevated roadways. Each system component has a certain characteristic associated with a specific option for that given component; for example, for the busway component, a certain speed would be associated with buses running on an exclusive street whereas a different speed would be typical for an elevated system. The characteristics associated with each of the options that can be exercised have been identified and given quantitative values based on field observations in Milwaukee and Chicago and on historical data. These values then represent the input variables of the model. In this model a central area transit system consists of 7 components, each of which has 2 or more options. By combining the 7 components into a transit system and in turn changing the options for each system component, a series of alternative systems can be developed. The model then simulates the operation of each system. From the results of the simulation, the alternatives can be evaluated for efficiency and time saving. The 7 system components and the possible options for each of them are listed in the following, grouped under three types—roadway components, station components, and vehicle components:

Roadway Components

1. Busway—This constitutes the roadbed, street, or structure on which the buses run; the right-of-way contains the following options: (a) buses operating in mixed traffic; (b) buses operating on exclusive lanes or streets and with at-grade intersections with other streets; (c) buses operating on grades separated by exclusive systems, such as subway or elevated busway.

2. Traffic signals—Where the buses operate at grade, traffic signals are major contributors to bus delays: (a) fixed-cycle signals; (b) bus-actuated signals; (c) no signals.

Station Components

3. Station layout—The station layout determines whether the buses stop in the through lane or in special bus bays: (a) bus stops in through lane; (b) bus stops in bus bay.

4. Station spacing and stopping configuration—Vehicles can have a number of options involving where and how often they stop: (a) all buses stop once every third block; (b) skip stop with 1 station every 2 blocks; (c) skip stop with 1 station every 3 blocks; (d) skip stop with 2 stations every 3 blocks.

Vehicle Components

5. Bus boarding—With the assumption that a bus has 2 doors, the question is how they can be used more efficiently during the peak hour when the passenger flow is basically one-directional: (a) one door for entry and one for exit; (b) mixed entry and exit at both doors.

6. Fare collection—Several alternatives can be tested to find a feasible solution corresponding to various levels of service: (a) exact fare paid when boarding; (b) no fare collection when boarding, but collected at the station, prepaid passes, pay as you leave, etc.

7. Vehicle size—With the likelihood of mini-buses it was felt that more than one vehicle size should be tested: (a) large bus (seat capacity = 50); (b) small bus (seat capacity = 30).

Combinations of all of the possible alternatives will give several hundred systems. It is neither feasible nor necessary to simulate such a number of alternatives to arrive at meaningful results. By looking at the various options mentioned under each system component, it was evident that several options will have identical operating characteristics for the purpose of simulation. To arrive at a reasonable number of systems reflecting a broad range of alternatives, certain combinations and eliminations of options were made, resulting in a set of 20 alternatives. The first 4 alternatives involve buses operating in mixed traffic, alternatives 5 to 13 involve buses operating on exclusive streets, and alternatives 14 to 20 involve buses operating on a grade-separated roadway. Under each of these sets of alternatives various changes in other roadway, vehicle, and station components are made, as shown in Table 1 and Figure 2.

Parameters for Test Run

With the definition of the alternatives and the simulation model completed, a number of test runs were made. These test runs were made using a set of parameters that represented a reasonably high-volume system operating over a single route during an afternoon peak period. The parameters used for the test runs are given in Table 2. The implications of these parameters as well as of the assumptions used should be fully understood before applying the results of the research to a particular area. If such an application is being considered, further analysis should be made to adopt the model to local conditions.

Figure 1. Computer flow chart.

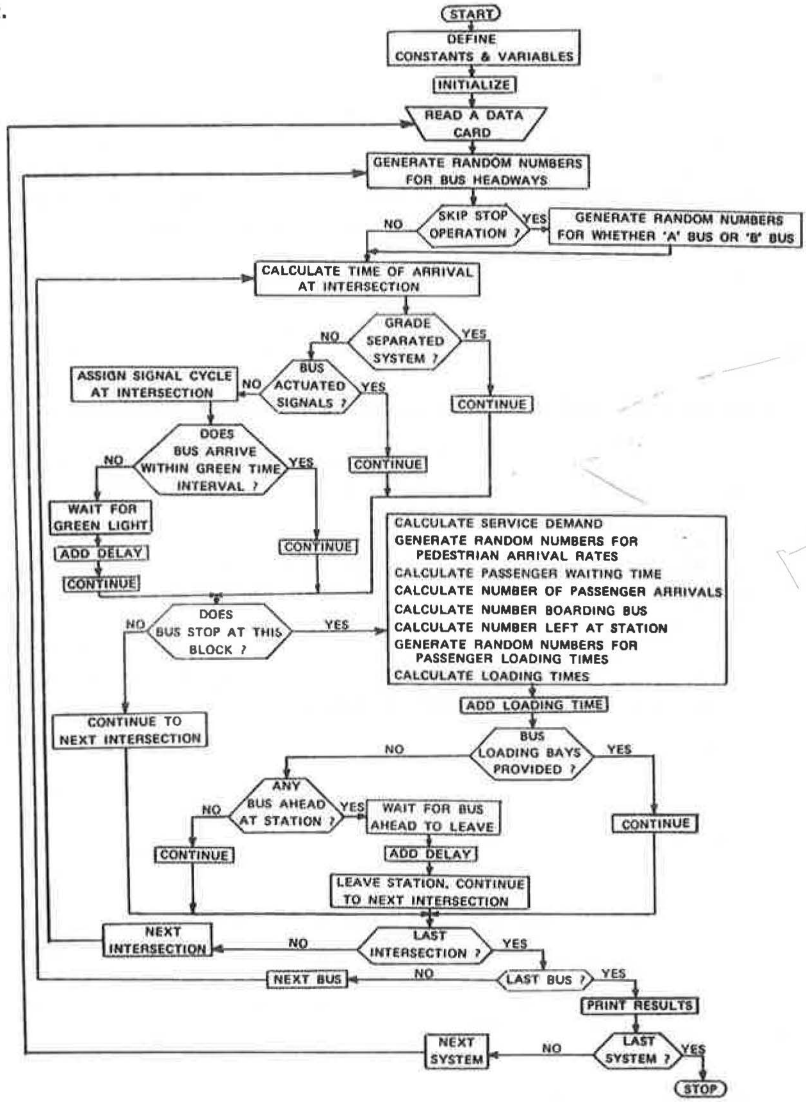


Table 1. Alternatives to be tested.

System No.	Busway: Mixed Traffic	Busway: Exclusive Street	Busway: Elevated or Subway	Station Layout: Stops in Through Lane	Station Layout: Stops in Bus Bay	Stopping Configuration and Distance Between Stations: Each Bus at Every Third Block	Skip Stop and 2 Stations for Every 3 Blocks	Skip Stop and 1 Station for Every 2 Blocks	Skip Stop and 1 Station for Every 3 Blocks	Number of Doors: 1 for Each Movement	Number of Doors: 2 for Each Movement	Fare Collection: Exact Fare When Boarding	Fare Collection: No Fare Collection When Boarding	Traffic Signals: Fixed-Cycle Signals	Traffic Signals: Bus-Actuated Signals	Traffic Signals: No Signals	Transit Vehicles: Large Bus (50 Seats)	Transit Vehicles: Small Bus (30 Seats)
1	X			X		X				X		X		X			X	
2	X			X			X			X		X		X			X	
3	X				X	X				X		X		X			X	
4	X				X		X			X		X		X			X	
5		X		X			X			X		X		X			X	
6		X			X		X			X		X		X			X	
7		X			X			X[a]		X		X		X			X	
8		X			X			X[b]		X		X		X			X	
9		X			X				X	X		X		X			X	
10		X			X		X				X		X	X			X	
11		X			X		X			X		X			X		X	
12		X			X			X[a]		X		X			X		X	
13		X			X		X			X		X			X			X
14			X	X		X				X		X				X	X	
15			X		X		X			X		X				X	X	
16			X		X			X[a]		X		X				X	X	
17			X		X			X[b]		X		X				X	X	
18			X		X				X	X		X				X	X	
19			X		X		X				X		X			X	X	
20			X		X		X			X		X				X		X

[a]'A' Stations and 'B' Stations at adjacent blocks. [b]One block between 'A' Stations and 'B' Stations.

The afternoon peak hour was simulated because it was felt that it would be more critical than the morning, since boarding consumes more time than alighting. Predominant boarding also involves having the bus filled up, thus leaving bus patrons at stations awaiting the next arrival. The supply of buses during the peak hour is determined by the number of passengers to be served; both are treated as input variables. The test route is 12 blocks long, with 12 signalized intersections and from 4 to 8 stations, depending on the station spacing.

For the test runs a peak-hour bus flow of 100 buses per hour was used. This results in a close headway between buses, which has a subsequent effect on the results of the simulation. For example, buses may form a platoon or queues at intersections and at loading points. This causes delays when bus loading bays are not provided and vehicles are forced to wait for the bus ahead to clear the station. Station delay can occur if a large number of passengers must be loaded at a station. These delays can in turn affect the next bus waiting at the station. The nature of the delays incurred will depend on other characteristics of the alternatives, such as the loading system and the nature of the signal system.

The bus flow rate (100 buses per hour) was chosen to be typical of what could occur in the central area of a large city during rush periods. The current flow rate of buses on Wisconsin Avenue in Milwaukee is 70 buses per hour during the afternoon peak period, and bus flow rates ranging from 90 to 175 buses per hour are found on such streets as Michigan Avenue in Chicago, Euclid Avenue in Cleveland, Market Street in San Francisco, and Hillside Avenue in New York. Bus flows of 70 to 174 vehicles per hour are expected to occur in downtown Milwaukee under the proposed Milwaukee Area Transit Plan.

RESULTS

For each of the 20 systems, a total of 100 buses were tested in each computer run, and 10 consecutive runs were made. For each alternative system, the computer printout gives the statistics for each bus at each station, a summary for each bus, and a summary for the entire 100 buses for each system. The input characteristics used were kept the same for all the systems so that the alternatives could be tested under identical conditions and unbiased comparisons could be made.

The results from the simulation of the 20 alternative bus systems are summarized in Table 3, which gives the average values obtained from 10 independent runs for each alternative system. A sensitivity analysis of the computer printout showed that the results settled down to a steady-state condition quite rapidly.

Figure 3 shows the results given in Table 3. It is a diagram showing for each system the average total time required for each bus to complete its run though the test area. The total time is divided into subareas to show what portion of the total time is used for traveling, loading, signal delay, and station delay.

Starting with a basic system with no improvements (system 1), from left to right in the figure one can see that the average time used per bus decreases as alternative improvements are introduced to the systems. The difference between alternatives 1 and 2 is that in alternative 1 all buses stop at the same stations whereas for alternative 2 a skip-stop operation is employed, thereby reducing station delay. In alternative 3, bus loading bays are provided, thus eliminating the station delay. For alternatives 1 to 4, the buses are running in mixed traffic; for alternatives 5 to 13, they are running on exclusive streets; alternatives 11, 12, and 13 have bus-actuated signals; in alternatives 14 to 20 the busway is grade-separated. A stepwise decrease in travel time is evident, with the largest decrease occurring between buses in mixed traffic and on exclusive streets, i.e., between alternatives 4 and 5. Where bus-actuated signals are used in connection with exclusive streets and for the grade-separated systems, the signal delays are eliminated. Systems 14 and 15 are both grade-separated, have the same number of stops, and are identical in all other respects except that for alternative 14 the buses stop in the through lane whereas in alternative 15 bus loading bays are provided. One can clearly see the extra delay imposed on buses in alternative 14 as they have to wait for buses ahead at stations. It should be recalled that the flow rate used in these runs was 100 buses per hour. At such a rate buses would often have to wait in the through lane for a bus ahead to complete its loading, and a higher total time would result. For alternatives 10 and 19, the passengers were allowed to board through 2 doors, and no fares were collected while boarding. Figure 3 shows that this reduces loading time to about half that of boarding through 1 door while paying exact fare.

Examination of Individual Components

To obtain a more accurate indication of what time saving could be expected from each single improvement, systems with identical component options were examined, varying only the options for the component being analyzed. For example, when the roadway component was to be examined to see what effect running buses in mixed traffic, on exclusive streets, or on elevated structures would have on the system operation, systems with similar options were analyzed, varying only the options under the roadway component. Systems shown under the same "level number" in Figures 4 to 10 have identical options for all components other than the particular component under examination. Figures 4 through 10 show the average time used per bus under each option for a particular component when other component options are kept the same. The vertical distance between the lines in the figures then represents the difference in total time consumed, or time saving, between the respective options being tested.

Comparison of Mixed Traffic, Exclusive Streets, and Grade-Separated Busways—The effects of having buses run on exclusive streets or on grade-separated busways as compared to operating in mixed traffic are shown in Figure 4. As could be expected, the separation of buses from other traffic causes a reduction in travel times for the vehicles. The magnitude of the reductions varies according to what options are considered under the other components. The time savings to be expected range from 15 to 20 percent of total time used in the case of exclusive streets and from 25 to 35 percent for grade-separated busways, as compared to buses operating in mixed traffic.

In Figure 4, the fact that systems 1 and 14 are plotted under the same "level number" means that their options under all components other than the roadway component are identical, such as stopping in through lane, each bus stopping at every third block, one door for boarding while paying exact fare, and so on. Systems 2 and 5 are plotted at level II, and this again signifies their similar options under all other components but that these options are different from those under level I; in this case, the difference is the skip-stop operation realized at level II. Levels III and IV reflect still other option selections.

Comparison of Through Lane and Bus Loading Bays—The results in Figure 5 show that the provision of bus loading bays at stations so that all buses are free to proceed as soon as their loading is completed gives a time saving of from 15 to 25 percent as compared to systems where the buses stop in the through lane and are forced to wait until any bus ahead has completed its loading.

Comparison of Buses Stopping at Same Stations and Skip-Stop Operation—A time saving of from 5 to 15 percent for skip-stop operation is indicated by the model. Figure 6 shows that the time saving depends on whether the buses stop in the through lane (level I) or in loading bays (level II) at the stations. Where bus loading bays are provided, the time saving from skip-stop operation will be less because there is no station delay to be saved.

Comparison of Station Spacing—Three systems with buses running on exclusive streets (level I) and 3 systems with buses running on grade-separated structures (level II) were tested. The results are shown in Figure 7. By increasing the station spacing from 2 stations for every 3 blocks to 1 for every second block or 1 for every third block, the total time savings that can be expected are about 5 and 10 percent respectively. This is attributed to fewer station stops, which means fewer decelerations and accelerations and less time spent for the opening and closing of bus doors.

Comparison of Boarding and Fare Collection—The 4 systems tested are shown in Figure 8 with exclusive street systems at level I and grade-separated systems at level II. The cases where people board through 2 doors and pay no fare while boarding show a total average time advantage of from 10 to 15 percent over the conventional method of boarding through 1 door and collecting exact fare while boarding.

Figure 2. Visual display of alternative systems.

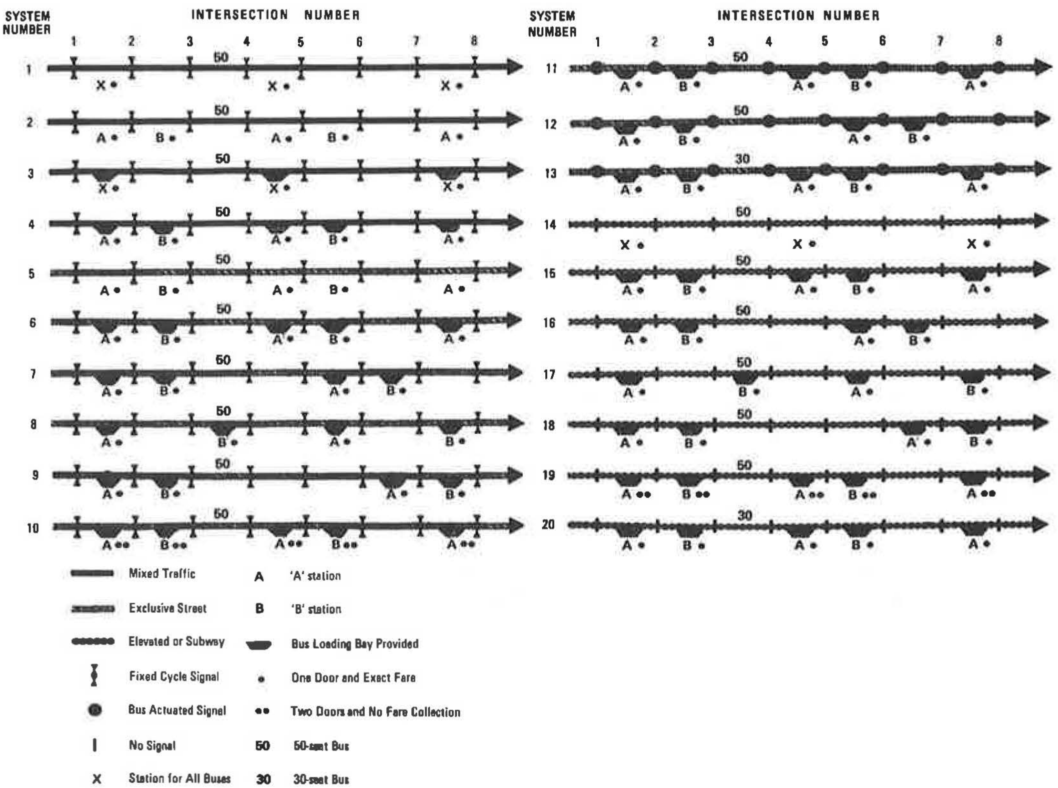


Table 2. Peak-hour input characteristics for test runs of model.

Characteristic	Amount
Size of area being tested (number of city blocks)	12
Maximum demand during peak hour (passengers per hour)	4,000
Minimum demand during peak hour (passengers per hour)	1,000
Peak hour bus flow (buses per hour)	100
Number of buses tested	100
Bus capacity (number of seats)	50
Maximum passengers allowed at one station	30
Minimum bus headway (seconds)	3
Cycle length for traffic signals (seconds)	60
Length of green time for traffic signals (seconds)	40
Time offset between adjacent traffic signals (seconds)	10

Table 3. Systems summaries.

System No.	Average Occupancy per Bus	Total Travel Time (min)	Percent of Total	Average Travel Time per Bus Min	Pers.-Min	Total Loading Time (min)	Percent of Total	Average Loading Time per Bus Min	Pers.-Min	Total Signal Delay (min)	Percent of Total	Average Signal Delay per Bus Min	Pers.-Min	Total Station Delay (min)	Percent of Total	Average Station Delay per Bus Min	Pers.-Min	Total Time Used (min)	Average Total Time per Bus Min	Pers.-Min	Efficiency Index (Adjusted) (occupancy/time used)
1	41	402	47	4.0	165	129	15	1.3	53	74	9	0.7	30	253	29	2.5	104	858	8.6	352	1.00
2	41	401	57	4.0	165	130	19	1.3	53	68	10	0.7	28	99	14	1.0	41	698	7.0	287	1.24
3	46	405	65	4.0	186	147	23	1.5	68	77	12	0.8	35	0	0	0	0	629	6.3	289	1.56
4	42	404	66	4.0	170	135	22	1.3	57	74	12	0.7	31	0	0	0	0	613	6.1	256	1.46
5	42	294	51	2.9	123	134	24	1.3	56	59	10	0.6	25	88	15	0.9	37	575	5.8	241	1.54
6	45	293	59	2.9	132	144	29	1.4	65	59	12	0.6	27	0	0	0	0	496	5.0	224	1.92
7	39	290	62	2.9	113	123	26	1.2	48	55	12	0.6	21	0	0	0	0	468	4.7	182	1.74
8	39	289	62	2.9	113	125	27	1.2	49	54	11	0.5	21	0	0	0	0	468	4.7	183	1.77
9	31	286	67	2.9	89	99	23	1.0	31	45	10	0.5	14	0	0	0	0	430	4.3	134	1.52
10	45	297	68	3.0	134	71	16	0.7	32	70	16	0.7	31	0	0	0	0	438	4.4	197	2.17
11	43	275	66	2.8	118	139	34	1.4	60	0	0	0	0	0	0	0	0	414	4.1	176	2.21
12	39	275	69	2.8	107	123	31	1.2	48	0	0	0	0	0	0	0	0	398	4.0	156	2.05
13	26	278	77	2.8	72	84	23	0.8	22	0	0	0	0	0	0	0	0	362	3.6	94	1.53
14	42	255	37	2.6	107	133	20	1.3	56	0	0	0	0	294	43	2.9	123	682	6.8	286	1.30
15	44	255	65	2.6	112	139	35	1.4	61	0	0	0	0	0	0	0	0	394	3.9	173	2.34
16	38	253	67	2.5	96	122	33	1.2	46	0	0	0	0	0	0	0	0	375	3.8	142	2.16
17	38	253	67	2.5	96	122	33	1.2	46	0	0	0	0	0	0	0	0	375	3.8	142	2.15
18	31	252	72	2.5	78	98	28	1.0	30	0	0	0	0	0	0	0	0	350	3.5	108	1.85
19	41	254	80	2.5	104	65	20	0.7	27	0	0	0	0	0	0	0	0	319	3.2	131	2.70
20	27	256	75	2.6	69	86	25	0.9	23	0	0	0	0	0	0	0	0	342	3.4	92	1.66

Figure 3. Time used along route for each system.

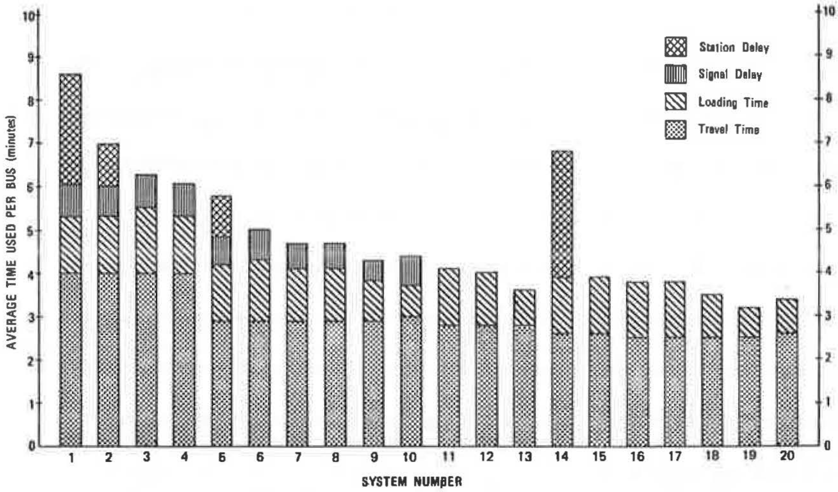


Figure 4. Time used per bus for systems having buses in mixed traffic, on exclusive streets, or on grade-separated structures.

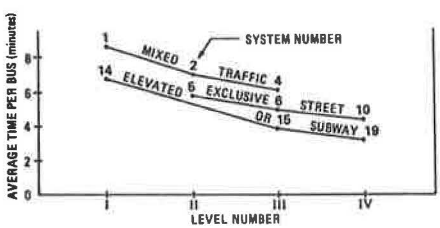


Figure 5. Time used per bus for systems having buses stop in through lane or in bus loading bays at stations.

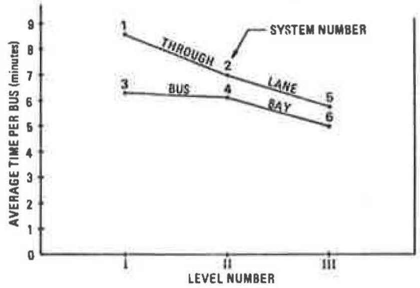


Figure 6. Time used per bus for systems having buses stop at the same stations or having skip-stop operation.

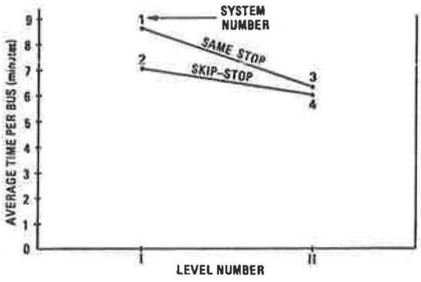


Figure 7. Time used per bus for systems having 2 stations for every 3 blocks, 1 station for every 2 blocks, or 1 station for every 3 blocks.

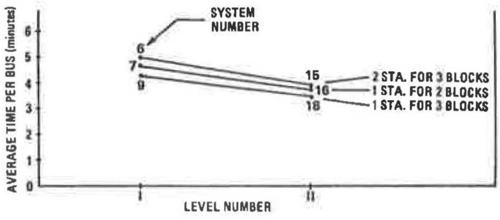
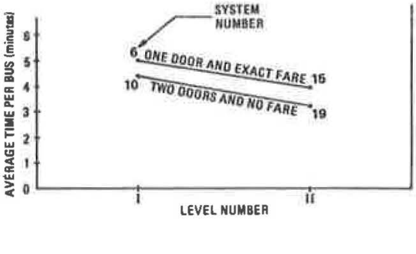


Figure 8. Time used per bus for systems with boarding through 1 door and payment of exact fare and for systems with boarding through 2 doors and no fare collection while boarding.



Comparison of Fixed-Cycle and Bus-Actuated Signals—Four systems having buses running on exclusive streets were tested with fixed-cycle signals and bus-actuated signals at intersections. At the fixed-cycle signals, the buses were given 40 seconds' green time from a 60-second cycle. The signals are progressive, with an offset of 10 seconds. Any cycle length, green time, and signal offset can be given simply by changing the number on the data card. From the input used in this test, the results show that by replacing fixed-cycle signals with bus-actuated signals one can expect a reduction in total time used of about 15 percent. The results are shown in Figure 9.

Comparison of Large and Small Buses—The results from the simulation of 2 systems having large (50-seat) buses and 2 systems using small (30-seat) buses are shown in Figure 10, with exclusive street systems at level I and grade-separated systems at level II. A time difference of 0.5 minute in favor of the smaller buses indicated that the use of small buses will reduce total running time by about 10 percent. This time reduction, however, was derived wholly from a reduction in boarding time because of the reduced carrying capacity of the smaller buses. As shown, the actual efficiency of systems having large buses was found to exceed that of systems using small buses.

Examination of Efficiency Ratings

In order to take into consideration the number of people carried as well as time consumed, a term called efficiency index was introduced. It is defined as the ratio of average bus occupancy to total time used through the test area, expressed as passengers per minute. The index was adjusted by a factor so that the basic system with no improvements (system I) would have an efficiency index of 1.0. For the 20 systems tested, the index has a range of from 1.0 to 2.7, as shown in Figure 11, with the high number indicating the most efficient system. The efficiency index was introduced primarily for the purpose of testing systems having vehicles of different seating capacity because, where the size of vehicles differs, a measure for time saving only will not give a true indication of the total benefits obtained. In Figure 11 the effect of using smaller buses rather than the conventional size with 50 seats can be examined by comparing systems 10 and 13 and 15 and 20. It was determined that, although the use of smaller buses will speed up operations, their reduced carrying capacity will cause the overall efficiency of operation to decrease by about 30 percent. All the systems can conveniently be measured by this index method; the increase in efficiency index will be in proportion to the percentage time saving found previously.

Staged Improvements

It will often be desirable to carry out transit improvements in stages, a strategy whereby the improvements are programmed for construction at a time when the demand warrants such action. By knowing the increase in efficiency that can be expected from various transit improvements, one can test, well in advance, alternative transit systems that will be needed to meet anticipated future demands. This will enable decision-makers to develop a program for planned expansion of their transit systems coordinated with other developments. Figure 12 suggests one stepwise improvement program by which the efficiency index can be increased from unity to 2.7. For example, it is found that an efficiency increase of, say, 30 percent is needed for downtown transit service within a certain time in order to maintain an adequate level of service. Figure 12 shows that the introduction of skip-stop operation and provision of bus loading bays at stations should accomplish this. With future improvements in mind, the provision of exclusive streets for buses, including, perhaps, bus-actuated signals at intersections, will further increase the efficiency. By improving boarding and fare collection methods and by grade-separating transit vehicles from other traffic, the efficiency can be given a further substantial increase.

CONCLUSIONS

This paper has described the development of a technique for the evaluation of the efficiency of alternative bus transit distribution systems in central areas. This was done through the use of a model that simulated the flow of buses through a downtown

Figure 9. Time used per bus for systems having fixed-cycle signals and for systems having bus-actuated signals.

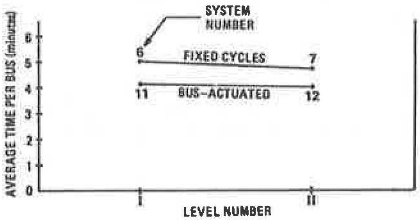


Figure 10. Time used per bus for systems with large buses and for systems with small buses.

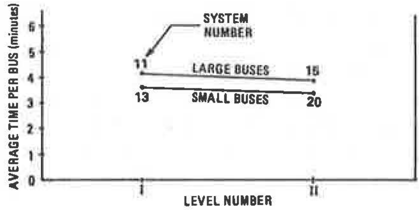


Figure 11. Efficiency indexes for the alternative bus systems.

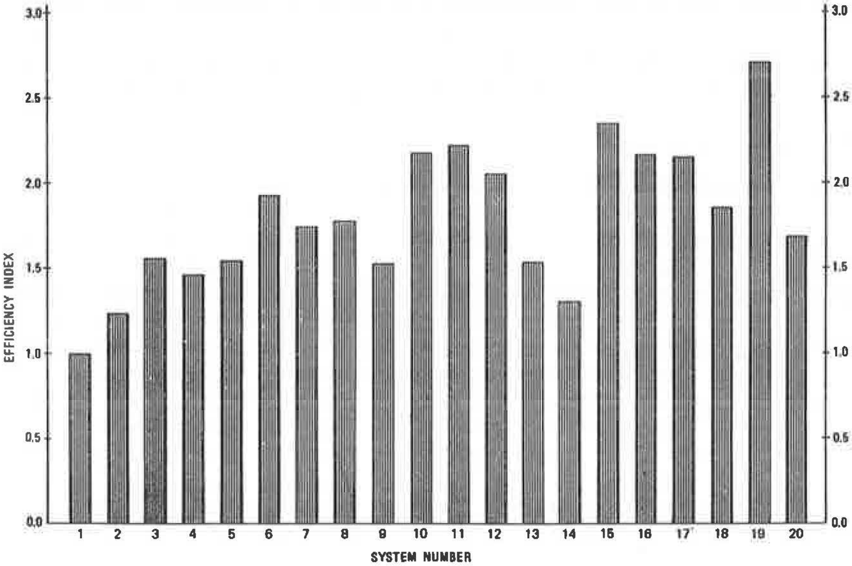
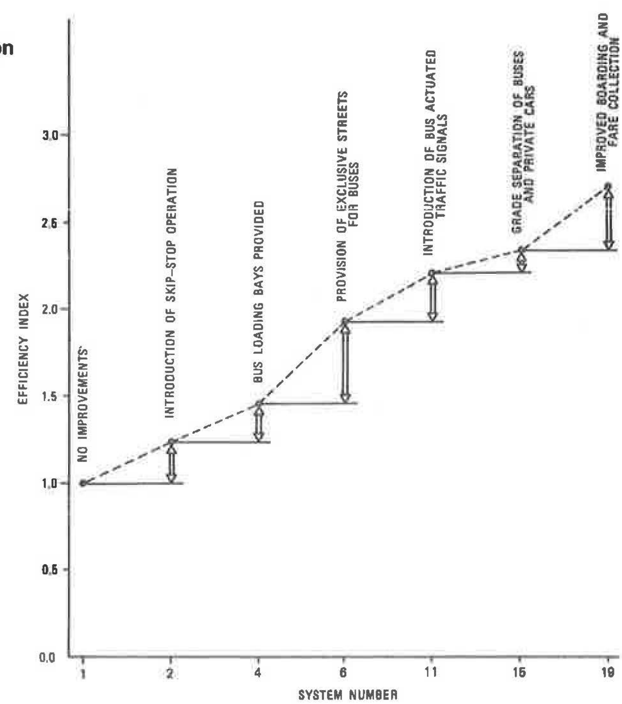


Figure 12. Increase in efficiency by introduction of improvements.



area. The simulation model proved to be a useful technique and demonstrated that substantial improvements in central area distribution can occur through the introduction of preferential bus treatments and facility improvements. Through a combination of several treatments, the operational efficiency of a bus system can be more than doubled as compared to conventional operation for the situations tested.

As compared to running buses in mixed traffic, the provision of exclusive bus streets or grade-separated busways yielding higher travel speeds will increase the system efficiency by as much as 15 to 20 percent and 25 to 35 percent respectively. By the installation of bus-actuated traffic signals at intersections, thereby reducing signal delays, the exclusive-streets systems can be made almost as efficient as the grade-separated ones, depending, of course, on the effectiveness of the signal actuation. At a supply rate of about 100 buses per hour, it was shown that providing bus loading bays at the stations could increase efficiency by 15 to 25 percent simply by the elimination of bus delays at the stations. Skip-stop operation contributes between 5 and 15 percent toward increased efficiency.

The tests for different station spacings indicated an efficiency increase of about 5 percent for every block increase in station spacing. However, one should keep in mind that an increase in station spacing will increase the walking distance for transit patrons, in addition to requiring large station areas. Also, excessive station sizes could complicate station operations and subsequently reduce efficiency.

During peak hours, when the service demand is heavy, the elimination of fare collection will allow passengers to board through both doors without delay for fare payment. This will reduce boarding times enough to allow an efficiency increase in the order of 15 percent. Although the use of smaller 30-seat buses, as compared to larger ones with 50 seats, will have a reduction in total running time of between 10 and 15 percent, the overall efficiency for the larger buses due to their higher carrying capacity was found to be almost 30 percent higher.

The model can be applied to test transit operation in any high-activity corridor after being calibrated to represent the characteristics of the specific area to be tested. It is capable of analyzing transit operation at various levels of demand, for any signal-cycle lengths, phase lengths, and progressive time offsets, in addition to any of the alternative improvement options discussed in this report. The results will provide the traffic and transportation planner with an insight into the benefits to be earned from certain actions and investments. The model is an effective tool that will allow the user to base decisions on expected benefits rather than on the unknown.

ACKNOWLEDGMENTS

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HIGH-QUALITY CITY-WIDE TRANSIT WITH BUSES

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The question examined was whether public transit could be made far more satisfactory and acceptable in middle-sized cities within a reasonable span of time. In that context the best answer was assumed to lie in greatly enhancing ordinary bus transit to make it a frequent, blanketing, day-and-night service. In the city, a frequency of 10 buses per hour from dawn till late evening is proposed. In the suburbs, commuter express buses would supplement the less ample regular-route service. The economics of enhanced bus transit were assayed by comparing the estimated expense of service, for a real city, with the expected revenue at several assumed patronage levels. The finding is that more appealing public transit is very likely to require subsidy, but the amount may be affordable. Because no technological breakthroughs would be required, buses might actually be in operation and providing superior service within a few years. Practical details on institutional and other aspects of such operations are discussed. Also demonstrated is the strong influence of existing streets and urban surroundings on the design of transit networks. To develop adequate public transit service within the new-style suburban environment will be difficult.

•THERE IS a belief that urban circulation and the urban environment might both be better if public transit had a far larger role. If that belief is valid it poses the challenge of providing greatly improved service that might attract many people—and doing so reasonably soon. This paper retraces work on that challenge relative to middle-sized cities, like those in upstate New York, that have retained an appreciable transit habit. Because the availability of advanced transit technology is not assured for major undertakings within the meaning of "soon", the basic challenge has been dealt with in terms of conventional equipment, chiefly buses.

The desired increase in the attractiveness of transit will surely depend on improvement in the quality of service offered. Because that might be expensive, the study was concerned with the economics of proposed improvements. The requisite improvement could doubtless be achieved by a generous supply of service, either on fixed routes or on a demand-responsive basis. The latter, innovative form of transit was deemed an inappropriate answer at this time for several reasons: Practical experience with demand-responsive transit operations is limited. Their applicability over the full extent of a middle-sized city has not been established. And there is lack of knowledge about the quality of service obtainable at any specific level of expense. By contrast, the relation between expense and quality seems more apparent for regular-route transit, and its total expense may be estimated readily. Conventional transit operations therefore form the basis for this study.

ASSUMPTIONS

The way to increase the appeal and use of transit seemed conceptually simple: The service should attempt to approach the characteristics of the private auto. In most respects buses do not duplicate autos and should not try to. But two qualities afforded by the auto do deserve emulation: availability (starting out whenever desired) and

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accessibility (getting from one place to any other). Those qualities might in principle be approximated by a blanketing, frequent, day-and-night, local bus service. Ideally, transit patrons then might gain some of the spontaneity and directness enjoyed by motorists.

To satisfy the criterion of adequate accessibility, it was assumed that buses would operate over an extensive route network patterned on a regular, orthogonal grid. (That pattern has the advantage of conceptual simplicity and seems well suited to serving scattered desire lines without forcing most travelers through downtown.) Routes might be spaced in a ½-mile-square mesh near the center; the grid might open to ½- by 1-mile spacing farther out, even covering some of the less dispersed suburbs. Few bus patrons using a network so fine-meshed should have to transfer more than once, and according to traditional standards the routes would be reasonably accessible.

A decent semblance of good availability could be obtained with 6-minute headways or a frequency of 10 buses per hour (so-called 10-bph service). If the headways are kept uniform, the buses need not be operated to a specified schedule. Patrons would then be freed from the inconveniences of traveling by timetable and clock. The 10-bph service would be operated in both directions over the entire bus-route grid through two straight shifts (nominally about 17 hours) on weekdays. Service at other periods, though not as frequent, would still offer comparatively good availability.

An economic assessment of this blanketing frequent-service concept was carried out using greater Rochester as the test site. Framed to the preceding standards of frequency and pattern, a hypothetical bus transit system (Fig. 1) was tested against the data base of the Rochester Metropolitan Transportation Study (RMTS). Rough economic calculations suggested that such a system might not be financially beyond reason. On the strength of that, further investigation was decided upon.

ROUTING ON EXISTING STREETS

The first task was to fit the idealized transit grid to the real streets of greater Rochester. It was soon evident that uniform route spacing must be compromised by the strongly radial street pattern within the city and by major barriers such as the river bisecting the city from north to south. Routing principles were therefore examined briefly in seeking alternatives to the desired orthogonal grid. A few ideas on transit routing resulted. For example, continuous routes are preferable to a chain of segments. Figure 2 shows that, at the price of some route indirectness, many patrons crossing the river would be spared multiple transferring.

In the suburban setting southeast of Rochester the attempt at network design met other adversities. Single-portal communities, traffic-impeding convolutions of subdivision streets, and the lack of urban continuity ("sprawl") all compounded the design problem. It is uncommon in that kind of setting to find essentially parallel highways spaced at intervals suitable for a transit route grid readily accessible by walking. Thus the proposed ½- by 1-mile suburban grid remains largely unattainable. Figure 3 shows the sparse route layout finally devised for the southeast section. It shows little resemblance to the tidy idealized grid superimposed on the corresponding section of Figure 1 (identified by corner tics).

The lessons taught by these efforts were twofold:

1. In cities lacking a regular street layout, the ideal of a uniform grid of transit routes may be quite infeasible; uneven spacing and irregular transit coverage must be accepted, along with wasteful double or triple frequency on certain route segments.
2. In most new suburban settings a comprehensive transit network catering primarily to pedestrian access is almost impossible to design and probably difficult to justify.

TRANSIT AND THE METROPOLITAN PATTERN

These experiences with transit routing lent support to a view of metropolitan development that is cognizant of transit. Not only is the performance of that mode in a given locale affected by the orientation of trips and the density of demand, but the street

Figure 1. Hypothetical transit grid.

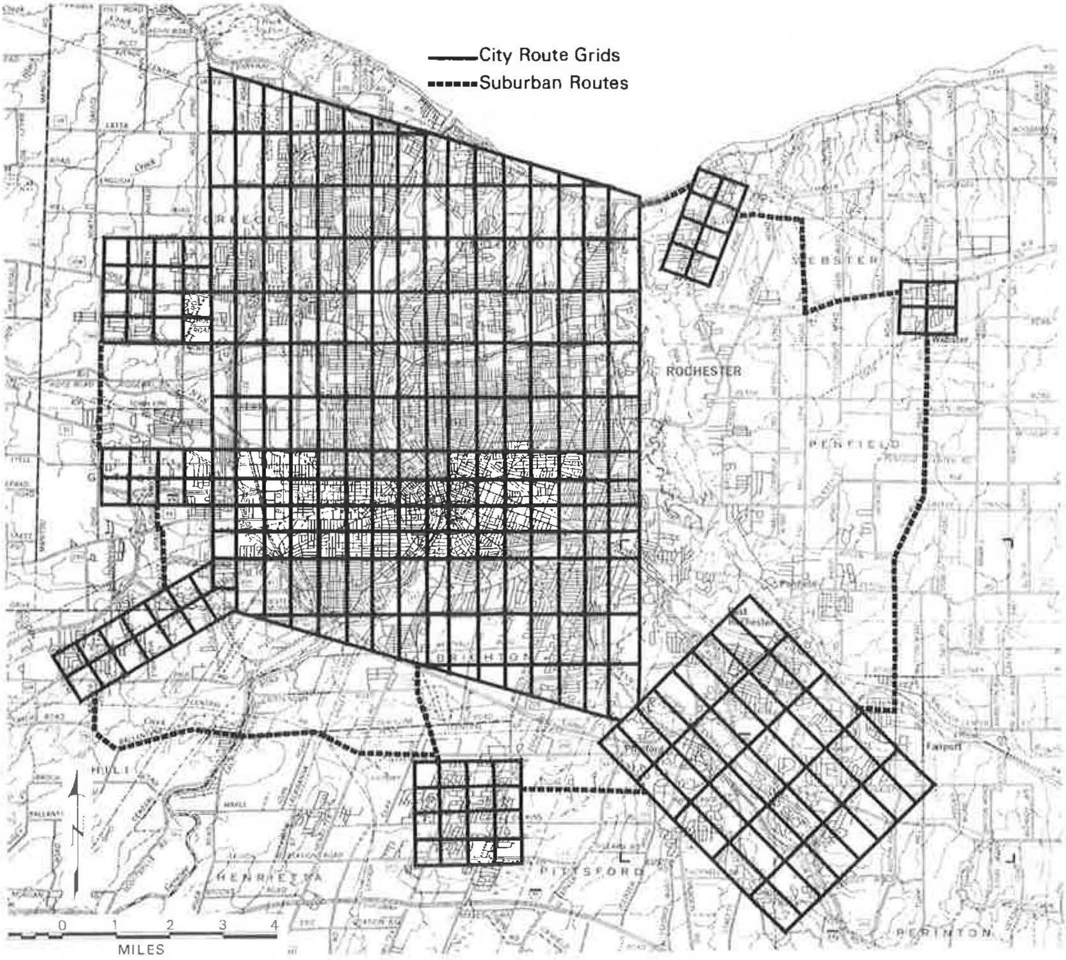
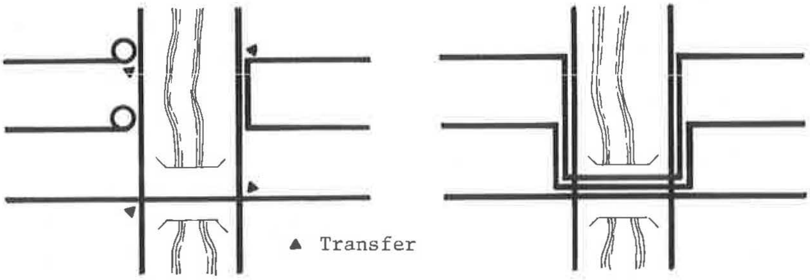


Figure 2. Indirect continuous routes save transferring.



pattern is also coming to be recognized as affecting service (1). The character of the streets and arterials can impinge on the movement of buses and on the ease of patrons in plying between buses and home. Figure 4 shows a middle-sized city and its environs. Conceptually, this metropolis comprises types of urban settings that are variously conducive or adverse to transit service: the central business district (CBD), the entire city, outlying older settlements, modern subdivisions—all of them set in a matrix of so-called sprawl. Disregarding municipal boundaries, the city may be regarded as the principal urban cluster that was built up by 1940, with a pattern and grain generally oriented to walking and public transit.

Such insights on metropolitan land used (and possible life-styles) gave an impetus for reappraising the notion of pervasive and frequent regional transit. In the city a high-quality service did still seem important as a modal alternative. Hopefully it would serve many persons for a variety of trip purposes. Hopefully, too, it would gain enough patronage to yield ample benefits to the public at large. Therefore the notion of frequent service blanketing the city still seemed relevant. A contrary appraisal was reached, though, for the suburbs. By the nature of their spatial patterns they are heavily automobile-dependent. Public transit has only ancillary roles in that environment, such as serving long-haul commuters and perhaps relieving parents of some of the chauffeuring of youngsters. (This is not to argue that there is hardly need for suburban transit. Much of that need, though, is apt to be denied fulfillment. The newer patterns of urban development often seem quite incompatible with forms of mobility that do not use personal motor vehicles.)

TOWARD A REALISTIC PROPOSAL

Evidently, then, any dramatic improvement in the quality of metropolitan transit should in a sense match the distinct kinds of settings to be served. A more practical proposal was accordingly put together, a group of services under the name "Tranef" (for transit network frequent). It is meant to serve the middle-sized city and its surroundings through this decade and the next. Four principal elements make up the Tranef proposal: enhanced city service, enhanced suburban service, commuter express service, and city flyer service.

The fundamental element, "enhanced" city transit, is shown in part by Figure 5. This service would be operated over a relatively fine-meshed grid that may be likened to the traditional radial transit routes supplemented by numerous crosstown routes. Enhanced suburban service, as shown in Figure 6, might traverse a few coarse grids linked by routes along major highways. Commuter express service, the third element, would be an operation during peak-hours mainly oriented to suburban commuting. In Figure 7 the solid lines trace some of the morning express trips in which buses typically might make a few residential stops and then run closed-door to a distant workplace or to the CBD. Figure 8 shows city flyer service: limited-stop operations along major city streets. City flyer buses would be scheduled in common with the enhanced suburban service, and indeed the two elements would function as extensions of each other.

Table 1 summarizes the availability by time period of the major elements of Tranef in the city and the suburbs. For any given element the frequency of service on workdays may differ from the frequency on other days and may also differ between the long daytime period and the late-night "owl" period. For anyone not familiar with public transit the frequencies specified in the table may have little real significance, but one may perhaps appreciate that the 10-bph specification means that a bus would go by in each direction every 6 minutes—or in about the time it takes to walk 3 blocks.

Tranef also has a fifth, and minor, element. It consists of the supplementary services that might be operated by the Tranef organization or by private carriers in coordination with the system. Examples include the following:

1. "Sectored" demand-responsive operations—Place- or time-restricted demand-jitney service for larger subdivisions might be patterned after the GO transit operation in suburban Toronto.

Figure 3. Suburban transit network.

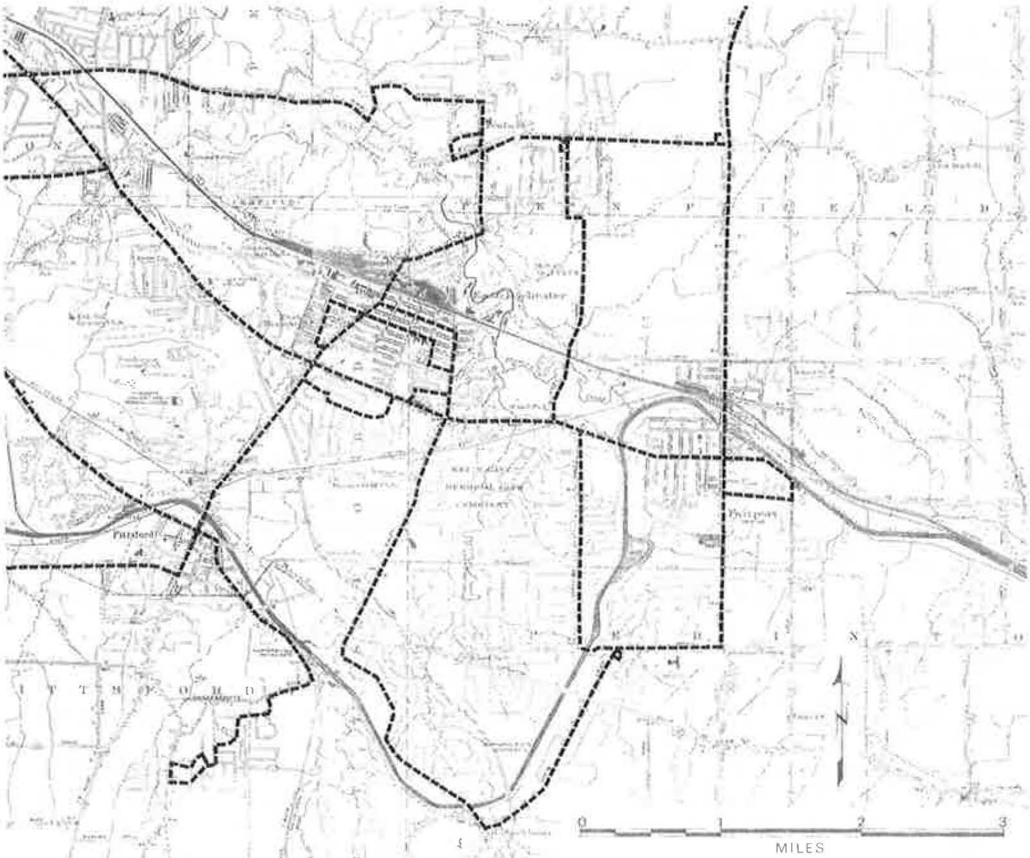
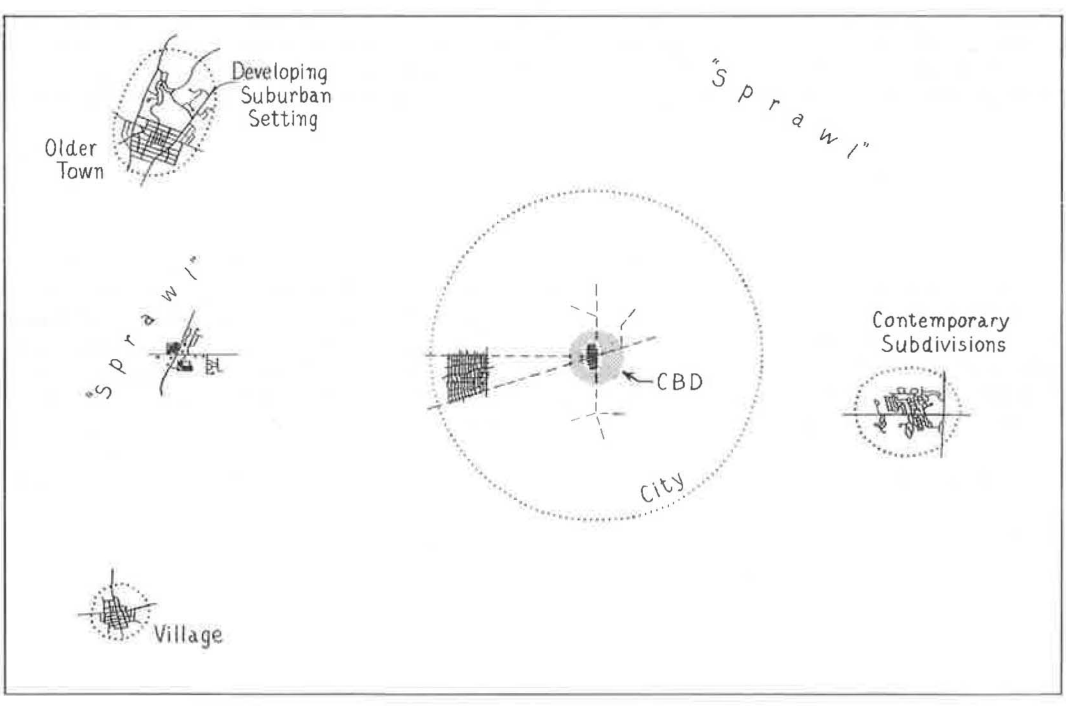


Figure 4. Middle-sized city and its surroundings (conceptual).



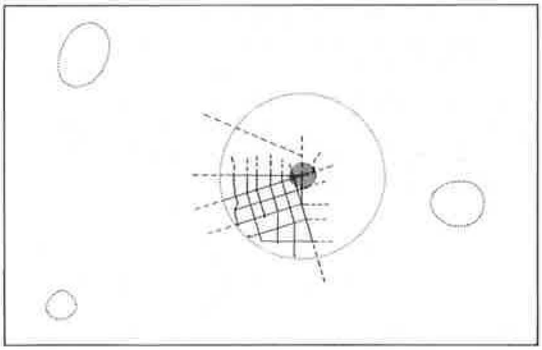


Figure 5. Enhanced city service (service frequency: weekdays, 10 buses per hour; Saturdays, Sundays, and holidays, 5; owl, 3).

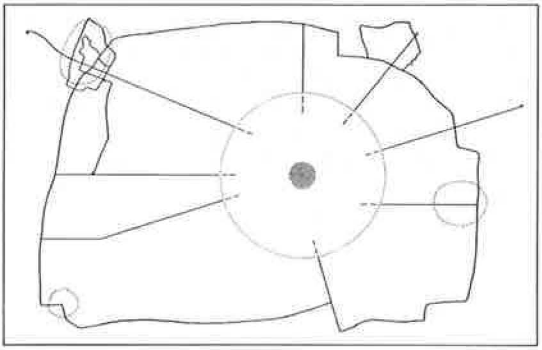


Figure 6. Enhanced suburban service (service frequency: weekdays, 4 buses per hour; Saturdays, Sundays, and holidays, 2; owl, 1).

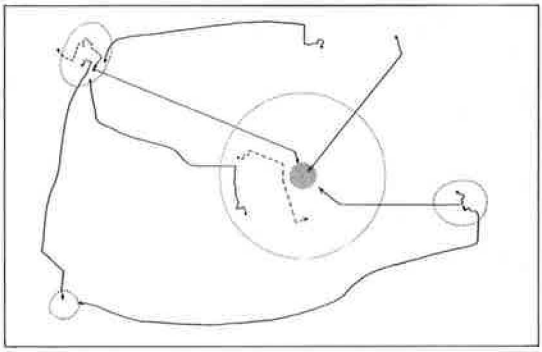


Figure 7. Commuter express service.

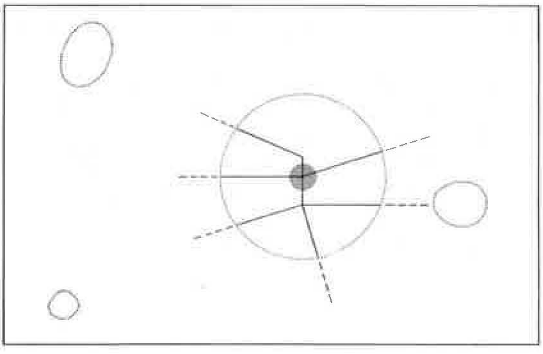


Figure 8. City flyer service (service frequency: weekdays, 4 buses per hour; Saturdays, Sundays, and holidays, 2).

2. Commuter trippers—Small buses might make twice-daily trips on special routes in the city, collecting employees from a residential locality and taking them to a common place of work. (This idea is illustrated by the longer dashed line in Figure 7.)

3. Subscription-jitney operations—In outlying communities, jitneys could transport commuters on a subscription basis between their homes and a commuter express terminal (as indicated in the northwest portion of Figure 7).

4. Commuter club arrangements—Using chartered buses, subscribers could operate a private service patterned on the successful Reston practices (2).

It may be instructive to examine a sample Tranef network (for enhanced city and suburban service) with respect to urban development and conventional transit routes. Such a network was laid out for metropolitan Rochester and is shown in Figure 9. In Figure 10 the contemporary public transit routes are superimposed, for comparison, over a faint copy of the Tranef network. Notwithstanding some similarities within the city, the Tranef network would function differently owing to both its additional crosstown routes and its unseen dimension of enhanced availability.

Viewing Tranef as a system, clearly it would supply good service where transit is most feasible: in the city. Enhanced service in the more developed suburbs may be regarded chiefly as an accommodation furnishing some mobility for youngsters and others without autos. By contrast, the commuter express operations (not mapped) cater to the most servable portion of the suburban market: long-haul commuters unwilling to fight traffic. Altogether, Tranef can be seen as a package of various transit elements that attempt to offer enough appeal to enough people in diverse groups to win the support necessary for a viable system.

Economics

Would Tranef be too expensive? Using greater Rochester as the test site, system economics were tentatively assessed by comparing assumed revenues with estimated expense. The specifications previously outlined, together with the network mapped in Figure 9, determine a fixed amount of service whose total annual expense may be estimated readily.

Input data for the economic assessment of city flyer and enhanced services are given in Tables 1 and 2. The assumed average speeds are believed to be reasonable. The data are reduced to the expense parameters of estimated fleet size, daily bus-hours, and daily bus-miles as follows:

$$\text{No. of buses} \quad B = F\left(\frac{L \cdot 2 \text{ ways}}{S}\right)$$

$$\text{Bus-hours of travel} \quad BHT = D \cdot B$$

$$\text{Bus-miles of travel} \quad BMT = S \cdot (BHT)$$

where

F = service frequency in buses per hour (one way);
L = length of route in miles (one way);
S = average operating speed in miles per hour; and
D = duration of service at a specified frequency in hours.

Expense parameters for the enhanced and city flyer elements are calculated and aggregated to annual average daily (AAD) amounts in Table 3. Table 4 summarizes the calculated fleet size. Tranef commuter express operations were synthesized from an examination of RMTS home-to-work trip-making data. Half a dozen district pairs were identified as candidates for suburban commuter express service, which was assumed to offer 8 runs per peak period on 12-minute headways. To assure that the expense of commuter operations was not understated, bus-miles and other parameters were arbitrarily doubled. They were further expanded by 60 percent to cover supplementary commuter trippers and commuter-club operations.

Table 1. Tranef availability: buses per hour for major elements, times, and locations.

	Weekdays			Saturdays, Sundays, and Holidays	
Service	Daytime (17 hours)	Peak	Owl (7 hours)	Daytime (17 hours)	Owl (7 hours)
City					
Enhanced	10		3	5	3
City flyer	4			2	
Commuter express		Varies			
Suburban					
Enhanced	4		1	2	1
Commuter express		Varies			

Note: Service of 5 buses per hour frequency or less is operated to schedule.

Figure 9. Tranef network (enhanced services only).

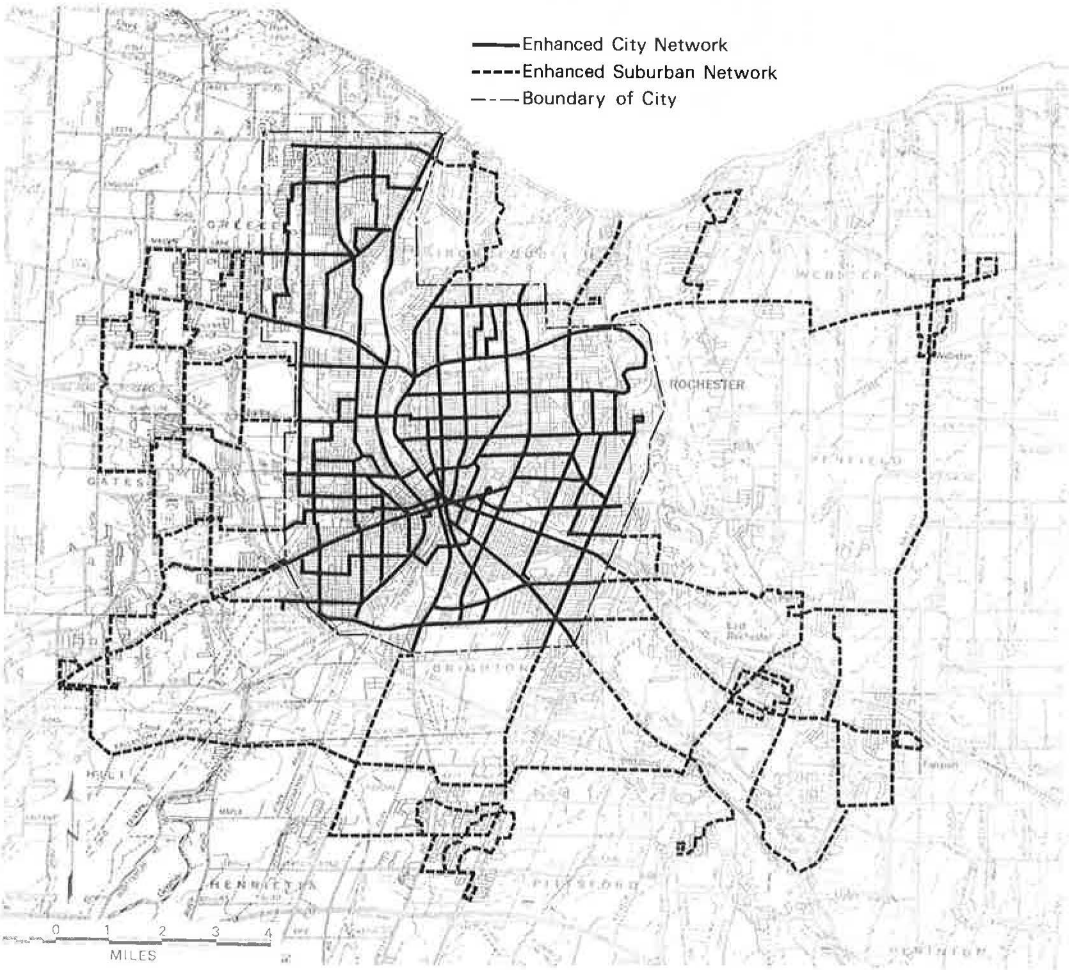


Figure 10. Contemporary public transit network.

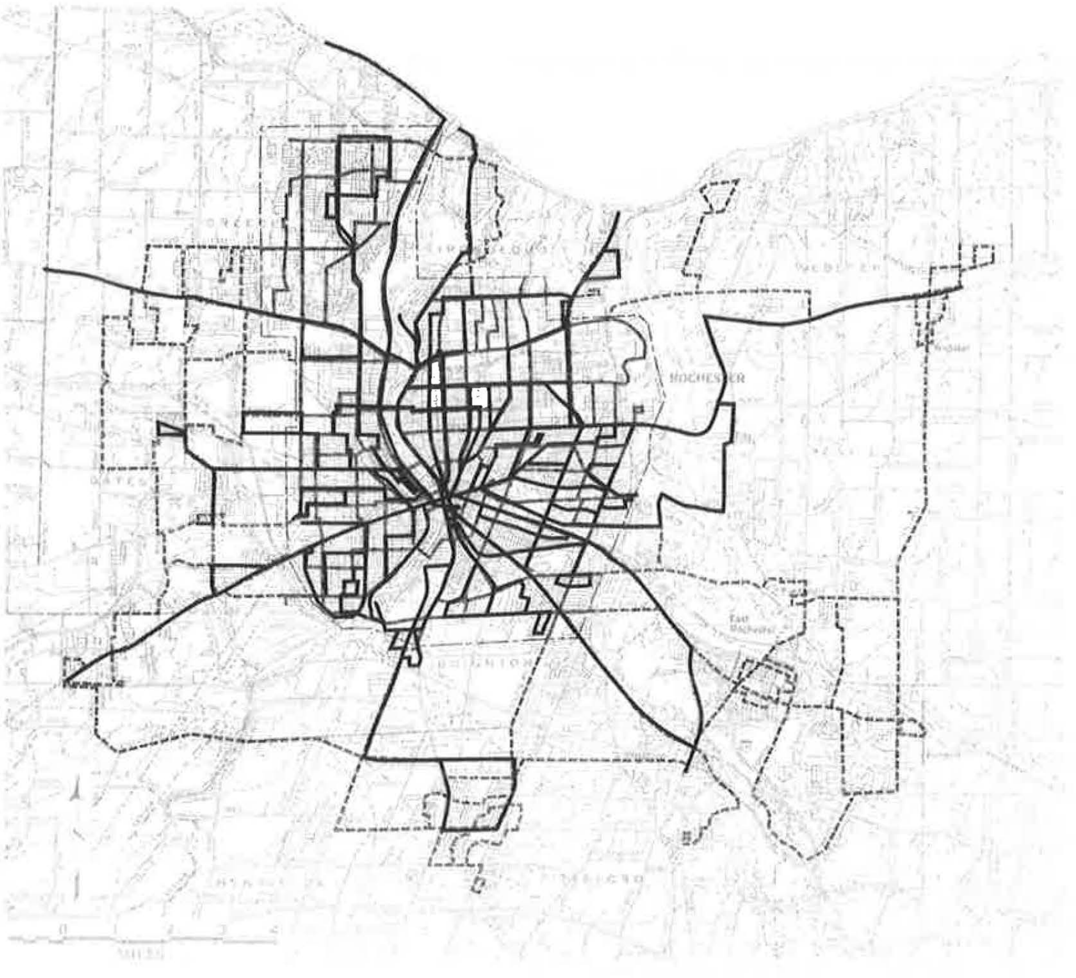


Table 2. Tranef route mileage and assumed speeds.

Network	Average Speed (miles per hour) Weekday	Night	Sat., Sun., Holiday	Route Miles
City	12	16	—	168
City flyer	15	—	16	61
Suburban	16	20	—	150

Table 3. Calculation of annual bus-hours and bus-miles.

Service	City $F\left(\frac{L \times 2}{S}\right) = B$	City $B \times D = BHT$	City $BHT \times S = BMT$	Suburban $F\left(\frac{L \times 2}{S}\right) = B$	Suburban $B \times D = BHT$	Suburban $BHT \times S = BMT$	Days Per Year	AAD Factor	BHT Σ	BHT AAD	BMT Σ	BMT AAD
Weekdays												
Enhanced	$10\left(\frac{168 \times 2}{12}\right) = 280$	280 × 17 = 4,760	4,760 × 12 = 57,120	$4\left(\frac{150 \times 2}{16}\right) = 75$	75 × 17 = 1,275	1,275 × 16 = 20,400	250	0.685	6,035	4,134	77,520	53,100
City flyer	$4\left(\frac{61 \times 2}{15}\right) = 32.5$	32.5 × 17 = 550	550 × 15 = 8,300				250	0.685	550	377	8,300	5,690
Owl												
Enhanced	$3\left(\frac{168 \times 2}{16}\right) = 63$	63 × 7 = 440	440 × 16 = 7,060	$1\left(\frac{150 \times 2}{20}\right) = 15$	15 × 7 = 105	105 × 20 = 2,100	365	1.000	545	545	9,160	9,160
Saturdays, Sundays, and holidays												
Enhanced	$5\left(\frac{168 \times 2}{12}\right) = 140$	140 × 17 = 2,380	2,380 × 12 = 28,560	$2\left(\frac{150 \times 2}{16}\right) = 37.5$	37.5 × 17 = 640	640 × 16 = 10,200	115	0.315	3,020	951	38,760	12,210
City flyer	$2\left(\frac{61 \times 2}{16}\right) = 15.2$	15.2 × 17 = 260	260 × 16 = 4,150				115	0.315	260	82	4,150	1,310
AAD totals										6,089		81,470
Enhanced										5,630		74,470
City flyer										459		7,000

The total expense for the entire Tranef service hypothetically supplied in the test metropolis is given in Table 5. (Jitney operations are not considered.) The expense formula is based on economic analyses by Simpson and Curtin recast to a 1971 level and rounded to

$$\text{Expense} = 1.075\ [(\$7 \times \text{BHT}) + (20¢ \times \text{BMT}) + (\$20 \times \text{bus-day})]$$

(The first term has been increased to $7 per bus-hour to reflect influences possibly peculiar to Tranef conditions of employment.)

For the concluding phase of the economic assessment, hypothetical operating revenue was calculated from patronage equivalent to several assumed levels of use (share of total trips). In 1963, the Rochester Transit Company is estimated to have achieved a 12 percent transit usage in an effective service territory of 340,000 population. Balancing subsequent decline against the large service improvement conjectured for Tranef, its patronage was calculated at use levels ranging from 15 to 30 percent of total trips. Regular Tranef operations were estimated to serve a population of 400,000. An average of 2.3 weekday trips per capita was assumed for trip-making via all modes. Tranef revenue was annualized on an assumed basis of 320 equivalent weekdays per year.

Calculated average weekday trips (AWT) and annual patronage, at four levels of use, are given in Table 6. The related economic indicators are based, where appropriate, on an average fare of 35 cents. The figures are intended to reflect all expenses, including depreciation, as though system finances were entirely a local obligation. For reference a monthly "household tax" required to subsidize the deficit is tabulated; this subsidy and the break-even fare are shown in Figure 11 through the expected range of the Tranef market share.

Tentatively, two inferences may be drawn. First, Tranef finances are highly sensitive to the volume of patronage. Second, at prevailing patronage and fare levels, Tranef does not seem hopelessly uneconomic, although a need for subsidy is very likely. (Yet, if usage as high as 25 percent of all person trips could be sustained at a fare of 40 cents, unsubsidized operation might be possible.)

SIZE OF A DEMONSTRATION

Amid rising environmental concern, Tranef emerges as a relatively near-at-hand means to lessen urban traffic pollution. The concept of a package of useful transit services covering a broad territory—not merely traversing a single corridor or sector—may be innovative enough to warrant a demonstration. To gauge what that might entail, some rough calculations were made using the Rochester data as a basis. The additional commitments required for a full demonstration there are summarized in Table 7.

It is interesting to note that the $20 million investment equals the purchase price of some 7,000 to 8,000 new autos. That is about half the number of autos replaced in a single year within the Tranef service territory. In "regional" terms, then, a demonstration would not represent a heavy capital commitment, although an operating subsidy that seemed substantial might be needed.

A proper demonstration of Tranef would necessarily be large and costly and ought to be carefully structured. The temptation to tailor away uneconomic service—and with it, perhaps too much of the basic package—should be resisted. The demonstration should continue sufficiently long—say, half a decade—to allow people and institutions to begin adapting to the new services.

It is evident that a 5-year Tranef demonstration would cost over $50 million. What might it show? It would bring a new order of mobility to many persons in the sizable group that is currently hobbled by not having an auto for personal use. Another issue is the degree to which superior extensive bus transit in a middle-sized city could affect the environmentally baneful dependence on private autos. In this regard, the demonstration might reveal (a) whether metropolitan traffic pollution could be abated significantly by Tranef; (b) whether traffic congestion and parking competition would be noticeably eased anywhere; (c) what steady-state transit patronage might be attained; and (d)

Table 4. Calculated fleet size.

Service	Peak	Spares	Total
Enhanced, city	280	30	385
Enhanced, suburban	75		
City flyer	33	2	35
Commuter express	56	4	60
Totals	444	36	480

Table 5. Annual expense of Tranef service.

Service	Expense Calculation	AAD Expense (dollars)	Annual Expense (millions of dollars)
Enhanced	1.075 [(7 × 5,630) + (0.2 × 74,470) + (29 × 385)] =	66,654	24.33
City flyer	1.075 [(7 × 459 + (0.2 × 7,000) + (20 × 35)] =	5,711	2.08
Commuter express	1.075 [(7 × 288) + (0.2 × 6,160) + (20 × 60)] =	4,782	1.74
Total annual expense of service			28.15

Table 6. Economic characteristics of Tranef at selected levels of use.

Item	Weekday Level of Use (percent) 15	20	25	30
Average weekday trips (thousand trips per day)	138	184	230	276
Patronage (million trips per year)	44.1	58.9	73.6	88.4
Revenue at 35 cents (million dollars per year)	15.4	20.6	25.8	30.9
Deficit (million dollars per year) (on $28.2 million expense)	12.8	7.6	2.4	(+2.7)
Break-even fare (cents)	64	48	38	32
"Household tax" (dollars per month) for 3.1 persons per household	8.30	4.90	1.55	—

Figure 11. Break-even fare, or subsidy required, relative to use.

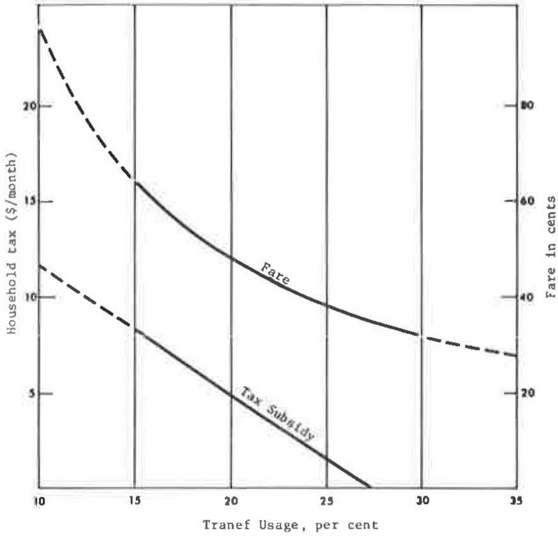


Table 7. Added commitments needed for Tranef service (RMTS demonstration).

Investment		
New buses, 220 at $45,000		$10 million
Equipment and garage, at $20,000 per bus		4 million
Start-up: promotion, training, etc.		6 million
Total investment	Approximately	$20 million
Labor		
New employees: approximately 1,000 (Current transit employment would be trebled.)		
Subsidy		
Uncertain, but might range between $6 million and $12 million annually.		

whether this kind of public expenditure could effectively be substituted for capital investment in transport facilities. In light of current controversy about building urban freeways and financing rail transit, the possible substitution of a moderate ongoing expense for a heavy fixed investment has major significance.

PRACTICAL CONSIDERATIONS

Tranef could be put into effect almost without recourse to new construction and new technology. Still, to do that would entail considerable effort beyond acquiring the additional financing, labor, and equipment. As evidence, there follows a sampling of the many considerations to be resolved in getting Tranef service under way.

Labor Relations

However vexing the problem of preventing any break in Tranef service may be, it must be faced. Tranef would expand transit employment markedly—in part at public expense—while making the community more dependent on the service. Thus the public is entitled to the security of uninterrupted service. Means of promoting three-way cooperation among Tranef management, labor, and the using-subsidizing public must have a high priority in any serious venture into the new concept.

Crossing Protection

Trying to cross a 4-lane suburban highway coursed by a large volume of fast-moving traffic can be an unpleasant and even deadly hazard for transit patrons, especially in winter dusk. A satisfactory remedy is not known. One possibility would be to restrict Tranef suburban stops to signalized intersections, at least during morning and evening peak traffic. (A demand-jitney service linking bus stops and homes could make that restriction more acceptable to patrons.) A more radical remedy would be to grant the transit buses, while stopped on busy highways, the same traffic-halting authority by which school buses are now protected.

Exclusive Bus Lanes

Exclusive transit lanes on arterial streets might significantly aid the speed and dependability of Tranef buses during the peak-traffic periods. Given the competition for street space during those periods, the designating of a lane for a single 10-bph route might be difficult politically, whereas a lane shared by two duplicating routes could much more easily be deemed warranted.

To keep transit lanes clear may require relentless enforcement. A sound legal base should be established for the necessary prohibitions, tow-away activities, and prosecution; penalties and court jurisdiction must also be clear. One approach to enforcement would depend on the local police to patrol and tow away under contract with the transit agency. An alternative approach would cede the exclusive lanes (by statute) for specific daily periods to the transit authority, whose own deputies, possibly off-duty police officers, would be responsible for removing and impounding any vehicle blocking a lane.

Prompt towing away of parked and "stopping" vehicles may be expensive, relative to the cost of a bus lane. For example, to create 10 lane-miles at an estimated $5,000 per mile would cost some $50,000. If enforcement activities used one officer at $5 per hour for 4 hours daily on 250 days per year, the expense would be $5,000 annually—or 10 percent of the capital investment.

Route Plowing and Sanding

All transit routes and bus stops ought to have high priority for snow and ice control. The usual practice of plowing street snow up onto the space between curb and sidewalk creates impediments for pedestrians. This plowed-up snow should be removed from bus stops so that patrons can get out to buses and back to the sidewalk conveniently and safely and with less delay. Legality and finances permitting, the sidewalks all along transit lines should also be kept passable—a task for which specialized equipment is now available. Indeed, the importance of walking as the primary access to transit suggests that the winter serviceability of sidewalks extending for several blocks from transit lines should be given attention.

Relations With Taxi Industry

The publicly assisted Tranef buses might, on first impression, appear detrimental to the taxi business. That could prove to be so. Yet the two modes are so inherently different that they would not, or should not, be in competition. Such an assertion gains support from a court decision in Michigan in the case of demand-jitney operations inaugurated by the Ann Arbor Transportation Authority.

Doorstep service is recognized as a feature that should, if feasible, be added to fixed-route transit both in the suburbs and in many localities at night. Incorporation of demand-jitney operations into the Tranef system has been mentioned previously, and such arrangements might be worked out cooperatively between Tranef and taxi interests.

Headway Regulation

The Tranef concept avoids the inconvenience of schedules by operating much of the service unscheduled but frequently. Uniform headways are then imperative, lest the benefit be dissipated by service gaps that inflict unexpected waiting on some patrons. A reason for instability of short-headway unscheduled service is evident: If one bus runs ahead, the following bus may become increasingly late in attempting to cope with a growing accumulation of patrons. (Instability can be serious on heavily patronized lines. One Canadian transit property is reported to have exacted the penalty of a day's pay for running early by even 1 minute.) Conventional scheduled service also becomes undependable and inconvenient when buses are early or late, causing missed connections or extra waiting.

The need for an inexpensive, automatic means for monitoring and regulating buses in service has long been felt (3, 4). Scattered reports on the development and demonstration of such equipment exist in the literature, but no complete system is known to be commercially available at present. Headway regulation is an example of a seemingly secondary matter that nonetheless deserves careful attention in the implementation of Tranef service.

CONCLUSION

In both regular-route and specialized express service, buses can provide relatively good coverage and frequency throughout the city while also meeting the needs of suburban commuters. Thus labor-intensive bus transit can distribute the benefits of improved service rather than concentrating them in a single sector, as often happens with capital-intensive transit improvements.

The economic results obtained in this study are preliminary and pertain to a particular city and therefore may not be applicable elsewhere. Nonetheless this paper is a useful reminder of the merits of buses in the planning of better transit for middle-sized cities.

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