PRACTICAL REQUIREMENTS FOR ADVANCED PUBLIC TRANSPORTATION SYSTEMS

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An analysis is given of urban transportation alternatives that shows that public transportation can be competitive in speed and convenience with the automobile. A comparison of direct community financial costs for transportation systems fulfilling requirements projected for Baltimore in 1980 is given to illustrate that a bus system offering good service is more expensive than the automobile-based system but that a simple automatic system could produce substantial savings. A plan for a demonstration to verify this conclusion is suggested.

•RECOGNITION of the destructive impact of the automobile on the quality of urban life has intensified interest by municipal and federal agencies in better public transportation. However, until recently no valid alternative to the automobile could satisfy the public demand for convenient comfortable service and be installed and operated economically. Consequently, urban planning groups and their consultants have generally concluded that public transit can play only a minor role in the total transportation picture, even though it may have significant benefits to the community in easing rush-hour congestion in critical areas, in offering minimal service to those who do not have access to an automobile, and in generating developments that bring tax revenue. In accord with this view, public officials are placing major emphasis on funding rapid transit systems and on refurbishing bus systems. These measures will relieve congestion along some corridors to the urban centers and will prevent the demise of some bus systems but will not stop the growth of automobile traffic because the average traveler will still find that he can get to his destination more directly and more rapidly by driving his automobile than by using the rail or bus system.

Unless transportation systems can be developed that will provide equivalent or better service than automobiles at comparable cost, they will not gain public acceptance. One of the major features of the automobile is its ability to go from any point in the city to any other by a direct route. This ability depends on the existence of a road network that provides close-range access to the entire developed metropolitan area. The fact is well illustrated by the 1980 projected traffic flow in the city of Baltimore shown in Figure 1 (1). The traffic flow lines are seen to cover the entire metropolitan area rather uniformly. The small fraction of total trips directed to the central business district (about 7 percent) is shown in Figure 2. Such patterns are typical of all American cities and demonstrate that public transit must provide area coverage with all regions equally accessible if it is to respond to the transportation needs.

Another major feature of the automobile is its immediate availability compared with the long delays and frustrations involved in conventional public transportation, which is operated with infrequent service and on unreliable schedules.

A third major point about automobile transportation involves its low apparent cost. The automobile driver is concerned primarily with his direct operating costs, which are usually underestimated, and overlooks fixed costs and maintenance. On this basis, automobile travel seems inexpensive, and bus or train fares of more than 5 cents/mile seem excessive to him.

The considerations given above show that public transit, to be competitive with automobiles, must offer

1. Direct access to any point in the metropolitan area (this implies a network of routes similar to the road network);

2. Door-to-door travel time comparable with that of the automobile (this requires a closely spaced grid of lines and stations to permit short walking distance at origin and destination, average line speed equal to or better than automobile speeds in urban travel, and service frequent enough to make waiting time negligible);

3. Low total operating cost (including amortization of installation costs) so that profitable operation of the system will be possible with a fare small enough to attract major public use; and

4. Social and environmental acceptability, including comfort, service to nondrivers, and compatibility with community aesthetic, social, and economic needs.

SYSTEM DESIGN

Let us now consider the system design requirements to provide the high-quality service discussed above. The grid spacing is the most fundamental factor in defining the system characteristics because it determines the walking distance to the stations, the line capacity needed, the total route mileage, and the practical line speed. If we note that the difference in travel time for a 5-mile trip at 60 mph versus 20 mph is only 10 min and that the same time is required for a walk of ½ mile, it is clear that the walking distance must be small if door-to-door times of public systems are to compete with automobiles, for which the typical walking and parking time is 2 or 3 min.

For a walking speed of 3 mph and average line speed V_T including stops, the average door-to-door time t_T in minutes for the public transportation system is

$$t_T = 20d_w + 60\,(d_R/V_T)$$

where d_w is the walking distance in miles for a complete trip, d_R is the riding distance in miles, and V_T is the average line speed.

For automobile travel that requires 2½ min for walking and parking, the door-to-door time is

$$t_a = 2\tfrac{1}{2} + 60\,(d_R/V_a)$$

where V_a is the average automobile speed in miles per hour.

Thus, if door-to-door time of public transportation is to equal automobile time for the same trip, we must have

$$d_w = \tfrac{1}{8} + (3d_R/V_T)\,[(V_T/V_a) - 1]$$

For a variety of reasons (2), V_T has a practical upper limit in the range of 40 to 60 mph. Therefore, because, average automobile speed in city driving is in the range of 15 to 25 mph, V_T/V_a has an upper limit of about 3. Thus, total walking distance d_w should be ⅝ mile or less for an average trip of 5 miles.

The route mileage is determined by the line spacing and the populated area to be served. A grid of routes with spacing of L miles between lines requires 2/L route miles/square mile. This would give a walking distance somewhat less than L miles; allowance is made for station location to favor short walks in employment areas and apartment locations.

The average number of vehicles in service depends primarily on the requirement to maintain throughout the populated area a high frequency of service that will effectively eliminate waiting to board or transfer. However, additional vehicles may be necessary to carry the rush-hour peak load in areas of high trip density. Both factors involve the average speed of the vehicle. The number of vehicles needed to provide a headway of Δt_H minutes is

$$N_H = \text{route mileage/vehicle separation} = (120/L\Delta t_H)\,\Sigma A_i/V_i \qquad (1)$$

where A_i is the area of zone i, ΣA_i is the populated area, and V_i is the average vehicle speed in zone i in miles per hour. The maximum line capacity occurs on lines entering the CBD or other small zones of high employment density. The rush-hour peak load is

Figure 1. 1980 travel desires from internal districts to internal districts.

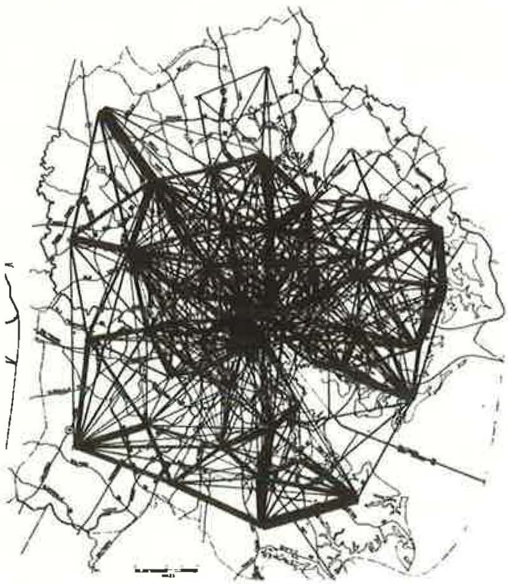


Figure 2. 1980 travel desires from internal districts to CBD.

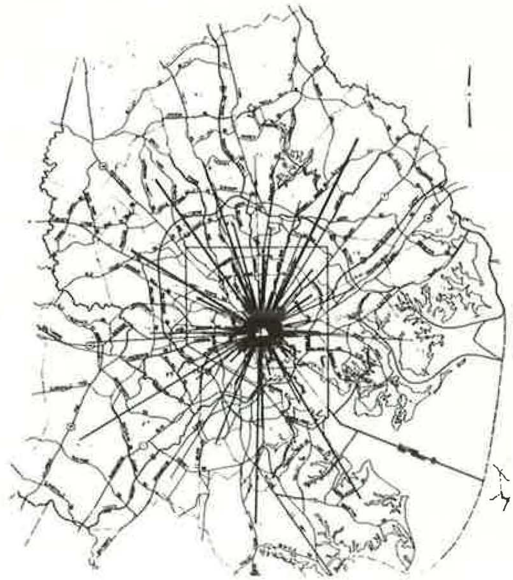


Figure 3. Measured and projected transportation data.

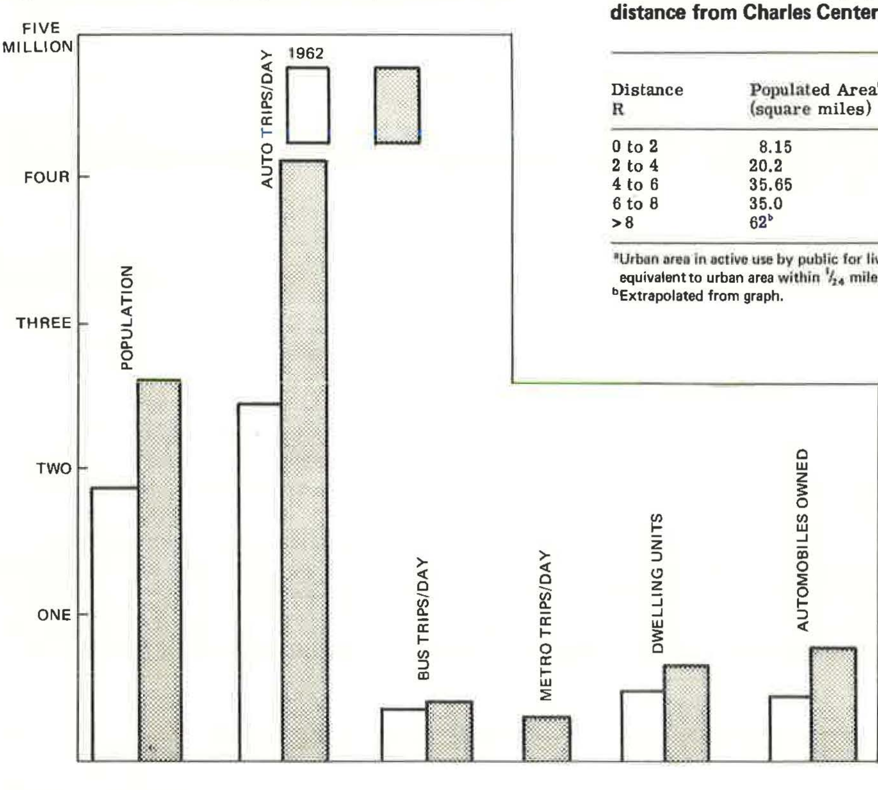


Table 1. Distribution of populated area by distance from Charles Center.

Distance R	Populated Area[a] (square miles)	Cumulative Populated Area (square miles)
0 to 2	8.15	8.15
2 to 4	20.2	28.35
4 to 6	35.65	64.0
6 to 8	35.0	99.0
>8	62[b]	161[b]

[a]Urban area in active use by public for living and commerce; roughly equivalent to urban area within 1/24 mile of a public road.
[b]Extrapolated from graph.

typically 10 percent of the daily number of trips. The number of vehicles, N_{P_i}, required during the peak hour to carry the load generated by a zone of high trip density is

$$N_{P_i} = T_i A_i / 10n = 60c / \Delta t_{pi} \tag{2}$$

where

T_i = the total trips/day/square mile in zone i,
A_i = area of zone i in square miles,
n = average number of passengers/vehicle entering (or leaving) zone i during peak hour,
Δt_{pi} = time interval between vehicles in minutes, and
c = number of routes entering zone i.

If Δt_{pi} is less than Δt_H, vehicles in addition to the number calculated in Eq. 1 will be required.

COST AND APPLICABILITY OF HIGH-QUALITY TRANSPORTATION

The criteria defined above may now be used to estimate the costs and applicability of potential systems that would provide high-quality public transportation. Three types of public systems will be considered and compared with the automobile-based system: (a) high-service bus network; (b) simple fixed-schedule automatic system employing small, mechanically linked vehicles circulating on nonintersecting east-west and north-south loops; and (c) sophisticated system employing self-propelled vehicles capable of being routed automatically from any point in the grid to any other without transfers or stops (this type of system is often called personal rapid transit).

Comprehensive data compiled in the analysis of the transportation needs of the city of Baltimore will be used in a specific example (1). However, the general results will be applicable to most large American cities. The data from the Baltimore study (1) are supplemented by information on a populated area from a detailed map of the area. The region extends to a radius of about 14 miles from the Baltimore CBD and comprises a total area of about 500 square miles. However, much of the area is undeveloped or occupied by bodies of water, parks, and facilities such as airports. Thus, the populated area that must be served by a public transportation system is much smaller than the geographical area.

Table 1 gives the populated area in Baltimore as a function of distance from the city center and shows that the total area in 1970 was about 160 square miles. On the assumption that population density remains constant in the occupied areas as a city grows, i.e., added population is accommodated by conversion of undeveloped land, the populated area may be estimated as 140 square miles in 1962 and as 200 square miles in 1980 (3).

Transportation statistics pertinent to the present study, including the measured data for 1962 and projected data for 1980, are shown in Figure 3 (1).

Cost and performance data for buses (4), for the projected Metro system (5), and for the automatic systems (6, 7) are based on data given in published reports. The costs computed are the best estimates that can be obtained with the data available. There are major differences in the manner in which costs of construction and maintenance of the guideways and supporting services have been considered. One can make fairly accurate estimates of annual costs for the automatic systems that would operate on exclusive guideways placed on existing rights-of-way. To obtain reasonably correct estimates of all annual costs for automobile-based and bus urban transportation systems has not been possible because those systems share use of streets and highways with systems that provide other essential services, e.g., delivery of goods, mail, and fire protection, so that even if one compiles the costs of street and highway construction and maintenance, lighting, traffic signals and policemen, and street signs there is no agreement on what portion of the total should be allocated to the urban transportation system or on the extent to which these costs are borne, by automobile user taxes. Although the costs of construction and maintenance of streets and highways and their essential supporting services are by no means negligible, they have not been considered here for the same reasons.

In view of this, cost estimates for the automobile-based system will be lower than the real costs, which may be much higher than any of us realize, but they do represent what most people consider to be the cost of driving their own automobiles. The road-related costs for high service buses would be less than those for moving an equivalent number of passengers by private automobile.

AUTOMOBILE-BASED TRANSPORTATION COST

In common with plans of other cities, Baltimore's present plans call for meeting future transportation needs by the predominant use of automobiles. The planned public systems are designed to offer minimal service to people without access to an automobile and to offer rapid transit along some high density corridors. It is expected that additional freeways will be built as needed to enable the city to handle future automobile traffic.

The total direct cost to the community of accommodating its urban transportation needs in this way may be computed from travel statistics (1). Data on automobile operating costs have been complied by the Federal Highway Administration (8). The direct costs of automobile fuel and maintenance totaled 7 cents/mile in 1970. Insurance and depreciation added an additional 5 cents/mile, based on an average yearly driving of 10,000 miles. The latter cost is properly associated with automobile ownership rather than operation and consequently is not included in our estimate of transportation operating costs. Based on the reported number of automobile trips shown in Figure 3, an average automobile occupancy of 1.5 persons per trip, and an average trip of 6 miles, the annual cost (in 1970 dollars) was $213 million for automobile-based transportation in 1962. The cost of the 1962 bus operation was $24 million (4). Thus, the total cost to Baltimore citizens of meeting their transportation needs within the city in 1962 was $237 million. On the same basis, the projected costs to meet the predicted 1980 transportation needs shown in Figure 3 are $365 million/year for automobiles and $30 million/year for bus transportation; $10 million/year, neglecting amortization, is estimated for the Metro planned to be in operation in 1980. Thus, the total cost is estimated to be $405 million/year.

On the assumption that all present automobiles were purchased in 1962 or will be replaced by 1980 at the 1970 average cost quoted by FHA of $3,185 each, the capital expenditure necessary to meet Baltimore transportation needs in 1962 was about $1.5 billion for automobiles and $31.5 million for buses. In 1980, the capital costs will be $2.4 billion for automobiles, $545 million for the planned Metro system, and $40 million for the bus system, giving a total of almost $3.05 billion. These costs do not include costs of additional freeways, which are estimated at about $650 million (1) but for which a major portion of the cost is expected to be borne by federal funds generated by user taxes.

HIGH-QUALITY PUBLIC TRANSPORTATION

In assessing the financial costs to the community for public transportation that would provide the high-quality service discussed above, one must consider what fraction of the total trips will be made by public transportation (modal split). The fraction will depend on relative travel time, trip purpose, and decisions of the regional and local transportation authorities concerning allocation of resources.

A study at IIT Research Institute (9) has shown that door-to-door time is the most important factor in determining modal split, and the time spent in walking and waiting is more important than transit time. Data on the running speeds of automobiles and buses from which a comparison of door-to-door travel time may be made have been compiled by the Washington Metropolitan Area Transit Authority and are given in Table 2. The running speeds listed for the buses include time for picking up and discharging passengers. Speeds of both automobiles and buses depend strongly on distance from the CBD and on whether radial or circumferential trips are made. Because the automatic system is not influenced by ground traffic, its speed is independent of location. Average running speeds quoted for automatic systems are 16 mph for the simple automatic system in which all stations are on line, 20 to 25 mph for operation of the simple system with off-line stations that permit express service, and 30 to 50 mph for the personal rapid transit. Metro systems designed to work with the local system and, therefore, laid out in a grid with optimum spacing of about $2\frac{1}{2}$ miles would be capable of an average speed of 60 mph or more.

Door-to-door times for the various system options can be computed from the data given in Table 2 if the time required for walking and transfers is added. These times are shown in Figures 4, 5, and 6. Added times are estimated as follows: In a $\frac{1}{4}$-mile grid, average walking time at 3 mph to or from a boarding point is 2 min. For the proposed network, the average trip will require 1 transfer, except for the personal rapid transit system. Waiting time is 1 min for boarding and for transfer for buses and requires 30 sec total for the automatic systems. Finally $2\frac{1}{2}$ min is allowed for automobile parking and walking.

Figure 5 shows that buses forced to operate in traffic of current densities would give door-to-door times about 10 min longer than those of automobiles for an average 5-mile trip. However, even the 16-mph automatic system would be superior to automobiles near the urban center and would be within 5 min of automobile times for most urban trips. There appears to be little advantage to speeds of more than 25 mph for trips even as long as $7\frac{1}{2}$ miles (Fig. 6). The combined local and rapid transit offers advantages compared to the 25-mph system only for trips longer than $7\frac{1}{2}$ miles. In view of the high capital cost of rapid transit systems, serious questions should be raised about widespread emphasis in urban plans for such systems.

Data shown in Figures 4, 5, and 6 give strong support for belief that the automatic system could achieve door-to-door times competitive with automobiles. If the high-quality bus service proved attractive, the resulting alleviation of traffic congestion would reduce the bus door-to-door times significantly, for speed of buses would then be limited primarily by road conditions and traffic controls. Time for passenger boarding and discharge would average about 1 min during rush hours.

Ridership of the systems can be estimated from data shown in Figure 7, which shows trip distribution as affected by trip purpose and length. Work and school trips account for about three-fifths of the total trips. High-quality public transportation would offer distinct advantages for those trips; the frustration of driving in traffic and the expense and nuisance of parking the automobile would be eliminated at no loss in trip time. Advantages of public transportation are less obvious for many of the remaining trips, which generally are short, do not involve parking difficulty, and place a premium on private use of the vehicle. However, nearly half of the population during an average weekday does not have access to an automobile, and good public transportation would greatly benefit those people. Therefore, the total number of trips in these latter trip categories might be expected to increase.

It seems reasonable to predict that two-thirds or more of all work and school trips and one-third of the other trips would be attracted to high-quality public transit if urban transportation authorities established policies to encourage use of public transit. This would give a ridership slightly above one-half of the total trips but would account for 60 percent of the total trip mileage because work trips are longer on the average than other trips. Because the average family would still want to have an automobile and current ownership is only slightly above 1 car/family, no appreciable change in the number of automobiles owned would be expected.

In the United States there are no public transportation systems that offer door-to-door travel time equal to automobiles for the average trip; therefore, there are no analyses based on transportation data from which an accurate estimate of modal split may be made for the systems discussed above. Public transportation carries more than half of the trips in the central areas of New York, London, Paris, and other major foreign cities, but it may be argued that a free choice of the automobile as an alternative is not available in those cases. Modal-split analyses based on surveys of current transportation usage (9) show that trip time is the major factor, but extrapolation from 10 percent ridership to 50 percent from the equations derived by multiple regression analysis would clearly not be valid.

Table 2. Running speed during peak hour.

Distance From CBD (miles)	Average Speed Including Stops (mph)		Average Min/Mile	
	Bus	Automobile	Automobile	Bus
0	10.2[a]	11.5[a]	5.22	5.86
$2\frac{1}{2}$	12.0	15.7	3.82	5.00
5	14.3	19.0	3.16	4.20
$7\frac{1}{2}$	16.1	23.0	2.56	3.73

[a]Extrapolated intercept.

Figure 4. Door-to-door time for 2.5-mile trip.

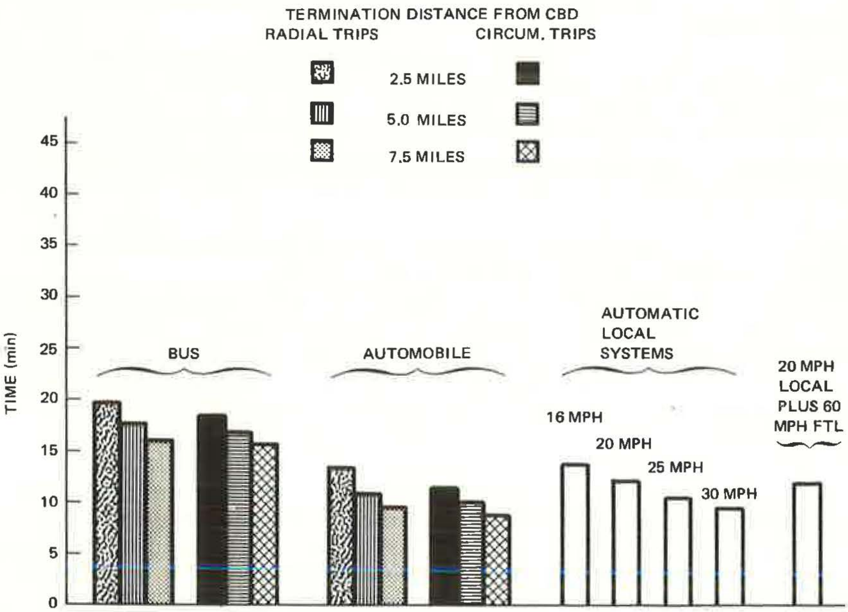


Figure 5. Door-to-door time for 5.0-mile trip.

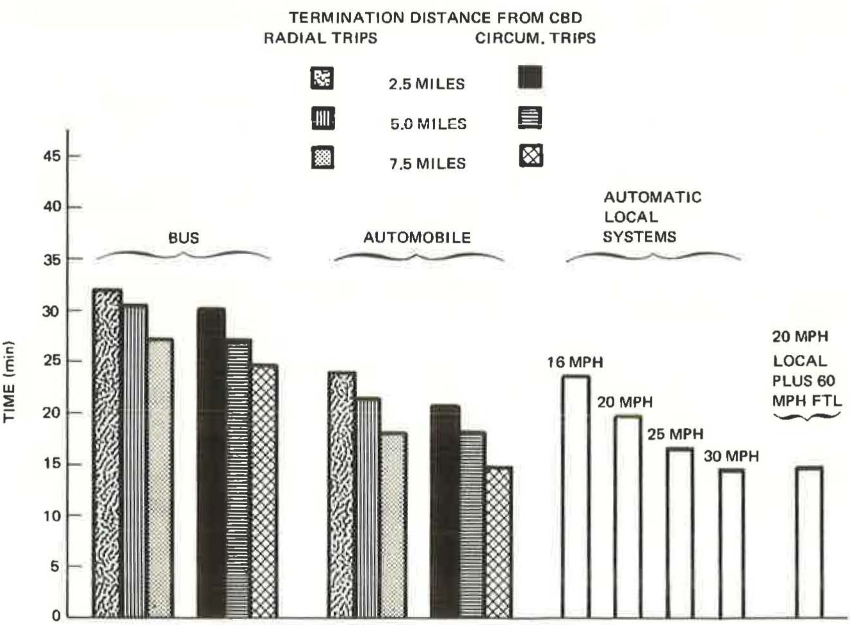


Figure 6. Door-to-door time for 7.5-mile trip.

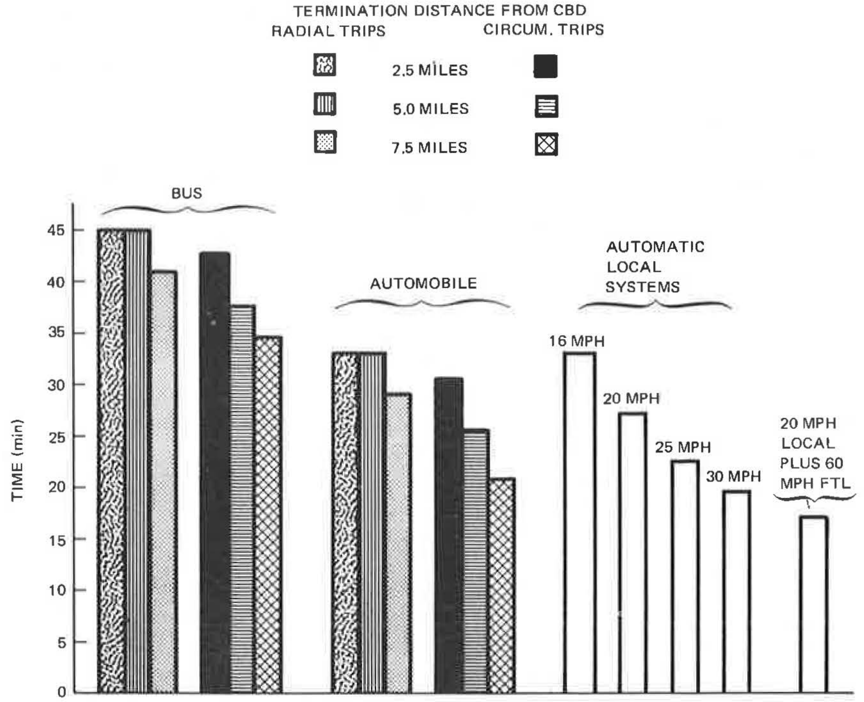
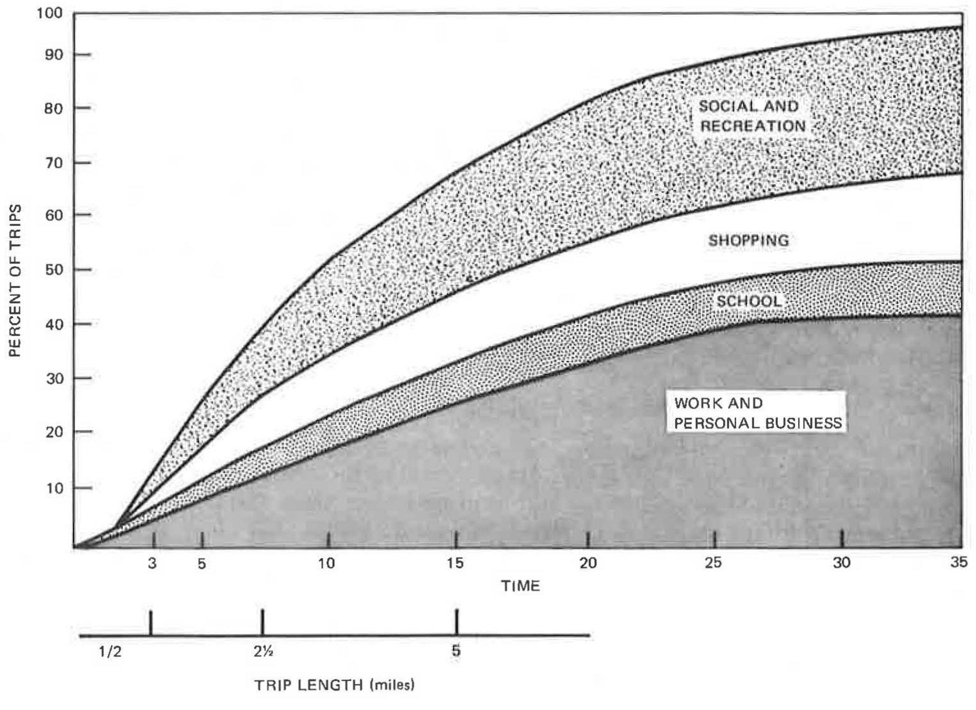


Figure 7. Percentage of trips by purpose and length.



HIGH-SERVICE BUS SYSTEM COST

Buses in current urban use operate at average running speeds of 3 to 5 mph less than automobiles. In initial operation of the high-service system, the buses would be limited to those speeds. However if the high-quality system were popular, automobile traffic would be greatly reduced. (For Baltimore, 3,200 buses would replace 41,000 automobiles and reduce the peak number of automobiles on the streets from 61,500 to 20,500.) Speeds equal to or better than automobile speeds attainable in current traffic would be possible if adequate priority were given to buses. Traffic signal control has been effective in improving bus speeds (10). It appears reasonable, therefore, for the present study to assume a uniform bus speed of 15 mph except for the central square mile of the city where a speed of 10 mph is used. With this assumption, the number of buses that would have been required for 2-min service throughout the 140 square mile area of Baltimore in 1962 is 2,248. The populated area of this region is expected to increase 43 percent by 1980 to 200 square miles, so that the number of buses required to provide 2-min service at that time would be 3,200.

There were 215,000 trips per day made to the CBD in 1962 (1). For an average work trip of 6 miles terminating in the CBD, which is approximately 1 mile square, the average bus speed would be 14.5 mph. We will also assume that on the average a bus entering the CBD during the peak hour carries 45 passengers. The Baltimore CBD is accessible on only 3 sides; hence, only 6 lines of the ¼-mile, 1-way grid network would enter the CBD, and total hourly capacity at 2-min headway would be 8,100. Therefore, to carry two-thirds of the rush-hour traffic, i.e., 15,000 trips/hour, each line would require buses at a time interval of 1.08 min. Alternatively, additional routes could be provided, e.g., 6 additional 2-way routes 6 miles long to accommodate the average work trip. Either alternative would raise the total number of buses needed in 1962 to 2,320. Selection of the second alternative would increase the total route mileage at 2-min separation to 1,160 miles. Because no increase in the center population is expected in 1980, no additional buses would be needed to carry rush-hour traffic to the CBD. Thus, the total number of buses required at that date would be 3,280.

The annual cost in 1962 of operating this bus system 140 hours per week with a 2-min headway throughout the area would be $255 million/year based on 1970 Baltimore bus operating costs of $1/mile. The corresponding cost in 1980 would be $360 million/year. The capital cost to purchase 2,500 (includes spares) new air-conditioned buses to meet the 1962 condition would be $113 million. To provide complete area coverage with 3,500 buses in 1980 would cost $145 million.

If the bus system succeeded in attracting half of the total trips, the automobile costs found in the previous section would be reduced by an amount equal to the direct cost of the automobile trips transferred to the bus. This would represent 60 percent of the automobile mileage; therefore, the remaining automobile costs would be 40 percent × 213 = $85 million for 1962, and $146 million for 1980. Thus, the total cost of the high-service bus option would be $340 million for 1962. In 1980 it is expected that a Metro system will also be in operation at an annual cost of approximately $10 million/year. Therefore, the total annual operating cost of the high-service bus option in 1980 would be $516 million/year.

FIXED-SCHEDULE AUTOMATIC SYSTEM

The simplest and least expensive type of automatic system that has been proposed for urban use employs mechanically linked passive vehicles that move around closed non-intersecting but overlapping loops to form a grid network. Cost and performance data have been presented for such a system (6). The system employs 2- to 4-passenger vehicles that maintain an average line speed of 16 to 25 mph and are spaced 5 sec apart to give capacity to carry the total peak load. Additional lines would be added to carry the peak load in the CBD. For the route mileage and capacity found necessary for Baltimore in the previous section, the annual operating expense of an installation to meet the 1962 traffic needs is estimated at $105,000/mile or $123 million/year. This includes depreciation at 2½ percent/year and amortization at 7½ percent/year of the capital cost of $580 million, which is based on free use of the right-of-way. For an installation to meet the transportation needs in 1980 the annual cost would be $173 million/year and the capital cost would be $822 million. Including automobile costs and Metro costs as explained in the previous section, total annual transportation costs for urban travel would be $208 million for 1962 and $329 million for 1980.

DEMAND-ACTUATED AUTOMATIC SYSTEM

The most flexible type of proposed automatic system employs self-propelled automatically controlled vehicles operating on an interconnected network. A number of systems of this type were analyzed in a recent study by the Applied Physics Laboratory in which performance characteristics and cost estimates were provided (6, 7). For a ¼-mile grid, the route mileage and system capacity needed to handle the 1962 Baltimore traffic would entail estimated annual costs (6) of $270,000/mile or a total of $378 million/year, which includes 7½ percent amortization and 2½ percent depreciation of the installation cost of $2.8 billion, but assumes free use of the public right-of-way. The annual cost and installation cost to meet the 1980 needs would be $686 million/year and $4.0 billion. Thus, total transportation costs including automobiles and Metro would be $464 million for 1962 and $842 million for 1980.

COST COMPARISON

The costs of the 4 systems discussed above are given in Table 3 and shown in Figure 8.

The impracticability of providing high-quality bus service on a continuing basis is clear because the added community costs compared to continued dependence on automobiles would amount to more than $100 million/year. On the other hand, the simple fixed-schedule automatic system would offer a saving of nearly $50 million/year in 1980 total transportation costs. The automatic personal transit would be excessively expensive to operate unless financing charges for capital investment could be neglected.

IMPLEMENTATION OF HIGH-QUALITY PUBLIC TRANSPORTATION

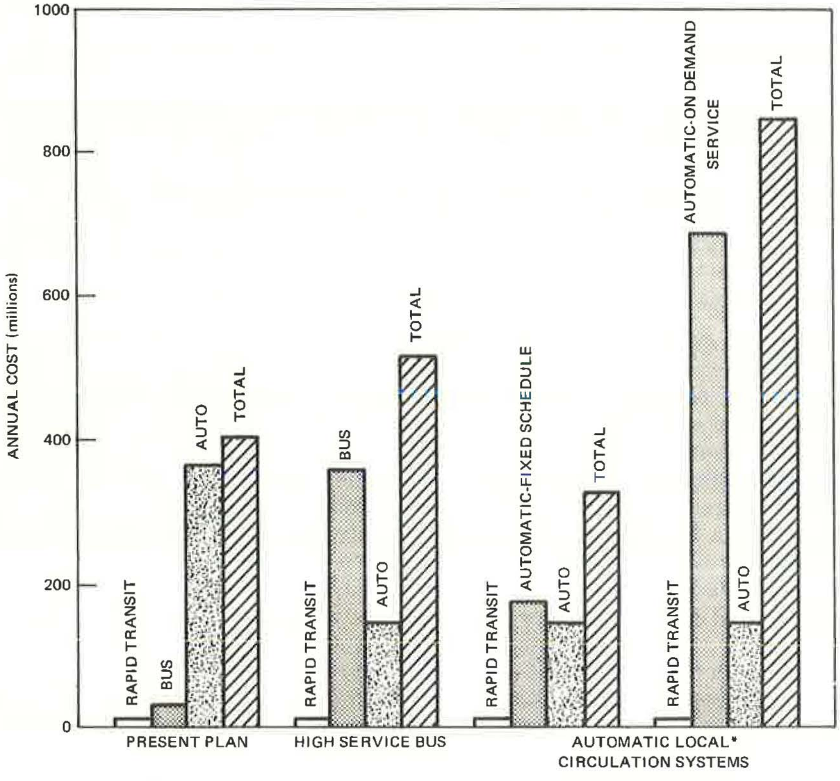
An impasse currently exists in attempts to demonstrate the value of the new automatic transportation systems for urban use because neither city officials nor the federal government is willing to risk the large capital costs for installation of area-wide systems without firm assurance that public ridership will be large enough to make the system an economically sound investment. On the other hand, limited demonstrations designed to test urban acceptance are bound to fail because installation of a few miles of line can offer useful transportation only to the small number of people whose trips originate and terminate within a few blocks of such a demonstration line. (Prototype demonstrations on a small scale are, of course, necessary to prove the technical operation of the system, to demonstrate safety and public acceptability, to indicate the environmental impact, and to provide firm data on operating and installation costs.) A way to avoid this impasse is suggested by the results of the previous section. Improvement of bus systems is a high priority program of the U. S. Department of Transportation, and funds are planned for the next few fiscal years that could support the purchase of enough buses to establish a high-quality bus system covering the inner 100 square miles of a typical city such as Baltimore. With a 5 cent/mile fare, public use of the system for 40 percent of more of the total trip mileage appears possible in view of the door-to-door time comparison discussed in the previous section and especially if predicted restrictions on urban traffic become a reality. To demonstrate such public acceptance will require a subsidy of about $100 million to support a 1-year test; $30 million of this would represent public savings in automobile expense, which could reasonably be paid with local taxes and would constitute the major part of the local contribution to a federal grant. If the high-quality bus service proved attractive to the public, the superior service of the automatic systems would unquestionably be even more attractive. It would then be possible for cities to finance installation of the simple automatic systems with revenue bonds because profitable operation with a 5 cent/mile fare would be ensured. Furthermore installation could proceed on a line-by-line basis, with every step in the process resulting in better service and more profitable operation.

Table 3. Transportation operating and capital costs (in millions of dollars).

	Automobile-Based		High-Service Bus		Automatic Fixed-Schedule		Automatic Demand-Actuated	
System	1962	1980	1962	1980	1962	1980	1962	1980
Automobile	213	365	85	146	85	146	85	146
Bus	24	30	255	360				
Metro		10		10		10		10
Automatic transit	—	—	—	—	123	173	378	686
Total	237	405	340	516	208	329	464	842

Note: Costs include amortization at 7½ percent per year and depreciation at 2½ percent per year on capital investments of high-service bus and automatic systems. Amortization of automobile costs is not included on the assumption that only automobile use and not automobile ownership will be affected by the availability of high-quality public transportation. Amortization of Metro costs is omitted because that will depend on policy with regard to federal contributions. In any case, these costs would add the same amount to all 4 alternatives.

Figure 8. Annual 1980 costs for transportation alternatives (amortization costs included for automatic systems).



NOTES: LINE AND STATION SPACING ARE ¼ MILE THROUGHOUT THE AREA WHERE SERVICE IS PROVIDED 20 HRS/DAY. HIGH SERVICE BUS OFFERS 2 MIN. HEADWAY; AUTOMATIC SYSTEMS OFFER 15 SEC. HEADWAY.

CONCLUSION

The foregoing discussion shows that public transportation can offer travel times competitive with the automobile provided that the system features area-wide service with closely spaced boarding points and short headways. It is suggested that such a system, if it were competitive in cost to the traveler, could lure a substantial fraction of the urban trips away from the present and projected overwhelming use of the automobile. Bus systems designed to provide high-quality service are shown to require a transportation cost to the community much higher than that which would result from predominant use of automobiles for transportation. Therefore, bus systems do not appear to offer a feasible alternative to automobiles for urban transportation without heavy subsidy. However, the simplest automatic systems, because they minimize labor costs, could save a community the size of Baltimore nearly $50 million/year compared to automobile-based urban transportation. Implementation of such automatic systems requires demonstration of their public acceptance, and this can be done only with large capital expenditure. It is suggested that a feasible method to eliminate risk would be to judge public acceptance of good transportation by installing high-quality bus service in a typical city under federal support. After public acceptance was shown, the city could proceed with the automatic system, assured that it would be preferred to automobiles and would be self-supporting with a low fare.

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DISCUSSION

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This paper is of unusual interest in that it shows the high capital and operating costs of those systems described as personal rapid transit. However, it assumes use of only 1 mode, aside from the walk to the station. But the fact is that modern rapid transit systems assume that passengers do not walk to the station but drive there in their automobiles or are driven by some member of the family. Feeder-bus service may also be used where population density will support such lines. Walking access, at 20 min/mile, is limited to a distance of about ½ mile; feeder-bus access at 6 min/mile can be used for distances of a few miles, while automobile access at 2.5 min/mile can expand the service area of a station from the 1 square mile of walking access to as much as 16 to 25 square miles making the feasibility of rapid transit a function of total population and not of population density.

In some of the paper, and in the data quoted from Wilbur Smith and Associates, use is made of the questionable person-trip unit. Figure 7 can be converted into a form that provides a significant measure of the amount of transportation furnished by various modes—the passenger-mile.

Reference is made to a high-service bus system. It is apparently assumed that bus operating costs are not dependent on operating speed, which is about 10 percent lower than scheduled speed because of terminal layover times of 10 percent of the time in motion. It was found by the writer, from data in the NYCTA Transit Record, that bus operating costs in that area are given by

$$C_s = 23.22s_3 + 19.02$$

where C_s is direct operating cost in cents per bus-mile, and s_3 is operating minutes per mile, which is 60 times revenue bus-hours for the period in question divided by revenue bus-miles in the same period.

It is not probable that bus schedule speed can approach automobile speeds as suggested by data given in Table 2. It is stated that each bus will carry 45 passengers, average. Loading delays are 2 to 3 sec/passenger, with exact fare systems. Somewhat lower delays are observed in Los Angeles where there is extensive use of monthly pass riding. But 45 passengers will involve a delay of the order of 2 min, and the observed operating speeds in New York are as follows:

Borough	Operating Speed (mph)	Estimated Scheduled Speed (mph)
Manhattan	5.93	6.52
Queens	8.59	9.45
Staten Island	10.73	11.80
Brooklyn	7.25	8.00

For this, reason, it is questioned whether the speeds mentioned by Avery are practicable or attainable. These corrections will tend to modify the conclusions as to cost of the suggested high-service bus system. It is also commented that the limitations on bus dimensions imposed by the highway codes make it impossible to design a bus that is a satisfactory transit vehicle. Considerations of the safety and comfort of passengers make it impossible to provide acceleration and braking rates that can compete with the passenger automobile except under the most extreme conditions of traffic congestion where neither one can move at a speed of more than a few miles per hour.

This paper describes proposed grid systems, with lines on close spacings, that are apparently intended to replace the automobile for most of the urban travel needs. It is pointed out that there are 3 types of urban travel: many-to-many or diffuse travel; many-to-one, as to a CBD; and one-to-one as between centers in an area. Of these, the automobile alone can provide satisfactory service in the first type. Demand is low along any of the numerous routes. Types 2 and 3 are best served by transit, with the automobile used for station access.

In CBD areas, it will be desirable to provide a secondary collector-distributor system of the automatic type, paralled by pedestrian walkways, to reduce walking distance, reduce or eliminate surface bus operation, and reduce the number of CBD subway stations required.

The costs indicated by the paper are such as to render it doubtful whether the systems of the personal type can be justified in any case.

AUTHOR'S CLOSURE

Holden's comments on transportation concepts that appear regularly in his magazine, City and Suburban Travel, have won him the high regard of his colleagues for his down-to-earth understanding of systems problems. His comments are, therefore, welcomed. However, in this instance he appears to have missed some points that were discussed in the paper only briefly.

With regard to his first comment, the paper does not assume use of 1 mode but rather explores the requirements and potential use of systems that could provide good service and thus be practical alternatives to the automobile-based transportation that he describes. Metro systems are included in the evaluation but not explored in detail because they carry only a minor fraction (5 to 15 percent) of the total trips—and trip-miles.

The trip-mile recommended by Holden is in fact used in the paper as a unit of travel where operating costs are compared. However, the number of trips is a more easily understood measure of urban travel by the average reader and gives a better indication of the amount of activity involved in daily transportation.

With regard to bus speeds, our data are based on average running speeds measured by the Washington Metropolitan Area Transit Authority and are given in Table 2. Bus costs computed by Holden's formula would average $1.12/hour versus $1.00/hour used in the paper, which is based on Baltimore operating costs. It is not expected that buses operating in automobile traffic would be able to match automobile speeds. Bus speeds would be improved if good bus service led to reduction in the number of automobiles or if priorities were given to bus travel. But the point of this comparison is to show that, if buses could be operated to match automobiles in door-to-door time, the operating cost would be so much higher than providing the same service with automobiles that the benefit to the community would be questionable.

Holden's final point is a common position but not verifiable because no grid system providing good access and frequent service has been installed anywhere in the United States since automobiles became common. The Paris public transit system provides an approximation to such area coverage and service within a radius of about $3\frac{1}{2}$ miles from the CBD and in this area carries 65 percent of the total trip-mileage; beyond this radius, public transportation offers poor service, and a high proportion of automobile owners prefer to drive their cars. This could indicate that good service attracts passengers from automobiles, but road coverage and automobile ownership in Paris are not comparable with U.S. conditions. As my paper shows, a closely spaced, area-wide grid system with small automatic vehicles would appear to offer service that would attract a major fraction of routine automobile trips. The lower operating cost of such a system could provide substantial savings in community transportation expenditures compared to the expense of continued dependence on automobiles for 80 to 90 percent of the total trip mileage.