URBAN TRANSPORTATION

The magnitude of the problem posed by urban transportation requirements is discussed. Prime requirements for transportation systems that could reduce rather than relocate existing traffic congestion are: availability throughout the metropolitan area, no waiting, average trip time no more than for automobile travel, capacity equal to present automobile usage, and economic feasibility. A system with the desired characteristics is described which employs a grid of high speed lines (HST) spaced at 2-1/2-mile intervals, supported by a local network covering the same area with lines spaced at 1/4-mile intervals, which employs continuous moving small cars, available for boarding at 1-second to 15-second intervals (ACT). The combined system would offer efficient all-weather transportation within easy walking distance throughout the metropolitan area which would be self-supporting with a 25¢ fare.

Poor transportation is now recognized as a major contributor to the problems that currently plague American cities. Automobile traffic chokes the streets generating pollution and noise, and public transportation facilities are generally so inadequate, unattractive, and unreliable that public use is almost confined to those who have no alternative way to travel. But nearly half of the population cannot use an automobile because they cannot afford one, are too young, too old, or too infirm. In this paper we shall first explore some of the reasons for this impasse and then examine what characteristics are needed in new systems to alleviate the difficulties. In the last part, the applicability of a potential system which would solve the problem is discussed.

The Urban Transportation Problem

Transportation Background and Statistics—Public transportation began in the United States less than a century and one-half ago. "Everybody walked to work in New York in 1825 unless he was rich enough to own or hire a carriage. Although the city had at that time nearly 200,000 inhabitants, it had no local passenger transportation service of any kind."[1] However, in 1827 twelve-passenger horse-drawn coaches were introduced, and in 1832 the horse-drawn street railway which could average about 5 miles per hour was in operation. By the mid-1880's there were 3,000 miles of such railways in the United States. The elevated railway appeared in New York in 1871. The cable car was introduced in San Francisco in 1873 with speeds up to 14 mph. The electric trolley car first saw service in Montgomery, Alabama, in 1886. By 1902 there were 22,000 miles of electrified trolley lines in the United States. Boston constructed the first subway between 1895 and 1898, followed by New York in 1904, Philadelphia in 1908, Chicago in 1943, and Cleveland in 1955. Motor buses were introduced in the 1920's and gained popularity rapidly because of their greater flexibility in routing and scheduling. Use of all forms of public transportation expanded until 1947 when 23 billion passengers were carried yearly in the United States, approximately half by rail and half by bus. Since then there has been a steady decline in patronage of public transportation systems to the present value of about eight billion passengers per year, despite the twenty per cent gain in national population and roughly doubled urban population.[2] The decline since World

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[1] John Anderson Miller, *Fares, Please,* Dover Publications, Inc., New York, 1960. (Quoted in Ref. 2.)

[2] *Dallas-Fort Worth Regional Transportation Study,* Texas Highway Department in cooperation with U.S. Department of Transportation, 1964.

W.H. Avery and G.S. McMurray

War II has been due to the rapid growth in automobile ownership and the advantages that the automobile has offered compared to public transportation in convenience, comfort, transit time, and reliability. The higher cost per mile of automobile travel and the much greater safety hazards compared to public transit have carried little weight in the determination of public preference for the automobile. This preference has induced State and Federal Agencies to budget large sums to support automobile travel, whereas attempts to raise money for development of better public transportation have been met with public indifference and active opposition by vocal pressure groups representing highway, automobile, and fuel interests. As a consequence both the equipment and quality of service of public transportation systems have deteriorated since 1947, and use of the public systems is now almost confined to nondrivers, who comprise about one-half of the population but only one-tenth of the trip-makers. However, in the last few years the problems of congestion, noise, and pollution caused by automobile traffic have become so aggravating that Federal and Municipal authorities are searching for new systems of public transportation that will offer service so attractive, convenient, and economical that a majority of urban travellers will forsake automobiles for the new super scafficawmobiles* when they become available.

Transportation in Cities Today—The magnitude of the problem may be understood by study of the excellent reports on transportation needs for some of the major U.S. cities. In this paper we shall pay particular attention to Washington and Baltimore for which data are presented in Tables I and II, but the statistics for all of the cities are remarkably similar. They show a number of surprising facts: In the typical city the number of trips on an average weekday by individuals moving to various destinations by vehicle is approximately twice the population, or an average of more than two trips per day for every person living in the metropolitan area. There are seven trips per day by the residents of the average dwelling unit. Most of these trips are by private automobile, with the average automobile carrying between 1 and 1½ people. The average work-related trip is five to eight miles in length and takes twenty to thirty minutes at an average speed varying from less than 10 mph in the Central Business District (CBD) to 20 mph plus in the suburbs. Non-work trips are roughly half as long in time and distance, and constitute only about one-third of the total trips. Approximately one-fourth of the total trips occur during the morning rush hours from 7:00 A.M. to

*Silent, comfortable, attractive, fast, fume-free, inexpensive, convenient, all-weather (mobiles).

TABLE I

WASHINGTON METROPOLITAN AREA STATISTICS* (1967)

Metropolitan Area Population†	2.7 million
Area with Population Density above 10,000/mi.^{2}	59 mi.^{2}
Area with Population Density 5,000-10,000/mi.^{2}	80 mi.^{2}
(Accounting For Approx. 2.3 Million Persons)	
Public Transit Passengers (11 months)	123 million
Transit Gross (11 months)	$33 million
Area Jobs	1.12 million
Federal Jobs	0.325 million
Area Payroll	$8,229 million
Based On Above Data	
Estimated Transit Passengers/ Average Weekday	0.5 million
Statistics for Other Large Cities Show Total Trips/Day = Twice the Metropolitan Population. If Same Ratio Is Applied to Washington, Total Trips/Day	Approx. 5 million
Thus Fraction Of Present Total Trips by Washington Transit	Approx. 10%

*Unless otherwise designated, data are from a tabulation quoted by *The Washington Post,* Financial Section, Jan. 7, 1968.
†*Census Tract Study—Transportation, Washington Metropolitan Area,* prepared by Office of Planning and Programming, Department of Highways and Traffic, District of Columbia, in cooperation with the U.S. Department of Commerce and Bureau of Public Roads.

TABLE II

BALTIMORE METROPOLITAN AREA STATISTICS*

Population: 1960 Census: 1.6 million
1960 Baltimore City Population: 0.939 million

Trips on Typical Weekday (1962) in Survey Area (Baltimore City and the More Densely Populated Portions of Baltimore, Howard, and Anne Arundel Counties)

		% of Total
Internal		
Auto Driver	1.42 million	41.8
(Average Auto Occupancy, 1.48 Pers.)		
Passengers in Autos, Transit Vehicles, Taxis, School Buses, Trucks	1.18 million	34.5
Truck & Taxi Driver Trips	0.48 million	14.1
External		
Auto & Truck Drivers & Passengers Into, Out of, or Thru Area	0.33 million	9.6
	3.41 million	100.0
Trips by Transit	0.33 million	9.6

Traffic Volume on Major Downtown Streets/Day—18,000 to 30,000 Vehicles

Average Auto Travel Speeds (Off Peak)

Baltimore City CBD	
High Density Zones	5 to 10 mph
Low Density Zones	30 to 40 mph
Average	20 to 30 mph
Baltimore City, Excluding CBD	
High Density Zones	15 to 20 mph
Arterial Streets	30 to 40 mph

Automobile Ownership by Households

No Auto	140,000 Families
One Auto	247,000 Families
More Than One Auto	94,000 Families
	481,000

*_Baltimore Metropolitan Area Transportation Study_, Wilbur Smith & Assoc., 1964.

9:30 A.M. and one-fourth during the period from 4:30 P.M. to 7:00 P.M.

For metropolitan Washington, with 2.3 million inhabitants, there are approximately 350,000 automobiles on the roads during these rush hours but only 1,000 buses (calculated from statistics in Table I). According to the Washington Metropolitan Area Transit Authority (WMATA), about one-seventh of the rush hour traffic is involved in commuting between the suburbs and the Federal Triangle. However, in most cities only about one-tenth of the total traffic moves between the CBD and the suburbs, the remainder being fairly uniformly distributed throughout the metropolitan area. Existing public transportation systems, which generally have been built with routes that radiate from the CBD, provide little crosstown service. They are therefore fundamentally not designed to give adequate service in the directions the majority of the travellers desire to go.

The service is also inadequate with regard to waiting time between buses (headway). For example, in Baltimore in 1962 (see Note on Table II), the average headway during rush hours was 9.9 minutes, and at other hours was 18.6 minutes. Minimum headways on the most popular routes were 3 minutes during rush hours and 7.5 minutes at other times. Data for Dallas show a clear correlation between headway and the ratio of trips by bus to total trips made within the area served. Figures 1 and 2 suggest that better service leads to a higher proportion of travel by bus so that if headway could be reduced to zero, between one-fourth and one-fifth of the riders in Dallas would choose to travel by bus. Since a North-South line serves only half of the possible directions of travel, one may infer that uniformly distributed, zero headway bus service would attract nearly 50% of the total travel.

There is other evidence that suggests that despite the present preponderant use of automobiles for city trips it would be a mistake to

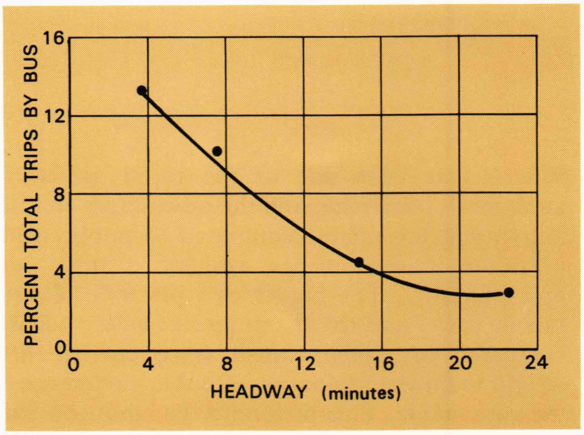

Fig. 1—Percentage of vehicle trips by bus versus minimum headway. (From Table 6.3, Ref. 2.)

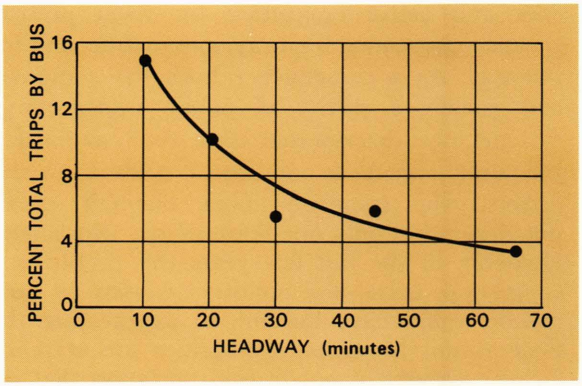

Fig. 2—Percentage of vehicle trips by bus versus maximum headway. (From Table 6.3, Ref. 2.)

conclude that the public is committed to this mode of travel. On the contrary, in the rare instances where public transportation is both convenient and attractive, a large fraction of the public does in fact show a preference for public modes of travel. In Skokie, Illinois, after modernization of the commuter railroad to connect with downtown Chicago and points north of Skokie, 60% of all commuters living within a half mile of the stations have adopted this system.[3] (Usage drops off rapidly with distance from the stations, falling to 35% at one mile and 19% at two miles.) A similar result has been found in Montreal where the new subway attracts a high proportion of all commuters within a half mile radius of the stations.

Several other points of interest deserve comment: The average family (3.5 people) in the United States spends one-seventh of its income on transportation. Thus the approximately two million inhabitants of either Washington or Baltimore with average family income of about $7,000 a year, are spending about $600 million every year, or $1 per weekday per person on transportation. The total is apportioned among direct expenses for bus fares or automobile operation and indirect expenses for insurance, interest on loans, taxes for road construction, snow removal, etc. The magnitude of the expenditures and the number of groups financially involved explain in part the intense resistance to any plan that would produce a major shift in funds from private to public modes of transportation. However, if only a small part of this money were diverted to funding construction of public transportation facilities, an expenditure of one to two billion dollars could be amortized over a twenty to thirty-year period.

Nearly 30% of the total area of a typical large city today is occupied by streets, alleys, and parking lots.[2, 4] What a pleasant change would result if even half of this area could be converted to parkways or parks! However, the predominant public demand as voiced by some prominent lawmakers is to convert even more space to freeways.

Freeway construction costs were estimated in 1962 to vary in Baltimore between $2 M (million) per mile in open areas to $8 M per mile in built-up districts. Costs for rapid transit estimated by the WMATA varied from $0.75 M/mile for single track railroad on grade (exclusive of property purchase) to $15 M/mile for double track subway in the CBD. Station costs varied from $175,000 for a 300-ft-long, simple commuter stop at ground level to $7 M for subway stations designed to emphasize aesthetic features. The overall cost for the Washington subway is estimated to average about $25 M per mile.[5]

Requirements for Public Transportation—The facts presented in the preceding section permit several conclusions to be drawn about the conditions that must be met by a public transportation system if it is to gain public preference and provide a solution to the problems of urban traffic congestion, inconvenience, and expense. As a minimum, to attract large public use:

1. The new system should provide uniform service to all parts of the metropolitan area from any point in the area, since desired travel directions are rather uniformly distributed throughout a metropolitan area.

2. Access to the system (i.e., stations) should be provided within easy walking distance, i.e., at intervals not exceeding one-half mile and preferably one-fourth mile throughout the area, so the rider can make the complete trip by public transportation.

3. Headway should be reduced to a time interval that seems insignificant to the boarding passenger, i.e., to a minute or less. This is most important to transferring passengers, for whom waiting at transfer points is particularly aggravating. Figure 1 indicates that bus usage on existing lines could increase by over 50% in Dallas if minimum headway were reduced from 5 minutes to zero.

4. Total trip time including walking should be comparable with automobile usage.

5. The costs for operation, maintenance, and amortization of the transportation system must be low enough to permit profitable operation with a fare that appears reasonable to the traveller.

In addition to these firm requirements, for which convincing statistical evidence is available, several additional features appear necessary or highly desirable to attract continuing public use of a public transportation system:

1. The comfort and ride quality must be at least comparable with those of automobiles, attention being given to air conditioning, comfortable seats and decor, freedom from crowding, quietness, and view.

2. The system should offer obvious advantages over automobiles in cost, reliability, safety, and travel time.

3. The system should provide service for non-drivers, now dependent on public transportation,

[3] *Skokie Swift—The Commuter's Friend,* Chicago Transit Authority, Research and Planning Department, 1968; CFSTI (Clearinghouse for Federal Scientific and Technical Information) PB 179 681.

[4] *Chicago Area Transportation Study,* State of Illinois, County of Cook, City of Chicago in cooperation with U.S. Department of Commerce, Vol. I, 1959; Vol. II, 1960.

[5] *Proposed Regional Rapid Rail Transit Plan and Program,* Washington Metropolitan Area Transit Authority, 1967; CFSTI PB 177 052.

at least as good and preferably superior to existing systems.

Finally, installation of the system should not disrupt neighborhoods or business, should not create pollution or noise, and should be socially and aesthetically acceptable in the community.

Potential Systems—Most existing public transportation systems do not attract the public because the equipment is outmoded, the service is poor, and access is inconvenient. Where good service and accommodations exist, public use tends to be high. It is interesting to examine, therefore, the degree to which present transportation facilities could satisfy transportation needs if financing were provided to install new equipment and increase lines and boarding points to give good service throughout a metropolitan area. Public transportation in metropolitan Washington and Baltimore is now provided almost entirely by buses that give fair to adequate service only during rush hours and only along lines mainly directed to and from the downtown areas.

Costs to provide bus service throughout the densely populated areas of these cities at one-minute intervals with East-West and North-South lines spaced ¼-mile apart were estimated. Costs would be so high for these systems that a fare in excess of 50¢ would have to be charged to operate profitably even with 75% of the total traffic travelling by bus. The major part of the cost of bus operation is for drivers' salaries so that use of minibuses offers no solution. The owner of D.C. Transit testified recently that 82% of the company's expenses are for labor costs. Since buses must operate in the presence of other traffic, service is inherently unreliable and subject to breakdown and tie-up in bad weather or traffic jams. These difficulties could be mitigated by traffic control that would favor bus travel, but the high cost of operation appears to pose a fundamental limitation. One is forced to conclude, therefore, that improvement of bus service will not offer a satisfactory solution to transportation needs.

Rail systems have advantages over buses in dependability and speed but are much more expensive to install, and the space and cost requirements for stations and lines are so large that it is not feasible to have them at close intervals. As an illustration, data based on the cost per mile of the Washington Regional Rapid Rail Transit (RRT) were used to estimate the cost of installing a rapid rail system to cover the Washington area with N-S and E-W lines spaced at 0.6-mile intervals with a station at each intersection. Even with such spacing, the average distance to a station is twice as far as most people would be willing to walk. The installation cost of that system would be about $10 billion, far beyond the sum that could be reasonably financed.

Evidently a public system can only solve the overall urban transportation problem if the cost for installation of a large part of it is far less than that of rail systems and if the operating cost is much less than that of buses, a major and constantly increasing part of which is required for salaries for drivers.

Considerations such as the above have led to many studies of potential new systems for urban transportation that would offer advantages when compared with buses and rail transit. One group of studies addresses the problem of traffic congestion by looking to methods of better traffic control and suggests solutions based on special-purpose vehicles that could be controlled automatically on specially prepared roadways to permit high-speed travel at separations much less than those presently required for manual control. These vehicles could be manually controlled to permit conventional operation on ordinary streets. Such "dual-mode" systems could offer quicker, safer travel for commuters and would permit more traffic on some of the existing roadways (suitably modified for automatic control). However, because of the space and expense required for control of queuing and for acceleration and deceleration at access points to the automated roadway, it does not appear feasible to have such roadways and access points at separations significantly closer than current freeway exits, i.e., about one mile apart. This would be too great a distance for the average traveller to board or leave the cars at the highway exit and walk the remaining distance to his destination. Thus, for convenient use of the autocar he would have to buy or rent a car that he could park at his home overnight and park at a garage near his office during the day. Thus the primary use of such dual-mode systems would appear to be as an alternative to rail transit or present freeways in speeding travel compared to present automobiles, with potential reduction in accidents, driver fatigue, and air pollution. The number of vehicles using the streets would not be especially reduced. Installation costs for such a system have been estimated at $6.2 M per mile for a guideway primarily on grade to $14.6 M per mile for a subsurface guideway, excluding right-of-way costs but including costs for 14,000 system-owned vehicles. Annual direct operating costs are $0.55 M per mile.[6]

Reducing Cost and Increasing Use of Rapid

[6]Robert A. Hayman et al, *Bi-Modal Transportation System Study,* Cornell Aeronautical Laboratory, Inc., Vol. I, March 1968; CFSTI PB 178 286.

Transit—The high cost of rapid transit systems suggests consideration of an approach that would employ a rapid transit network with lines and stations spaced several miles apart, supported by a slower (and therefore less expensive) system that could provide service within easy walking distance to all points within the larger grid. Bus systems (minibuses are often proposed), moving walkways, and small vehicles moving along simple guideways have been proposed for such "distribution" systems. Because each minibus requires a driver, operating costs for such systems designed for peak loads are greater than those for standard buses. Moving sidewalks are estimated to cost $5 M/mile to install. Guideways, control systems, and station costs for the small vehicle systems that have been proposed, employing either electric motors installed in each car or employing linear induction motors installed in the rail, have led to estimates in the vicinity of $5 M/mile for installation.

Although the systems described above would meet many or all of the desired requirements for comfort, speed, and safety, none offers a solution to the urban transportation problem because the cost is too high to permit installation of enough lines and stations to give access to stations within walking distance throughout a metropolitan area. We must therefore look for a means of transportation that can meet the performance requirements and still be inexpensive enough to permit closely spaced lines to be installed. Search for such a means has led us at APL to examine the potential of a system concept based on ski-lift designs that have proven cheap enough to be installed and operated profitably in remote areas where transportation volumes are very limited. Installation costs of ski-lift systems are indeed far below the figures quoted for the systems described above—gondola ski-lifts can be custom installed in mountainous terrain for about $300,000/mile and operated for less that $100/day per mile of line. Closely-spaced cars can transport large numbers of passengers per hour. Thus, the ski-lift type of system in a version modified for urban use appears uniquely suited to meet an essential part of the urban transportation need. If installation and operating costs could in fact be much less than those of alternative systems, many times as many miles of line could be installed, and a N-S, E-W grid with lines every quarter mile throughout a metropolitan area could become a reality. It has appeared worthwhile therefore to study in further detail the possibilities of this method. The study has produced encouraging results and has led us to design an urban system on the ski-lift concept called the Aerial Car Transit or ACT system which is described in the next section.

Aerial Car Transit (ACT) System

The primary objective of the Aerial Car Transit system is to provide transportation at low enough cost so that city-wide coverage, with stations within easy walking distance everywhere in the metropolitan area, will be economically feasible. To achieve this objective the system must strive for the utmost simplicity. At the same time it must offer service attractive enough to gain public preference over automobiles for the majority of trips, and the installation must be aesthetically acceptable in the urban environment. This requires that guideways and stations be small and unobtrusive as well as low in cost.

To meet these requirements the ACT design differs in some details from ski-lift systems. Instead of hanging gondolas from a moving cable, which can sway in the wind and produce an undulating motion of the car, the ACT system employs an overhead rail to support the cars. Each car is suspended from a carriage with four rubber-tired wheels which ride on two rails within an enclosed beam and is towed by a cable. This arrangement protects the cable and carriage from the weather, gives a smooth, quiet ride and permits the gondolas or cars to be stabilized against wind effects. The cars, approximately 7 ft high, 5 ft long

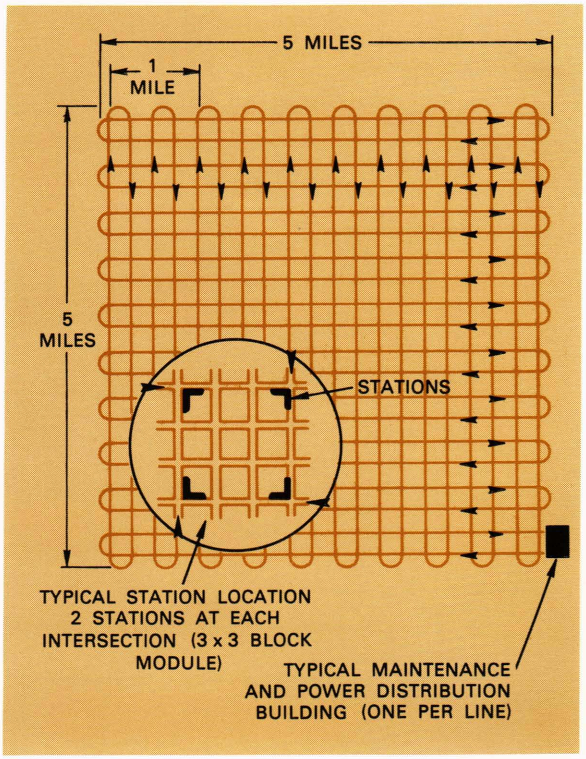

Fig. 3—Assumed ACT grid system.

and 3 ft wide, are designed to accommodate two seated passengers with additional space for two standing adults, or for luggage or packages. The enclosed beam, 1½ ft high and 1 ft wide, is supported above the curb line by poles, comparable in dimensions with street lighting poles, which are separated by about 90 ft in a typical installation.

To form a transportation system, ACT lines are arranged in loops as shown in Fig. 3 producing a grid or network following existing streets. North-South directed and East-West lines are situated approximately ¼ mile apart throughout the urban area. Stations are placed at every line intersection. Thus, every point in the area is within an average walking distance of less than 660 feet from a station. With the grid arrangement, only one transfer is generally required for a person to go from any point in the area to any other. Two alternative routes are avilable with one transfer and many alternatives with two transfers. A short walk, with no waiting, similar to that between up and down escalators in a department store would be required for transfer.

The ACT cars will move at a line speed of 20 mph but will decelerate to 5 mph or less and ordinarily descend to ground level in the stations to accommodate boarding or disembarking passengers who will enter and leave the cars by means of a moving walkway which matches the car speed. (See Fig. 4.) The walkway is wide enough (about 7 ft) so that the cars can be in contact with the central section of the walkway and allow space for entering passengers on one side and for leaving passengers on the other.

The walkway is of novel construction. The entrance and exit sections of the walkway move at the conventional escalator speed of about 1½ mph but the speed is gradually varied from the ends toward the center to give a constant 5 mph for the length of the boarding zone. Passengers entering the station can therefore board the walkway with accustomed convenience and then be comfortably accelerated to 5 mph to match the speed of the car in the station. Disembarking passengers slow down in the same way to conventional speed before stepping off the moving walkway.

A lighted display at the entrance to the walkway will indicate the occupancy and available space in an approaching car and provide a boarding signal so that the passenger will board the walkway and

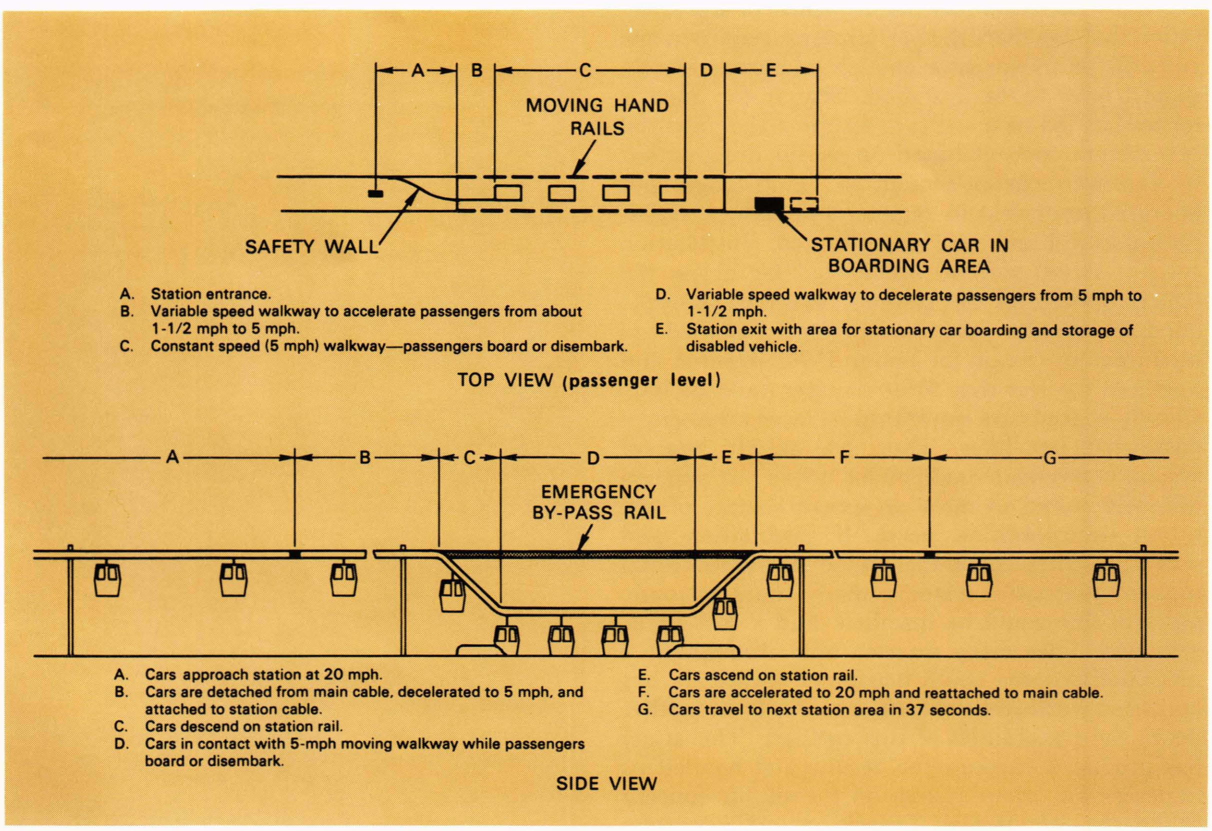

Fig. 4—Layout for ACT system station area.

be accelerated to arrive at the beginning of the boarding zone at the same instant that the car with available space settles on the walkway. The doors will be opened automatically and boarding will require only a single step into the car. Departing passengers will leave from the other side to prevent interference.

Station length will depend on the time allowed for boarding and on the car speed in the station. Studies show that the average time required for boarding buses is 2 seconds, and elevators in hotels and office buildings are often set for 3 seconds. It therefore appears that allowance for a total boarding or unloading time of 6 seconds for ACT would be reasonable. Passengers who reached the end of the boarding zone without boarding would experience no hazard, but would simply slow down and step off the exit end of the walkway. For a station speed of 7½ ft/sec (about 5 mph) and boarding time of 6 seconds the station length will be 80 to 90 ft, allowing 20 ft for acceleration and deceleration, 45 ft for the boarding zone, and 14 to 25 ft for entrance and exit space.

For those people who for any reason would find it inconvenient to board or leave the ACT car via the moving sidewalk, an alternative method will be provided. A stationary car will be located just beyond the end of the walkway which a passenger can board like a conventional automatic elevator. After he signals readiness, the car will be elevated by a lift to a height at which the carriage can be placed on a spur rail. The car will then wait until a signal for merging with the line is received after which it will be accelerated to join with the main flow. When the passenger signals his desire to stop at a station, the car will enter the station in the usual manner, but when it reaches the end of the boarding zone a mechanical switch will detach the car from the ascending section of the overhead rail. The car will remain in contact with the moving walkway to the exit, from which it will be moved to the stationary boarding position. Cars for this type of service would be available at about 2-minute intervals.

This same procedure provides a safety measure which would be automatically activated if for any reason a car door were obstructed or not able to close when the end of the boarding zone was reached. The disabled car would be routed to the stationary car area. Other safety features have been included in the system. Stations will be monitored continuously by closed-circuit TV, with one monitor assigned to inspect eight stations on a regular schedule. If a serious problem arose, the station monitor could shut down the station or line until the problem was corrected. Minor problems such as the malfunction of a single car, could be solved without interrupting the main service. Station monitoring will be a deterrent to those considering acts of vandalism or crime. Immediate boarding will inhibit loitering and will remove the hazard now involved in waiting at lonely bus stops. Hazards of riding in unattended cars should be minor because transit time between stations (where the cars will be observed) will be only 37 seconds.

For a line speed of 20 mph and station speed of 5 mph, the average speed is 16 mph including time for acceleration, deceleration, and transit through the stations. The speeds chosen are arbitrary, but the average varies little with other selections, as shown in Table III.

TABLE III

DEPENDENCE OF AVERAGE SPEED ON LINE SPEED

(Boarding Time 6 Seconds, Acceleration and Deceleration at 4 mph/sec)

Line Speed (mph)	15	20	25
Av. Speed (mph)	13.2	16.3	18.5

Because higher line speeds require longer times for acceleration and deceleration, the average speed is rather insensitive to such changes. However, the power required increases with the square of the line speed. Thus, 20 mph seems to be nearly optimum. Similarly, the average speed depends little on station speed if a constant 6-second boarding time is maintained.

ACT Capacity—Line capacity is determined by the number of cars that can pass through the station per second, which is directly proportional to the car density (number of cars per unit length of line) and station speed. The minimum spacing in the station is 7½ feet (to allow clearance between cars on the inclined rail). Thus for a 7½ ft/sec station speed, cars can pass through at a rate of one per second, or 3,600 per hour. With two seated and two standing passengers the maximum capacity is therefore 14,400 persons per hour. The spacing is increased in proportion to velocity as the cars accelerate to line speed, so that the line spacing at 20 mph and maximum capacity is 30 ft between cars. Capacity of the ACT system can be appreciated by comparison with that of freeways, which carry a maximum of about 2,000 vehicles per hour per lane.

The maximum ACT capacity will be required only for areas of high population density or for particular locations such as stadiums or concert halls. The average requirement will be much less and can be accommodated with cars spaced farther apart on the line and with lower station speeds. If the car spacing on the line is increased to 90 ft, the station speed can be reduced to 1⅔ mph and a conventional non-accelerating sidewalk about 20 ft long employed, with a reduction in station length to 35 or 45 ft. For this speed the maximum line capacity would be 4,800 pass./hour, or about equivalent to a conventional bus on a schedule of one every 33 seconds. Even further reduction in station size and speed would be possible for the major part of the urban area. For example, if car availability at 15-second intervals were judged to be adequate, cars could be halted, lowered to ground level for 6 seconds for boarding, then raised to line elevation and allowed to proceed before another car entered the station zone. A simple enclosure would suffice for the station in this case.

The capacity required for a particular ACT line will depend on the distribution of homes, shops, and businesses in a particular area and can be only roughly estimated in advance. However, some general requirements can be derived from the statistics typical of city travel. As noted earlier, in all American cities the total number of trips on an average weekday is twice the city population. We may therefore approximate the number of trips per day for any square mile of the city by multiplying the population density in that area by two. In typical large cities the maximum population density is about 40,000/mi^2 and the metropolitan limit is drawn where the density falls below 2,500-4,000/mi^2, i.e., one or two houses per acre. The average density varies from 25,000/mi^2 in New York City to 2,500/mi^2 in Dallas and Houston. Of the twenty major cities in the U.S., twelve have an average population density in the range 10-15,000/mi^2 and five between 5,000 and 10,000. The 140-square-mile developed portion of the Washington metropolitan area has a population of 2.3 million. Baltimore City, with an area of 72 mi^2 has a population (1962) of 940,000. Thus these cities range from 16,000/mi^2 to 13,000/mi^2.

The system must be capable of handling morning and afternoon rush-hour traffic which has a peak hourly rate roughly one-tenth of the daily total. Now if we note that one ACT line serves an area one-half mile wide and we assume that the average trip is five miles, we see that if everyone in the area served used the ACT line—and *all travelled in the same direction*—the maximum required capacity would be twice the population density, *P*, multiplied by 5 (miles) x ½ (mile) and divided by ten, or $P/2$ per hour. For the typical area where trips are fairly uniformly distributed in N-S E-W directions, the peak load would be $P/8$. Table IV shows the ACT car spacing with four passengers per car that would be required to carry the traffic for these two cases.

Cost—The cost of installation and operation of an ACT system will depend on the number of miles of line required and on the capacity needed in different parts of the metropolitan area. Therefore estimates have been made for several types of installation ranging from the lowest capacity, appropriate to low-density suburban installations, to high-capacity systems suitable for the CBD. The results are summarized in Table V. Since most of the system components are available from industry, the estimated costs are mainly based on listed prices. On other items such as the moving sidewalk and cars, estimates are based on current prices for similar items such as escalators or automobile bodies. One-half to one-third of installation costs are for stations. The system cost includes provision of one shop for each ten miles of line. Yearly operating costs total roughly one-seventh of the installation cost, of which direct costs for power and labor account for about 40% of the annual total, indirect costs for depreciation are about 15%, and amortization of the capital expenditure for system installation is about 45%.

Estimated costs for the ACT system are compared with quoted values for some other public transportation systems in Fig. 5. The costs are for a very high demand that would be found only in the CBD. Actual installation costs tend to exceed preliminary estimates; hence the final values may be significantly different but the three-fold differ-

TABLE IV

ACT CAPACITY TO CARRY PEAK LOAD

		All Traffic One Direction		*Traffic Directions Uniformly Distributed*	
Population Density/mi^2	*Peak Load/hr*	*ACT Cars/min (One Line)*	*ACT Car Spacing (ft)*	*ACT Cars/min (One Line)*	*ACT Car Spacing (ft)*
2,500	1,250	5.2	346	1.3	1,384
5,000	2,500	10.5	173	2.6	692
10,000	5,000	21	86	5.2	346
25,000	12,500	52	35	13	140

Spacings varying from 35 ft to 1,400 ft are indicated, corresponding to car arrival rates from 1 per second to 1 every 40 seconds.

TABLE V

COST SUMMARY FOR ACT SYSTEM

PER MILE OF LINE

	High Capacity 14,000 Pass./hr	*Low Capacity 4,000 Pass./hr*	*Minimal Capacity 400 Pass./hr*
Installation	$836 K	$460 K	$300 K
Annual Operating Cost	127 K	73 K	54 K
Direct	50 K	32 K	26 K
Depreciation	17 K	9 K	6 K
Amortization	60 K	32 K	22 K
Cost per Day (24 hrs–365 days/yr)	350	200	150
Cost/Pass. Mile (Assumes daily trips = 10 x peak load requirement and average trip of 5 miles)	0.05¢	0.10¢	0.75¢

ence in operating cost (including amortization) in favor of ACT provides convincing evidence of the major cost advantages of ACT per mile of line for a high capacity operation.

The Integrated ACT-HST System

The ACT system with average speed of 16 mph would require an unacceptably long travel time for journeys beyond about eight miles, which are typical in large cities with suburbs. The ACT system installation should therefore be supplemented by a high speed transit (HST) system with stations a few miles apart, and lines arranged in a network covering the urban area. Many HST systems are available ranging from trains now operating in the New York Subway to those of modern design and improved performance such as the Washington RRT or BARTD system in San Francisco and some more advanced concepts like the GE-Safege[7] which rides on an overhead rail or Edwards GVT.[8] Maximum speeds vary from 45 to 80 mph with conventional rail systems, to over 200 mph for the proposed GVT for a three-mile link. Average speeds vary with station spacing and boarding time allowance as well as with line speed, because appreciable time and distance are required for acceleration and deceleration. The maximum limits for acceleration and deceleration are based to a great extent on requirements for passenger comfort (tolerable jerk) and also on the need to reduce acceleration rate as maximum speed is approached. Table VI shows that for station spacings of less than one-half mile, these limits

[7]*General Electric Aerial Transportation System,* General Electric Co., Tech. Report GEA 8603, 1967.

[8]L.K. Edwards, "High Speed Tube Transportation," *Scientific American* **213,** August 1965, 30-40.

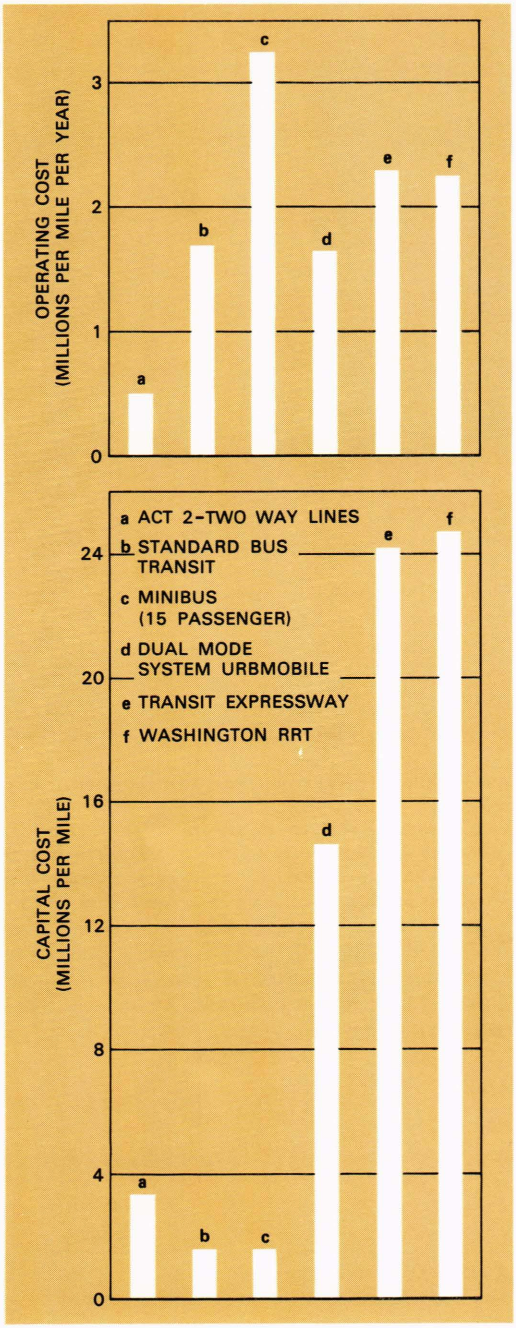

Fig. 5—Cost of transit systems designed to meet requirements for at least 27,000 passengers per hour peak capacity.

Bus and minibus costs were based on D.C. Transit costs and 16 mph average speed. Urbmobile costs were based on estimates for installing the system in Buffalo (Ref. 6); the underground system was selected since right-of-way costs were not available for above-ground installation. Cost of Transit Expressway was based on estimates for installing the system in Baltimore. WRRT costs were based on data given in Ref. 5. Note that costs of feeder bus service to achieve this patronage were not included.

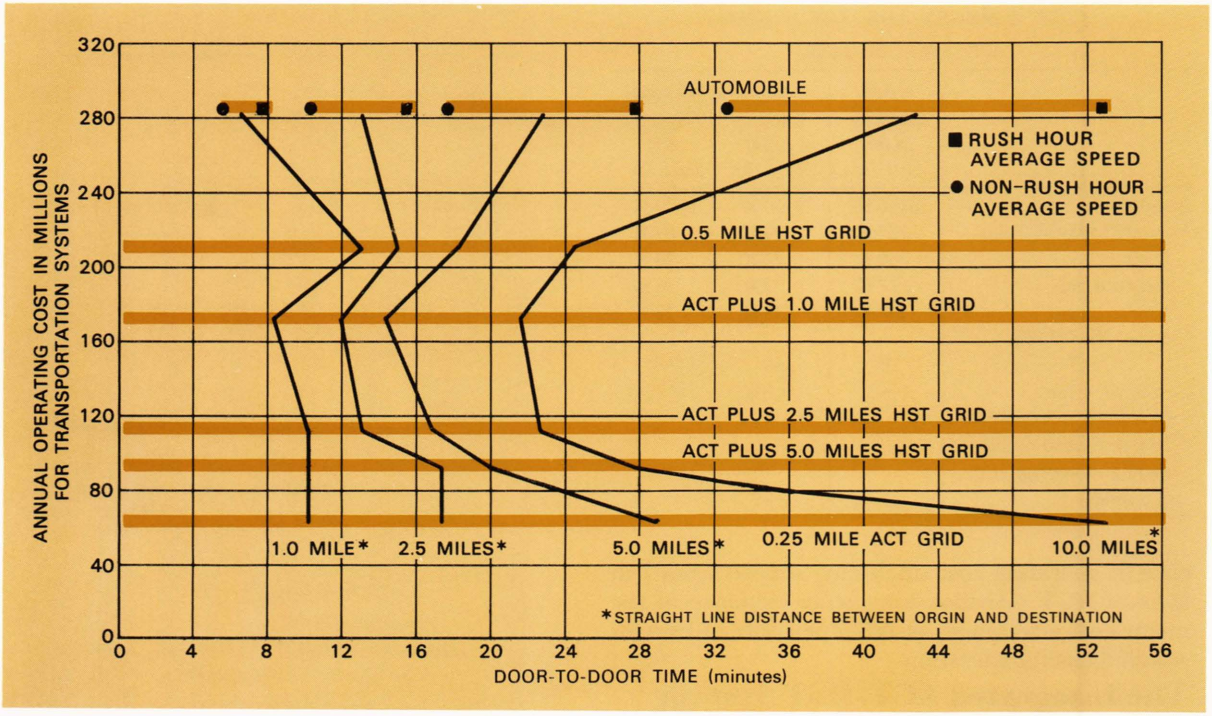

Fig. 6—Typical travel times and annual operating costs for ACT, HST, and ACT-HST systems and private automobile.

Trip length used to compute travel time frequently exceeded the distance between origin and destination because of the location of the transportation lines.

Travel time included an average walking time for both trip ends of 5 minutes for ACT and 10 minutes for HST, when it was the only system used. Waiting time was 1 minute for HST, no waiting time for ACT.

Auto travel times include 0.5 minute for starting up and 2 minutes for parking and walking. Average speeds were 60 mph for HST, 16 mph for ACT, and 15 and 25 mph for the automobile.

Annual operating costs were estimated as follows: for HST, \$0.5 M/mile; for ACT, an average of \$0.076 M/mile; and for the auto, 10¢ per mile, with an average trip length of 4.5 miles and an average occupancy of 1.3 persons/car for 2.6 M trips/day.

TABLE VI

PERFORMANCE CHARACTERISTICS OF SEVERAL HST SYSTEMS

	New York Subway	*Transit Expressway*	*Washington RRT*	*BARTD*	*GVT*
Average Acceleration, mph/sec	2.5	2.2	ca. 3.0*	2.2	3.5
Top Speed, mph	45	50	75	80	227†
Calc. Av. Speed mph, for Station Space of					
¼ mile	22	22	24	22	26
½ mile	30	31	34	31	39
1 mile	36	38	45	44	59
2½ miles	41	44	59	60	100
5 miles	43	47	66	69	150
10 miles	44	48	72	74	170

*Calculations of average speed were based on acceleration and deceleration curves for straight, level track. Variations in track layout may reduce average speeds.

†For station spacing at 3 miles, maximum speed is 227 mph; for 10-mile spacing, 242 mph.

are more significant in establishing average speed between stations than the maximum speed of the transit system.

Let us now consider how the annual operating costs and average trip times would depend on several combinations of HST systems with ACT installed in a ten-mile-square area to provide a ¼-mile ACT grid (providing lines in any one direction at ½-mile intervals) and HST grids with spacings of ½ (without ACT), 1, 2½, and 5 miles. The results are shown in Fig. 6. The times shown are average values to complete a trip between two typical points separated by a given distance by the route of minimum time. For the HST, an average walking time of 5 minutes at each end of the journey,† an average wait of 1 minute to board, and 1 minute to transfer from one line to another, if necessary, were assumed. For the ACT system, average walking time was 2½ minutes at each end. No waiting time is needed. Annual operating costs are based on 24-hour/day 7-day/week operation of ACT, and 20-hour operation of HST on the schedule proposed by the WMATA, which has reduced service at off peak hours and on weekends. Number of trips per day is based on two trips per person per day and a population density of 13,000/mi^2.

†Applies only to the HST system with ½-mile spacing.

Figure 6 shows clearly that an HST line spacing of about 2½ miles would be optimum, since travel times would be only slightly higher than those for the 1-mile grid and trip cost would be only slightly above that of the ACT alone. Average speeds would be close to or better than those for automobile travel at all distances.

Application of ACT-HST System—It is interesting to consider the applicability of the above discussion to the problems of providing public transit for Washington, Silver Spring, and Baltimore. Let us look first at Washington.

Washington. The regional rapid rail transit system proposed after thorough study of the design and installation and operating costs will provide 2-minute service during rush hours and four-minute service during most of the remaining

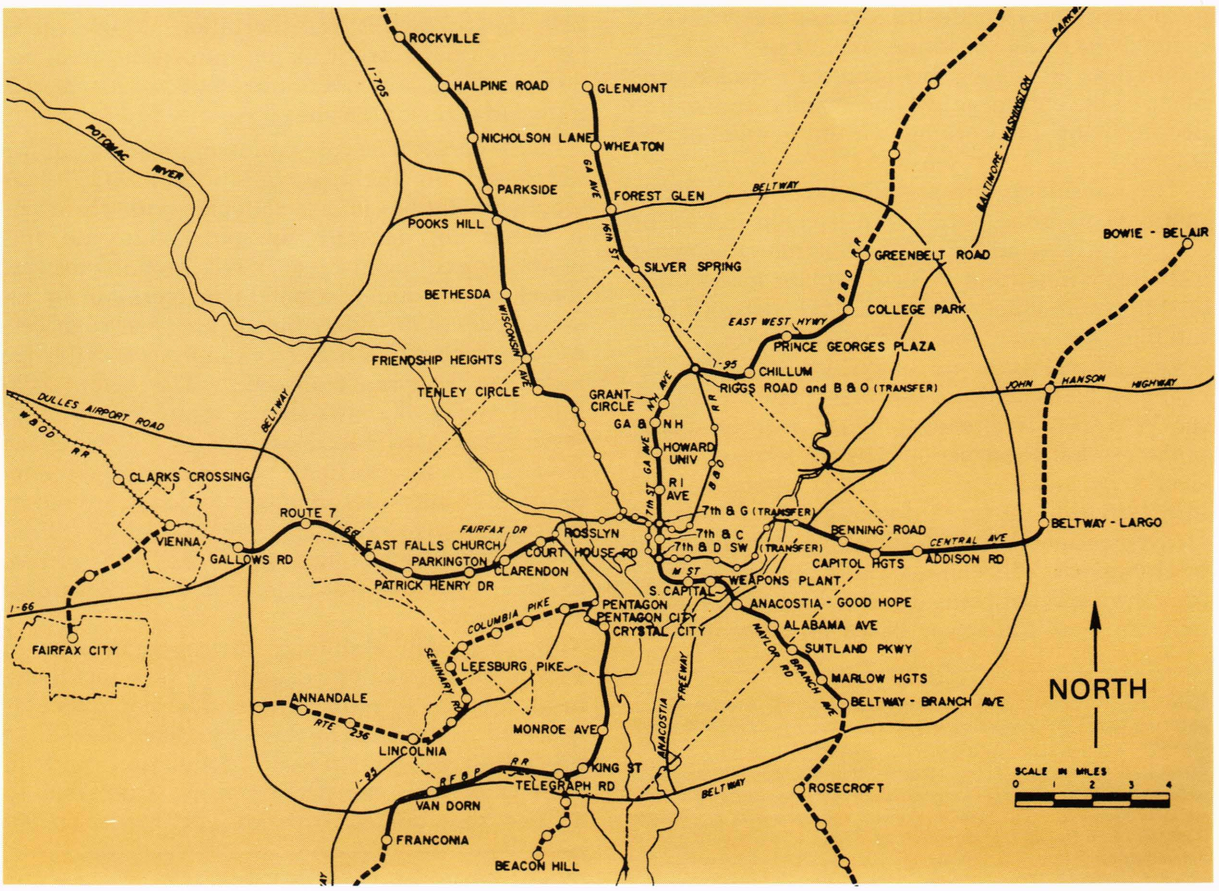

Fig. 7—Proposed regional system, 1967, Washington Metropolitan Area Transit Authority. (From Ref. 5.)

hours. The planned routes‡ are shown in Fig.7.[5] Travel time from the boundaries to downtown is about twenty minutes, so that excellent service is provided to the city from the suburbs. Capacity of the system is expected to be ample to carry the expected peak load in 1990. Cost of the system is estimated at 2.4 billion dollars. The plan and the expected cost are both impressive. However, several points need to be considered.

We note first that the area population is expected to be 4.2 million people in 1990. Thus, if current trip patterns continue, there will be over 8.4 million trips per day in the metropolitan area. WMATA estimates that in 1990, the RRT will have 281 million passengers per year. From this we may estimate 889,000 average weekday passengers,§ which is still only 10½% of the total trips in the area. Thus the rapid rail transit system will carry twice as many passengers as the present bus systems in Washington, but it will still carry only a minor fraction of the total traffic, which in 1990 will require twice as many automobiles, freeways, and other roads as now exist.

The reason for the continued low patronage of the RRT is that the system is designed to give good service only for the trips in and out of Washington, which will constitute only about 15% of the total trips. As shown by Montreal, Skokie, and other cities, patronage will be mainly drawn from people living or working within ½ mile of the stations.

The considerations presented earlier indicate that high usage of public transit could indeed be secured at low additional cost if minor changes were made in current WMATA plans for location of stations and lines, and an ACT network was installed to cover the metropolitan area.

One is reluctant to introduce concepts for changing plans made for the Washington RRT, as the WMATA is already plagued with so many problems that construction is being delayed. But it should be noted that if station spacing were increased from the current average of 1.2 miles to an average spacing of 2.5 miles, 44 stations could be eliminated. The elimination of specific stations from the approved plans (or alteration of line location) must, of course, be based on more detailed study than was undertaken for this paper; however, scrutiny of current plans shows that in a downtown area 2½ miles square there are 17 stations—all of the subway type with costs in the range of 4 to 7 million dollars per station. If approximately 10 miles of line that would be unnecessary with an ACT installation were also eliminated, the money saved would pay for the construction of an ACT network to cover the entire metropolitan area and would almost pay for 21 miles of circumferential HST lines which would greatly add to the system's usefulness. This would give point-to-point accessibility throughout the densely populated region that would be competitive in speed with automobiles, safer, and more reliable, and would be self-supporting with a uniform 25¢ fare from any point to any other. The cost estimates on which these statements are based are presented in Table VII.

The example above emphasizes some points needing more attention in planning urban transportation systems. The expected increase in population makes it essential to plan to reduce the number of autos on the streets (not just in the CBD) by making it possible for travelers to make *total trips* by public transportation. Many plans just relocate the problems of auto traffic (congestion, parking, air pollution) and *do not provide* transportation for the auto-less.

Silver Spring. The cost estimates presented above are based on the assumption that ACT lines would be laid out in a rectangular grid. However, it would not generally be possible to do this following existing streets. It has been of interest therefore to examine a potential line plan for an actual part of the Silver Spring area where streets are distributed in a pattern exhibiting short-range order but long-range disorder. The layout presented in Fig. 8 shows that a reasonable grid to serve the area is indeed possible by following the streets with intersections at approximately one-fourth mile intervals, although the loops are not at all regular. The plan also shows two-way lines connecting with planned RRT stops to accommodate rush-hour traffic to and from downtown Washington.

Baltimore. The Baltimore metropolitan area in 1962 had a population of about 1.1 M people living in an area of 91 square miles. The population is expected to increase by 48% by 1980.[9] Based on the predicted increases in population and in number of trips per person, it is reasonable to assume that 3.6 M trips will be made on an

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‡The 1967 proposed routes have been used for all studies in this paper as they were supported by detailed cost analysis and traffic forecasts.

§Based on the Chicago Study (Ref. 4, Vol. II), annual passengers were converted to average weekday passengers by dividing by 316 weekday equivalents. The Alan M. Vorhees and Associates Washington Area 1980 Rail Rapid Transit Patronage Forecast (1967) used a lower annualization factor for Chicago (292), but excluded substantial railroad commuter traffic to derive annualization factors for transit-oriented cities (Chicago, Philadelphia, Boston). Their annualization factor for Washington, adjusted to include tourist traffic, was 293.

[9]Parsons, Brinckerhoff, Quade, and Douglas, *Baltimore Area Mass Transportation Plan. Phase II—Long Range Program*, prepared for the Metropolitan Transit Authority of Maryland, Baltimore, October 1965.

TABLE VII

COST ESTIMATE FOR COMBINED HST-ACT SYSTEM FOR WASHINGTON METROPOLITAN AREA

	Stations	Miles of Line	$M	$M
Washington Regional Rapid Rail Transit				
Installation Costs (95.6 miles of line, 82 stations, 24,420 parking spaces)				2,146
Vehicles				220
				2,366
Annual Operating Costs (excluding amortization)			36.6	
Proposed Line & Station Changes				
Space stations at 2.5 mile intervals	–44			
Eliminate dual line from Riggs Road to 7th & G	– 4	– 7		
On Benning Rd. line eliminate line from Weapons Plant to 7th & D and connect at Weapons Plant to Branch Ave. line	– 4	– 2.5		
Add line from Bethesda to Route 7 on Gallows Rd. Line	+ 4	+10		
Add line between Patrick Henry Station and station in town from Leesburg Pike on the Columbia Pike line		+ 3		
Connect Bethesda to Silver Spring	+ 1	+ 5		
Connect Pentagon to South Capital		+ 3		
	–47	+11.5		
Estimated Cost Reduction*				–450
				1,916
Allowance for additional costs				+ 54
HST System—Estimated installation costs for modified RRT system				1,970
Estimated annual operating costs (direct & depreciation)			40.0	
Estimated amortization (at 7½%)			148.0	
ACT System				
Installation Costs for lines to cover 139 mi² area				512
Annual Operating Costs (including amortization)			78.0	
HST-ACT System				
Installation Costs				2,482
Annual Operating Costs			266.0	
Potential Revenue with 25¢ Fare				
If all 1990 trips were made by HST-ACT: 8.4 M x $0.25 x 316 days = $664 M/year				
To meet annual operating costs requires: 266/664 = 40% of total trips				

*Based on cost of miles of line and stations.

Note: To construct RRT, WMATA plans to finance $800 M to be supported by revenue and expects to obtain $1.6 billion from Federal, State, and County grants. With that financing plan only 26% of total trips would be required to equal annual operating costs.

TABLE VIII

COST AND REVENUE FOR BALTIMORE HST-ACT SYSTEM

	$M
Installation Cost	
HST (65 miles of line with stations at 2.5-mile intervals)	1,140
ACT (installation in 91 mi.² area)	335
	1,475
Annual Operating Costs	
HST	
Direct and Depreciation	25
Amortization at 7½%	85
ACT (Including Amortization)	51
	161
Potential Revenue with 25¢ Fare	
With all 1980 trips (3.6 M) by HST-ACT	316
To meet annual operating costs requires 51% trips by HST-ACT	161

average weekday in this area. The traffic requirements for this part of the city could be handled by installing the ACT system and a HST network. Costs and revenue for this system with a 25¢ fare per trip are presented in Table VIII. The ACT-HST system in Baltimore could also operate profitably with half of the total trips with a 25¢ fare for a trip anywhere in the area. Trip times would be less than 30 minutes from any point in the area to the CBD and less than 45 minutes from points at opposite boundaries, including a 6-minute walk.

Conclusion

The discussion of urban transportation presented here shows that it would be feasible to install a self-supporting transportation system combining a simple low-cost local service with a high-speed transit network that would provide fast economical

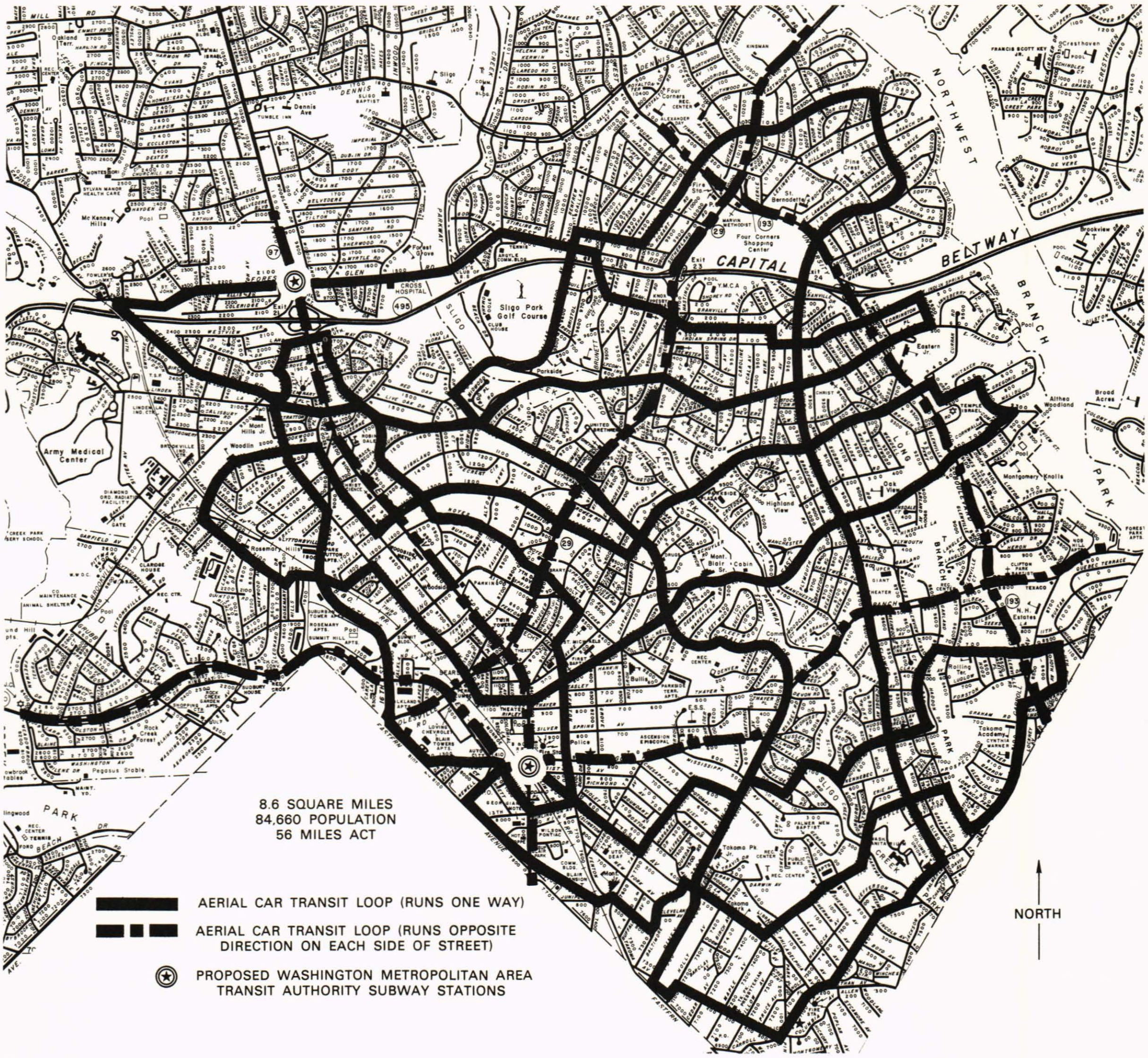

Fig. 8—Sample ACT layout for Silver Spring area.

transportation with no waiting from any point in a metropolitan area to any other with fare as low as 25¢, and transit time from suburbs to CBD or from one suburb to another in less than 30 minutes. The local service would be provided by cable-drawn, continuously moving small cars suspended from an overhead rail, with lines arranged to form a grid or network covering the metropolitan area with ¼-mile spacing. This (ACT) system would have boarding points at every line intersection. The high-speed transit system would also form a network but with lines and stations spaced roughly 2½ miles apart. Trains would be scheduled to run at 2-minute intervals.

The system would provide quiet all-weather service with no pollution and with aesthetic compatibility with the environment. It would offer an attractive solution to the need of the non-drivers and disadvantaged for transportation to jobs and services not now accessible to this large minority of the urban population.

Acknowledgment

Miss Martha Neuman calculated the trip times and system operating costs; Mr. F.F. Mark and Mr. W.C. Caywood calculated the performance characteristics of the HST systems. Their assistance is gratefully acknowledged.