Comparison of Dual Mode and Other Urban Transportation Systems

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To obtain a greater understanding of how dual-mode transportation systems compare in effectiveness to other urban transportation systems, a study was initiated to evaluate the service, costs, and impacts of several urbanwide transportation systems. The study objective was to obtain insight into applicability and utility of systems rather than to make definitive statements on the inherent worth of individual systems.

A comparative study was made of the following urban transportation systems: highway, comprehensive bus, exclusive bus, rail rapid, dial-a-ride, dual mode, and personal rapid transit (PRT). To permit analysis of relatively "pure" forms of the systems, transit service in each system was provided to the entire urban area; i.e., no attempt was made to select the most efficient service areas in the city for each particular system. Line-haul systems were augmented with conventional bus feeder routes. In addition to equivalent coverage for all systems, approximately equivalent service was provided to establish a consistent basis for comparison. The service criterion selected was an access time of 8.5 min between initiation of travel (or request for service) and motion of the first vehicle boarded. This constraint allowed evaluation against a consistent service level; it did not necessarily permit the most effective service by each individual system in terms of frequencies and line spacings. Thus, a relative measure of system utility based on fixed requirements could be obtained. The study could not determine that any system examined could not be an effective urban transportation mode.

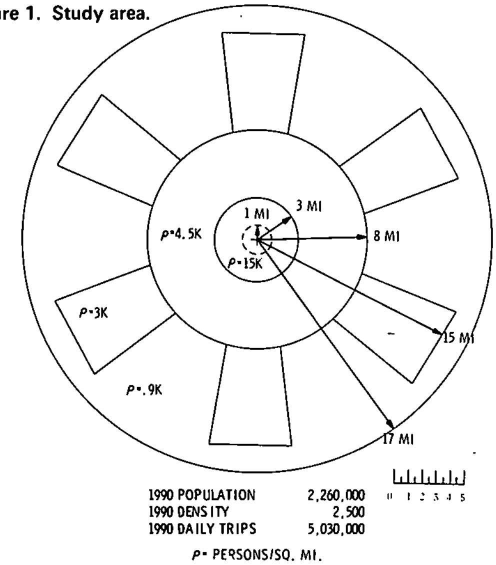
The urban area was designed by averaging the projected 1990 characteristics of the 30 largest U.S. urban areas (excluding New York, Chicago, and Los Angeles, whose inclusion in the sample would have biased the data excessively). The resulting area, shown in Figure 1, is a circular urban area with a radius of 27 km (17 miles), a population of 2.3 million, and an average density of 965/km^2 (2500/mile^2). The central business district (CBD) has a radius of 1.6 km (1 mile), and there were six major radial population corridors. Daily trips total 5 million. The characteristics of the seven urban transportation systems are described below and summarized in Table 1.

1. The highway system assumes a policy of continued emphasis on the use of the automobile and on the provision of limited bus service (not matching the service criterion) operating approximately as such systems do today. In this system 282 km (175 miles) of new freeway, beyond those existing in 1970, are constructed. No freeway is constructed in any of the other systems.
2. In the comprehensive bus system, increased density of bus routes is provided throughout the urban area, and no additional freeway is constructed. All buses are local; no express service is provided. Standard 50-passenger buses are used.
3. In the exclusive bus system, standard 50-passenger buses operate on radial and circumferential exclusive roadways. Express service to the CBD is provided from each station on the radials, and local bus service operates on radials and circumferentials. Feeder service to exclusive bus stations is provided by 25-passenger buses operating at comprehensive bus route densities.
4. In the rail rapid system, electrically powered 80-seat rail cars operate in trains to provide service on a track network identical to the layout of the exclusive bus roadways. The same bus feeder service is provided to the rail stations as to the exclusive bus stations. All trains are locals.
5. In the dial-a-ride system, 12-passenger, demand-responsive minibuses operate throughout the area. Short trips are accomplished on a single vehicle; longer trips require transfer to express minibuses.
6. In the dual-mode system, small 4-passenger, electrically powered vehicles are rented from the system operator by individuals. They are driven manually on streets to the guideway entrance and then operate automatically on the exclusive guideway. Electrically powered dial-a-ride buses provide local service for short trips on streets throughout the area. Longer trips involve single-vehicle service using the guideway for some portion of the trip.
7. An extensive personal rapid transit guideway network throughout the urban area provides station-to-station, nonstop, demand-responsive service by small 4-passenger, captive vehicles. Access to stations is by walking.

To meet the service criterion of an 8.5-min access time, extensive networks with 1760 km (1100 miles) of comprehensive bus routes and 1320 km (825 miles) of PRT guideways are required. Dual mode, making extensive use of highways for collection and distribution, requires more than 240 km (150 miles) of guideway.

Exclusive bus and rail rapid need 175 km (110 miles) of exclusive rights-of-way and also use 1200 km (750 miles) of feeder service. The highway system has 800 km (500 miles) of limited bus service to complement the 282 km (175 miles) of additional freeway constructed.

Figure 1. Study area.



RESULTS OF THE ANALYSIS

Table 2 gives the service levels attained by the various systems. The 4 percent daily use of the bus system in the highway system approximates that attained by contemporary limited bus systems. About a quarter of the persons traveling to and from the downtown area during the peak periods use this bus system. Exclusive bus and rail rapid systems, which have networks almost identical to each other and considerably better coverage than the limited bus in the highway system, have twice as much use. Because buses can be operated as express services and at higher frequency than trains, the exclusive bus system has a slight edge of peak-period CBD travel. The use of the comprehensive bus system is slightly higher than that of the exclusive bus and rail rapid systems, primarily because it provides better local service and, in many cases, more direct service. The dial-a-ride system, a labor-intensive system, attracts almost the same ridership as the capital-intensive PRT system. This implies that ridership is sensitive to level of service, whether that level is achieved through labor-intensive or capital-intensive means. The dual-mode system, which has a mixture of dial-a-ride minibuses and small personal vehicles, has the highest average daily use and captures almost two-thirds of the peak-period CBD trips.

Table 1. System characteristics.

System	Freeway (km)	Transit Length (km)	Transit Type	Transit Vehicle Passenger Capacity	Suburban Collection and Distribution	Line-Haul Travel	Downtown Collection and Distribution
Highway	282	800	Limited bus	50	Fixed-route, fixed-schedule bus to destination or transfer point	Fixed-route, fixed-schedule local service	Fixed-route, fixed-schedule local service
Comprehensive bus	0	1760	–	50	Fixed-route, fixed-schedule bus to destination or transfer point[a]	Fixed-route, fixed-schedule local service on radial and circumferential streets[a]	Fixed-route, fixed-schedule local service[a]
Exclusive bus	0	175 1200	Busway Feeder bus	50 25	Fixed-route, fixed-schedule feeder bus to exclusive busway station	Express and local service on radial busways; local service only on circumferential busways	Buses leave busway to provide fixed-route, fixed-schedule local service on downtown streets
Rail rapid	0	175 1200	Rail Feeder bus	80 25	Fixed-route, fixed-schedule feeder bus to rail rapid station	Local (all stops made) rail rapid service on radial and circumferential lines	Local rail rapid service on underground routes
Dial-a-ride	0	–	Minibus	12	Demand-responsive bus service to destination or transfer point	Express and demand-responsive service on radial and circumferential streets	Demand-responsive service on downtown streets to destination
Dual mode	0	240	Guideway Special vehicle Minibus	 4 12	Special vehicle to guideway entrance; demand-responsive minibus service to destination or onto guideway	SPV operates under automatic control on guideway (nonstop); minibus operates under automatic control on guideway (nonstop, no driver)	On guideway directly to station near destination
PRT	0	1320	Guideway, special vehicle	4	PRT guideway station	Express (nonstop) PRT service on guideway	On guideway directly to station near destination

Note: 1 km = 0.6 mile.
[a]More extensive coverage than limited bus system in highway case.

Table 2. System service.

System	Transit Use (percent) Daily	Transit Use (percent) CBD, Peak Period	Avg Door-to-Door Speed (km/h) Transit	Avg Door-to-Door Speed (km/h) Region	Peak-Period Speed on Surface Arterials (km/h)	Regional Daily Time Savings Relative to Highway (years)
Highway	4	26	14.2	27.2	25.6	–
Comprehensive bus	9	44	19.2	25.6	25.6	-2
Exclusive bus	8	42	24.0	25.6	27.2	-2
Rail rapid	8	41	25.6	25.6	27.2	-2
Dial-a-ride	13	52	24.0	25.6	25.6	-13
Dual mode	17	61	35.2	28.8	30.4	+25
PRT	14	53	36.8	27.2	28.8	+23

Note: 1 km/h = 0.6 mph.

Transit mode average door-to-door speed reflects the total travel time from origin to destination, including all waiting, transfer, and walking time. In the highway system, the transit mode referred to is the limited bus system. The average for the dual-mode system reflects both minibuses and personal vehicle travel. Better accessibility and higher line-haul speeds permit all modes to increase average speed compared to the limited bus.

Congestion is greatest during peak periods, and one measure of the effectiveness of each of these systems in reducing congestion is speed on surface arterials during peak periods. Reductions in congestion due to the introduction of transit systems provide benefits to highway as well as transit users. Systems that rely heavily on the use of buses on local streets have a lesser effect in reducing congestion than new technology systems or highway systems.

The travel times of the systems, reflecting both automobile and transit mode travel of each alternative, are compared to those of the highway system. The values given in Table 2 represent the number of years of travel time saved by all travelers every day. Relatively small changes occur with the comprehensive bus, exclusive bus, and rail rapid systems. Travel by dial-a-ride involves increased trip distances, compared to direct automobile trips, and the large number of small buses on highways contribute to congestion. Dual mode and PRT, being fast themselves and diverting previous highway users onto exclusive guideways, attain rather large savings in travel time—as much as 25 years saved every day.

Any savings in travel time are achieved at a cost, as shown by data given in Table 3. The system capital costs range from a low of less than $100 million for comprehensive bus to more than $3 billion for the PRT. The $1.4 billion for the highway system is primarily the cost of constructing the 282 km (175 miles) of new freeway. For the 2 bus systems, which operate totally on the street network, capital costs are predominantly those for bus purchase. For all other systems, the costs of acquisition of rights-of-way and construction of guideway and associated station facilities predominate. The dual-mode vehicle costs include the purchase of dial-a-ride minibuses and small personal vehicles, the latter then being rented to users.

The same fare was charged for the same origin to destination trip in each system. Thus, revenues reflect ridership and distribution of transit trip lengths typical of each system. System annual net revenue is the difference between revenues and the operating costs, excluding all debt service. Figure 2 shows the annual capital and operating costs incurred by the system operator and the revenues for each system. The bus systems are all dominated by operating costs, reflecting the intensive use of labor. The remaining systems, which rely more heavily on automation, are capital intensive. Dual mode is the only system for which revenues exceed operating costs. The lowest costs are incurred by the limited bus system associated with the highway system. This system also provides the lowest level of service. Clearly some form of capital subsidy is required for all of the systems examined.

Figure 3 shows the annual system operating and capital costs versus the modal split attained by each. The increasing trend shown by the band indicates that increased ridership for transit is attained through increased investment to improve service.

One of the primary objections to continued freeway construction in urban areas is the resultant community disruption. Construction of the 282 km (175 miles) of freeway displaces almost three times as many households as the 1320 km (825 miles) of the PRT system (Table 4).

Projected tax revenue changes throughout the region are greatest for those systems that permit the largest increase in accessibility. Energy consumption and pollution are calculated on an annual basis for all forms of transportation, except goods movement, within the region. Because of the heavy energy consumption rate of buses and the high level of service provided, introduction of the bus systems resulted in increased consumption of energy for regional transportation. The greater energy use of the dual mode and PRT systems compared to the highway system reflects one price paid for higher speeds attained. Pollution figures mirror energy use and reflect pollution at power generating stationary sources (for the electrically powered systems) as well as that produced by moving vehicles.

Figure 2 shows the cash flow of the system operator—the annual costs and revenues associated with the operation of each system. Figure 4 compares the annual incremental costs and benefits to the entire region for each of the alternatives examined. These incremental values reflect the total annual capital and operating costs and aggregated benefits of all transportation systems in the region, including automobile as well as transit for each alternative, and are relative to the costs and benefits of the highway system. The total benefits are an aggregation of travel time savings, land value increases, tax revenue increases, and savings in household displacements. Based on the assumed dollar values assigned to quantitative impacts, all systems except dial-a-ride achieved regional benefits greater than costs. Dual mode and PRT resulted in the largest surplus of incremental benefits over incremental costs, but the benefits were obtained at the highest costs.

IMPLICATIONS OF THE ANALYSIS

The analysis suggests specific areas of effective application for each urban transportation system. That is, each system seems to have a given application in which it appears to be most attractive. These qualities of system effectiveness can be characterized by attributes such as trip length and service area trip density, as shown in Figure 5. Trips are characterized as short (neighborhood, local) versus long (across the urban area). Service area trip density varies from low (fringes between suburban corridors) to high (central business district).

A highway system—that is, the automobile—is represented by the dashed line that includes all trip lengths and almost all service area trip density categories. In high population density areas where there is congestion, the automobile is not an effective system. Throughout the rest of the range it provides fast, versatile, flexible, door-to-door, demand-actuated, attractive service to those who can afford and can operate an automobile. To those who cannot drive, a limited bus system can provide a minimal level of service.

A comprehensive bus network, with vehicles operating on existing streets with many stops, provides relatively slow service, and, even with high frequencies, results in long travel times. Only in serving short to medium trip lengths is it able to maintain relatively acceptable trip times. Medium to high trip densities are required to provide adequate load factors.

Since exclusive bus and rail rapid systems both use exclusive rights-of-way to increase trip speed, both require medium to long trip lengths to make this speed advantage apparent. Further, station spacing is typically relatively wide, essentially prohibiting short trips. At least a medium service area trip density is required to justify the cost of acquiring right-of-way and construct-

Table 3. System costs.

System	Capital Cost System	Capital Cost Vehicle	System Operating Cost	System Annual Capital and Operating Cost	System Cost per Passenger Trip	System Annual Net Revenue
Highway	1400[a]	14[b]	15[b]	17[b]	0.30	-1[b]
Comprehensive bus	70	64	64	74	0.60	-10
Exclusive bus	250	63	88	120	0.90	-39
Rail rapid	1300	82	82	210	1.60	-33
Dial-a-ride	130	110	260	280	1.40	-180
Dual mode	2400	830	120	470	1.60	+13
PRT	3400	160	160	540	2.60	-74

Note: All values are dollars, and all values are in millions except passenger trip costs.
[a]Highway and bus systems. [b]Bus system only.

Figure 2. Annual system costs and revenues.

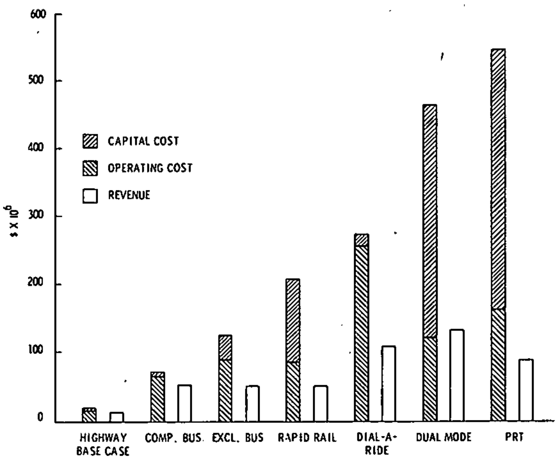


Figure 3. Annual system costs and use.

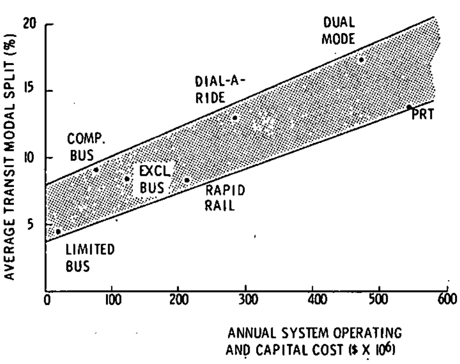
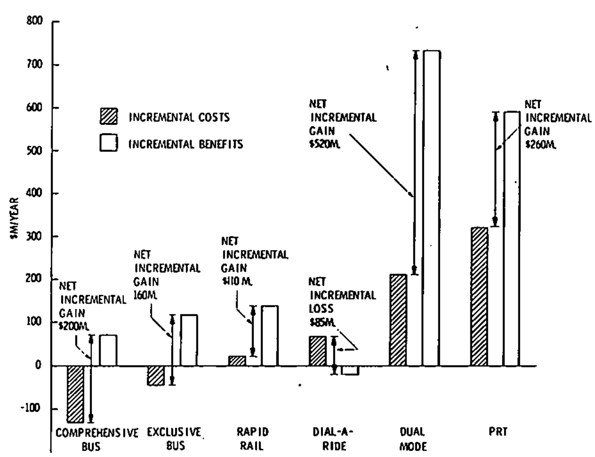


Table 4. System impacts.

System	Households Displaced	Tax Revenue Changes[a] ($)	Annual Transportation Energy Consumption[b] (pJ)	Annual Transportation Pollution Generation[b] (Gg)
Highway	17 000[c]	–	15.8[c]	24.9[c]
Comprehensive bus	20	+14	16.9	26.8
Exclusive bus	200	+22	16.9	29.5
Rail rapid	500	+24	15.8	25.4
Dial-a-ride	90	+6	16.9	26.3
Dual mode	6 100	+80	17.9	27.2
PRT	7 000	+63	17.9	26.3

Note: 1 J = 0.0009 Btu; 1 kg = 2.2 oz.
[a]Relative to highway.
[b]Goods movement not included.
[c]Highway and bus systems.

Figure 4. Annual system incremental costs and benefits.



ing exclusive guideways. At medium trip densities, exclusive bus is more attractive; increased trip densities would tend to favor rapid rail.

Dial-a-ride systems can operate most efficiently where there is relative commonality of origins and destinations for all passengers in one vehicle and minimization of diversions to accept or discharge riders. The longer the potential trips and the more diverse the possible origins and destinations are, the more difficult it becomes to achieve reasonable load factors at acceptable frequencies. Thus, dial-a-ride appears to be most suited for the service of short trips in areas with medium trip densities. Smaller vehicles and altered operating strategies may make the system applicable to lower density areas as well. With a more concentrated demand, the larger buses and more structured service of a comprehensive bus system are more economical.

A dual-mode system incorporates exclusive guideways similar to those in the exclusive bus and rail rapid systems. As described above for those systems, therefore, it is most effective for medium to long trips. Collection and distribution by the small personal vehicle are the same as the automobile, making it applicable in low to medium trip density areas. The minibus operates as a dial-a-ride collector-distributor, making it applicable in medium density areas, as described above. Since dual mode combines a highway collector-distributor with an automated exclusive guideway and since it encompasses personal vehicles and buses, it includes many of the functions carried out by the other systems examined. Thus, dual mode is, really, a combination of systems and has a broader range of effective application than any of the other systems examined except the highway.

The primary advantage of a PRT system is that it provides personal service from origin to destination (with short walks) on exclusive right-of-way. Its primary disadvantage is the requirement for the construction of an extensive high-capital-cost guideway. The capital costs of guideway are justified if they can be defrayed by heavy use of all guideway segments. Thus, PRT requires fairly high trip volumes, with diverse origins and destinations, and medium to high service

Figure 5. Effective system performance based on trip length and density.

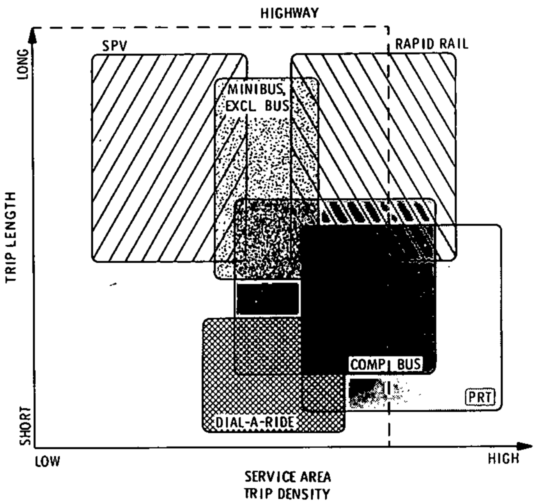
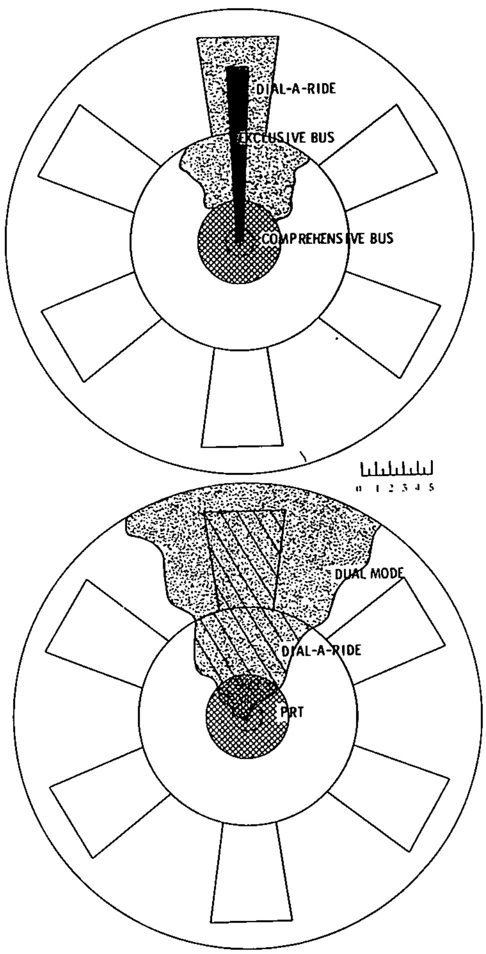


Figure 6. Examples of system combinations.



area trip densities. Such concentrations, occurring in limited areas, make the system applicable to short to medium trip lengths. Because of its exclusive guideway, use of automation, and multiorigin to multidestination, demand-actuated service, it stands out from all other systems in its ability to handle heavy traffic in highly congested urban cores.

Only a transit system combination, dual mode, made a relatively positive showing in this analysis. It is apparent from this discussion that total urban transportation needs can best be filled by a combination of systems. System combinations can be chosen (Figure 5) that may be effective as urbanwide transportation forms. An example is shown in Figure 6.

For the medium density areas, a dial-a-ride system may be effective in providing local service as well as acting as a collection-distribution system for an exclusive bus system operating in high trip density (radial and circumferential) corridors. In higher density areas, a comprehensive bus system may provide better circulation and feeder service than dial-a-ride.

Another possible approach is also shown in Figure 6. Dual-mode small personal vehicles are used for collection and distribution throughout the region, including fringes between suburban corridors. Dual-mode dial-a-ride buses provide service between origin and destination pairs with sufficient demand, and single-mode dial-a-ride buses provide feeder service to the exclusive guideway. PRT vehicles provide circulation in the core area and are used throughout the dual-mode guideway network. For trips where dual-mode (origin to destination) dial-a-ride service is not warranted, the user can take a dial-a-ride bus to the guideway and there transfer to a PRT, which goes either to the destination or to a station at which the user transfers to another dial-a-ride bus for the final leg of the journey. The network is as extensive as a typical dual-mode guideway system, with a more dense PRT network as an integral part in the core. The entire exclusive guideway network is shared by dual-mode small personal vehicles, dual-mode dial-a-ride minibuses, and personal rapid transit vehicles, thus defraying the capital cost of the fixed facilities over a broad range of users.

CONCLUSIONS

This study provided insight regarding the relative effectiveness of dual mode and other transportation systems. The conclusions reached are the following.

1. Increased transit ridership is obtained when quality and level of service are increased, which, in turn, requires greater expenditures. In general, then, transit ridership seems to vary with system cost.
2. Each transportation system seems to have a given application for which it appears to be most suited. These qualities of system effectiveness can be characterized by attributes such as trip length and service area trip density.
3. From the results discussed above, the total urban transportation needs can best be filled by a combination of systems, each of which is used in the application for which it is most suited.
4. A dual-mode system comprising both personal vehicles and buses is, in itself, such a combination, but can also be enhanced by judicious integration with other modes.