# ECONOMIC FEASIBILITY OF DUAL-MODE BUS TRANSIT SYSTEMS

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The success of several exclusive-lane bus demonstrations in effectively attracting and moving urban peak-hour commuters has brought more attention to the concept of large dual-mode buses as a realistic near-term solution to the increasing urban transportation problem. This paper analyzes the cost components and travel time relations for several configurations of such automated, large-bus, dual-mode systems in a hypothetical high service level urban transportation network. There is a twofold output: order-of-magnitude cost estimates for implementing and operating dual-mode bus systems for comparison with other types of new urban transportation systems and order-of-magnitude comparative cost estimates for various configurations within the dual-mode system. Several major conclusions are reached. The dual-mode system appears to offer high-speed, line-haul capability combined with the local street flexibility necessary in low-density passenger service areas at levels that make it attractive and economically viable. Significant travel time reductions occur with the introduction of the first 20 percent of line-haul guideway at relatively low cost. In comparison to dual-mode systems, public street nonguideway systems are less costly, but the great increases in travel time over just a 20 percent line-haul guideway would seem to make them unattractive in a cost-time trade-off. The rail rapid line-haul, feeder-bus local service configuration is proportionately more costly than a dual-mode system and, thus, would likewise fail a cost-time trade-off.

•THE success of several exclusive-lane bus demonstrations in effectively attracting and moving urban peak-hour commuters has brought more attention to the concept of large dual-mode buses as a realistic near-term solution to the economic and service difficulties of supporting effective urban transit service. A dual-mode bus system would operate on public streets as a conventional bus to pick up and discharge passengers in the trip-end portions of the route. On line-haul portions of the route it would operate as a fully automated high-speed vehicle on a grade-separated private guideway. Thus, it offers a new transportation system that combines the high-speed capability of a rail system on a private guideway over the long line-haul distances with the flexibility and adaptability of a city transit bus in the passenger pickup and discharge areas.

The combination of high-speed line-haul, public street pickup and distribution convenience, and elimination of vehicle transfers would make it possible for the dual-mode system to serve, with reasonably attractive travel times, those areas where the cost of extensive fixed guideways cannot be justified. Such a system seems especially appropriate for the peak period radial work trip from the low population density outlying residential areas to the city central business district (CBD).

This concept of public transportation as a solution to increasing radial peak-hour work trip problems has received more attention as the benefits of exclusive-lane demonstrations become more apparent. Projects such as the Shirley Highway in Washington, the Blue Streak in Seattle, and the I-495 exclusive lane in New York-New Jersey have proved to be effective methods of attracting and moving peak-hour commuters. This paper upgrades the exclusive-lane system to various configurations of an automated dual-mode bus system and analyzes the travel time and cost component relations in a hypothetical urban transportation network.

## THE SYSTEM

The hypothetical urban public transportation network designed for analysis consists of a total of 96 miles of line-haul routes, equally divided into eight 12-mile routes radiating from a presumed CBD. A system of this length was selected because it approximates several systems planned or under construction and because it offers full benefits of large-scale implementation and operation. Eighty-two stations are contained within the line-haul system when it is fully private guideway equipped. Sixty-four of these stations, eight per line, have integrally operating feeder service routes, operating on public streets, radiating from them to a 10-min travel time radius. The remaining 18 stations are located within the center city core, within walking distance of their service radius, and offer no feeder service (Fig. 1).

The dual-mode vehicles have immediate easy access and egress to and from the line-haul guideway at each station, with no passenger transfer to another vehicle required. When operating in the guideway mode, the vehicle is controlled automatically as to speed, headway, steering, and braking. Bus operators would remain with the vehicles while they are operating in the guideway mode. (Substantial labor savings could be realized here, however, because, by design, operators are not required when the vehicles are in the automated guideway mode.) The vehicle would be propelled by electric-motor supplied power from an external source on the guideway. Operating in the public street mode off the guideway, the vehicle would be electrically propelled by the same motor utilizing power stored in batteries or fuel cells. Battery-powered transit buses are now operated in Germany and have speeds up to 43 mph and a range of 40 miles. The power storage devices for our hypothetical system are presumed to be recharged concurrently with the vehicle's operation on the guideway and to store sufficient energy to operate off the guideway for the periods required in the feeder service.

The service level set for the system provides for 4,000 available passenger seats to depart from each of the network's 64 ten-min feeder zones during a 2-hour morning peak period. A like number depart from the CBD for each zone during a 2-hour evening peak period. Lower service levels are provided during the remainder of the service day. The dual-mode vehicles have been calculated to have a seating capacity of 50 passengers. A sufficient number of feeder routes are operated in each service zone to provide a bus to each of the 4,000 seated passengers within a walking distance of 1,500 ft at headways of 10 min. The 10-min service radii range from 2.5 miles at the outermost zone on each line to 1.25 miles at the innermost zone where travel congestion and population densities are higher.

It must be emphasized that these analyses in no manner consider the relations of service to demand or what demand is required to economically support the various system configurations. The purposes of the analyses are to compare the capital investment and operation and maintenance costs of alternative system configurations within a given route system, given a set service level, and to determine the travel times produced by each configuration. Thus, capacity, headways, and route-miles are held constant in these analyses. The variables are system configuration, cost, and travel time. This approach allows trade-off analyses of cost versus travel time, depending on system configuration, given a set level of service.

## COST-ESTIMATING METHODOLOGY

The unit costs assigned to the various components in these analyses were determined to be typical of several recent or proposed systems in various metropolitan areas. In most cases they are near the midpoint of the cost range for each component. Significant variances from the midpoint exist where costs of a majority of the systems examined tended to be much higher or lower than the midpoint of the range (2). The order-of-magnitude context of the paper must be emphasized, and the reader is cautioned that the costs developed for these analyses of a hypothetical system are typical of a widely divergent group of existing and proposed systems and cannot be used for estimating system costs for any specific proposed transportation system.

In costing the system components, no consideration was given to the research and development costs involved to achieve successful operational level development of the new facilities and equipment. Costs were assigned to components with the assumption that all potential cost reduction methods available or in sight were instituted and that all new technologies were operationally available. Where new technologies are required, such as the dual-mode vehicle itself, the assigned costs are based largely on current market prices of similar equipment and/or components, with an additional cost factor added in most cases.

Capital investment costs were reduced to annual capital costs by use of conventional engineering economy capital recovery factors. The rate of interest is assumed to be 6 percent. Salvage values of retired capital equipment are not considered. The assumed service lives are as follows:

| Item | Years |
|---|---|
| Right-of-way | Infinite |
| Route construction | 50 |
| Guideway construction | 50 |
| Stations | 50 |
| Yards and shops | 50 |
| Electrification | 50 |
| Vehicles | |
| Dual-mode | 15 |
| Rail | 30 |
| Diesel bus | 12 |
| Control and communication | 30 |

Although estimation of service lives in any analysis is always open to question, the lives selected here are considered reasonable for transit systems in the United States.

Operation and maintenance costs for the most part are based on the data for typical new systems, again with representative costs being at or near the range midpoint. Significant modifications were made in the dual-mode operating expense category because of the combined guideway-nonguideway nature of these systems. Cost-estimating relations for that category consider the operating cost characteristics of both modes, including nonguideway public street use tax payments in lieu of the Highway Trust Fund motor fuel tax applicable to diesel bus operation.

## ALTERNATIVE CONFIGURATION COSTS AND PERFORMANCE

Five configurations within the 96-mile line-haul route system are developed for analysis, each with the same line-haul routes and 10-min feeder zone service:

1. Rail rapid line-haul, 100 percent guideway equipped with diesel feeder bus service in each of the 64 feeder zones;
2. Dual-mode bus system, 80 percent of the line-haul portion private guideway equipped;
3. Dual-mode bus system, 50 percent guideway line-haul;
4. Dual-mode bus system, 20 percent guideway line-haul; and
5. Diesel bus system, 100 percent public street line-haul.

Capital investment costs, operation and maintenance costs, total annual cost, annual cost per line-haul route-mile, number of vehicles required, and travel times for the end-of-line passenger and for the average passenger are given in Tables 1 and 2. Because route construction in general, and subsurface route construction in particular, weighs so heavily in total system costs, three alternative subsurface, at-grade, and elevated configurations are postulated within each of the five basic comparative configurations. Vehicle requirements include a 10 percent spare-vehicle component in all fleets.

**Figure 1. Schematic representation of hypothetical urban transportation network.**

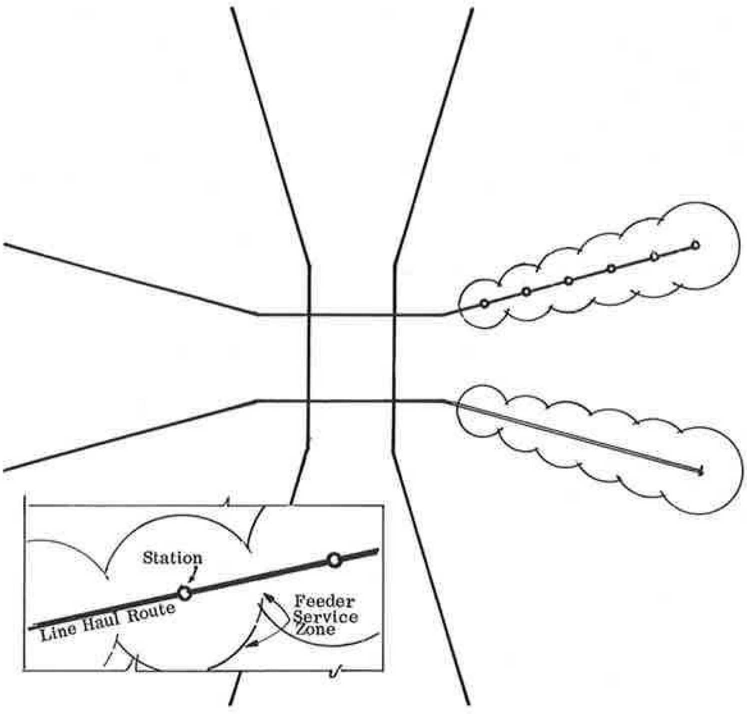



**Table 1. Comparative costs and travel times of alternative network configurations.**

| Item | Rail Rapid Transit Feeder Bus, 100 Percent Guideway, 96 Miles | | | Dual-Mode, 80 Percent Guideway, 77 Miles | | |
|---|---|---|---|---|---|---|
| | 40 Subsurface, 51 At-Grade, and 5 Elevated | 20 Subsurface, 71 At-Grade, and 5 Elevated | 96 At-Grade | 30 Subsurface, 43 At-Grade, and 4 Elevated | 15 Subsurface, 58 At-Grade, and 4 Elevated | 77 At-Grade |
| Capital investment costs (in thousands of dollars) | | | | | | |
| Right-of-way | 5,040 | 6,840 | 8,640 | 4,230 | 5,580 | 6,930 |
| Route construction | 48,659 | 30,937 | 13,699 | 37,184 | 23,892 | 10,988 |
| Guideway construction | 2,414 | 2,304 | 1,633 | 1,923 | 1,841 | 1,310 |
| Stations | 30,537 | 20,799 | 12,458 | 24,403 | 17,505 | 8,565 |
| Yards and shops | 1,956 | 1,956 | 1,956 | 271 | 271 | 271 |
| Electrification | 6,018 | 6,018 | 6,018 | 4,633 | 4,633 | 4,633 |
| Vehicles | 26,620 | 26,620 | 26,620 | 14,388 | 14,388 | 14,388 |
| Control and communication | 1,752 | 1,752 | 1,752 | 1,405 | 1,405 | 1,405 |
| Subtotal | 122,996 | 97,226 | 72,776 | 88,437 | 69,515 | 48,490 |
| Operation and maintenance costs (in thousands of dollars) | | | | | | |
| Operating expense | 40,513 | 40,513 | 40,513 | 50,456 | 50,456 | 50,456 |
| Power | 6,240 | 6,240 | 6,240 | 5,005 | 5,005 | 5,005 |
| Vehicle maintenance | 6,110 | 6,110 | 6,110 | 3,043 | 3,043 | 3,043 |
| Guideway maintenance | 3,072 | 3,072 | 3,072 | 2,464 | 2,464 | 2,464 |
| Subtotal | 55,935 | 55,935 | 55,935 | 60,968 | 60,968 | 60,968 |
| Total annual cost (in thousands of dollars) | 178,931 | 153,161 | 128,711 | 149,405 | 130,483 | 109,458 |
| Number of vehicles required | 1,056 (rail) 1,126 (diesel bus) | — | — | 2,149 | — | — |
| Cost per line-haul route-mile (in thousands of dollars) | 1,864 | 1,595 | 1,340 | 1,556 | 1,359 | 1,140 |
| Travel time (min) | | | | | | |
| End-of-line passenger | 39 | — | — | 41 | — | — |
| Average passenger | 28 | — | — | 26 | — | — |

In all cases, the line-haul route-mile cost is computed by dividing the total annual cost by 96 (the length of the total line-haul system), regardless of the percentage that the line-haul is conducted in the guideway mode versus on public streets. This is done so that the relation to travel time remains constant. The guideway in any configuration is always assumed to start at the center of the eight radial routes and radiate outward. This alleviates the slowest portion of the line-haul trip if it is conducted on the public streets. Public street line-haul average speeds range from 10 to 15 mph.

In those configurations where the number of vehicles required exceeds the practical limits of headways when loaded individually on the guideway system, it is assumed that the individual dual-mode vehicles can be combined into trains and operated on the guideway. Optimum scheduling is assumed so that minimum travel time is lost in physically assembling trains and waiting for individual vehicles in order to assemble trains.

Travel time computations include the average wait for the bus in the feeder zone (5 min), the average feeder-zone ride (5 min), transfer time if required (2 min), dual-mode train assembly time, and line-haul travel time. Walk time to the bus in the feeder zone and walk time to the destination are not included. The following analyses and comments are based on system configurations of approximately 40 percent subsurface guideway and 60 percent at-grade or elevated.

Tables 1 and 2 and Figure 2 show that travel times are considerably reduced when the guideway mode is introduced to alleviate the slower portions of the line-haul trip. For the end-of-line passenger, the total trip time is reduced from 82 min on a totally nonguideway system to 54 min on a system equipped with private guideway for 20 percent of the line-haul portion. This 28-min reduction for a 20 percent line-haul private guideway constitutes a reduction of 34 percent in travel time. Extending the guideway to 50 percent of the line-haul reduces end-of-line travel time to 47 min, a reduction of 35 min (43 percent). For the average passenger on the system—the passenger at the median of all feeder service passenger travel times—travel time is reduced by 14 min (27 percent) by the introduction of the 20 percent line-haul guideway. Extending the guideway to 50 percent reduces travel time from 52 to 27 min, a reduction of 25 min (48 percent).

The average passenger gains a reduction of only 1 min by extension of the guideway beyond 50 percent because at 50 percent his line-haul trip is almost completely on the guideway mode. The end-of-line passenger, of course, continues to gain a reduction in comparative travel time with every addition to the guideway portion. It is important to note that the significant reduction in travel time for the end-of-line passenger occurs in the introduction of the first 20 percent of guideway.

The costs associated with achieving these reduced travel times for the end-of-line passenger and the average passenger are also given in Tables 1 and 2 and shown in Figure 3. Here we see that the significant reductions in travel time effected by the introduction of the first portions of the guideway occur at relatively low cost in comparison to the latter additions of guideway, which reduce travel time at a much lower rate.

The analysis of percent line-haul guideway versus cost is continued in Figure 4, which shows the relation of annualized investment costs and operating and maintenance costs. Although annualized investment costs increase with increases in percentage of guideway, it is especially useful to note here that operation and maintenance costs decrease approximately 27 percent between the nonguideway configuration and the full guideway line-haul configuration. This reduction in operation and maintenance costs occurs primarily because the lower trip times on the guideway mode produce higher vehicle efficiencies and allow smaller vehicle fleets. This can be a very important factor in system configuration decision-making when considering long-range operation and maintenance costs because it is these costs that are subject to escalation in future years, especially in the area of labor costs. Nonguideway configuration vehicle requirements are nearly 50 percent greater than the 80 percent guideway dual-mode configuration requirements, which directly require a much greater labor component subject to wage escalation. This would seem to bear out recent planning criticisms that more consideration should be given to operation and maintenance costs when evaluating total system costs and trade-offs.

Table 2. Alternative network configuration costs and travel times.

| Item | Dual-Mode, 50 Percent Guideway, 48 Miles: 20 Subsurface, 25 At-Grade, and 3 Elevated | Dual-Mode, 50 Percent Guideway, 48 Miles: 10 Subsurface, 35 At-Grade, and 3 Elevated | Dual-Mode, 50 Percent Guideway, 48 Miles: 48 At-Grade | Dual-Mode, 20 Percent Guideway, 19 Miles: 19 Subsurface | Dual-Mode, 20 Percent Guideway, 19 Miles: 9 Subsurface, 8 At-Grade, and 2 Elevated | Dual-Mode, 20 Percent Guideway, 19 Miles: 19 At-Grade | Nonguideway Street Transit Bus (public streets) |
|---|---|---|---|---|---|---|---|
| Capital investment costs (in thousands of dollars) | | | | | | | |
| Right-of-way | 2,520 | 3,420 | 4,320 | 0 | 990 | 1,710 | – |
| Route construction | 24,281 | 15,420 | 6,849 | 19,547 | 10,493 | 2,711 | – |
| Guideway construction | 1,263 | 1,208 | 816 | 427 | 597 | 323 | – |
| Stations | 15,065 | 11,008 | 5,321 | 9,104 | 6,263 | 2,206 | – |
| Yards and shops | 291 | 291 | 291 | 354 | 354 | 354 | 382 |
| Electrification | 2,888 | 2,888 | 2,888 | 1,191 | 1,191 | 1,191 | – |
| Vehicles | 15,452 | 15,452 | 15,452 | 18,853 | 18,853 | 18,853 | 13,332 |
| Control and communication | 876 | 876 | 876 | 347 | 347 | 347 | – |
| Subtotal | 62,498 | 50,425 | 36,813 | 49,823 | 39,088 | 27,695 | 13,714 |
| Operation and maintenance costs (in thousands of dollars) | | | | | | | |
| Operating expense | 49,852 | 49,852 | 49,852 | 55,879 | 55,879 | 55,879 | 60,560 |
| Power | 3,120 | 3,120 | 3,120 | 1,235 | 1,235 | 1,235 | – |
| Vehicle maintenance | 16,156 | 16,156 | 16,156 | 19,712 | 19,712 | 19,712 | 15,140 |
| Guideway maintenance | 1,536 | 1,536 | 1,536 | 608 | 608 | 608 | – |
| Subtotal | 70,664 | 70,664 | 70,664 | 77,434 | 77,434 | 77,434 | 75,700 |
| Total annual cost (in thousands of dollars) | 133,162 | 121,089 | 107,477 | 127,257 | 116,522 | 105,129 | 89,414 |
| Number of vehicles required | 2,308 | – | – | 2,816 | – | – | 3,028 |
| Cost per line-haul route-mile (in thousands of dollars) | 1,387 | 1,261 | 1,120 | 1,326 | 1,214 | 1,095 | 931 |
| Travel time (min) | | | | | | | |
| End-of-line passenger | 47 | – | – | 54 | – | – | 82 |
| Average passenger | 27 | – | – | 38 | – | – | 52 |

Figure 2. Effect of guideway on travel time.

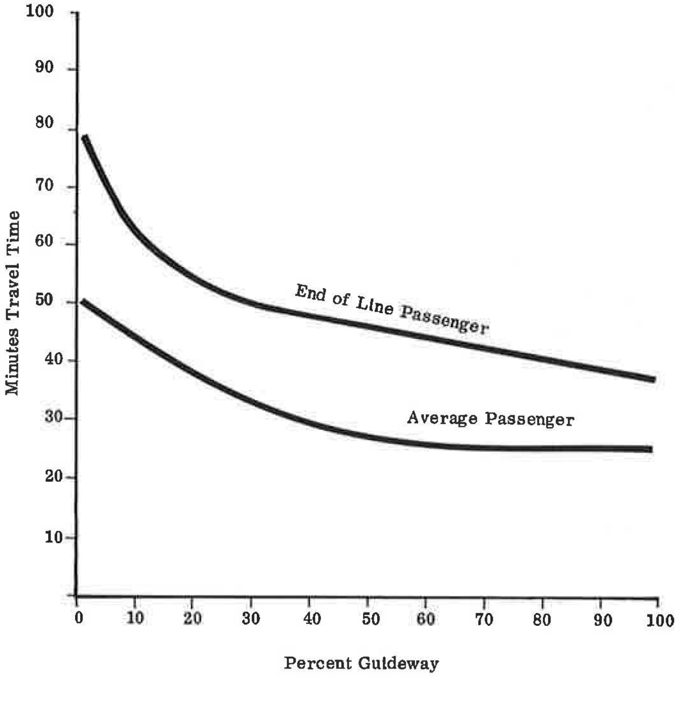


Figure 3. Annual cost of travel time levels.

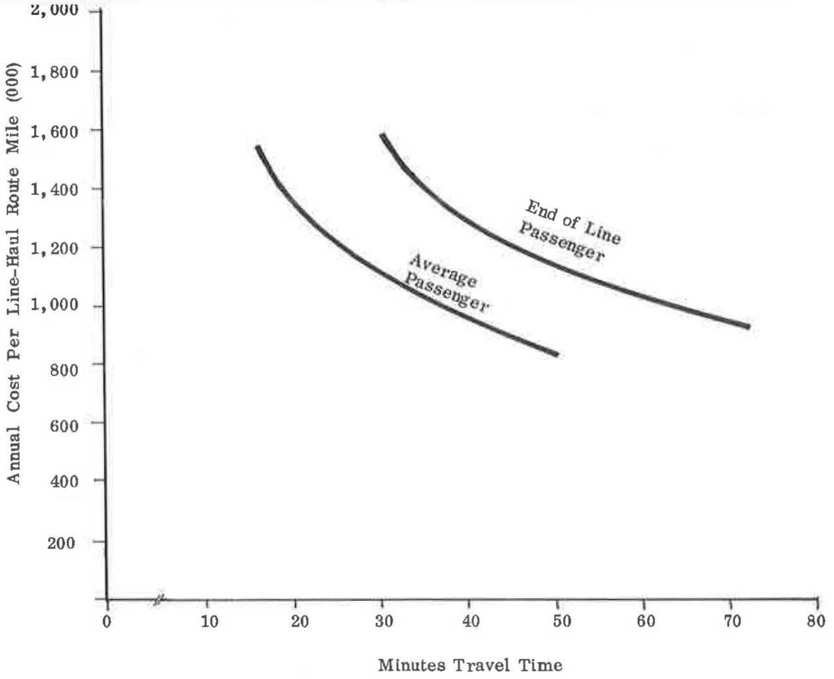
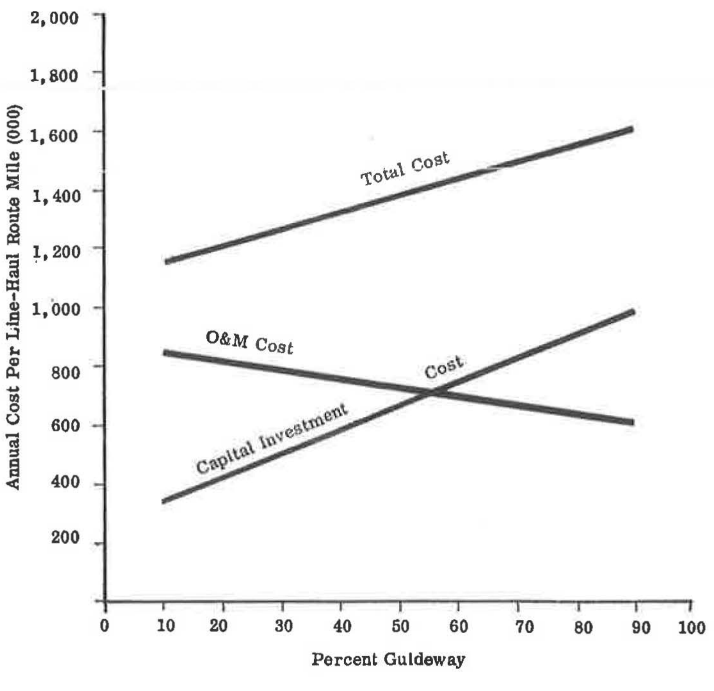



Figure 4. Effect of guideway on annual cost.



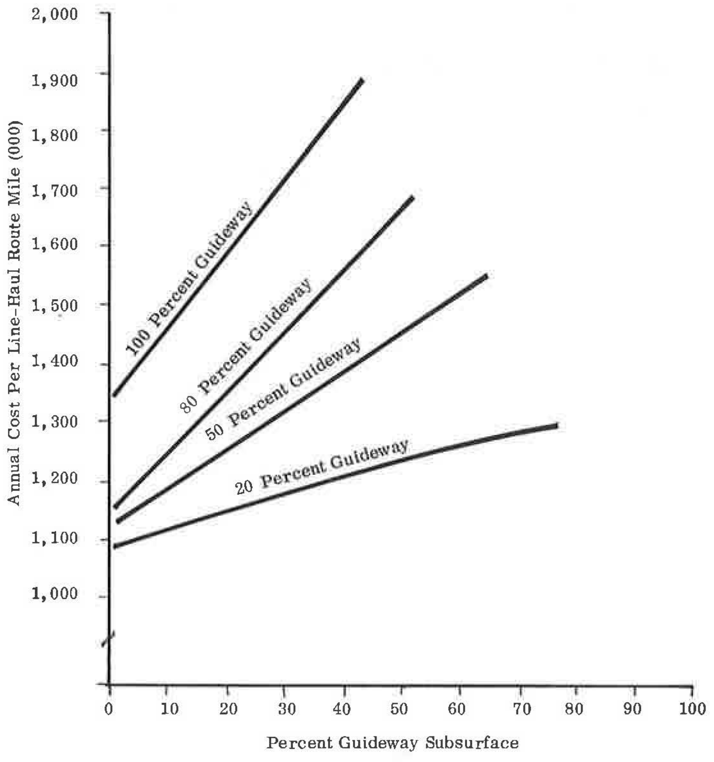
The importance of route construction costs, especially the single subcomponent of subsurface (tunnel) route construction, in total system investment costs is well known. In some recent urban rail systems, total route construction costs make up 40 to 55 percent of total system capital investment costs. In these systems subsurface route construction alone typically represents 35 to 50 percent of total system investment costs. The cost relations of the various line-haul guideway configurations to the percentage of subsurface route construction in our system are shown in Figure 5. Costs are seen to increase greatly in the higher percentage guideway configurations when subsurface construction is used to a large extent.

When comparing the costs of the three types of route construction, at-grade, elevated, and subsurface, one should note that, when route construction and guideway construction are combined, at-grade and elevated systems costs are approximately equal. Subsurface systems costs, in contrast, are approximately six times greater than those of at-grade or elevated systems. The same relations are true in general for at-grade, elevated, and subsurface stations.

## CONCLUSIONS

The purpose of these analyses was twofold: to develop cost estimates of dual-mode transit systems for comparison with other types of urban public transport systems and to develop cost comparisons of various configurations within a dual-mode system, which could be applied in general to other types of urban public transport systems. In drawing conclusions from these analyses, several factors affecting urban transportation system cost immediately become evident. First, the dual-mode system does appear to offer high-speed line-haul capability combined with the flexibility and adaptability necessary in low-density passenger pickup and discharge areas at relatively low increased cost. Significant travel time reductions occur with the introduction of the first 20 percent of guideway at relatively low cost in comparison to later additions of

**Figure 5. Effect of subsurface guideway construction on annual cost.**



guideway, which reduce travel times at a much lower rate.

The advantage of dual-mode transit in not requiring the passenger to transfer to another vehicle when entering the line-haul portion of the trip is not of significant importance in overall trip travel time reduction. It could be very important, however, in eliminating the negative factor of the inconvenience of physically transferring from one vehicle to another and the interrupting waiting period involved therein, as is encountered in subway-feeder bus systems.

In comparison to dual-mode systems, public street nonguideway systems are less costly, but the great increases in travel time over just a 20 percent line-haul guideway would seem to make them unattractive in a cost-time trade-off. The rail rapid line-haul bus-feeder service configuration is proportionately more costly than a dual-mode system and, thus, would seem to also fail in a cost-time trade-off.

It is clear that long-range operation and maintenance costs should receive serious analysis in system planning, especially in those aspects subject to escalation. Likewise, it is clear that subsurface construction, such as that involved in typical urban subway systems, is the one design variable that contributes most heavily to increased cost. Significant cost reduction can be achieved by minimizing subsurface construction.

## ACKNOWLEDGMENT

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