Costs of Urban Transport Systems of Varying Capacity and Service

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This report defines a framework for properly conducting cost analyses and utilizing the results for decision making, and roughs out "cost boundaries" for evaluating present-day technologies by establishing, on an analytical basis, the situations and conditions under which particular forms of transport offer cost or service economies.

The central focus of the cost analyses was provision of services to commuters traveling between home and downtown work places during the so-called rush hours. The systems analyzed include the principal transport modes, and incorporate high-performance and volume-carrying capabilities seldom encountered or needed on other than urban, radial, CBD-oriented transportation facilities. The hourly passenger volumes analyzed range from 5,000 up to 50,000, include costs for 6-, 10-, and 15-mi route lengths, and account for cost variations resulting from changes or additions in service and capacity (such as changes in schedule frequency, or the addition of "outbound" or minor flow direction capacity, or "along-the-line" capacity).

Costs per passenger trip are provided for the principal trip functions (residential collection, line-haul, and downtown distribution), both separately and in combination, and for each of the variables listed.

•THE PURPOSES of this paper, and the research underlying it, were (a) to define a framework and methodology for costing alternative urban transport systems such that they can be fairly and reasonably compared; (b) to identify the service and design variables which most intimately affect the relative cost structure and attractiveness of various transport systems; and (c) to specify as closely as possible the conditions under which particular forms of transport seem to offer lowest cost transportation. The last of these three objectives was accomplished by comparing the costs of alternative modes of transport whereby the required passenger volumes and service levels for each of the modes were equivalent (or at least reasonably so).

The results of the costing analysis, and the conclusions stemming therefrom, are probably valid only to the extent that the unit costs are representative or typical of expected conditions. Therefore, the generality of the analysis is restricted. Nevertheless, the wide range of volumes, route lengths, and types of transport service analyzed tends to offset the restriction and lend considerable support to the overall programing task.

COST ANALYSIS: PROCEDURES AND ASSUMPTIONS

A central purpose and objective of the cost analyses included in this study is to provide some perspective for the (relative) cost comparison problem, and to properly define the framework for conducting cost analyses and utilizing the results for decision making. A correlated objective of the costing is to rough out the boundaries for present-day modal technologies, to establish the general situations and conditions under

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which particular forms of transport appear to offer cost or service economies, and to define more particularly the trade-off between cost and service.

Functional and Technological Systems and Components Costed

Although this analysis is general enough to apply to any situation which has comparable volume and service conditions, it nevertheless has as its primary focus the downtown to-and-from home, rush-hour movement. Seldom, for example, do other than urban radial, downtown-oriented transportation facilities mass passenger volumes so large as to approach the volume levels considered. The analysis included hourly passenger volumes from 5, 000 up to 50, 000; by contrast, peak-hour volumes even on heavily traveled Massachusetts Route 128 approach only 10, 000 passengers. On the densest portions of the Jones Beach (N. Y.) Parkway and the New Jersey Turnpike, perhaps as many as 10, 000 passengers travel during peak hours.

Another way of highlighting the difference in density of downtown-oriented travel and that outside the downtown area is to note that in Chicago the downtown (or central) area consists of just over 1 percent of the region's land area, but attracts almost 8 percent of the region's person-trips, accounting for about 16 percent of the regional person-miles (1). Two things should be noted from these data, however. First, the extreme densities of the downtown area certainly account for the massive hourly volumes on radial facilities leading into and out of the area. Second, and of perhaps greater importance, in terms of total passenger movements (i. e. , daily and hourly passenger trips and passenger-miles) the downtown-oriented travel hardly represents the total urban transportation problem. As a consequence, attention devoted exclusively to the downtown rush-hour movement and improvements proposed primarily or exclusively for this portion of the total urban area movement are likely to fall short of solving the urban transportation problem and will, in all probability, represent suboptimal investments.

These remarks are intended merely to re-emphasize that neither the system designs nor the cost analysis in this paper is aimed at urban area transportation in its entirety, but only one small part of it. In fact, the downtown rush-hour movement is the simpler part of the more general problem, and thus lends itself to more straightforward analysis, because of the more intensive focus of downtown destinations (i. e. , lack of many destinations with large time and space separations) and the somewhat uniform distribution of origins along radial paths.

By the way of considering various transport systems for downtown movement, the total home to-and-from downtown trip pattern was separated into its functional components of (a) residential collection service, (b) line-haul service, and (c) downtown distribution service. The residential collection portion of the system serves to collect and distribute travelers at the residence or home end of downtown trips, and may be characterized as local service which feeds passengers onto the line-haul subsystem. The residential collection system movement requires an entirely separate feeder service (and a passenger transfer) for some of the technological systems, though others (such as auto travel from home, to and from work) provide continuous movement with no transfer at the intermediate point or junction between residential collection and line-haul systems.

The major portion of the home-downtown trip is traveled over the line-haul system, a grade-separated, high-speed, and high-volume transportation facility operated on private rights-of-way on which access is limited to one-mile stations or ramps. Through movement without transfer is provided on the line-haul system between the line-haul entering station and the downtown area discharge point (and vice-versa). The downtown distribution function wherein passengers are moved between their downtown discharge point and final destination may, of course, be handled in a number of ways, such as by walking, private auto, taxi, or transit service, the last three using either the city street system or grade-separated (subway or elevated) facilities. Also, the downtown distribution system may be directly connected with the line-haul system and thus provide "no transfer" service, or may operate as a completely separate function.

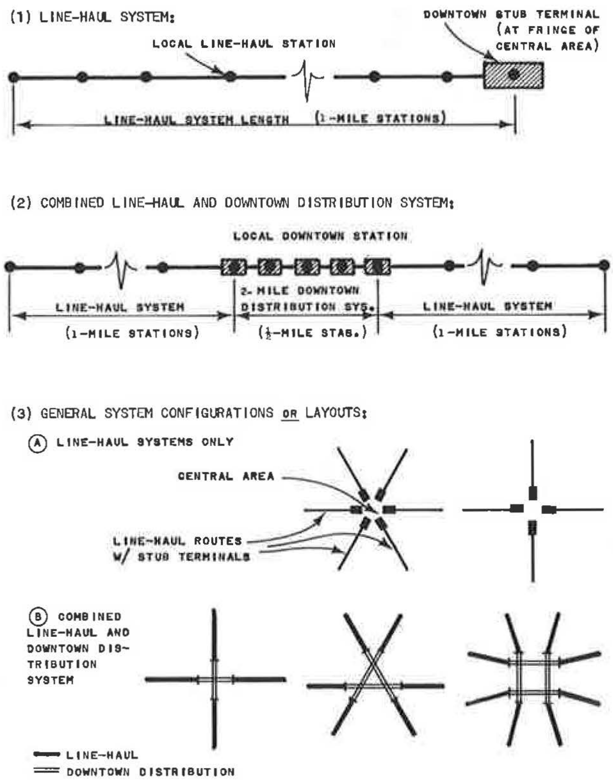

Figure 1.

The general layout of the line-haul and downtown distributions for each leg or route is shown schematically in Figure 1, parts (1) and (2). Part (3) of Figure 1 shows some general configurations for integrating several line-haul legs or routes, or several combined line-haul and downtown distribution routes, into larger-scale and perhaps regional rapid transit systems for downtown movement.

Certainly the passenger has his primary interest and concern with the total trip, and thus with all three trip functions—residential collection, line-haul and downtown distribution. Even so, it is advisable to make distinct separations between functions and to segregate the system design and costing into these three parts, at least initially. If this separation is made, and if the costs are determined for each functional component, it will be possible to assess the cost of providing different types of service, of eliminating transfers, of eliminating waiting time at feeder bus stops, etc. Consequently, the analysis and costing have proceeded in steps, with each successive section introducing an additional function. The design and costing steps were as follows:

1. Line-haul system with downtown stub terminals at fringe of core.
2. Residential collection system operating independently and separately from line-haul system (for bus and private auto only).
3. Residential collection system integrated with line-haul system to provide "no transfer" service (for bus and private auto only).
4. Downtown distribution system (underground) integrated with two-connecting line-haul systems to provide "no transfer" service.
5. Combined downtown distribution (underground), line-haul, and residential collection system, all connected and integrated to provide "no transfer" service between home and downtown (for bus and private auto only).
6. Combined downtown distribution (on city street system), line-haul, and residential collection system, all connected and integrated to provide "no transfer" service between home and downtown (for bus and private auto only).

Analysis of the line-haul system (Item 1), and of the combined line-haul and downtown distribution systems (Item 4), was made for private automobile travel, for bus transit, and for rail transit travel. The costs for separate feeder bus service, for "park 'n ride," and for "kiss 'n ride" service over the residential collection system (Item 2), were computed, and when combined with the rail transit line-haul system cost (Item 1), or the joint (integrated) line-haul and downtown distribution system cost (Item 4), permit determination of the total home-downtown passenger trip costs for rail transit travel. These total rail transit costs can, in turn, be compared with those of bus transit travel and private auto travel (Item 5) to provide relative if not absolute cost comparisons for downtown travel for various volume levels and route lengths. Furthermore, where there are apparent service differentials between the modes these may be related to the cost differentials (if any) to determine by imputation the "value of service" (given, of course, that decision makers would prefer to make the additional expenditures to gain the extra service).

Specification of Urban Transportation System Service and Design Variables

Each community obviously has its own set of travel conditions, its own land-use pattern, economic level, and thus its own unique transport system requirements. Simply, travelers in one community may be unable or unwilling to afford the same level or quality of transportation service as another. Thus no "optimum" or best system or mode, or even level of system investment, can be ascribed for all situations. (The same result can derive because of differences in topography, geology, land use, etc.) Even so, it is reasonable—and probably necessary—to specify the broad limits and conditions under which certain system designs and technologies generally are most economic. This will aid in the selection of the "most reasonable" system alternatives (in terms of layout, mode and service) for deeper and more intensive investigation by individual communities, and in a sense guarantee against failure (for any of a number of reasons) to consider certain systems of high potential.

In specifying the particular systems which would be costed in this study, it was necessary to consider many design and operating variables and to account for the performance or service capabilities of the system. Purposefully, the system design does not correspond to many, if not most, currently familiar transport systems generally in operation. For indeed, if one never considered building or operating a transportation system different than that of today or than that of long experience, no mechanism would exist for assuring that current operation was "best" or even "near best" and little improvement could be expected over the years.

Certainly there are an unlimited number of choices open for consideration by the engineer or planner in the process of searching for the "best" system. Although this severely complicates the design and evaluation process, it nevertheless points to a critical responsibility of professionals—that of considering all alternatives of high potential rather than just the design that is intuitively felt to be best.

In this respect, many transportation professionals have in a real sense failed; that is, they have seldom included evaluations of systems different from the norm, systems of varying operation or service. Too often they have arbitrarily concluded that certain kinds or amount of transport service must be provided, without measurement and evaluation of the consequences of not providing the service.

As is pointed out in some detail in later sections, the cost analysis conducted for this report is not directed at the urban transportation problem, nor does it necessarily define or include the "best" design (at any given volume level and route length). Although it is common for many professionals to view the downtown rush-hour movement as the urban transportation problem, it must be emphasized that such is not necessarily the case. Perhaps, for example, it would be better or more feasible to make no further investments within and to or from the downtown area and to continue putting up with present levels of congestion, discomfort, inconvenience, and expense.

Rather than being directed at the entire urban transportation question, this cost analysis has been narrowly restricted to what is principally the downtown rush-hour movement problem, not because it seems to represent the highest potential for profitable transportation investment, but simply because it has received the most attention and controversy. Furthermore, this treatment does not permit determination of the "best" system, or evaluation of the profitability of any of the alternatives considered. No conclusions can be drawn about the latter merely because all reasonable service levels were not costed, all types of service were not included, and no interaction with demand was considered. Thus, questions of feasibility can be subjected only to qualitative judgment, inasmuch as the supply side was treated (analytically) without regard to questions of demand.

The essence of the costing procedure was to design and cost different technological systems for carrying specific passenger volumes under the same conditions of service; put another way, the question is asked: What would it cost to move specific passenger volumes between specific points and at specified speeds (and other service conditions) by different technological systems? Obviously, this should not be interpreted to mean that the demand for or use of the system (if it were built and operated as designed) would in fact be the same as the volume level for which the system was designed and costed (although such remains a possibility). Thus, this is merely a statement as to what it would cost to own and operate a particular system under specific service or operating conditions and if a specific passenger volume did in fact move between specific points.

The preceding remarks hopefully have emphasized the rather obvious notion that the specific cost data may be considered precise only for the assumed conditions of service, volume, and design. Change the input variables—the volume levels, the route lengths, the design speed, the schedule frequency, etc. —and the costs will invariably change. Even so, this does not necessarily mean that the relative cost position of the technological systems will change. Thus the data probably are most useful in the sense of describing general and broad limits for cost relativity.

In selecting various systems for costing, in terms of both design and service variables, an attempt was made to describe somewhat realistically the current and perhaps near future transportation market and consumer preference patterns for what is principally the rush-hour, home to-and-from downtown movement. The major input variables in this respect are transport type, hourly volume level (and its O-D pattern and distribution), route length, station (or ramp) spacing, overall trip speed, schedule frequency, and seating space (or comfort level).

For all but three of these design and service variables—transport type, volume level, and route length--only one set of input data was costed; but for certain specific route lengths and volume levels, abbreviated cost data were prepared for other service conditions. Again, this is not to say that other sets of input data would or would not prove more economic, but rather a limitation imposed by the time and cost restrictions under which the research was conducted. Obviously, more than one volume level and route length were chosen for costing in order to render the analysis applicable to more urban situations.

The choice of specific volume levels, although arbitrary, was directly related to available peak-hour cordon count data for most urban downtown or core areas throughout the nation. In the 25 largest metropolitan areas in the United States, only one city (New York) encounters peak-hour passenger volumes in excess of 250, 000 and only three cities experience volumes in excess of 150, 000. Placing these data on an approximate sector or corridor basis such that a better description is provided for defining corridor or radial transportation facilities, it is apparent that existing corridor or sector peak-hour passenger volumes (excluding New York City) range from 3, 000 or 4, 000 up to 40, 000. Eliminating the three largest cities (in terms of peak-hour downtown passenger volumes), it is important to note that the largest or maximum corridor volume approaches only 30, 000 passengers per hour, and that virtually all cities are far below the 20, 000 level. It would seem, then, that the general corridor volume limits of 5, 000 to 50, 000 passengers per hour would include virtually every American urban area situation and perhaps include an allowance at the high volume level for extremely high peaking situations or potential growth. In addition to the 5, 000 and 50, 000 volume levels, costs were included for intermediate volumes of 10, 000, 20, 000, and 30, 000 passengers per hour (for a corridor).

Two aspects concerning the volume characteristics which were used in the design require discussion. For the initial cost computations (the cost computations made for all six volume levels and three route lengths--18 combinations in all; however, the effects of including additional transport services, but only for a single volume level and route length, are described later in this report), the following conditions were generally assumed:

1. Hourly passenger capacity would be required and provided only in the major flow direction. (Thus, in a morning peak hr, for example, no outbound capacity would be provided.)
2. Hourly passenger flows entering (or leaving) the 1-mile line-haul stations would be destined for (or originated at) the downtown area. (Thus, in a morning peak hour, for example, no passengers would enter at an outlying station and depart from the line-haul system at a station prior to reaching the downtown area.) Although no "along-the-line" movement was assumed, the system was nevertheless designed so that little additional rail or bus transit equipment, labor, or facilities would be needed to provide this service.
3. Hourly passenger capacity would be provided for a 2-hr period in the morning and a 2-hr period in the afternoon; no passenger capacity would be provided during other hours.

Many will voice concern about these assumptions, and assert that "... this assumption makes the whole study of a purely academic nature... " and that "... no such method of operation is or would be used."

The most disturbing feature about such comments is that many transit operators and highway engineers advocate a purely status quo system design and operation; the feeling seems to persist year after year that the "only way to run a railroad is the way we run a railroad," and that we must continue to provide certain transport services just because we now provide them.

Although there are strong political arguments for such a philosophy, and although there may even be strong economic justification for such, it is nevertheless the burden of the transportation engineer to prove the point. It is his responsibility to determine what it will cost to provide certain services and to determine whether or not the public is willing to pay the costs, for whatever reasons it may prescribe. In short, it is not absolutely necessary to provide outbound passenger service, or so-called "along-the-line" service, or even off-peak-hour service.

Thus, it is the objective of this analysis to first determine the costs of basic or "barebone" downtown-home, rush-hour movement, and then to determine the incremental costs of providing additional transportation services, such as outbound or along-the-line travel.

The first two assumptions listed do not restrict the peak-hour transportation service as much as might be suspected. Regarding passenger service in the minor flow direction during peak hours, conditions vary from city to city, and from line to line. In the Pittsburgh study, for example, at the maximum load point for the system as a whole, the minor direction volume (as a percentage of the total two-way peak-hour volume) was about 15 percent for transit travel and about 25 percent for private auto travel; at the central area, though, the minor direction volume was only 10 percent of the total two-way peak-hour flow (2). At the maximum load point for three major lines of the Washington, D. C., bus transit system, the outbound volume during the morning peak hour is about 16.5 percent of the total two-way volume. Data for rail transit lines are usually indicated between 10 and 15 percent of the two-way flow (Table 1). The importance of these data is simply to point out that outbound or reverse flow volumes are often not significantly high, relative to the inbound flow, during morning peak hours. In a later section, the costs of providing this minor direction capacity or service will be noted for a single volume level and route length to permit a more exact assessment of the relative economics of its inclusion.

As for the provision of "along-the-line" service, little demand presently exists for such service on rail transit systems, and seldom exceeds 10 percent of the total corridor flow (Table 1). Nevertheless, both the bus and rail transit line-haul systems have been designed, and their performance and equipment requirements calculated, on the basis that along-the-line service could be provided for travelers moving in the major flow direction with little additional equipment requirements in meeting this additional service condition; thus, equal overall average speeds were provided for both bus and rail transit modes while including along-the-line stops for both modes. A relevant question is, of course, how much lower would the bus system costs have been if the along-the-line restriction had not been included? (That is, if the buses were operated at their top speed capability and were not restricted so that along-the-line stops could be made, how much would the utilization rates have been increased, and the equipment and labor costs reduced?) There would be one important difference in the character of the along-the-line service offered by rail transit and that offered by bus transit. The nature of the rail transit operation is such that along-the-line service would be identical with the through (or downtown-oriented) service in terms of both speed and schedule frequency. However, for bus transit along-the-line service, every bus would not stop at every line-haul-station along the route (as the rail transit trains would), but would generally stop at every other line-haul station. Consequently, the average bus headway for along-the-line passengers would generally be twice the headway for downtown-oriented passengers entering at line-haul stations.

TABLE 1

PERCENTAGES FOR OUTBOUND (REVERSE) FLOW AND ALONG-THE-LINE TRAVEL DURING AM PEAK HOUR[a]

Rail Transit System and Line	% of Total[b] Moving Outbound[c]	% of Inbound Departing Prior to Downtown[d]
New York City:		
Manhattan-Brooklyn	8	NA
Bronx-Manhattan	11	NA
Queens-Manhattan	7	NA
East-Westside, at 60th St.	12	NA
Chicago:		
Congress-Douglas Park-Milwaukee	21	13
North leg of North-South	40	NA
South leg of North-South	13	NA
Cleveland:		
Westside	NA	4
Eastside	NA	9
Both	14	6
Toronto, Yonge St.	10	30
Philadelphia, entire system	23	NA

[a]NA = not available. [b]Total two-way flow. [c]Reverse flow; data from transit authorities (letters to author). [d]"Along-the-line" travel (3).

The last of the three assumptions on volume characteristics was that pertaining to the provision of passenger capacity only during the morning and afternoon rush-hour periods, each of 2-hr duration. Although this assumption has been subjected to repeated criticism, it nevertheless remains as one of the least critical assumptions in this study from the standpoint of determining the relative costs of providing transport by one mode of travel or another, particularly when comparing the two transit modes.

This cost analysis has not assumed the simultaneous existence of three kinds of systems (or three modes of travel), each offering a different character of service and all built and operated in the same corridor, and then attempted to stratify the travel movement and to split trips among modes. Rather, it has asked: If one system or another were built to handle given passenger volumes, and if each system were built to provide equivalent service (or what seems equivalent), which would cost the most and which the least? And it is asked how the relative cost would change with differences in route length and volume level, etc.

The relative costs of alternative systems of equivalent service can be computed and meaningfully compared on any time basis desired, whether it be 4 hr, or 24 hr, or a year, so long as all the volume and service characteristics for all systems are kept equal during the period of comparison. To the contrary, the relative costs of different systems have little meaning when either the volume or service characteristics are not controlled; herein lies the distinct failure of virtually all existing cost comparisons. (There are many examples of this in the literature. One might be to compare the cost of building and operating an urban highway system for moving downtown-oriented and cross-regional or circumferential trips with the cost of building and operating a transit system for moving only downtown-oriented or radial-type trips; here, of course, there would be no control on the volume characteristics, either in terms of volume level or O-D pattern. As for controlling service characteristics, this aspect is virtually always ignored—incorrectly, of course. Riding in comfortable automobiles, while seated and out of the cold and rain, can hardly be considered equivalent service with waiting even only 5 min for a transit vehicle, in which one-third or one-half of the passengers must then stand.) If both conditions are met, and if both volume and service are controlled, then use of a 24-hr period rather than just four rush hours for costing will not alter the relative costs, although it is likely that the absolute costs would be lowered in most cases.

It is appropriate to ask, though, how the relative and absolute costs for each of the four-rush-hour, downtown-oriented travel systems would change if they were built and if the off-peak-hour volume and service characteristics for all regional travel were not controlled. The answer to this question involves, unlike the (supply) cost analysis conducted, consideration and evaluation of both supply and demand. First, to the extent that the assumptions regarding equivalent service were correct, the cheapest or lowest cost system would experience the highest demand for downtown-oriented passenger travel, and the highest cost system the lowest demand; where the costs were equal, the demand would be equal for the systems. Similarly, during off-peak hours the relative demand pattern for downtown-oriented travel would remain the same as that during the peak hours, providing of course that equivalent service was retained for the three systems, and providing the relative cost structure for the systems remained the same. This, of course, is an assumption that is hard to validate without actually examining the detailed cost structure. Although the additional transit expenditures—both capital and operating—would be quite small compared to the peak-hour costs, the same might hold true for auto travel, but for different reasons.

However, for non-downtown-oriented travel, it is evident that the service for various cross-town types of trips would not be equivalent for all systems, particularly because of the extensive and interconnected city street system, which provides local access to the residential areas and which spreads across the region. This service differential certainly would be a major factor in the determination of the actual demand or use that each of the systems would experience during the off-peak hours. Thus, the combination of the differing volume and service characteristics during off-peak hours would probably result in different demands for the systems even if the costs were equal for all modes. The importance of this cannot be overstated,

TABLE 2

COMPARISON OF RUSH-HOUR TRAVEL BY VARIOUS TYPES OF FACILITY[a]

System or Transit Facility	% of Total Daily Volume Traveling During Four Peak Hours
Rail transit systems:	
New York City	49
Chicago	58
Toronto	51
Cleveland	58
Philadelphia	58
Bus transit systems:	
Chicago	40
Washington, D. C., 3 major lines	53
Highway systems, in vehicles:	
Chicago	32
Detroit, Ford-Lodge Expressway	28
Chicago, Congress St. Expressway	30
Washington, D. C., Memorial Bridge	44
Boston, Route 128	29
Railroad commuter systems:	
Chicago	72
Washington, D. C., Pennsylvania RR	68
Philadelphia, Pennsylvania RR	68

[a]Data generally apply to 1960-1962 traffic and flow counts; but the Pennsylvania RR commuter figures are for 1958.

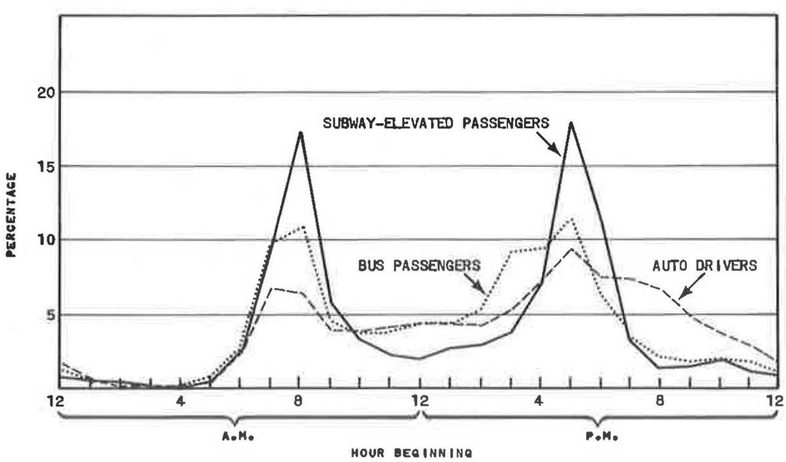

Figure 2. Hourly volume as a percentage of total daily trip volume of each mode—Chicago, 1956.

and that these differentials do in fact occur is evidenced by data on the distribution of passenger volumes throughout the day by mode of travel; that is, by differences in peaking that occur for different modes of travel (Table 2 and Fig. 2).

These data generally indicate that for off-peak travel, which includes most of the non-downtown-oriented travel throughout the region, substantial differences do exist between the modal systems—otherwise the degree of peaking (i. e., percentage of daily travel during the four peak hours) would remain the same for all modes. Essentially, the systems with higher peaking percentages (such as railroad commuter and rail transit) must offer less overall regional travel flexibility and service than those with less peaking (such as bus transit and auto travel). The net result of extending the cost analysis to a 24-hr period instead of 4-hr rush period costing, and of including all regional trips--both downtown- and non-downtown-oriented travel—would certainly be to reduce off-peak costs (on a relative basis) most for auto travel, followed by bus transit, and then rail transit. (The long-distance railroad commuter data are included in Table 2 only for comparative purposes, as this type of travel has not been included in this study.)

Of equal importance in this costing with regard to the time period of analysis is the matter of for whom the system costs are incurred, and therefore to whom they must be attributed. If the basis of design and justification of downtown-oriented systems is to be the rush-hour flow, and this seems particularly true in the case of rail transit systems for downtown-oriented rush-hour movement, then the full costs for providing that service must be attributed to those rush-hour travelers; or to put this another way, if the rush-hour downtown movement was not as massive and highly peaked as it is, but was at the same level as the off-peak-hourly flow, it is doubtful indeed if the construction of expensive, high-capacity, and inflexible (in the sense of not serving all types of regional trips) rail transit systems would ever be considered. But rather, it is more likely that low-capacity, low-cost and highly flexible systems would merit attention. Consequently, the full costs of constructing highly peaked, downtown movement systems probably should be charged to the passengers moving during those rush periods; furthermore, the full costs of operating and maintaining the equipment, structures, and rights-of-way for that period should also be allocated to them. Only those costs incurred exclusively for the provision of off-peak passengers—such as wear and tear on equipment (thus, not only maintenance, but a portion of the capital costs), additional labor, power, etc.—should be charged to the off-peak patrons. The result is that little net effect will be made on the rush-hour costs, relative or absolute, by the inclusion of off-peak travel.

Variable route lengths were specified for costing for two purposes: (a) to provide data for different sizes of communities (in terms of geographical distribution and density); and (b) to categorize in quantitative form any changes which might occur in the relative position of alternative technological systems. Viewing, for example, the increase in work trip length that has occurred since World War II, and the expectations for continued suburbanization, the lengths of corridor or radial line-haul facilities might be expected to increase still further. If the distance from the Central Business District (CBD) to the first outer belt is accepted as the general line-haul route length, it seems reasonable to conclude that most urban radials (or line-haul routes) are in the range of 6 to 15 miles. For an intermediate route length, 10 miles seemed to be reasonable and to include a number of general urban area situations. (It should be noted here that attention regarding transit systems was restricted to urban rapid transit technologies and did not include consideration of the longer length commuter railroad operation.)

For the line-haul cost analyses, a 1-mi station spacing (or ramp entrance and exit spacing) was used for each of the route lengths and to distribute the volume uniformly along the route. (Station spacing for downtown distribution routes was set at ½ mile.) Uniform distribution of volume along the route does not seem unrealistic, particularly for operations during rush hours (1, p. 38; 3, pp. 532-3). As for the station spacing, there seems to be considerably more variance. The older rapid transit systems in the United States generally average about ½-mi station spacing, whereas most of the newer transit facilities have (in an effort to increase travel speed) increased the spacing considerably. The Congress Street line, for example, has spacing of about 0.7 mi; the

Cleveland rapid transit system about 1.2 mi; the proposed Washington, D. C., rapid transit system averages about 1.2 mi.

The importance of the station spacing used for design and costing of alternative transport systems can hardly be overstated. First, no definitive conclusions can be reached about the best or "optimal" solution without varying station spacings (as well as the other input variables) and testing their impact on the cost and market in turn; this certainly would be the logical next step for a community actually faced with the specific question of what to do or not to do. Second, the 1-mi station or ramp spacing for the line-haul route represented somewhat of a compromise between overall travel speed and flexibility or convenience of station locations (relative to residential homes). Longer station spacing will offer higher overall travel speeds, but lower convenience in terms of the trip between home and line-haul station; shorter station spacing produces the opposite tradeoff. In the balance, it is difficult to state with any degree of precision what the effects of assuming different spacings would be on the cost or market. At any rate, it is not at all clear that higher line-haul speeds do offer the great advantage (relative to the loss of convenience) assumed by so many. Third, the particular station spacing was chosen in relation to the overall travel speed assumption. If, for example, station spacing had been reduced while maintaining the same overall travel speed requirement (35 mph in this analysis), higher powered and more expensive rail transit equipment would have been required, thus increasing capital and operating costs. Bus transit and passenger car system costs would also have been increased, although the former would suffer only minor increases (and only for very short 1- and 2-mile runs); the automobile system would be affected only in terms of having lane capacity reduced slightly, and perhaps negligibly. Without actually changing the spacing, and recomputing the costs (which, again, should be done by communities actually facing the problem), it is difficult to draw any definitive conclusions about the relative increase in cost for rail and bus transit systems.

The particular design speed level selected for this analysis (35 mph) represents a compromise between high speed (or service) on the one hand, and high cost on the other. (As pointed out previously, it must be examined in light of station spacing considerations, cost, and the market.) Most urban communities do not presently provide speed standards so high, either by transit or by private auto. At the same time, considerable evidence does exist to indicate that urban travelers are willing and able to afford higher service (i. e., lower travel times) than they are now offered. The speed chosen, then, is an implicit recognition of the presumed market structure of the present and the near future.

Two other points regarding the required overall travel speed are worth noting. One, the selection of the particular travel speed (together with the station spacing) is extremely critical to the costing and to the relative economy of one mode of travel as opposed to another. Analysis indicates, for example, that as required overall speeds increase—particularly above the 35-mph level—private auto travel enjoys a cost advantage relative to transit travel, and secondarily, bus transit has a cost advantage over rail transit. Similarily, a reduction of the required overall speed (below the 35 mph level) would reverse these relative cost positions, and work primarily to the relative disadvantage of auto travel, and secondarily to bus transit travel. Two, it is worth repeating that several speed levels should be chosen for design and then costed in detail for determination of the most nearly "optimal" system in any realistic situation. It is not sufficient to merely say that one system or technological mode is cheaper than another at some arbitrary design and service level. It may well be, for example, that the community for which the system is being designed either feels that it cannot (or does not want to) afford a level of service so high or feels that it would like to afford an even higher speed standard.

Two other service variables were controlled in the cost analysis of the different systems: these were schedule frequency and seating space (and vehicle seating capacity). Both of these service inputs are important to the cost results and to the relative economy of the various modes. Of the two, schedule frequency is probably the most difficult to specify with any degree of reliability. The basic problem is to set a minimum frequency of service for all of the modes costed; that is, each mode must provide service at each line-haul station (or feeder bus stop) at least at certain specified intervals so as to retain comparability in service between the modes. Put another way, if one mode offered service every 5 min and another every 30 min, with all other service variables for the two modes held constant, it is clear that the two modal systems would not be comparable and no direct conclusions can be reached regarding the relative cost position unless travelers place no value on the additional service frequency.

Obviously, the automobile offers the utmost in flexibility with regard to schedule frequency, particularly when the driver engages in no form of car pooling. Essentially, the minimum schedule frequency for transit modes (or, maximum headway between vehicles or trains at each stop) must be set such that the differential between automobile and transit service frequency is not so large as to inhibit the modal choice, given equal cost and other service for auto and transit travel. In other words, given that auto and transit service and cost were identical except for schedule frequency, what is the specific frequency of service level at which the average traveler would option out of a transit mode merely because of the frequency differential?

No reliable information is available which can be used for this schedule frequency criterion; thus, it was necessary to rely largely on judgment. In the costing, two types of schedule frequency standards were used: (a) a maximum vehicle or train interval (headway) of 2 min at each line-haul station; and (b) a maximum vehicle interval of 10 min at each feeder bus stop (for the residential collection system service). It is difficult to substantiate the specific criteria chosen other than in a general and intuitive fashion.

Perhaps it is worth reemphasizing that each of the service criteria, and particularly the required speed and maximum service headway standards, were chosen not just in light of present-day market demands and preferences, but in terms of consumer preference attitudes and income expectations over the service life of the transport facilities being costed. Viewed in this fashion, it does not seem unreasonable to typify the market demands in terms of an overall travel speed (on the line-haul facility) of 35 mph and of a schedule frequency of 2 min or less at the line-haul stations and 10 min or less at each residential collection area feeder bus stop.

In some respects, control of the seating space and "comfort" requirements for the various travel modes is not an altogether insurmountable problem, although in others it is overly difficult. For example, travel by rail and bus transit is certainly not very dissimilar when considering riding comfort and privacy afforded the individual traveler. On the other hand, an inspection of existing rail and bus transit operations reveals that rail transit operators allocate less of the car or vehicle floor space to seated passengers than do bus operators. (Obviously, the differential for present-day operations is due partially to the fact that the two modes are providing different types of service, and have different trip length and loading factor characteristics.) However, given that the rail and bus transit modes were going to perform the identical function and handle the same volumes at equivalent levels of service, there is no justification for permitting a higher percentage of standees on one mode than on another. In other words, the amount of floor space per passenger should be equal for rail transit cars and buses. (For the costing, bus seating standards were used in computing rail transit car seating capacity.)

Again, in recognition of what are perhaps apparent consumer preference patterns of today and estimating what they might be over the life of the transportation facilities, the rail transit car or bus transit vehicle capacity was set equal to the number of seats per car or vehicle (that is, a seat was provided for every passenger). In essence, of course, the cost of providing transportation service at certain speeds and service levels and where every passenger will have an available seat has been determined. Many might argue that "no one operates a transit system this way" (a remark which is correct, and perhaps regretable); at the same time, perhaps the public would be willing to afford such a service, particularly in the face of rising real income and general affluence. It is questions of this nature that should be raised for consideration and for which quantiative answers should be sought. Transit system operators should not always assume, for example, that they cannot afford to provide a seat for all peak-hour travelers, particularly in the face of rising incomes, increasing trip length, and without even determining what it would cost to eliminate standees. In the recently proposed Washington, D. C., rail transit system design, for example, the requirements were based on the assumption that approximately 50 percent of the peak-hour travelers would be willing to stand during the design year (1980).

In any case, the thesis must be rejected that rail and bus transit systems now being proposed and designed for the next 20 years or more cannot or should not be designed on the basis of no standees during peak hours merely because no system is now operated in that fashion and because travelers today are willing to accept standing conditions during peak hours. Acceptance of such a thesis is tantamount to assuming a static society and economy, and unchanging consumer preference patterns.

A more important problem in regard to the question of standees and vehicle seating capacity is that of placing the seating space and "comfort" requirements of automobiles and transit modes on an equivalent or comparable basis. This is, of course, no mean task. There are distinct and wide differences in comfort, convenience, and privacy offered travelers in these two modes. Automobile travelers have more comfortable seats, can smoke or listen to the radio, and can choose to ride alone or with riders of their choice. On the other hand, all transit travelers can avoid the driving task and can read newspapers, whereas only the automobile riders (as distinguished from auto drivers) have this privilege. Balancing this wide set of variables, it seemed reasonable to resolve the problem by using a passenger car "seating capacity" (or occupancy because of extremely high divisibility) of 1.6 seats (passengers) per auto. (Some caution must be exercised when comparing this figure with recorded data in the literature. Virtually all car occupancy data are recorded by purpose of trip rather than by period of travel. Because this analysis is concerned with rush-hour travel over a 2-hr period, it would be incorrect to compare with car occupancy for work trips alone.)

An additional factor that had to be considered in setting the car occupancy or "seating capacity" was the inconvenience and time delays involved in picking up riders. Difficult as they are to assess, it does seem reasonable to expect that they are far from negligible. (In fact, the decline in car occupancy rates over the past 15 to 20 years would seem to verify this.) If it is assumed, for example, that a delay of 5 min results from picking up each rider, on the average, automobile drivers will be delayed 3 min with a car occupancy of 1.6 (and thus 0.6 riders on the average). On a pure time scale, this would be equivalent to the delays encountered while waiting for feeder buses with a headway of 6 min which is just slightly lower than the headways actually provided by the separate feeder bus service. However, recognizing the comfort differential between the two kinds of residential collection service (that is, between car pooling and feeder bus service), it is suspected that the automobile service is considered higher quality by travelers because most of the waiting or delay time could be accomplished indoors and out of the rain and cold.

LINE-HAUL SYSTEM SERVICE AND COSTS

Basic Line-Haul System Design and Operation

This section includes a discussion of the cost characteristics of the line-haul components or portions of urban transportation systems (see Fig. 1). In particular it describes the manner in which the cost data were derived and the effect on system costs of changing some of the more important design and service parameters. The particular line-haul system analyzed consists of 1-mi entry and exit stations or ramps along the route length and a downtown stub terminal (or parking garage) located approximately at the fringe of the downtown area. Costs are computed separately for nine "basic line-haul systems" (private automobile, bus transit, and rail transit systems, each of 6-, 10-, and 15-mi lengths and having as nearly as possible the same service and volume characteristics). In this analysis, as in all others presented in this and later sections, the costs are determined for moving a fixed number of passengers between common points. Thus, the relevant unit cost in the analysis, as in actual system design and operation, is not the cost per available passenger seat, but rather the cost per required passenger seat or trip performed. (Here, of course, the distinction, is made between passenger seat capacity and passenger seat demand, the latter being the more relevant quantity.)

Although other system components (such as residential collection and downtown distribution systems) must ultimately be combined with the line-haul system in order to compare total trip service and cost, it nevertheless is meaningful to examine line-haul operations separately. For the present purposes it is assumed that regardless of the nature, type or mode of the line-haul system, the line-haul facility is served in the residential and downtown areas by common collection and distribution systems, the costs of which are identical whether the line-haul service is by auto, bus, or rail transit, and which do not affect the cost of the "basic line-haul" systems. Thus this separate analysis of the line-haul segment is used as a building block in the final system costing.

The specific service, volume, and operating requirements assumed for the initial or basic line-haul analyses are:

1. Passenger volumes are distributed uniformly along the route length and passenger volumes and capacity are provided only in the direction of major flow. (The latter condition is ultimately relaxed and the costs of providing service in the return direction are considered.)
2. Average overall travel speeds (to include all loading-unloading and acceleration-deceleration delays) are 35 mph for the passenger-carrying portion of the round trip; on the empty, return-haul portion, buses or trains operate at top speed.
3. No "along-the-line" movement is included; however, to simplify the costing of "along-the-line" service for express buses such as is included at a later point, equipment and labor requirements are computed while assuming that along-the-line stops would be made at every other 1-mi station. Thus, in later costing exercises the only costs that have to be added at low volume levels to provide this service are on-off ramps and bus loading and unloading slots at each of the line-haul stations; at higher volume levels, however, some additional equipment and labor are required, and in one case additional terminal space.
4. For passenger trips to and from the downtown terminal, trains or buses are required to provide a scheduled frequency, at both line-haul stations and downtown terminal, of at least every 2 min. The effect on costs of relaxing this condition also is considered later in the section for certain of the basic line-haul systems.
5. Equal seating space standards are used for rail and bus transit and a seat is provided for every passenger; automobile "seating capacity" is assumed to be 1.6 seats per auto.
6. Line-haul stations are located at 1-mi intervals, with the first station located 1 mile from the downtown stub terminal.

The rail transit design and operation is conventional except in two respects. First, double-trackage is necessary in the passenger-carrying direction for the two highest volume cases (40,000 and 50,000 hourly passengers) but only a single track is used for the empty, return-haul trip, as trains operating non-stop, express, may safely maintain less than one-half of their loaded-run headways. This is extremely important because four rather than three tracks would be required if passenger-carrying capacity and headway were to be provided in both directions. Second, where two tracks are used (in the major flow direction) the second track is extended only to the point where additional capacity is needed and thus does not extend for the entire route length. The particular rail transit car used in the analyses provides for the required movement at least cost while also meeting the necessary performance capabilities. (In this respect, "least cost" must be construed quite broadly and to include much more than just the rolling stock cost. For example, as car length is increased the number of rail transit cars required is reduced as well as the annual car mileage; but at the same time, the unit cost per car and the gross weight increase. Also, depending on the volume level, etc., the station length may increase with long car lengths, because of lower divisibility. All these tradeoffs were considered in selecting the "most economical" or least cost equipment.)

For bus transit, high-speed non-stop service between each line station and the downtown terminals almost certainly would be most economical, and considerably cheaper than these analyses indicate. However, a 35-mph overall average speed restriction and allowance for the additional delays (such as acceleration-deceleration and loading and unloading) for "along-the-line" stops have been incorporated into the preliminary line-haul estimates. In short, non-stop express service between line-haul and the downtown terminal is not assumed; instead, the round-trip travel times include allowances for delays for "along-the-line" stops. (The importance of this to both bus and rail transit should not be underestimated. If "along-the-line" service stops were not included for both types of transit, higher operating speeds could be maintained, thereby increasing utilization rates and reducing equipment and labor costs.)

Although the 2-min schedule frequency restriction does not affect rail transit operation and costs materially (more attention will be given to this later in this section), it does have a substantial impact on bus operations and costs at the two lowest volume levels (5,000 and 10,000 passengers per hour). As indicated in Table 3, extra buses are operated merely to meet the 2-min headway restriction for 6 of the 18 volume and route length combinations. Thus, for these six cases, the capital, operating, labor, right-of-way and maintenance costs of the bus operation are significantly increased. A quantitative statement of these cost increases is presented later in this section. In assessing the relevance of this factor, it should be noted that probably no more than a dozen American cities have peak-hour corridor volumes in excess of 10,000 hourly passengers.

The underground, downtown bus terminal included as part of the basic line-haul system is designed to avoid a reduction in the capacity of through bus lanes by providing sufficient capacity to "dissipate" the deceleration-acceleration and loading-unloading delays that occur in the terminal. For all practical purposes this design objective is accomplished by widening out the through roadway in the terminal area in much the same way as toll roadways widen at toll booth plazas; Figure 3 illustrates in a general way the bus terminal design. Two other features related to the bus terminal design and operation are that (a) fare collection is accomplished in the mezzanine of the terminal station in much the same fashion as is now done on rail transit systems, and (b) a third loading-unloading door is added to the bus. Both of these changes reduce loading and unloading times, permit loading and unloading at all doors and on both sides of the bus, reduce the terminal area length, increase bus equipment and operator utilization rates, and thereby reduce capital charges for terminal and equipment, as well as labor costs.

The bus transit system had another service restriction imposed upon it which should be noted. The downtown bus terminal design was required to include at least one bus slot for each line-haul station on the route length in order to minimize passenger crowding on loading platforms and passenger inconvenience in locating bus loading areas. Because of this restriction, in 10 of the 18 cases (combinations of volume level and route length) the terminal length had to be extended and the terminal costs were increased. If "along-the-line" service were actually provided rather than simulated, this requirement would not be as necessary. Or, of course, other alternatives exist—such as merely enduring the additional inconvenience and crowding or installing better routing and informational devices. The extra costs entailed as a result of this design assumption are detailed later.

Another important aspect is the effect on bus system costs of the short 1- and 2-mi bus runs from the first and second line-haul stations. To meet the 35-mph overall speed requirement, these short-run buses must be underloaded; i. e., due to the amount of time needed for loading or unloading, acceleration-deceleration, etc., the full bus seating capacity cannot be utilized. As a result, the number of bus vehicles entering (and leaving) at the 1- and 2-mi line-haul stations is abnormally large. As shown in Rows (a) of Table 3 (which gives the hourly number of buses entering per line-haul station according to distance from the downtown terminal, or length of run), the number of buses required to serve the 1-mi station is about four times greater than the number required at stations more than 2 mi from the terminal, despite the assumption of uniform passenger volumes (i. e., equal passenger volumes at each station). The effect on bus equipment and labor costs, on the level of highway capacity needed, and on bus

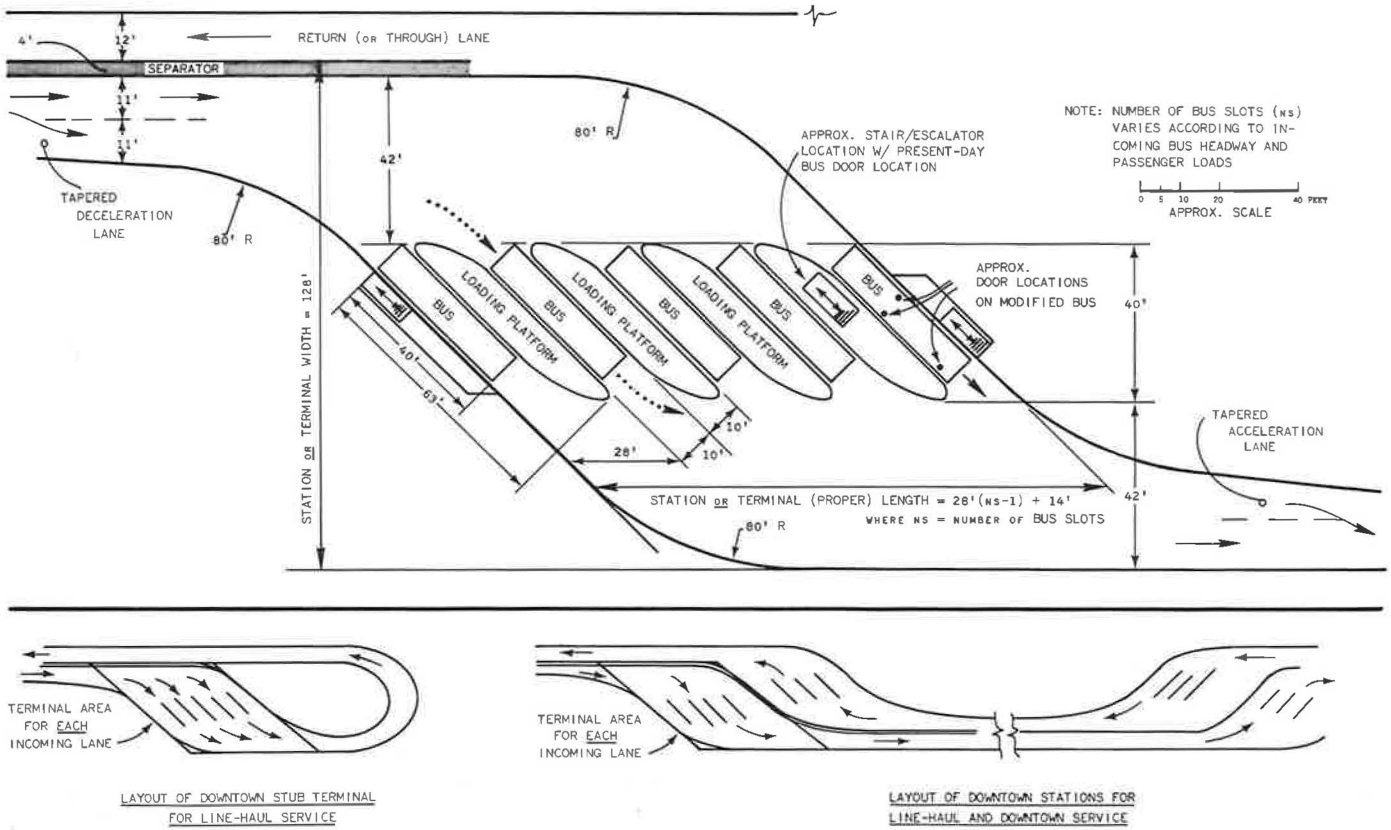

Figure 3. Approximate design (45° angle) station or terminal layout for each incoming lane.

TABLE 3

NUMBER OF BUSES PER HOUR ENTERING AT INDIVIDUAL STATIONS (i.e., Hourly Bus Trips per Station) AND NUMBER OF SEPARATE BUS UNITS NEEDED PER STATION IN DIFFERENT BUS TRANSIT CONFIGURATIONS

Uniformly Distributed Hourly Passenger Seat Requirement		6-Mile Route			10-Mile Route			15-Mile Route		
		One-Mile Station	Two-Mile Station	All Other Stations	One-Mile Station	Two-Mile Station	All Other Stations	One-Mile Station	Two-Mile Station	All Other Stations
50,000	(a)	695	190	167	417	114	100	278	75	66
	(b)	59	25	41	36	15	34	24	13	30
40,000	(a)	556	152	134	334	91	80	223	61	53
	(b)	48	20	33	29	12	27	19	8	24
30,000	(a)	417	114	100	250	69	60	167	46	40
	(b)	36	15	25	22	9	21	15	6	18
20,000	(a)	278	76	66	167	46	40	112	31	(30)
	(b)	24	10	17	15	6	14	10	4	14
10,000	(a)	139	38	33	84	(30)	(30)	56	(30)*	(30)*
	(b)	12	5	9	8	4	10	5	4	14
5,000	(a)	70	(30)*	(30)*	42	(30)*	(30)*	(30)*	(30)*	(30)*
	(b)	6	4	8	4	4	10	3	4	14

(a) = Number of buses entering each station along the route per hour; number in ( ) indicates that maximum headway requirement was controlling (i.e., extra bus units were required just to meet the 2-min headway restriction).
(b) = Bus units (and drivers) needed to meet bus requirements in (a); equipment and labor utilization rates have been taken into account here.
* Using TGH Model 3102 bus in place of TDH 5303.

terminal requirements, is obvious. However, some of this excess capacity can be absorbed by using smaller bus units, as was done in the cases noted in Table 3. In approximately 6 of the 18 volume and route length combinations an extra lane of highway in each direction is required as a direct result of the underloading of short-run buses. The effect on costs is somewhat greater, as the extra lanes are required at the portion of the line-haul system having the greatest number of lanes, and as the unit cost per lane rises as the number of lanes increases.

Also of considerable importance is the way in which the unit construction and right-of-way (or land acquisition) costs are determined for both the bus and automobile highways. Data on construction and right-of-way costs for urban interstate highways, designed and built for general use by all types of vehicles, were obtained and analyzed to obtain approximate relationships between highway costs per lane-mile and highway route length and width (in number of lanes). In turn, the results of the U. S. Bureau of Public Roads Highway Cost Allocation Study were applied to these relationships to determine what proportion of the total mixed highway costs (designed for joint use by passenger cars, buses, and trucks) would be required for an all-passenger automobile highway and for an exclusive bus highway. The resulting unit costs are given in Table 4.

Car occupancy, parking requirements, and auto ownership and accident costs are of particular importance in determining the costs of the private automobile line-haul system. Passenger car occupancy is particularly important because of service implications and the effect on system costs. The occupancy figure of interest for the present analyses is that occurring during rush hours and in the major flow direction. For these costing analyses, a figure of 1.6 passengers per auto was used, and in general is felt to be conservative. This compares with the 1.9 occupancy reported in the 1955 Washington, D. C., O-D survey (see p. 29 of "Mass Transportation Survey—1959), with some 1961 peak-hour major flow direction data recorded on the Washington, D. C., Pentagon network, which ranged from 1.64 to 1.92, and with 1.8 used in the National Capital Transportation Agency report for peak-hour downtown trips (Appendix, Volume III, Traffic Forecasting, p. 80).

Parking charges were derived from the unit cost data given in Table 5. Capital charges for parking garage construction and site acquisition are reasonable for large urban areas and perhaps too generous for smaller ones; together with the costs of garage maintenance and operation they account for some 40 to 50 percent of total pas-

TABLE 4

CONSTRUCTION AND RIGHT-OF-WAY COST PER MILE (According to Route Length and Number of Lanes) FOR ALL-BUS HIGHWAYS AND ALL-PASSENGER-CAR HIGHWAYS

No. of Lanes[a]	Cost per Mile ($ millions)								
	Right-of-Way			Construction			Total		
	6-Mi Route	10-Mi Route	15-Mi Route	6-Mi Route	10-Mi Route	15-Mi Route	6-Mi Route	10-Mi Route	15-Mi Route
(a) All-Bus Highway									
2	0. 380	0. 315	0. 196	0. 805	0. 713	0. 605	1. 185	1. 028	0. 801
4	0. 516	0. 429	0. 267	1. 968	1. 740	1. 478	2. 484	2. 169	1. 745
6	1. 584	1. 315	0. 820	4. 216	3. 736	3. 170	5. 800	5. 051	3. 990
8	5. 320	4. 415	2. 750	7. 480	6. 615	5. 610	12. 800	11. 030	8. 360
(b) All-Passenger-Car Highway									
2	0. 380	0. 315	0. 196	0. 651	0. 576	0. 489	1. 031	0. 891	0. 685
4	0. 516	0. 428	0. 267	1. 604	1. 420	1. 205	2. 120	1. 848	1. 472
6	1. 584	1. 315	0. 819	3. 496	3. 094	2. 625	5. 080	4. 409	3. 444
8	5. 320	4. 416	2. 750	6. 150	5. 443	4. 619	11. 470	9. 859	7. 369

[a]Both directions.

TABLE 5

COMPARATIVE UNIT COSTS FOR PARKING[a]

Type of Parking	Location	Cost per Space ($)			
		Capital		Annual Main. and Oper.	Daily Parking[b]
		Site Acquis.	Site Devel. and Constr.		
Garage	Central, downtown	1, 500	1, 600	155	1. 38
	Fringe, downtown	1, 100	1, 600	155	1. 28
Lots	Fringe, along 6-mi line-haul rt.	800	400	60	0. 59
	Fringe, along 10-mi line-haul rt.	700	400	60	0. 56
	Fringe, along 15-mi line-haul rt.	600	400	60	0. 54

[a]Estimates derived from refs. (4), (5), (6), (7).
[b]Includes amortization and 6% interest on capital. If parking lot site development capital cost of $400 per space is assumed, with annual maintenance and operating expense of $60 per space and an all-day (8 hr) parking charge of $0.85, the implied site acquisition cost is at least $1,900 at 6% interest. This is not inconsistent with figures for garages, because they assume multi-story operation.

senger-car system costs. Unit costs for "fringe downtown garages" were used for the basic line-haul and residential system cost analysis (i. e., where all line-haul systems were assumed to terminate at the fringe of downtown). For comparison, the central downtown garage costs imply an average daily parking charge per space (including 6 percent interest or return on capital) of $1. 38 while the equivalent fringe garage charge is $1. 28.

On the surface these may appear to be high parking charges and in excess of those presently charged in existing lots or garages. However, such comparisons may be irrelevant because of differences between the costing procedure used throughout this study—for all modes and for all capital items—and that in practice at existing garages and lots. Again, the full depreciation and interest costs are charged entirely to the rush-hour travelers even though some portion or all of the facility in question may experience joint use with other travelers. In this regard, the parking garage or lot is a case in point because it may also be (and usually is) used by off-peak, evening and/or weekend travelers and because one may easily argue that it is only fair that some of the basic land acquisition costs, for example, be charged to them as well. Regardless, these joint costs—just as the capital items for rail and bus transit—were not split among the different groups, and thus the costs used herein should be higher than those generally experienced in the marketplace. Furthermore, sunk cost aspects may produce differences between existing prices and the costs given.

Also, it should be pointed out that in this cost analysis downtown rush-hour automobile parkers were not split into those using parking lots and those using parking garages, but were all placed into fringe garages. This assumption certainly would tend to overstate the parking costs for the line-haul system with terminal parking at the downtown fringe, but to an unknown extent. Remembering, however, that the concern here is with the downtown core and its surrounding ring, it might be reasonable to expect little distortion. For example, a downtown core of about 2 to 2¼ sq mi will include perhaps 300 blocks; for a city with 10,000 hourly passenger (corridor) volume level, with five or six corridors, with two hours of peak flow, and 1.6 passengers per auto, the parking requirements for rush hours would be about 150 blocks for parking lots, or about 30 blocks for five-story parking garages. The latter case does not produce land-use percentages out of line with existing data in medium to large central areas.

A particularly difficult problem is the treatment of ownership and accident charges for automobiles using a passenger-car line-haul system. As previously stated, the principal justification for constructing any commuter system is assumed to be the downtown travel occurring during the four daily peak hours, and the full costs of each system accordingly are charged to these peak users. Inasmuch as the rolling stock for the two transit systems is fully charged to rush-hour travel, costs for the passenger-car system are allocated on a similar basis.

This presents serious difficulties, however, because on the average less than 20 percent of annual automobile travel is accomplished during the rush-hour periods. Annual passenger-car travel in recent years has averaged about 9,500 mi per year, whereas rush-hour trips average only about 6 mi and therefore account (on the average) for only about 3,100 mi a year, or approximately one-third of the mileage driven by the average car if it were driven to work every day. It therefore seemed reasonable to assume that cars purchased and used solely for the purpose of rush-hour travel should have somewhat lower average capital costs than existing double-purpose or joint-use vehicles. Thus, the commuter car is assumed to cost $1,600 and have a life of 60,000 mi for depreciation purposes. Annual capital charges are computed on the basis of a 6 percent interest rate and the annual accident charges for rush-hour passenger cars are set at $100. For the 10-mi route length, for example, this accident charge results in an accident cost of about $0.036 per vehicle-mile, a seemingly high charge. Given the way in which insurance charges are now typically structured, however, such rates are probably not too far out of line with what must be paid by many who keep a car strictly for commuting purposes, and with the higher accident rates experienced during rush hours.

Some of the more pertinent unit costs have been included in the foregoing paragraphs, particularly for automobile and bus systems; the remaining unit cost data for buses and autos, and those for rail transit not included here, are noted in the Appendix. However, it will be useful to note some of the unit cost data for the rail transit at this point. First, for the grade-separated rail track construction (to include electrification, structures, trackage, utility relocation, and engineering and contingency fees) the assumed unit cost per two-track mile was $3.625 million and that per three-track mile was 50 percent more. Second, the rail transit right-of-way (or land acquisition) costs were computed as a proportion of the bus transit R-O-W costs (Table 4) according to the ratio of rail transit R-O-W width to bus highway R-O-W width for the particular route length and volume level; the average R-O-W width required for different sizes of facilities is given in Table 6. For example, at the 10,000 hourly passenger level and for a 6-mi route length, a two-track (two-way) rail transit line is required and a two-lane (two-way) bus highway is required; the total R-O-W width for rail is 116 ft and for bus is 260 ft. Thus, the rail transit R-O-W cost per mile for this case is 116/260 times the bus R-O-W cost (of $380,000 per mile) (Table 4), or approximately $169,500.

TABLE 6

SUMMARY OF RIGHT-OF-WAY REQUIREMENTS

Type and Size of Transit Facil.	Total Average ROW Required (ft)
Rail:	
2-Track	116
3-Track	131
Bus:	
2-Lane	260
4-Lane	280
6-Lane	290
8-Lane	300

TABLE 7

LANE AND TRACK CAPACITIES USED IN ANALYSIS

Mode	Lanes or Tracks in Each Direction (no.)	Maximum Capacity (no./lane/hr)[a]
Rail transit	1[b]	72 trains/track-hour, no stops 38 trains/track-hour, stops and 10 cars/train 51 trains/track-hour, stops and 2 cars/train
Bus transit	1[b]	480 buses/lane-hour on line-haul highway
Passenger car	1	1,000 autos/lane-hour
	2	1,600 autos/lane-hour
	3	1,665 autos/lane-hour
	4	1,675 autos/lane-hour
	5[b]	1,650 autos/lane-hour

[a]Number of vehicles on trains per lane or track per hour. [b]Or more.

In determining facility requirements both the vehicle and track or lane capacity were important. The vehicle passenger seat capacities used in this analysis were: 50 seats per bus (except for the short 1- and 2-mile bus runs where only 12 and 44 seats, respectively, could be used and still meet the overall 35-mph speed requirement); 1.6 seats per auto; and 79 seats per rail car. The various lane and track capacities utilized in the costing are given in Table 7: for the rail operation the headways, and thus track capacity, varied with the train length, two cases of which are indicated.

Cost Components for Primary Line-Haul Systems

The one-way passenger trip costs for the line-haul systems previously described are shown in Figure 4 and the total annual costs for the 10-mi route length systems are shown in Figures 5 and 6.

The unit cost curves of Figure 4 show several important relationships. First, the slope or "flatness" of the unit cost curves suggests the relative divisibility of the three different modes; these are much as might be expected. The auto system is particularly capable, with respect to both equipment and number of lanes, of being "tailored" to meet different volumes. At higher volumes and short route lengths the bus system is nearly as divisible as the auto system. Below passenger volumes of 20,000 per hour, however, three indivisibilities cause unit bus costs to rise. First, because the bus roadway width reaches a minimum (one lane in each direction, grade-separated, and including a median strip) further reductions in this roadway cost will be small. (It should be noted that if systems can be designed to maintain flow and performance of expressways so that buses can share the facility, and still maintain high performance, these roadway costs become nearly as divisible as for the auto system. Furthermore, some further though small economies might be achieved by using somewhat thinner pavements, etc., at the lower volume levels.) Second, at the 5,000 and 10,000 hourly passenger volume levels, the headway restriction of 2 min requires that more buses be operated than are needed to supply the required bus seat capacity, especially for the 10- and 15-mi route lengths (see Table 3). For example, at the 5,000 hourly passenger level, and for the three route lengths of 6, 10, and 15 mi, only 17, 10, and 7 hourly bus trips are required to provide sufficient seats; yet, because of the service or frequency restriction, 20 hourly bus trips are provided in each case. The increases in bus equipment and operators which result, and the effect on the unit costs, is obvious. Third, the bus system's divisibility is affected by the requirement that the downtown bus terminal have at least one bus slot for each line-haul station; in 10 of the 18 volume and route length combinations this specification resulted in the construction of more bus slots than are necessary merely to handle the number of incoming and outgoing buses.

Rail transit generally has less divisibility than the other two modes and the cost curves with the steepest gradients, except at the very highest volume levels. The primary reason for low divisibility of rail transit systems, and thus for decreasing unit costs with increases in volume, is that a minimum of two tracks is needed for all volumes. (Two rail tracks are required for the entire route length for the lower four volume levels, and three tracks for the highest two.) At lower volumes the track con-

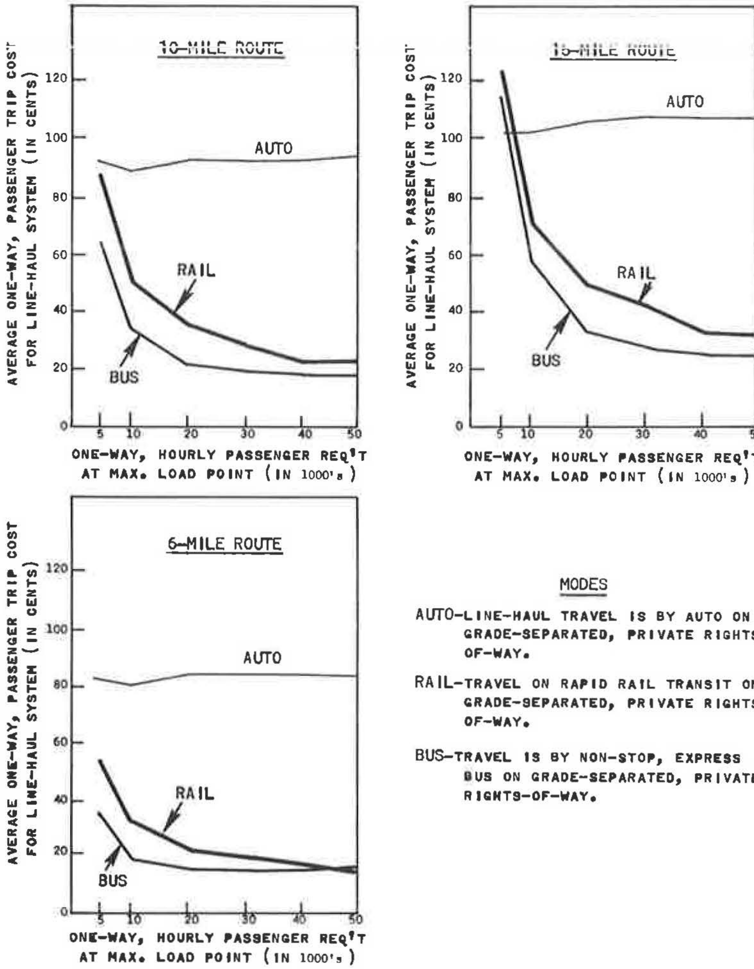

Figure 4. Basic line-haul system costs including downtown stub terminal or parking garages.

struction costs range between 53 and 25 percent of total costs. Futhermore, because maintenance of way and many costs of conducting transportation are directly related to the amount of trackage required these costs exhibit a similar relationship with volume.

The foregoing discussion of the nature of the cost structure, divisibilities, and unit costs can be quickly understood by examination of Figures 5 and 6, which show a breakdown of the total annual system costs of the rail, bus, and auto line-haul systems of 10-mi length. System divisibilities may be compared by observing the changes in total and component costs relative to volume increases.

Of the three systems, rail transit is more capital intensive than the others: the capital costs for rail range between 54 and 66 percent of the total costs, whereas the comparable figures for auto are 50 and 55 percent, and for bus are 35 and 44 percent.

Route length and volume affect the relative costs in two general ways (Fig. 4). As route length increases for a given volume, the percentage difference in cost between the modes increases. For example, at the 10,000 volume level, rail costs are about 60 percent higher than bus costs for a 6-mi route length, but only about 45 percent higher for a 10-mi, and 20 percent higher for a 15-mi route. Also, if route length is held constant rail costs decrease relative to bus as volume increases. At higher vol-

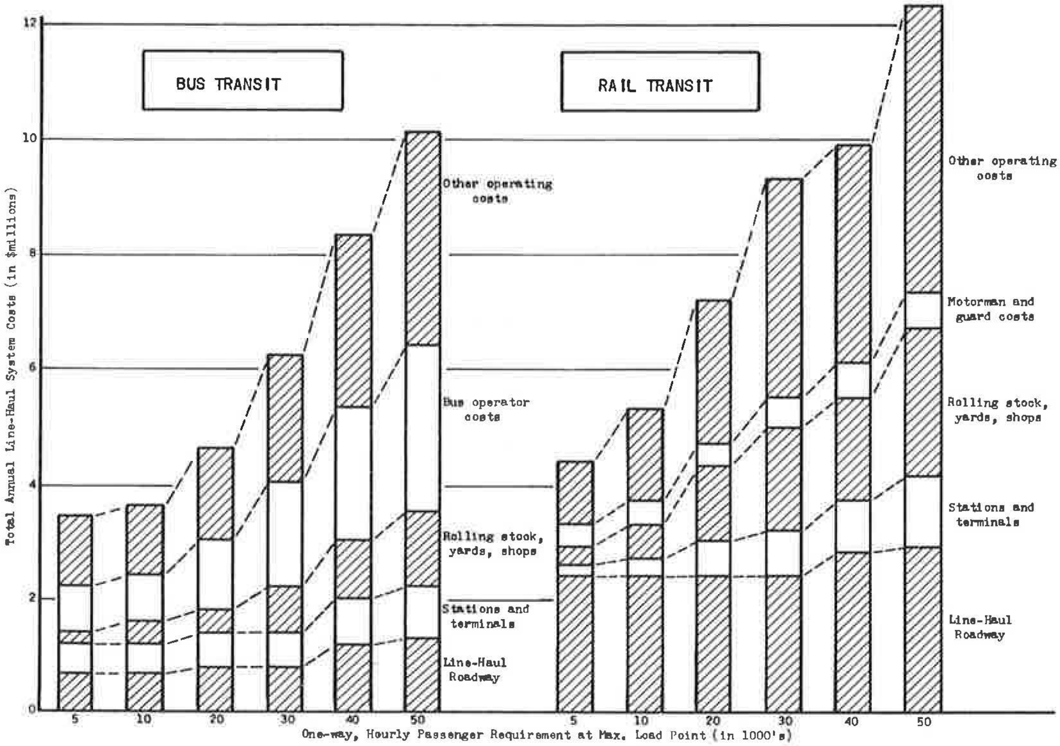

Figure 5. Line-haul system with downtown fringe terminal, 10-mile route.

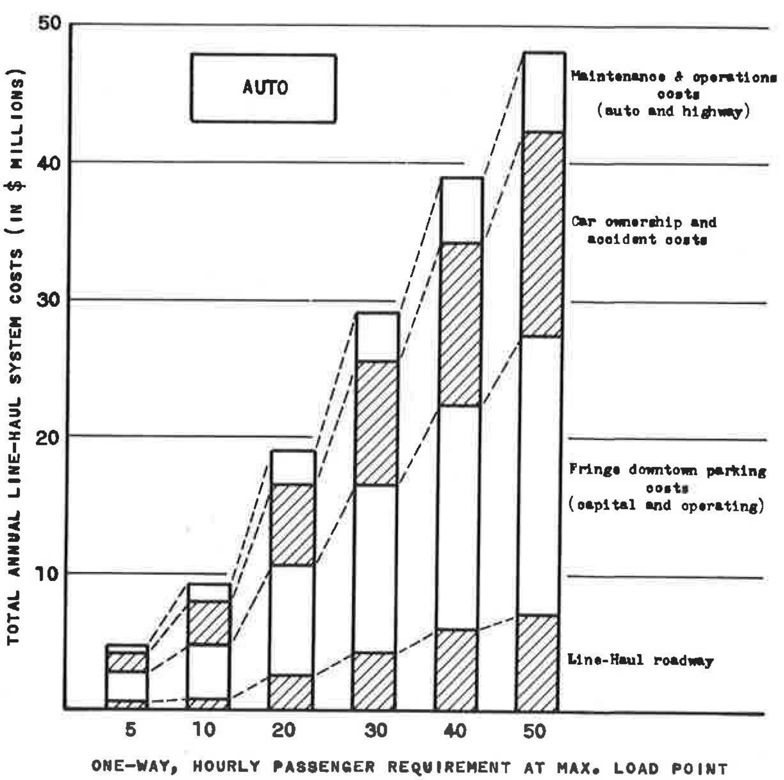

Figure 6. Line-haul system with downtown fringe parking, 10-mile route.

ume levels, rail track capacity can be more closely matched to volume (e. g. , use of a third track for the high-volume portions of the route length and use of longer trains for large volumes adds to the relative economies of rail. Underutilization of capacity and lack of divisibility at lower volume levels cause the absolute unit costs of both rail and bus transit to increase markedly but, as noted previously, the relative cost advantage of bus over rail decreases at the lower volume level because of the 2-min headway restriction, and because of the number of downtown terminal bus slots that must be provided.

Effect of Design and Service Changes on System Costs

Numerous design and service variables substantially affect both the absolute and relative costs of the basic line-haul systems. Some of the more important of these are (a) overall travel speed; (b) station spacing; (c) provision of outbound passenger capacity; (d) provision of "along-the-line" service; (e) schedule frequency of transit service; (f) percentage of passengers standing; (g) extent of car-pooling; and (h) design of downtown terminal. A number of these factors are analyzed quantitatively (the cost effects of providing these different line-haul system services are computed only for the 10-mi route length) and reported later, while the remaining are merely discussed and evaluated qualitatively.

Overall Travel Speed. —Although all three modal systems have been designed to provide identical average overall travel speeds and time spent in vehicles, the total time required for a line-haul trip will vary from mode to mode because of differences in waiting times. Because the line-haul and feeder vehicle (the latter for residential collection) are not separate vehicles in the auto line-haul system, no allowance is needed for waiting time at the line-haul station and the total line-haul trip travel time may be computed by simply applying a travel speed of 35 mph to the distance from the line-haul station to downtown. The time delays for car-pooling are included as part of the residential collection travel times.

By contrast, bus and rail transit passengers will experience a delay equal to one-half of the average bus or train headway after arrival at the individual line-haul stations (times for walking to and from line-haul stations are treated as part of feeder or residential collection travel times and not included here). These waiting times, shown in Figure 7 for the 10-mi route length, are not large, being less than 1 min for all cases. Delay is, however, in all cases greater for rail, the difference being greatest for the shorter route lengths and higher volume levels and negligible for longer route lengths and lower volume levels. Figure 7 shows both trip travel time and waiting time differentials for the 10-mi route length. These may appear as trivial differences, but it should be noted that they stem directly from the maximum headway assumptions, that these assumptions have an important effect on cost, and that because waiting time involves exposure to weather even a short wait may have an adverse and sometimes significant effect on passenger demand.

A number of reasonable questions and implications might be raised regarding the differences in waiting time and cost for the various modes, such as given in Table 8.

An important question arises with respect to the consequences of raising the overall line-haul travel speed, which was set at 35 mph for all modes. To increase the line-haul speed would result in lowering the total passenger travel time from about 10 min to about 9 min at 40 mph, or to about 8 min at 45 mph; obviously, these travel time savings might result in some increases in system cost. With passenger-car travel, increases would probably be only negligible, and would accrue from higher operating expenses and through small reductions in highway lane capacity (thus necessitating more lanes); for both the bus and rail transit systems, it is difficult to anticipate the exact cost effect of increasing the overall speed because of cost tradeoffs. For example, with the rail transit system, heavier, higher powered, and more expensive rail cars would be required and maintenance and operating expense increases would also result. However, with a higher overall speed, the utilization rates (i. e. , round trips per vehicle-hour) would increase, thus reducing the equipment and labor needs, and offsetting the other cost increases. For the bus transit system, higher overall speeds could probably be delivered at less total system cost than that for the 35-mph basic line-haul sys-

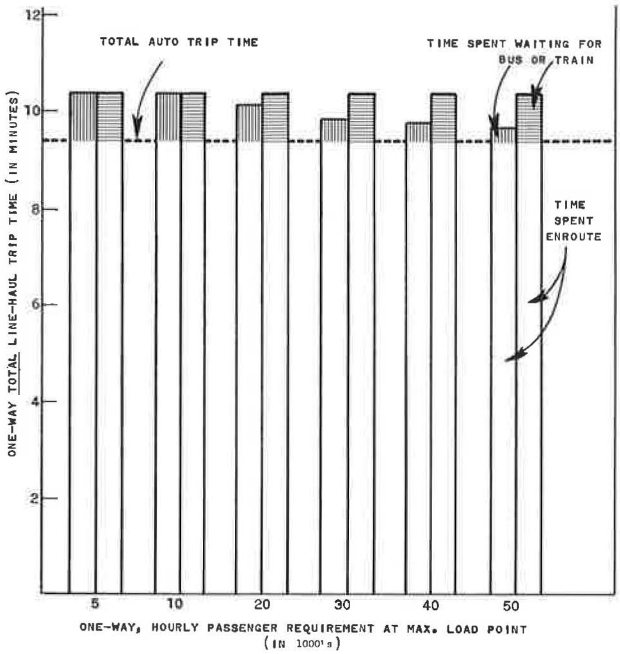

Figure 7. Average one-way total trip time and passenger delay; basic 10-mile line-haul system.

tem. Whereas a higher overall speed would reduce the bus seating capacity and increase equipment, labor and highway costs for the short runs (assuming the use of the same buses and no added power), increased utilization rates would result on longer runs (and may result for all runs because of higher speeds on the empty, express return-haul trip); in all probability, a net increase in utilization rates and decrease in equipment and labor requirements would occur, thus, producing overall cost decreases as well as higher speeds.

TABLE 8

AVERAGE BASIC LINE-HAUL SYSTEM DELAY, TRIP TRAVEL TIME, AND ONE-WAY PASSENGER TRIP COSTS FOR 5-, 20-, AND 50-THOUSAND VOLUME LEVELS AND A 10-MILE ROUTE LENGTH

Volume Level (pass./hr)	Modal System	Avg. Total Travel Time on Line-Haul System[a] (min)	Avg. Waiting Time (sec)	Avg. One-Way Passenger Trip Cost ($)
5,000	Auto	9.4	0	0.93
	Rail transit	10.4	55	0.87
	Bus transit	10.4	58	0.66
20,000	Auto	9.4	0	0.94
	Rail transit	10.4	55	0.36
	Bus transit	10.1	42	0.23
50,000	Auto	9.4	0	0.95
	Rail transit	10.4	55	0.24
	Bus transit	9.7	17	0.20

[a]Includes waiting time at line-haul stations.

Adding Outbound (or Return Direction) Capacity. —Earlier, data were presented on the use of reverse direction rush-hour passenger capacity on existing urban transport systems. It should be emphasized that whereas most existing systems provide this type of service, and that proposed systems assume that its provision is necessary, such an assumption should not be made without review. At the very least the additional costs should be compared with the benefits expected to result from provision of such services.

As with the basic line-haul system, costs of outbound service depend on the operating conditions imposed. For the present analysis these were assumed to be (a) outbound hourly passenger volumes are 20 percent of (and in addition to) the inbound volumes; (b) the outbound required headway or schedule frequency is 6 min or less; and (c) overall travel speed is 35 mph. These service conditions, less stringent than those used for the inbound service, permit operation economies for both rail and bus transit. For example, short-lining and skip-stop operation are permitted for the rail transit system; this is particularly helpful in the two highest volume cases, which require double trackage in both directions, because with the reduced frequency only one return track will be needed for outbound capacity and the other return track can be used for express, non-stop return trips. As before, the multiple-trackage was required for only a portion of the route length. However, the triple track arrangement for the basic line-haul system had to be replaced by a four-track system because outbound capacity was required. Similarly, only a portion of the inbound buses were required for the outbound volume movement, permitting the remainder to operate non-stop for the empty return trip.

The capital costs of the rail transit system are increased by addition of the outbound service because it is necessary (a) to provide four instead of three tracks for the 40- and 50-thousand inbound volume cases; (b) to enlarge the downtown terminal for the 40- and 50-thousand inbound volume cases; and (c) to provide extra rolling stock, yards, and shops, at all volume levels. Also, additional rail maintenance and operating expenses are incurred for the extra rail equipment, for maintenance of way, for conducting transportation, etc. In the two high-volume cases, the trackage costs accounted for almost 50 percent of the cost increases; for the other cases, the additional rolling stock accounted for one-third to one-half of the cost increases. For the bus system, extra rolling stock, yards, and operators were required, and terminal facilities had to be enlarged for the four highest volume levels, and additional bus operating expenses were incurred for all cases. Terminal cost was by far the largest single item in the bus cost increase, accounting for more than 46 percent of the total increase in three cases and 20 percent in the fourth. Average unit costs (per passenger trip) at each volume level for each 10-mi system with and without outbound service are compared in Figure 8. In all but the low-volume auto systems the incremental costs for the additional outbound passengers are below the average costs of the basic system, thus resulting in a decrease in average system costs per passenger trip when the outbound service is added. The unit cost increases for the auto system at low-volume levels result from unutilized outbound highway capacity. For the 5,000 inbound passenger volume level, for example, the outbound volume is only 1,000 passengers an hour. At 1.6 passengers per auto, the total number of autos per hour distributed over the entire 10-mi route length is only 625; thus, on the average, the hourly vehicular volume along the route is only 313 vehicles—far below any reasonable highway lane capacity.

Provision of "Along-the-Line" Inbound Capacity. —Assumptions used in the computation of cost for providing "along-the-line" inbound service are (a) "along-the-line" volume is an additional 10 percent of the inbound rush-hour volume; (b) a seat is provided for each passenger; (c) overall travel speed is 35 mph; and (d) "along-the line" volume destination points are uniformly distributed along the route length. As an example, the resulting distribution of just the "along-the-line" trips along the route is shown for the 50,000 inbound volume level in Figure 9 for the 10-mi route.

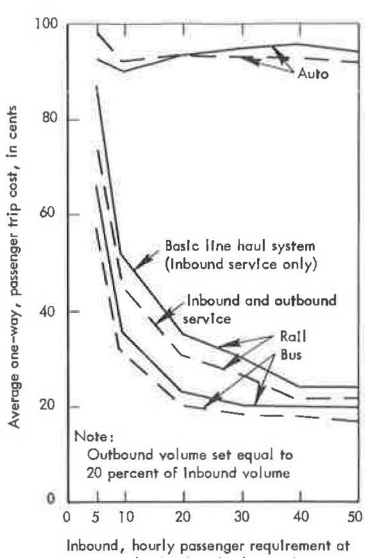

Figure 8. Average one-way passenger trip costs for the 10-mile basic line-haul systems with and without outbound service.

Inasmuch as the scheduling and utilization rates for the basic line-haul rail and bus systems were computed by simulating "along-the-line" service stops, additional costs are incurred for adding inbound along-the-line service only in cases where passenger volumes are pushed above already provided passenger seats. Actually, only small additional costs (such as increases in maintenance of way and equipment due to increased gross ton-mileage) are encountered on the rail transit system, because the unutilized seat capacity is always large enough to handle an additional 10 percent of "along-the-line" passengers.

If 10 percent standees were permitted,

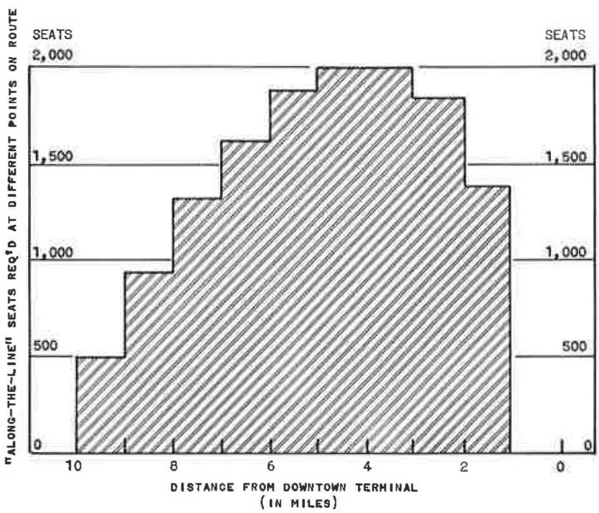

Figure 9. "Along-the-line" seats required along the route (over and above inbound seats) for 50,000 inbound volume level and 10-mile route length.

there also would be little additional increase in costs to provide "along-the-line" service for the bus system, even at higher volume levels. Inasmuch as these "along-the-line" trips are shorter than the inbound trips (an average for the 10-mi route of 3.0 mi compared with an average of 5.5 mi for downtown trips), it might seem unnecessary to provide seats. However, because the basic line-haul rail system automatically can provide each "along-the-line" passenger a seat without additional cost, it seems reasonable to require this service of the bus system as well.

As previously discussed, virtually no costs are added to rail transit with the addition of "along-the-line" service. There are only small increases for increased rail transit maintenance of way and equipment, conducting transportation and power due to the larger number of passengers to be handled at "along-the-line" stations and to additional car weight. These increases are so small that they can be and are ignored here. Bus system costs increase from 6 to 10 percent at the various volume levels. As shown in Table 3, for the 5,000 and 10,000 volume levels bus headway requirements create unutilized bus seat capacity (as with the rail system); thus, no additional bus equipment or labor is required. The major cost increase for "along-the-line" bus service is the extra capital needed to provide additional ramps, slots, and loading-unloading facilities at the line-haul stations. (These costs were estimated at $350,000 per station on the basis of data taken from "Mass Transportation Survey" (D.C.) (5).) This accounts for all of the cost increase at the two lower volume levels and for 30 to 55 percent of the increase at the other volume levels.

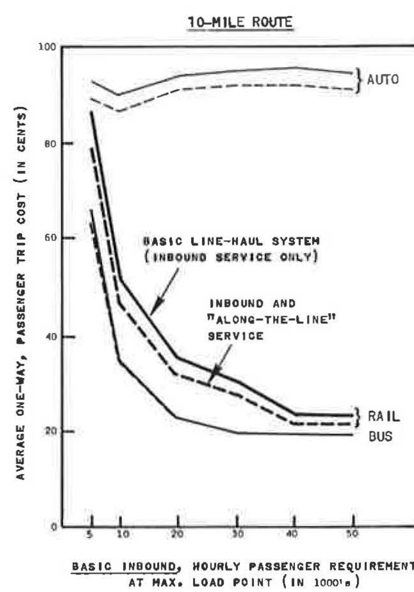

Figure 10. Average one-way passenger trip costs for 10-mile basic line-haul systems with and without "along-the-line" service.

Virtually all of the remaining cost increases are attributable to additional drivers and bus operating expenses.

It is evident from Figure 10 that the incremental unit costs of providing "along-the-line" service at inbound volumes above 20,000 per hour are virtually equal to the average unit costs for the basic (inbound) bus line-haul system, whereas at volumes below that level the smaller increment in costs causes average unit costs to fall. Rail transit costs incur practically zero incremental costs at every volume so that average unit costs are lower with the additional service at every volume level. Addition of "along-the-line" service to the passenger-car system lowers average costs at all volume levels mainly because of lower parking costs and shorter trips for "along-the-line" auto travelers.

Elimination of First Line-Haul Station. --A seemingly high cost aspect of the basic line-haul transit systems is the provision of service to the first station; that is, the station located 1 mi from the downtown stub terminal. Actually, the determination of whether such services are expensive depends on the point of view, or, more precisely, the unit of measure employed. The 1-mi trips have a very high average cost per passenger-mile of service performed, but because the trip itself is short have a low or below average cost per passenger trip. System average one-way passenger trip costs before and after elimination of the 1-mi service differ little (Fig. 11) for the 10-mi transit systems. Virtually no observable change occurs in the one-way passenger trip cost by the rail mode at all volume levels (other than the 20- and 30-thousand volume levels, where a 4 to 5 percent decrease in unit costs occurs). For bus transit there is essentially no change at high volumes, but average trip costs increase 5 to 7 percent at the two lower volumes. Auto passenger trip costs, by contrast, increase by about 4 percent at all volume levels once the first line-haul station volume and incremental costs are deleted.

Service to the first station is not, however, particularly cheap on a per mile basis. Table 9 gives the average costs per passenger trip and per passenger-mile for the basic systems and incrementally for serving travelers going only to the first line-haul station at the 10,000, 30,000, and 40,000 volume levels over a 10-mi route system. It is clear that the average additional cost per passenger-mile is quite high for serving these first line-haul station travelers and many times higher than that for serving all line-haul system travelers. On the other hand, the cost per trip of 1-mi rail transit riders is not too far out of line with that recorded for the basic line-haul system, whereas the auto and bus system 1-mi travelers generally experience considerable economies relative to the overall system riders for these two modes.

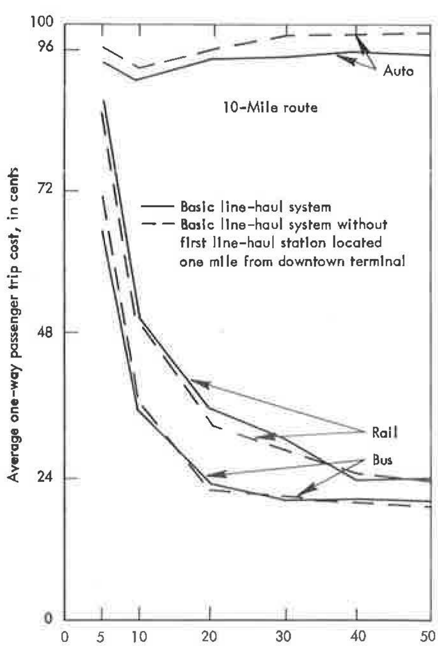

Figure 11. One-way, hourly passenger requirement for basic line-haul system at max load point, in thousands.

Bus transit, in fact, is a remarkably efficient means of meeting the travel needs of short-trip travelers at volumes up to 30,000 hourly passengers. For example, although it costs an additional \$0. 56 and \$0. 41 per passenger trip, respectively, to provide 1-mi service with a rail transit system at 10,000 and 30,000 volume levels and \$0. 56 and \$0. 58 by auto, the same service costs only \$0. 19 and \$0. 13 extra per trip by bus. Moreover, the bus transit system analyzed is probably not the most efficient that might be designed for meeting such needs, because it is a system operat-

TABLE 9

COMPARATIVE PASSENGER TRIP AND PASSENGER-MILE COSTS FOR BASIC LINE-HAUL SYSTEM TRAVELERS, AND FOR THOSE GOING ONLY TO FIRST LINE-HAUL STATION (LOCATED 1 MILE FROM FRINGE DOWNTOWN TERMINAL)

System (or Section and Mode)	Avg. Cost for System or Section ($)					
	Per Pass. Trip			Per Pass. -Mile		
	10,000/Hr. Volume	30,000/Hr. Volume	40,000/Hr. Volume	10,000	30,000	40,000
1st Line-haul station travelers[a]:						
Rail	0.36	0.41	0.19	0.36	0.41	0.19
Bus	0.19	0.13	0.23	0.19	0.13	0.23
Auto	0.56	0.58	0.59	0.56	0.58	0.59
Basic line-haul system travelers:						
Rail	0.52	0.31	0.24	0.094	0.055	0.044
Bus	0.35	0.20	0.20	0.064	0.037	0.037
Auto	0.90	0.95	0.96	0.163	0.173	0.174

[a]Service costs computed on an incremental basis assuming that remainder of basic system was in existence.

ing over a high-performance, limited-access facility, and the buses were limited to a load of only 12 passengers in order to meet the 35-mph speed requirement. It would seem entirely reasonable to serve such short trips, for which travel time may not be a major consideration, by a surface bus system for which the cost per passenger trip might be considerably lower. It is also clear that if an average flat fee per passenger trip is charged, as is the usual practice on transit systems in North America, it generally pays bus transit operators to provide service to short-haul travelers, whereas it generally does not pay for a rail transit operation to do so.

Changes in Headways. --To illustrate the potential effects of changing the maximum allowable headway or schedule frequency, the basic 10-mi line-haul system costs were recomputed with 5-min headways replacing the 2-min maximum headways employed in the original analyses. The results (Fig. 12) show that increasing the maximum headway from 2 min to 5 min has little effect on transit system costs and none on auto system costs. For the rail transit system the increase in maximum headway reduces one-way passenger trip costs by less than $0.01 and overall system costs by less than 2 percent. On the other hand, for the bus system at volume levels beneath 20,000 hourly passengers significant economies can be achieved by an increase in the maximum allowable headway. For example, at the 10,000 hourly volume level bus system achieves an overall reduction of 18 percent in total system cost and a reduction of $0.07 per trip; at the 5,000 volume level the economies are even more significant, being 32 percent of total cost and $0.21 per trip. These economies in the bus system are achieved by reducing the unutilized capacities that must be introduced into the system at lower volume levels to maintain 2-min service frequency. The importance of this finding should not be underestimated, because a considerable proportion of total urban transit service is provided by buses meeting peak hourly demands in these lower ranges of the analysis.

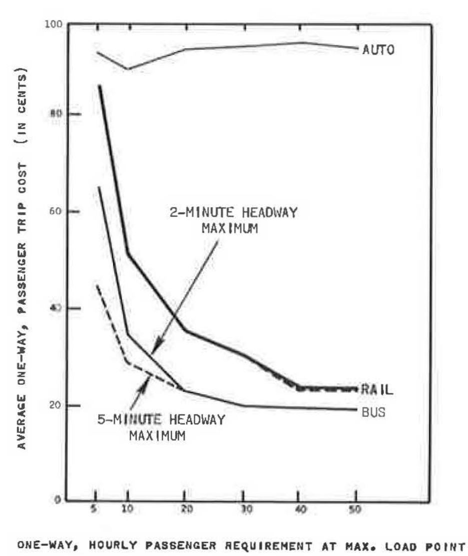

Figure 12. Effect on one-way passenger trip costs for the basic 10-mi line-haul systems of reducing schedule frequency from 2 to 5 min.

The important question from the standpoint of the urban traveler is to what extent any cost reductions that might be achieved by reducing headways would be offset by increases in waiting time and inconvenience, with possible reductions in demand. For example, at the 5,000 hourly volume level increasing the maximum allowable headway from 2 min to 5 min increases average waiting time for the user of bus transit from 58 to 139 sec, and reduces costs from \$0.66 to \$0.45. The obvious question, therefore, is whether many actual or potential users of bus transit find a saving of \$0.21 a trip worth waiting an extra 80 sec per trip. Considering an even broader range of possibilities, the individual consumer is confronted (in the case of 5,000 hourly volume levels over 10-mi route systems with either 2- or 5-min transit headways) with a series of choices of the following kind: (a) going by auto at an average one-way trip cost of \$0.93 with no waiting time; (b) going by rail transit at a cost of \$0.87 per trip with 55 sec of waiting time (only the rail transit system with 2-min headway has been considered because the 5-min rail system reduces service without reducing costs materially); (c) going by bus transit with a waiting time of 58 sec and a cost of \$0.66; or (d) going by bus with a waiting time of 139 sec and a cost of \$0.45 per trip. Without considerable knowledge of the demand structure for urban travel it is not, of course, possible to make specific statements about which of these alternatives would be chosen and, more importantly, in what number they would be chosen within specific cities. Nevertheless, such questions should be raised and answered explicitly when actually planning urban transportation systems.

Changes in Automobile Occupancy Rate.—It is quite clear that cost reductions can be achieved in the automobile line-haul system simply by increasing occupancy. For example, increasing passenger occupancy by 12 percent from 1.6 to 1.8 passengers per vehicle results in a cost reduction of approximately 11 percent for the 10-mi auto system, the one-way passenger trip cost dropping from about \$0.90 to \$0.80. Corresponding and almost proportional reductions in cost can be achieved by further increases in passenger-car occupancy. For example, increasing auto occupancy up to five passengers per vehicle would cut the cost per trip for the 10-mi route system to approximately \$0.30 or less at all volume levels. Figure 4 shows that the auto under such circumstances would be quite cost competitive with rail transit at hourly volume levels of 20,000 or less and with buses at 15,000 or less. Of course, any such auto cost reduction must be "paid for" in terms of a reduction in the quality of service rendered; the low automobile occupancy rates observed in U. S. cities suggest, in fact, that the increased discomfort or inconvenience of car-pooling is not worth the cost saving to most commuters. It suggests, however, that engineers and planners should view car-pooling as a mode of low-cost transit available right now—a mode with service characteristics perhaps as attractive as almost any conceivable rail or bus system. (The only service characteristics of car-pooling that are clearly inferior to public transit are schedule frequency, loss of flexibility (in time of trip and destination), and the fact that the driver must devote his full attention to driving. For workers keeping regular hours (and having common residential areas and workplaces), however, this should not be too serious a drawback.) Thus, failure of car-pooling to attract more patronage implies that many commuters do place a high value on convenience and service and that public transit faces serious obstacles in trying to win patronage back from the private auto.

The cost changes effected by increasing the car occupancy from 1.6 passengers per auto to 1.8 are shown in Figure 13 for a 10-mi route length and all volume levels. At the lowest volume level (5,000 hourly passengers), an \$0.11 cost reduction has resulted, thus placing the auto system passenger trip cost at \$0.84. This is \$0.03 less than the rail transit figure of \$0.87, and some \$0.18 above the bus transit unit cost.

Perhaps it has not been sufficiently stressed that an automobile transport system—through its operation, car occupancy, and parking characteristics—offers an advantage to travelers unmatched by virtually any other type of transport (save possibly taxi) with regard to its ability to "tailor" service and cost to its users. Should a traveler desire the maximum of comfort and convenience, and be able and willing to afford the additional costs, the option is available for driving alone without riders, for using luxury cars (and perhaps having a chauffeur), for having unexcelled schedule frequency, and for parking almost immediately adjacent to his workplace, although at a cost of perhaps $1.50 per passenger trip. At the other end of the scale, travelers car pool up to five or six persons per auto, drive cheaper cars, park at much cheaper parking lots (but walk considerably longer distances), and thus reduce passenger trip costs to perhaps $0.10 or $0.15. Obviously, these options, and all between the two extremes, are available to users of the same system and at the same time; travelers may, as well, change their habits from day to day and from year to year as their tastes and incomes permit. By contrast, transit systems--and particularly fixed rail transit operations—offer no such range of opportunities for directly affecting one's service and cost; in general, and on a fairly long-term basis, only a single level of service and at one cost is available.

Changes in Downtown Stub Terminal Design.—As noted earlier, and as shown in Figure 5, the station and terminal costs account for a sizeable portion of the transit system costs, particularly for the bus transit system at low volumes where no divisibility occurs. Lack of divisibility resulted directly from a design assumption calling for at least one bus slot for each line-haul station served (and from the headway restriction); this assumption increased the number of bus slots over that necessary to handle the bus and passenger volumes in 10 of the 18 volume level and route length cases.

The additional bus slots do simplify the bus operation and offer a superior service for the passengers, because both drivers and riders always know exactly the position where they are loading. Also, the loading passenger always knows that the next bus to arrive will be going to one particular line-haul station. If, however, the number of bus slots were limited just to the number needed to dissipate the acceleration-deceleration and loading-unloading delays, and if the foregoing design restriction were dropped, several changes would result (in addition to cost reductions). Buses and passengers going to and from more than one line-haul station may use the same bus slot; consequently, in the earlier cases where the design restriction controlled, passengers would experience more crowding on the bus loading platforms and would sometimes have to let one or more buses pass before their particular bus arrived.

The cost effects of eliminating this design restriction for the 10-mi route length are

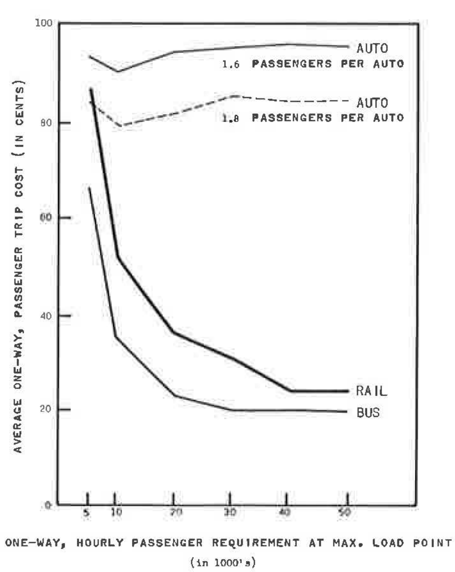

Figure 13. Average one-way passenger trip costs for 10-mile basic line-haul systems with varying passenger car occupancy rates.

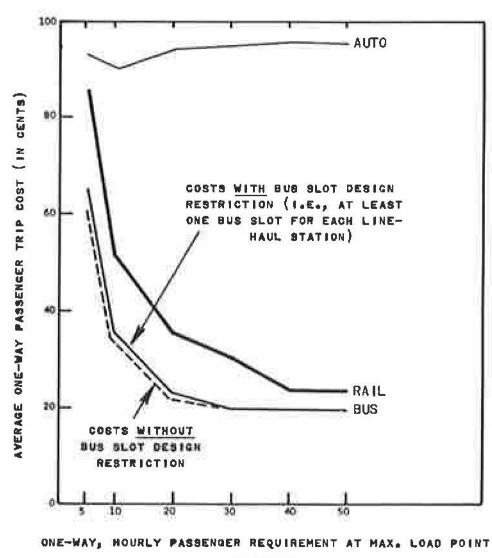

Figure 14. Average one-way passenger trip costs for basic 10-mile line-haul systems with and without bus terminal design restrictions.

shown in Figure 14. The cost reductions range from 1.5 to 7 percent of the total annual system costs, and produce passenger trip reductions up to about $0.045. (Although the exact figures were not developed, it is worth noting that even greater economies would result from relaxing this restriction for the 15-mi route length.)

RESIDENTIAL COLLECTION SYSTEM COST ANALYSIS

This section is concerned with the cost of providing transportation for passengers between home and the intermediate point where they enter or exit from the line-haul system, and with evaluating the effect of the residential collection system operation on the combined line-haul and residential collection system cost and operation.

Generally, two types of residential service were considered and costed: (1) residential service directly connected and integrated with the line-haul operation, thus requiring no passenger transfer; and (2) residential service operated separate from the line-haul system, and therefore requiring passenger transfer at the intermediate point. The two types of residential collection area transportation were evaluated both for bus transit and auto travel, and the specific kinds of service costed were as follows:

1. Feeder bus service, operated separate from the line-haul operation.
2. Feeder bus service, (integrated with line-haul express service), whereby line-haul system express buses also operate in the residential collection area as feeder buses.
3. Auto travel, whereby the auto travelers continue on downtown over the line-haul system.
4. "Park 'n ride" auto travel, whereby an auto is used between home and the line-haul station transfer point (where the auto is parked).
5. "Kiss 'n ride" auto travel, whereby the passenger is driven to and dropped off (or picked up) at the line-haul station transfer point.

Finally, residential collection and line-haul system cost and performance were evaluated under varying conditions of residential density.

Description of Residential Collection System Design and Service Variables

The requirements (and thus costs) for residential collection area service are dependent on a number of variables; the most important, however, are the land use pattern and the conditions for establishing a reasonably equivalent level of service. The assumptions regarding land use patterns and residential densities were generally based on Chicago data, whereas the trip generation rates (i.e., number of rush-hour passenger trips made per residential unit) were based on Pittsburgh data. Both the residential densities and rush-hour passenger trip rates were varied with the distance along the route length, but available data did not permit additional stratification according to the hourly volume level in the corridor.

It is important to note two assumptions made in the process of determining the number of residential blocks or land area required to build up the hourly passenger requirement at each line-haul station. (For the 30,000 volume level and 6-mile route length, for example, 5,000 passengers will enter each line-haul station during each rush hour. The problem is next to determine how many blocks of mixed land use will generate exactly 5,000 passenger trips during each rush hour. Once this land area is determined, the amount of travel within the residential collection area (between home and the line-haul station) will follow directly.)

First, in the determination of appropriate residential densities and of the extent to which other than residential land uses required land in the area adjacent to the line-haul stations, public open space, vacant land, water and unusable land uses were not included in stating residential land as a percentage of total land use. In effect, this means that all land adjacent to the line-haul station is used "productively." This assumption raises the density of occupied land and results in what might be described as a "corridor land use plan" with people (probably) living closer to line-haul facilities and stations than they otherwise might or than is presently experienced.

Second, in developing and using initial or basic trip generation rates no distinction was made between rush-hour passenger trips to (or from) the downtown area and those to (or from) other areas within the region. Effectively, then, the implicit assumption was made that all downtown travelers would live immediately adjacent to the line-haul facility and that all travelers to other parts of the region would live at farther distances from the line-haul facility. Although the assumption has some validity, the interdependency probably is not nearly as strong at present and thus the residential collection trip lengths and transportation requirements are understated. To the contrary, this does not mean that high-density corridor-type developments, with strings of high-rise apartments, will not be the fashion of future decades. In fact, there is considerable impetus in Washington, D. C. --even to the extent of having a Presidential directive to the effect--for carrying out such a land use plan.

To bracket both potential and present land use patterns, and more particularly to evaluate in detail the high-density pattern currently receiving the attention, concern, and backing of rail transit enthusiasts and urban land use conservation advocates, the costing first was developed for high residential densities and then extended to account for differences occurring with somewhat lower or medium densities. The comparative analysis of the two density levels will be particularly useful in (a) determining changes in the relative cost structure of the various modes; and (b) noting changes in absolute transportation costs which stem from the differing land use patterns (i. e., a mechanism is provided for evaluating in a general way the transportation "price" that must be paid for more residential privacy and larger grounds).

The problems in establishing a reasonable set of equivalent service conditions are many and complex, and hardly lend themselves to either precise analysis or judgment. Even so, it was necessary to prescribe rough limits for the initial analysis. The major service restrictions were as follows:

1. Equal overall travel speeds need not be maintained for all modes on the residential collection system portion of the trip.
2. Running speeds for buses and autos (but excluding delays for loading/unloading, accelerating-decelerating, picking up riders, parking at lots, etc.) on residential streets assumed to be 25 mph.
3. Feeder bus headways of no more than 10 minutes.
4. A seat provided for every passenger.
5. For "park 'n ride" service in residential area, 10 percent car-pooling (i. e., 1. 1 persons or seats per auto).
6. Feeder bus routes no more than $1\frac{1}{2}$ times longer than the most direct route between bus stops and line-haul stations.

Also, it should be re-emphasized that no stratification or split was made for passengers traveling over the residential collection system; that is, all passengers traveling to and from the line-haul system were assigned to either feeder bus, or some type of auto travel, rather than split among different types of residential collection system service. In terms of comparing the cost rank or position of rail and bus transit systems, this assumption makes little difference; on the other hand, it probably does change the hierarchy or ranking of auto and transit systems (to the great disadvantage of the auto mode). As is shown shortly, for example, costs for residential area travel by "park 'n ride" service are considerably higher than those by feeder bus (either a separate feeder operation or as an extension of the line-haul operation); thus, if it was assumed that some given percentage of the transit line-haul travelers used 'park 'n ride" service, the total cost of transit trips would be higher than shown, thus increasing transit unit costs relative to auto unit costs. The importance of such a change is noted later in this section.

System Cost and Performance for High Residential Density

The resulting total home-to-downtown travel times for the three principal systems, including a breakdown for vehicle running and passenger waiting or walking times, are shown in Figure 15 for the 10-mile route length. It is evident that absolute travel times and the time differences between modes are narrowed as the volume level decreases; this is mainly due to the fact that as the volume level decreases the percentage of line-haul travelers walking directly to the line-haul station increases. Inasmuch as walking

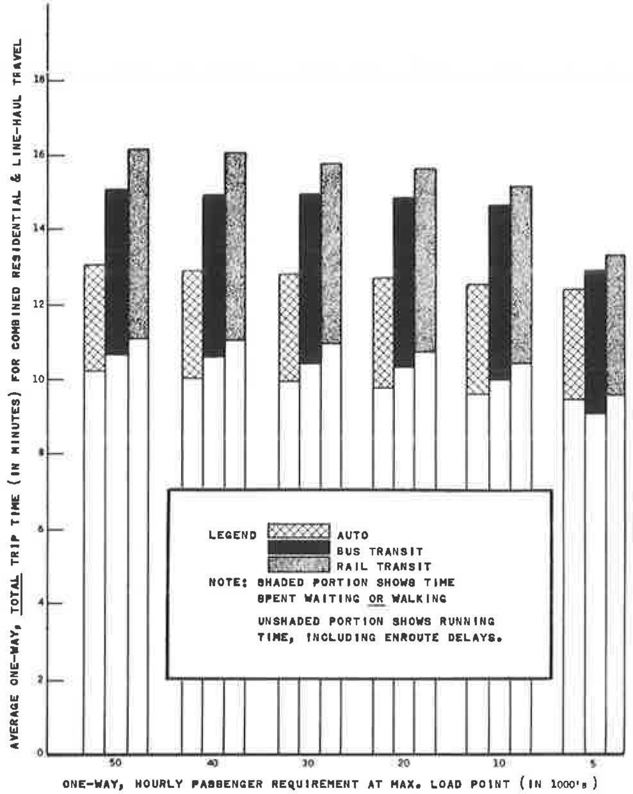

Figure 15. Average one-way total trip time for combined residential and line-haul travel; 10-mi route length and high residential density.

passengers incur neither the feeder bus waiting times (these run between 2 and 5 min) nor feeder travel times, considerable time is saved, on the average.

The rail transit travel times for the trip between home and the downtown terminal run from 3 to almost 8 percent (0. 4 to 1. 2 min) longer than bus transit travel times; the rail transit times run from 7 to 25 percent (0. 9 to 3. 3 min) longer than auto travel times for the residential and line-haul trip. Viewed in absolute terms, the travel time differentials do not seem severe. On the other hand, two other aspects may be critical. First, it should be recalled that neither the combined (or integrated) feeder-express bus operation nor the auto system require passenger transfers at the intermediate line-haul station point (where passengers move between residential collection and line-haul systems). The other aspect of service worth noting regards the amount of time that is spent walking and waiting for the three modes.

The difference between waiting and walking times for bus and rail transit are almost negligible; they run from 0. 1 to 0. 7 min longer for rail than for bus. The "waiting" time for auto, as pointed out earlier, derives from delay which the auto driver incurs while picking up riders or car-poolers (which was set at 3. 0 min for a car occupancy of 1. 6). Including even this auto "waiting" time, the transit modes still require some 0. 9 to 1. 6 min more waiting and walking time than auto travel. This difference has been held distinct merely because it is felt this type of delay is probably more important to travelers than that encountered while actually moving or enroute.

Table 10 gives the percentage of travelers moving between home and the downtown terminal that walk directly to line-haul stations and thus do not require any type of residential collection system service. (These figures are shown for the entire route length; at individual points or stations along the route, the percentage may run as low

TABLE 10

PERCENTAGE OF TRANSIT PASSENGERS WALKING DIRECTLY TO LINE-HAUL STATION[1] FOR UNIFORMLY DISTRIBUTED ONE-WAY HOURLY PASSENGER REQUIREMENT

Route Length (mi)	Transit Passenger Walking (%)					
	50,000 Pass./Hr	40,000 Pass./Hr	30,000 Pass./Hr	20,000 Pass./Hr	10,000 Pass./Hr	5,000 Pass./Hr
6	8	10	13	21	39	68
10	11	14	18	26	45	77
15	14	17	22	32	56	90

[1] The percentage of passengers using the rail transit line-haul system (or line-haul bus and separate feeder bus) and who must suffer an extra transfer (which does not occur with either auto or combined feeder-express bus service) is equal to 100 minus the percentage given here.

as 6 percent or as high as 100 percent.) At high volumes, from 10 to 20 percent walk directly to the line-haul facility, whereas at low volumes anywhere from 20 to 90 percent walk to the transit line-haul system.

Available data are so limited as not to permit a definitive conclusion regarding the validity of the assumption or the way in which the walking assumption affects the relative cost structure. Again, it was assumed that all commuters residing within two blocks of a line-haul station walked directly to the station. However, 34 percent of the commuters using the Highland Branch rail tranist line in Boston walked to the facility (8), whereas only 6 percent of the commuters on the Cleveland Westside line walked to the facility (9). These two lines correspond roughly to the lowest volume level of the current analysis. For the Congress Street-Douglas Park rail transit line in Chicago, whose major direction volume places it generally in the 10,000 hourly passenger volume level of this analysis, about 50 percent of the commuters walk to the line; in Toronto, about 15 to 20 percent walk to the subway whose volume is approximately in the 20,000 hourly passenger class (major direction). The comparison between actual data and those produced by the walking assumption in this analysis is given in Table 11. Although it is difficult to generalize from these limited data, it appears that the two residential density levels chosen for analysis generally bracket many situations of interest, though it appears that neither combination of residential density and walking distance tends toward the middle of the range. It is important to note here that the percentages used in this analysis should be higher than those recorded on actual facilities because the data here include passengers who do not use existing transit facilities because of cost and service differentials other than those assumed herein.

Results of Residential Collection System Cost Analysis for High Residential Density.--The five types of residential collection area service mentioned earlier were costed, and the detailed results analyzed. The additional or incremental costs for adding residential service to the basic line-haul system (on an annual basis) are shown in Figure 16.

TABLE 11

COMPARISON OF ACTUAL AND COMPUTED PERCENTAGE OF PASSENGERS WALKING DIRECTLY TO LINE-HAUL STATION

Facility	Approx. Hourly Pass. Vol. During Peak Hour[1]	Pass. Vol. Walking (%)		
		Actual	Computed[2]	
			High Res. Density	Med. Res. Density
Boston, Highland Branch	< 5,000	34	68-90	24-45
Cleveland, Westside	5,000	6	68-90	24-45
Chicago, Congress-Doug. Pk.	10,000	49	39-56	12-22
Toronto, Younge St.	20,000	15-20	21-32	6-11

[1] In major flow direction. [2] Based on data assumed in cost analysis.

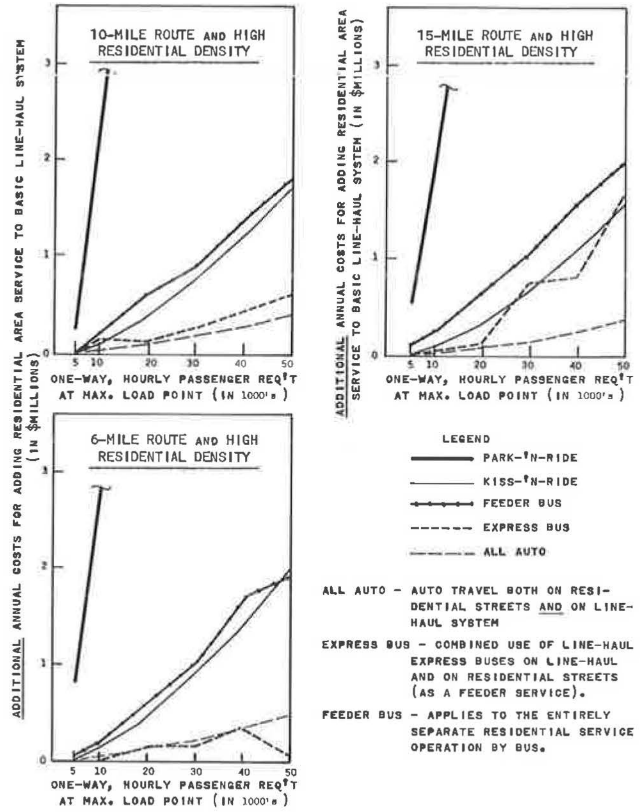

Figure 16. Additional costs for adding residential collection system service (to basic line-haul system) at high residential density.

These costs were first separated from the line-haul system costs to permit closer examination of the cost effects of this additional service. In general, it is concluded that "all auto" or passenger car travel--between home and the downtown terminal—will experience a cost decrease relative to the other types of travel, though for short route lengths the passenger car and combined (integrated) feeder-express bus operations are little different in terms of additional costs for residential service. However, given that line-haul travel is to be made by either bus or rail transit, it is evident that the combined (or integrated) feeder-express bus operation enjoys a cost decrease relative to line-haul rail transit travel in combination with any type of residential feeder service, and relative as well to line-haul express bus travel in combination with any type of separate residential feeder service.

Furthermore, for the three types of separate residential feeder service (feeder bus, "park 'n ride," and "kiss 'n ride") it is clear that "kiss 'n ride" service is always the least costly--if, of course, one ignores the "discomforts" and "inconveniences" endured by the housewife or person performing chauffeur duties; also, the "park 'n ride" service runs five to ten times more expensive than the next most expensive type of residential feeder service, the feeder bus. Here, too, no account is made of the fact that the "park 'n ride" traveler suffers no waiting or walking times or "discomforts" at the home end of the journey.

To help explore these service inequalities, and other aspects, the additional costs for residential service have been computed on a unit passenger trip basis; the data are shown in Figure 17, except for the "park 'n ride" costs, which are too large to be included on the graphs. (In each case, the additional annual costs were divided by the number of residential travelers who made use of the particular kind of service; thus,

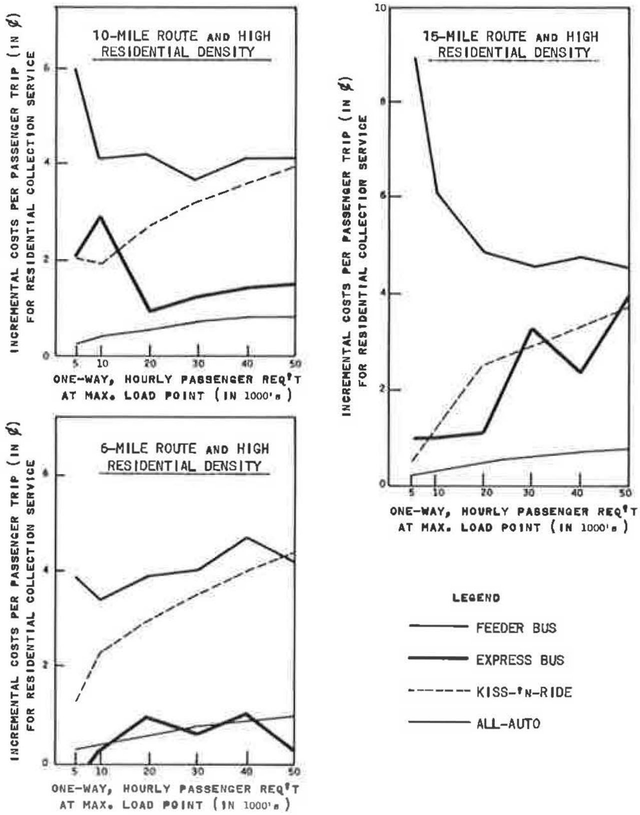

Figure 17. Incremental costs per passenger trip for adding residential collection system service to line-haul system at high residential density.

for all modes and types of feeder service the passengers walking to line-haul stations were excluded, and no residential collection system costs were apportioned to them.) The separate feeder bus service unit cost ran from $0.034 to $0.090 per trip; by contrast, the additional combined feeder-express bus costs ran from only $0.002 to $0.039 per trip. The "kiss 'n ride" costs ranged from $0.005 to $0.044 per trip, while the "park 'n ride" costs ranged little from $0.48 per trip. These high "park 'n ride" costs contrast with additional all passenger car system costs of $0.002 to $0.010 per trip. For residential system "park 'n ride" vehicles, the annual insurance cost was reduced to $20, rather than the $100 fee charged to vehicles moving to and from downtown during peak hours.

A word of caution must be expressed at this point; the foregoing comparisons are meaningful only in terms of examining the effect on the relative cost structure of the principal modes for travel over both the residential collection and line-haul systems. In other words, a comparison between feeder bus and passenger car costs for the residential collection system only helps to appreciate which of the two modes of travel is improving its cost position. At the same time, however, some of these unit residential system costs can be compared, meaningfully, and can add to insight even without combining them with the line-haul costs.

For example, given just one specific type of line-haul travel, incremental and unit costs of the different types of residential system services can be compared. This is done in Table 12 first for rail transit line-haul travel and then for bus transit line-haul travel; for simplicity, only one volume level (30,000 line-haul hourly passengers) and one route length (10 miles) has been examined.

TABLE 12

COMPARISON OF INCREMENTAL AND UNIT COSTS OF VARIOUS RESIDENTIAL SYSTEM SERVICES

Type of Service		Travel Time[1] (min)			Incremental Cost per Pass. Trip ($)
Line-Haul	Res. System	Running	Waiting/ Walking[2]	Total	
Rail transit	Kiss 'n ride	0.6	0.8	1.4	0.032
	Feeder bus, sep.	1.7	6.2	7.9	0.037
	Park 'n ride	0.6	2.3[3]	2.9	0.483
Express bus	Combined feeder bus	1.2	4.6	5.8	0.012
	Kiss 'n ride	0.6	0.5	1.1	0.032
	Sep. feeder bus	1.7	5.9	7.6	0.037
	Park 'n ride	0.6	2.0[3]	2.6	0.483

[1]For passengers using feeder service only; does not include passengers walking directly to line-haul station, thus requiring neither bus nor auto residential collection system service.
[2]Includes waiting time for feeder service and for line-haul vehicles; also includes walking times to feeder bus stops (at 2 min per block).
[3]Includes 5 min delay per rider, and 1 min parking delay.

Given a rail transit line-haul system (and particular volume, route length, and service conditions as assumed), the cheapest type of feeder service would be "kiss 'n ride" travel by a slight margin of only $0.005 per trip over feeder bus. In a sense, then, if the more expensive of these two service types is selected, passengers might be assuming that it is worth spending an extra $0.005 per trip and worth enduring an extra 6½ min of travel time (and discomfort) just to avoid inflicting "discomfort" and "inconvenience" upon the housewife or whomever must drive the passenger to the line-haul station. In similar fashion, "park 'n ride" service may be compared in turn with each of the other two types of residential travel. For example, if travelers use "park 'n ride" service instead of feeder bus service, they will avoid some 5 min of waiting and walking, and the associated inconvenience, but will incur extra costs of almost $0.45 per trip. Or, if travelers wish to avoid the inconveniences to the household caused by cheaper "kiss 'n ride" travel service, they must be willing to spend 1½ min longer traveling and to spend an extra $0.45 per trip if they select "park 'n ride" travel instead. Although assembling cost and service information in this fashion does not necessarily indicate which type of service is "best," it will certainly serve to improve the decision making process. Obviously, a strict line cannot—and in fact should not--be drawn here, as the market structure is highly stratified. It is useful, however, to oversimplify for purposes of illustration.

The same sort of analysis can be applied to the different types of residential feeder service for bus transit line-haul travel, but with one important difference. The difference is with respect to the combined or integrated feeder-express bus service, whereby the line-haul express buses continue onto residential streets, providing feeder or residential collection system service as well. One interesting point is that the combined bus service is both cheaper and faster than express bus line-haul in combination with a separate residential feeder bus service; and, perhaps more importantly, the combined bus service requires no intermediate transfer for the passenger at the line-haul entry (and exit) station. Thus, combined or integrated feeder-express bus service is superior to the separate feeder bus service in all respects. This, it should be noted, is only true for the high residential density case, as is explained later in this section.

Despite the advantages of the combined bus service relative to a separate feeder bus operation, the lower travel and waiting times of both "kiss 'n ride" and "park 'n ride" service impel one also to include comparisons with these types of service. The "kiss 'n ride" residential service, for example, is only slightly more expensive (about $0.02 per trip) than the combined bus service, but is 4.7 min faster (most of this time saving results from waiting time reductions); however, "kiss 'n ride" service requires a passenger transfer at the intermediate line-haul station, and inconveniences the driver, probably to some considerable extent. Viewing the "park 'n ride" service, which also requires an intermediate transfer for the traveler, it is evident that the cost per trip is about $0.47 greater than combined bus service but that the passenger will save slightly more than 3 min, mostly in waiting time. Perhaps the only conclusion that can be drawn is that the case for combined bus service--relative to both "kiss 'n ride" and "park 'n ride"—is much stronger than the case for feeder bus service in combination rail transit line-haul travel.

Cost Analysis for Combined Residential and Line-Haul System Travel for High Residential Density.—The costs for providing both residential collection and line-haul system service between home and the downtown terminal are summarized (on a passenger trip cost basis) in Figure 18.

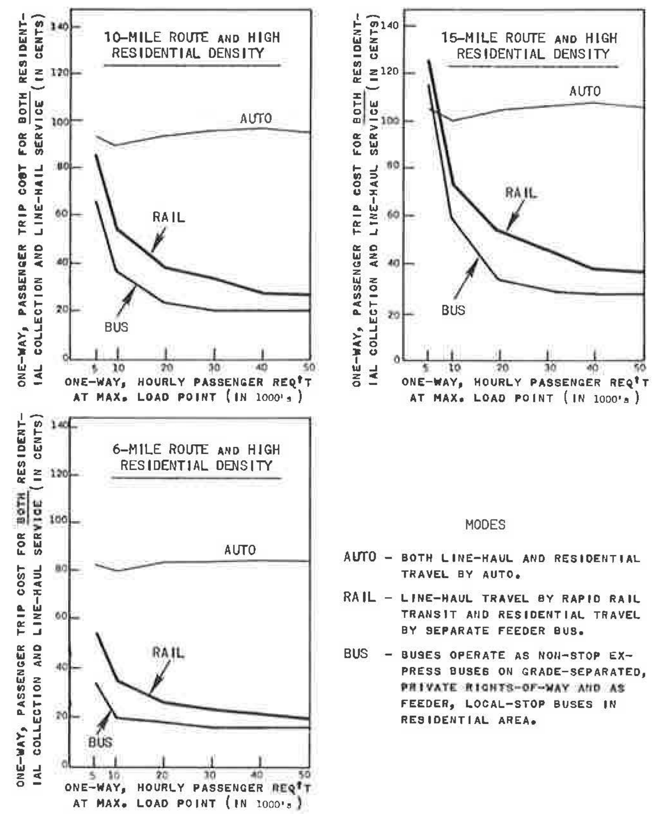

Figure 18. Line-haul and residential collection area systems costs (including downtown terminal and parking) for high residential density.

The effect on the total trip cost structure of adding residential collection system costs to those for line-haul travel can be assessed by comparing Figures 4 and 18. The basic change may be expressed fairly accurately by noting that the rail mode unit costs were increased more than those for other modes at the four highest volume levels, although the unit costs for rail increased only 5 to 10 percent. (For the combined rail mode, the residential portion of the cost ranges up to 19 percent of the combined system cost; for bus, the residential portion is, at most, 13 percent; and for auto travel, only slightly over 1 percent.)

Inasmuch as the relative cost structure changed very little upon adding the residential feeder travel, the arguments and conclusions reached in the preceding section on line-haul system costs are virtually unchanged, with one exception. The major difference in comparing the alternative modes at this point is what appears to be a rather major service inequality between the rail transit mode and the two others because an intermediate transfer is required for those travelers using feeder bus service in conjunction with the rail transit line-haul system (whereas no transfer is required for the integrated bus or all passenger car systems). Table 13 compares the cost and service differences for the modes at three volume levels for the 10-mile route length.

Much as before, one might properly question whether the service differentials justify the extra costs. For example, at the 50,000 volume level, will travelers be willing to spend an additional $0.74 per trip (over bus travel) to use passenger cars from home to downtown and thus to save slightly more than 2 min, and avoid waiting inconveniences? Or to pay an extra $0.71 per trip to save about 2 min at the 20,000 volume level? Probably not, in most cases, but at the 5,000 volume level the cost differences are small enough to make the question more than academic; here, travelers

TABLE 13

COMPARISON OF COST AND SERVICE DIFFERENCES AT THREE VOLUME LEVELS FOR 10-MILE ROUTE LENGTH

Line-Haul Volume Level[1] (pass./hr)	Travel Mode	Wtd. Avg. Travel Time[2] (min)			Avg. Pass.-Trip Cost[2] ($)
		Running	Waiting/ Walking	Total	
50,000	Bus transit	10.7	4.6[3]	15.3	0.21
	Rail transit	11.2	5.3[3]	16.5	0.28
	Pass. car	10.2	3.0	13.2	0.95
20,000	Bus transit	10.4	4.7[4]	15.1	0.23
	Rail transit	10.9	5.1[4]	16.0	0.39
	Pass. car	9.9	3.0	12.9	0.94
5,000	Bus transit	9.2	3.9[5]	13.1	0.66
	Rail transit	9.7	3.8[5]	13.5	0.88
	Pass. car	9.6	3.0	12.6	0.94

[1]One-way, 10-mi route length. [2]Approx., over (high-density) residential and line-haul systems. [3]11% walk to line-haul facility. [4]26% walk to line-haul facility. [5]77% walk to line-haul facility.

would have to spend an extra $0.28 per trip to use cars instead of bus transit, to avoid whatever inconveniences they might associate with bus transit, but would save only one-half minute in travel time. On the average, it is difficult to judge; but it is clear that some travelers would and others would not, depending on their personal preferences and evaluation of privacy, etc. Though the question remains unanswered, it is stated in terms much easier to deal with.

As for a comparison between rail and bus transit, there seems to be little question that for this type of system layout, and for the prescribed movement between home and downtown, bus transit is superior to rail transit. Not only is bus transit--of the nature designed, with express service on the line-haul system and with integrated continuous residential collection area service as well—cheaper (bus transit runs from 7 to 41 percent cheaper than rail transit for the different combinations of volume and route length) and faster than rail transit, but its travelers also enjoy a non-transfer service between the feeder bus stop and the downtown terminal, whereas the rail transit system requires passenger transfer at the line-haul station where the rail line-haul and feeder bus systems meet.

Cost Effects from Changing Design or Service Variables at High Residential Density.—To change variables such as headway, or to add outbound or "along-the-line" capacity, and so forth, produces results quite similar to those presented in the section on line-haul system cost; in fact, at low volume levels, where the majority of passengers walk directly to the line-haul stations and thus little residential collection system service is required, the results would be almost identical. Placed in other terms, for the four lowest volume levels, the incremental residential collection system costs are, at most, 9 percent for the rail transit mode, 4½ percent for the bus system, and less than 1 percent for all auto travel; thus cost variations for the basic line-haul system which result from service changes are virtually unaffected by the inclusion of the incremental residential collection system costs. In addition, there seems little necessity for repeating the earlier analysis of cost variations which stem from adding outbound capacity, adding "along-the-line" capacity, increasing maximum schedule frequency, eliminating bus terminal design restriction, or increasing car occupancy.

However, to extend the sensitivity analysis of service and design changes, it is helpful to examine the cost effects that result from (a) reduction of parking costs and (b) reduction of automobile capital and accident costs. For the parking charges, the initial set of unit costs (see Table 5) may be manipulated, for example, to determine the point at which fringe downtown parking site acquisition costs become cheap enough to justify parking lots instead of multi-story garages; for the data shown, the break-even point would be at about $2,700 per (ground level) parking space. For this extended analysis, however, the site acquisition cost is reduced to $1,500 per (ground level) parking space; for this figure, the total daily parking cost per vehicle is about $0.75, instead of the $1.28 used for the initial or basic system costing. For the automobile capital cost, a figure of $1,200 is used in place of the $1,600 used in the basic analysis. (The auto capital cost reduction generally can apply to all situations, whereas the parking ROW cost reduction would only be possible--if then—in situations of low density, and low hourly (corridor) passenger volumes.)

The parking site acquisition cost change produces a net passenger trip saving of about $0.17, while the reduction in automobile capital cost results in a passenger trip saving of only $0.035 for the 6-mile, $0.042 for the 10-mile, and $0.052 for 15-mile route length.

One might argue further that the automobile used exclusively for commuting purposes (as is the case here) would have annual accident insurance costs more in the vicinity of $60, rather than the $100 used in the basic system costing. With this reduction, the passenger trip costs would be reduced by another $0. 049. These three cost reductions would total about $0. 25 to $0. 27 per passenger trip, or about 25 to 31 percent.

Substantial as these reductions may seem, however, their effect on the relative cost structure of the three modal systems is surprisingly small (though not necessarily unimportant) as shown in Figure 19. The reason the "crossover points" for the three sets of modal curves change relatively little (in terms of the whole range of volumes) is, of course, that the intersections or crossovers occur in the regions where the transit curves have high slopes or gradients and the auto curve is almost flat. These data can, perhaps, be described more meaningfully by examination of the cost information in Table 14. In the two higher volume cases (for a 10-mile route length), it would be difficult to argue that (on the average) even with the substantial cost reductions passengers would select the auto mode over the bus transit system with cost differentials per passenger trip of $0. 27 and $0. 45, respectively, for the 10, 000 and 20, 000 volume levels; for the 15-mile route length, the cost differentials of $0. 14 and $0. 45 appear only slightly less formidable. To the contrary, however, if such cost reductions were reasonable expectations (a not too likely situation) for the 5, 000 volume level situation, it is evident that the auto system would be the most feasible for the 15-mile route length and 10-mile route length, the latter even with the $0. 02 cost differential over the cheapest mode (bus transit).

In conclusion, it seems that these substantial reductions in auto costs would provide a cost advantage for an all-auto system—relative to other modes—only at volumes of perhaps 6, 000 hourly passengers or below for 10-mile route lengths, and at volumes of

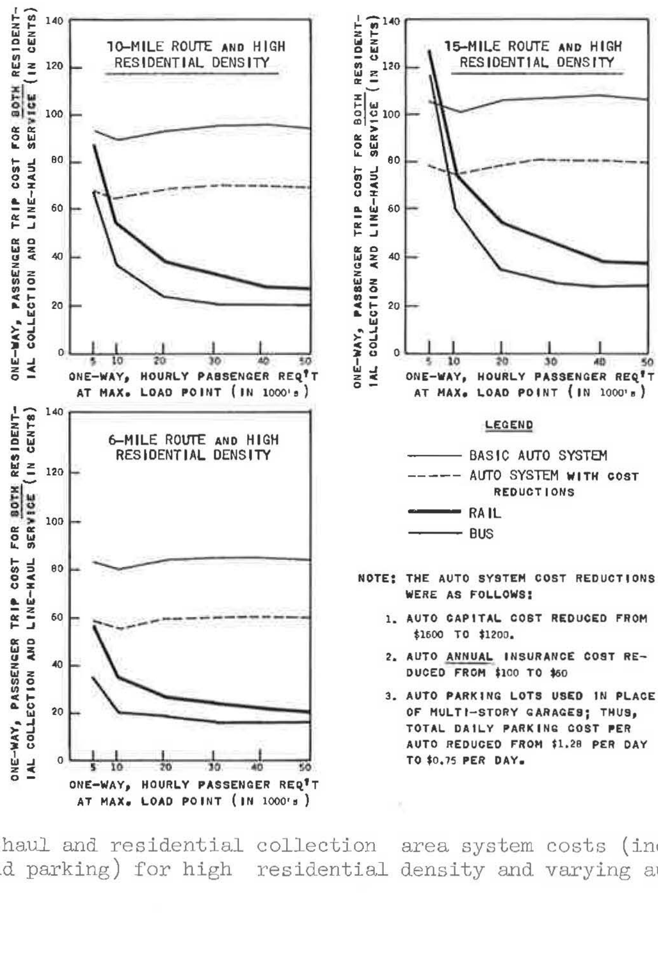

Figure 19. Line-haul and residential collection area system costs (including downtown terminal and parking) for high residential density and varying auto costs.

TABLE 14

PASSENGER TRIP COSTS FOR COMBINED LINE-HAUL AND (HIGH DENSITY) RESIDENTIAL COLLECTION SYSTEMS

Volume Level (pass./hr)	Line-Haul Mode	Pass. Trip Cost ($)			
		Basic System		System with Cost Reductions[1]	
		10-Mile Rt. Length	15-Mile Rt. Length	10-Mile Rt. Length	15-Mile Rt. Length
5,000	Auto	0.94	1.06	0.68	0.79
	Rail	0.88	1.27	0.88	1.27
	Bus	0.66	1.18	0.66	1.18
10,000	Auto	0.90	1.01	0.64	0.74
	Rail	0.54	0.76	0.54	0.76
	Bus	0.37	0.60	0.37	0.60
20,000	Auto	0.94	1.06	0.68	0.79
	Rail	0.39	0.53	0.39	0.53
	Bus	0.23	0.34	0.23	0.34

[1]Parking, auto capital, and insurance costs reduced.

perhaps 9,000 or below (where previously it was perhaps 6,500) for 15-mile route lengths; for 6-mile route lengths, its relative cost position would appear to be unaffected in the range of volumes analyzed and would still be much more expensive than bus transit.

System Cost and Performance for Medium Residential Density

As previously noted, the basic costing for the residential collection system utilized what might be described as high residential densities for computing the amount of residential land required to assemble the various hourly passengers and which determines the transport system requirements. In reality, however, considerably more is involved than just simple residential density. The important variables are:

1. Residential density as a function of distance from line-haul system stations.
2. Propensity of downtown peak-hour commuters to reside in closer proximity to line-haul stations than non-downtown peak-hour travelers.
3. Walking distances which passengers are willing to endure.

Each of these variables is important in determining the residential collection (and line-haul) system requirements; and, each may or may not act independently of the other two. For example, dwellers who most prefer to reside in high-rise apartment houses may also tend to be downtown workers and to prefer residence in proximity to line-haul stations and the land uses that so often accompany such.

Information is not available in sufficient detail to afford much insight into such questions or relationships, however, and thus one can only hypothesize broad limits for analysis. In fact, considerable caution must be exercised to prevent development of incorrect trip generation rates, etc., on the basis of existing data. As an illustration, consider how one might develop representative rates for the number of home-to-downtown rush-hour passenger trips per block (and the associated walking distances of such passengers).

A major problem associated with establishing proper trip generation rates is that of scale; that is, available data are summarized for land tracts of considerably larger size than desirable here. In the recent origin-destination study in Chicago (1), for example, data were gathered and recorded (within the city of Chicago itself and outside the CBD) for areas of 1 sq mile; consequently, if the number of hourly downtown trips were averaged over the entire 1-sq mile area, a tract which includes about 160 blocks, the rates might be understated for areas close to line-haul facilities and overstated for areas farther away. Consequently, if the total of trips generated by that 1-sq mi area were more than that required by a line-haul facility in question, and if the average trip generation rate for the entire area were used, the residential collection system requirements would be overstated. Furthermore, the use of present-day information for placing limits on trip generation, etc., may overlook the possibility that through land use control and/or changing consumer preference patterns the residential density and generation rates may change substantially. In other words, generation rates for future years may not be similar to those in existence today.

The determination of walking distances which passengers will endure and yet not suffer an inconvenience so great as to cause them to option out of a service, or to pay to avoid the walking trip, is difficult indeed, but extremely important in establishing residential collection system requirements. It affects the latter because both the number of residential area blocks served directly by the line-haul system and the number of feeder bus stops vary with the walking distance. (If, for example, passengers are willing to walk no more than w blocks, the number of blocks served directly by the line-haul station or by each feeder bus stop is $2w^2$.) However, this type of walking distance data can not be determined merely by observing present-day walking patterns of transit users, unless transit and auto cost and service were equivalent in every other respect, which is seldom the case.

Changing either of the foregoing variables—trip generation (or residential density) rates or walking distance—will invariably change the number of passengers who walk to the line-haul station and the number of feeder bus stops required and thus will change the residential collection system requirements and costs. In the high residential density analysis, and in this medium residential density analysis, the maximum walking distance was set as 2 blocks; however, the trip generation rates for the two cases were varied. The way in which they were varied can be shown in a number of ways, though only one will be noted, which will make it possible to compare these analysis assumptions with data recorded in particular cities. The relevant data are given in Table 15.

If cities are successful in formulating and carrying out so-called "corridor" plans such as that currently being promoted in Washington, D. C. (10), wherein park and other open land uses are to be concentrated between corridors and radial facilities, it is not unlikely that trip generation rates of the order shown in the high residential density analysis will develop.

Results of Residential Collection System Cost Analysis for Medium Residential Density.—The use of lower residential density (or trip generation) rates affects both the system travel cost and the service, the latter in two ways. First, for some modes of travel the percentage of travelers who must endure a transfer between residential feeder and line-haul systems will increase, and second, the overall running and delay time for travelers will increase. Table 16 gives the percentage of inbound hourly passengers who must transfer under conditions of high and medium densities. If, aside from the time delays suffered, passengers feel that the discomfort and inconvenience of transferring is highly disagreeable, the lowering of residential densities will result in large dis-benefits for the two travel modes having a separate feeder bus service at other than high volume levels. On the other hand, with either all private automobile travel or a combined feeder-express bus system the lowering of densities will have no effect on this aspect of service.

Table 17 gives data on the second aspect of service—travel time between home and downtown terminal. These travel times should be compared with those for high residential density, as may be seen for the 10-mile route length in Figure 20. A number of important things are evident from these data and comparisons. First, whereas the travel times were not markedly different among the modes for the high density situation, there are considerable and certainly greater differentials for the medium density case. For the four volume cases analyzed, the largest time differential between transit and auto travel for high density occurred at the 30,000 hourly passenger level and amounted to 2.2 and 3.1 min, respectively, for combined feeder-

TABLE 15

TRIP GENERATION RATES RECORDED IN CHICAGO AND WASHINGTON AND USED IN COST ANALYSIS

Dist. Along Line-Haul Facility[1] (mi)	Rush-Hour Pass. Trips to Downtown Area (no./100 dwelling units)			
	Chicago, 1956[2]	Washington, D. C., 1955[3]	Cost Anal. of This Report	
			High Density	Medium Density
½ - 2½	-	22	83	17
2½ - 4½	17	26	102	12
4½ - 6½	17	25	117	10
6½ - 8½	17	17	124	12
8½ - 10½	13	18	126	17

[1]From CBD. [2]Deduced from C.A.T.S., Vol. II, Table 32, Table 17, and pages 58 and 59. [3]Deduced from HRB Bull. 224, p. 15.

TABLE 16

PERCENTAGE OF DOWNTOWN RUSH-HOUR TRAVELERS WHO MUST TRANSFER AT JUNCTION OF LINE-HAUL AND RESIDENTIAL COLLECTION SYSTEMS

One-Way Volume at Max. Load Point (pass./hr)	Passengers Who Must Transfer (%)							
	All Auto		Separate Feeder Bus and Line-Haul Rail Transit		Separate Feeder Bus and Line-Haul Bus Transit		Combined or Integrated Feeder-Express Bus	
	High[1]	Medium[1]	High[1]	Medium[1]	High[1]	Medium[1]	High[1]	Medium[1]
5,000	0	0	10	66	10	66	0	0
10,000	0	0	55	83	55	83	0	0
20,000	0	0	74	92	74	92	0	0
30,000	0	0	82	94	82	94	0	0

[1] Residential density level.

TABLE 17

COMBINED TRAVEL TIME[1] BETWEEN HOME AND DOWNTOWN TERMINAL AT MEDIUM RESIDENTIAL DENSITY

One-Way Volume at Max. Load Point (pass./hr)	Combined Travel Time[1] (min)							
	Auto		Feeder Bus and Line-Haul Rail		Feeder Bus and Line-Haul Express Bus		Combined Feeder-Express Bus	
	Running	Total	Running	Total	Running	Total	Running	Total
5,000	10.1	13.1	10.3	16.6	10.3	16.6	10.3	15.8
10,000	10.4	13.4	10.3	17.2	10.3	17.2	10.3	16.3
20,000	11.0	14.0	11.6	19.1	11.6	18.9	11.6	18.2
30,000	11.5	14.5	12.2	19.7	12.2	19.4	12.2	18.9

[1] Weighted average travel times for all line-haul passengers, including walking-to-line-haul-system passengers. Includes both residential collection and 10-mile line-haul systems.

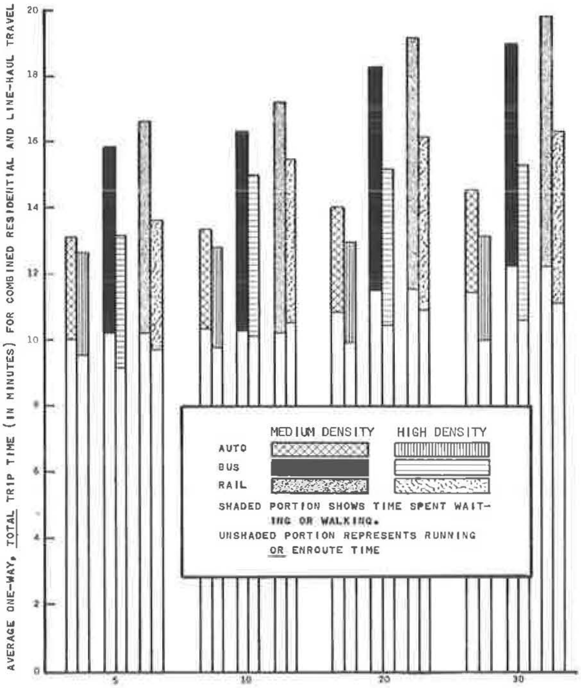

Figure 20. Home to downtown terminal trip times under varying conditions of residential density and volume level (for a 10-mi route length).

express bus and for rail transit; with a separate feeder bus service for medium density, however, these time differentials increased to 4.4 and 5.2 min, respectively. Furthermore, most of this time differential is accounted for in increased waiting-walking time rather than running time. If the underlying hypothesis is correct—that the discomfort of walking to and of waiting for buses and trains and of undergoing vehicle transfers is of primary importance to urban travelers—it is clear that the different types of travel modes can no longer be considered equivalent, but that the auto mode is superior to both bus and rail transit, with the combined feeder-express bus mode falling next in preference.

At this point, another conclusion may be in order. With the lowering of residential density, it is evident that the resultant travel time increases were fairly small for auto travel (ranging from ½ to 1½ min) but considerably larger for the transit modes. For the combined feeder-express bus transit operation the increases ranged from 2.7 to 3.7 min (again, most of this increase) was due to waiting-walking time increases), whereas for the rail transit and separate feeder bus operation they ranged from 3.1 to 3.6 min (mostly due to waiting-walking time increases). It is doubtful, for example, that urban dwellers would allow this little extra auto travel time to influence their decisions regarding residential location (ignoring, for the moment, any other cost or service differences between high and medium density situations); however, were transit systems to be the primary travel mode, it is legitimate to ask whether or not the additional travel time, waiting discomfort, and transfers are worth whatever amenities are associated with lower residential densities (again, ignoring other cost and service differentials). This is discussed later in this section.

Table 18 gives the incremental costs per passenger trip for residential collection system service (for the 10-mile route length) under conditions of high and medium density and for four different volume levels. These data are useful (a) in determining which modes of travel improve or change their relative cost position with density variations, and (b) in determining the relative desirability of the various types of residential collection service for each type of line-haul system.

In terms of cost increases with decreasing residential density, the park 'n ride service (in combination with either express bus or rail transit line-haul systems) experienced less increase than the other types of service, and was followed by all passenger car (as part of entire trip travel by private auto), then kiss 'n ride and separate feeder bus (in combination with either express bus or rail transit line-haul systems), and finally the combined feeder-express bus service. More importantly, at the lowest volume level, it is evident that the relative cost position improvement of all passenger car travel is reasonably large, particularly when compared with the separate feeder bus and the combined feeder-express bus services; however, as the volume level increases, the relative cost advantage diminishes rapidly. For example, at the 5,000 hourly passenger level, auto travel is only \$0.014 higher for medium than for high residential density, whereas separate feeder bus is \$0.129 higher, resulting in a \$0.115 relative

TABLE 18

INCREMENTAL UNIT COST PER PASSENGER TRIP[1] FOR RESIDENTIAL COLLECTION SYSTEM SERVICE AND 10-MILE ROUTE

Volume at Max. Load Point (pass./hr)	Incremental Unit Cost (\$)									
	All Auto		Kiss 'n Ride in Res. Area		Park 'n Ride in Res. Area		Sep. Feeder Bus in Res. Area		Combined Feeder-Express Bus	
	Med. Res. Density	High Res. Density	Med. Density	High Density	Med. Density	High Density	Med. Density	High Density	Med. Density	High Density
5,000	0.016	0.002	0.034	0.020	0.474	0.476	0.188	0.059	0.297	0.020
10,000	0.018	0.004	0.048	0.019	0.480	0.479	0.122	0.041	0.239	0.029
20,000	0.027	0.005	0.072	0.027	0.488	0.484	0.088	0.042	0.164	0.009
30,000	0.036	0.007	0.095	0.032	0.496	0.483	0.090	0.037	0.126	0.012

[1] Some unit costs may appear to be out of line; however, the base volume (number of passengers using residential service) is substantially different for the two density cases.

TABLE 19

INCREMENTAL UNIT COST PER PASSENGER TRIP FOR MEDIUM DENSITY RESIDENTIAL SERVICE AND VARIOUS MODES, AND ASSOCIATED TRAVEL TIME[1] ON RESIDENTIAL STREETS FOR 10-MILE LINE-HAUL ROUTE LENGTH

One-Way Volume at Max. Load Point	Kiss 'n Ride Res. System Travel		Park 'n Ride Res. System Travel		Sep. Feeder Bus Res. System Travel	
	Time (min)	Cost ($)	Time (min)	Cost ($)	Time (min)	Cost ($)
5,000	0.8	0.034	2.3	0.474	8.3	0.188
10,000	1.1	0.048	2.6	0.480	8.1	0.122
20,000	1.6	0.072	3.1	0.488	9.3	0.088
30,000	2.1	0.095	3.6	0.496	10.0	0.090

[1] Only for those passengers using residential collection system service; not including passengers walking directly to line-haul station. Includes walking, feeder bus stop wait, car rider wait, and parking time; waiting time for line-haul vehicle not included.

cost improvement for auto travel over separate feeder bus. But at the 30,000 level, auto travel is $0.029 higher and separate feeder bus only $0.053 higher; thus the relative cost improvement for auto is down to only $0.024 (as compared to $0.129 for 5,000 hourly passengers).

Another aspect of the relative cost position is noteworthy. If the combined feeder-express bus mode is compared with separate feeder bus in combination with either express bus or rail transit line-haul systems, it is evident that the no-transfer through bus service incurs higher cost increases with the lower density; however, as the volume level increases, this cost disadvantage lowers considerably (in fact, at very high volume levels, it is likely that little if any cost disadvantage would result). For example, at the 5,000 hourly passenger level, the cost advantage of separate feeder bus over the combined feeder-express bus service is $0.148 per passenger trip, while at the 30,000 level, the cost advantage is reduced to $0.061.

Questions may be raised, and in part answered, regarding the "best" type of separate residential collection system service for either express bus or rail transit line-haul systems under medium density conditions. For this purpose, some of the relevant data are summarized in Table 19.

The three types of separate residential service shown in Table 19 can be combined with either express bus or rail transit line-haul systems. Although in most cases the kiss 'n ride service is both quickest and cheapest, it is not clear that it is the "best" way of providing residential service because of the inconvenience to the driver or chauffeur. If park 'n ride is compared with separate feeder bus service, it is difficult to characterize the market (as a group) and thus say which service is best. For example, at low volumes (such as 5,000 hourly passengers) would passengers be willing to spend an extra $0.286 per trip just to avoid walking to and waiting at feeder bus stops, and save about 6 minutes? Certainly some more affluent passengers would, but in general it seems safe to assume not.

Table 20 gives the appropriate cost and travel time data for comparing separate feeder bus service that is linked with an express bus line-haul system with a combined

TABLE 20

INCREMENTAL UNIT COST PER PASSENGER TRIP FOR MEDIUM DENSITY PRESIDENTIAL SERVICE (FOR 10-MILE ROUTE LENGTH) BUS TRAVEL MODES, AND TRAVEL TIME BETWEEN HOME AND DOWNTOWN TERMINAL

Volume at Max. Load Point (pass./hr)	Separate Feeder Bus and Express Bus Line-Haul			Combined Feeder-Express Bus Service (no transfers)	
	Pass. Transferring (%)	Residential System Cost ($)	Total Travel Time (min)	Residential System Cost ($)	Total Travel Time (min)
5,000	66	0.188	16.6	0.297	15.8
10,000	83	0.122	17.2	0.239	16.3
20,000	92	0.088	18.9	0.164	18.2
30,000	94	0.090	19.4	0.126	18.9

feeder-express bus system. This table includes the incremental costs of adding residential service (over and above express bus line-haul system costs) and the entire residential and line-haul trip travel times. (It would be inappropriate to compare just the residential system travel times, as the combined bus operation eliminates transfers and waiting times at the line-haul junction.) With these two modes of travel, the question is whether or not it is worth an extra $0.036 to $0.109 per passenger trip to save from 0.5 to 0.8 min and to avoid the discomfort and inconvenience of a transfer, in most cases. Although it is difficult to generalize about the market, a positive reply seems assured in the highest volume case, though not necessarily in the other cases.

Cost Analysis for Both Residential and Line-Haul System Service for Medium Residential Density.—The costs of providing both residential collection and line-haul system service for four different modes of travel are shown in Figure 21; these costs were prepared only for the 10-mile route length and for one-way hourly passenger volumes of 5,000, 10,000, 20,000, and 30,000. Also, for comparative purposes, the passenger trip costs are shown for both high and medium residential density situations.

The net effect of the incremental cost differences for the high and medium densities discussed in the previous subsection is apparent on examination of Figure 21. Although auto travel, and secondarily rail transit, improved its cost position relative to the combined or integrated feeder-express bus operation, it nevertheless is evident that the integrated feeder-express bus operation—on an overall home-to-downtown-terminal trip basis—is still cost superior to all modes other than express bus line-haul combined with separate feeder bus. Placed on other terms, with lowering of residential densities, the cost positions of bus and rail transit do not change, though the absolute

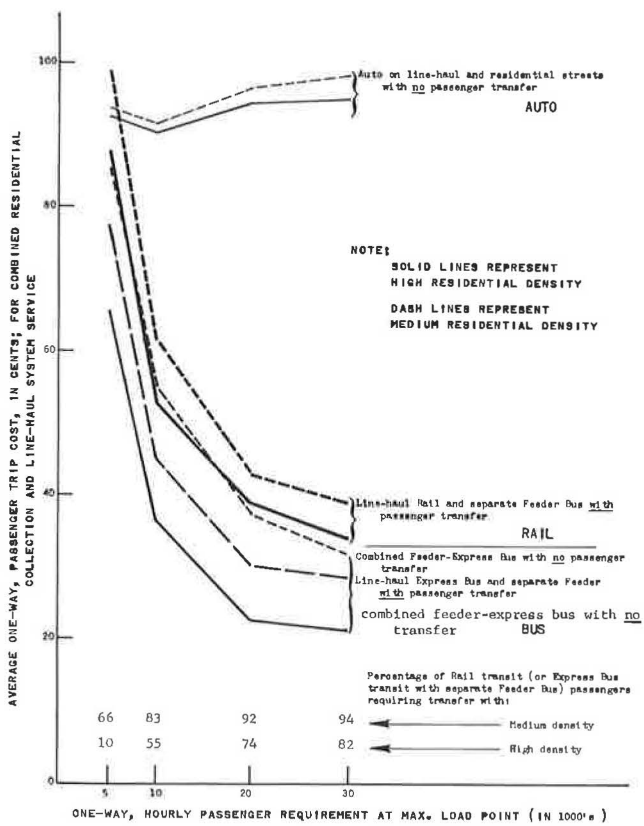

Figure 21. Combined line-haul and residential collection system passenger trip costs under condition of varying density; 10-mi line-haul route.

and percentage difference in costs between the modes decreases. This pattern is more significant, furthermore, as the volume level increases.

As the densities decrease, the auto mode improves its cost position more than the other modes, though auto travel still appears somewhat more expensive than the integrated feeder-express bus operation, and considerably more so than the express bus line-haul operation combined with separate residential bus feeder service.

The major cost and service data and conditions for these four types of transport systems are summarized in Table 21. These data permit conclusions little different from those expressed in the high density analysis. Of the transit modes, and for the particular service conditions, bus transit is clearly more desirable than rail transit, as it is faster, involves no passenger transfers, and the rail system runs from 16 to 20 percent more expensive than the higher quality combined or integrated feeder-express bus. (Rail runs 27 to 35 percent higher than the other bus mode.) Furthermore, even with the addition of other services and capacity (such as outbound flow and along-the-line service) the cost and service positions or ranking will not change for the transit modes (though the absolute and percentage differences between the bus and rail modes will decrease such that bus will still be at least 10 or 15 percent cheaper). (However, it should be noted that auto travel suffers considerably in this respect, particularly at low volume levels, with the addition of outbound capacity and along-the-line service.

Properly, however, one should ask whether auto travel might be considered more attractive than either of the bus modes. The question is difficult to answer because of tradeoffs in cost and in service; involved are differences in travel time, waiting time, passenger discomfort and inconvenience, and cost. (It will be noted that the passenger trip cost differences between the two bus modes are smaller in Table 18 than in Table 19; this results from the fact that the annual cost differences for the overall residential and line-haul system are spread over the combined hourly line-haul passenger volume, whereas those in the incremental residential system costing were spread over only those passengers using the residential service, and not including those walking to the line-haul system.) However, comparing the two types of bus service (Table 21), the service differentials appear quite large enough to justify the additional costs of the faster, no-transfer, combined or integrated feeder-express bus service. If this conclusion is correct in most cases, it is relevant to ask whether passengers at the 5,000 and 10,000 volume levels, respectively, would be willing to spend an extra $0.087 and $0.361 per trip to save 2.7 and 2.9 min travel time, and thus travel by auto instead of express bus. At the lower volume level, it would probably not be unreasonable to conclude that the overall market would support the additional costs. In the other cases, at 10,000 and higher volume levels, some pessimism must be expressed regarding the overall market; in short, it seems doubtful that the average passenger would support the higher quality auto service (relative to express, no-transfer bus service).

Cost Effects from Changing Design or Service Variables at Medium Residential Density.—As additional services or capacity are provided, the cost structure changes for the different modes, though in the main no significant changes will take place in the

TABLE 21

PASSENGER TRIP COST[1] AND TRAVEL TIME[1] FOR BOTH LINE-HAUL AND MEDIUM DENSITY RESIDENTIAL COLLECTION SYSTEM TRAVEL OVER A 10-MILE LINE-HAUL ROUTE LENGTH

One-Way Volume at Max. Load Point (pass./hr)	Res. and Line-Haul Auto		Res. Feeder Bus and Line-Haul Rail		Res. Feeder Bus and Line-Haul Exp. Bus[3]		Pass. Transferring[4] (%)	Combined Feeder-Exp. Bus[5]	
	Cost ($)	Time[2] (min)	Cost ($)	Time[2] (min)	Cost ($)	Time[2] (min)		Cost ($)	Time (min)
5,000	0.945	13.1	0.996	16.6	0.784	16.6	66	0.858	15.8
10,000	0.915	13.4	0.617	17.2	0.456	17.2	83	0.554	16.3
20,000	0.963	14.0	0.436	19.1	0.306	18.9	92	0.377	18.2
30,000	0.983	14.5	0.389	19.7	0.288	19.4	94	0.322	18.9

[1] Total, home to downtown terminal, per passenger trip. [2] Includes waiting and walking time.
[3] Not included in high residential density tabulation because combined feeder-express bus service was both faster and cheaper and involved no transfers. [4] For two modes with separate feeder bus service.
[5] With no transfers.

basic ordering or ranking. The addition of along-the-line service would, for example, tend to shift the rail and auto unit cost curves of Figure 21 uniformly downward at all volume levels. Much as indicated in the line-haul system cost analysis, the express bus line-haul system combined with separate feeder bus would be shifted downward at the two lower volume levels, but would remain virtually unchanged at volume levels of 20,000 and above. However, for the combined feeder-express bus system, no additional costs would be incurred, thus the unit costs would fall in similar fashion to the rail and auto systems. Therefore, the relative cost positions of passenger car, rail transit (with separate feeder bus), and the combined feeder-express bus would generally be unchanged if along-the-line service were to be added. (For the combined bus service and medium residential density, the controlling restriction in scheduling buses and establishing bus equipment and labor requirements (and thus roadway and terminal capacity, etc.) was the 10-min maximum headway at each feeder bus stop in the residential area. To meet this restriction, many extra buses had to be scheduled, with the result of considerable underloading and excess capacity. At the 5,000 to 30,000 volume levels, the resulting excess and unused capacity, which can in turn be used for along-the-line riders, was, respectively, 50, 28, 40 and 22 percent of the bus seating capacity.)

If outbound capacity (or, more accurately, capacity in the minor flow direction) were to be added to each system, the unit costs for the bus and rail transit modes would decrease at all volume levels, though the rail mode would decrease slightly more than the bus systems. Even so, the cost position or ranking would remain virtually unchanged. More importantly, however, at the 5,000 and 10,000 hourly passenger volume levels, the unit costs for the auto system would increase (while transit costs decrease), thus the joint effect would be to spread the auto and transit system unit costs by about an additional \$0.10 to \$0.15 per passenger trip at the 10,000 and 5,000 volume levels, respectively. This differential might indeed be (and probably is) enough to lower the volume level at which auto systems become competitive.

Different assumptions with regard to basic costs and system design might work to the advantage of either auto or bus modes. For example, reductions in costs for fringe downtown parking site acquisition might lower auto unit costs by as much as \$0.17; reductions in auto capital costs might lower the unit costs by as much as \$0.042 more; and accident cost reductions might further reduce the auto trip costs by as much as \$0.049 per passenger trip. Obviously, in situations where these auto cost reductions represent reasonable expectations, auto travel is certainly competitive with all modes at the 5,000 hourly passenger volume level, and a likely choice at the 10,000 level.

Finally, some discussion is warranted regarding two design variables which influence scheduling and costing of the residential collection system (for the combined feeder-express bus operation they affect the entire residential collection and line-haul system requirements and costs). These are the maximum schedule frequency (or bus headway) at the feeder bus stops and the walking distance for transit patrons at both feeder bus stops and line-haul stations. The assumptions used (for both high and medium density) were (a) a maximum feeder bus stop headway of 10-min (that is, a bus arrival at least every 10 min); and (b) a maximum walking distance of two blocks (and therefore an average walking distance of one block).

At high residential densities these two assumptions were relatively unimportant, and the unit costs fairly insensitive to changes in them. For the medium residential density case, however, the costs are almost directly dependent on them, and thus it is important to characterize the cost and service effects of changes in their values. First, the walking distance used is probably a lower bound, and any changes should be upward. Second, the maximum headway value may or may not represent a limiting condition, and depends somewhat on the cost sensitivity.

Changes in headway and walking distance will, of course, have different degrees of impact at different volume levels; in general, as the volume level increases, the percentage cost reductions from increasing maximum headway and walking distance will decrease. For example, additional analysis of these variables has shown that for volumes above 30,000 hourly passengers, increases in headway where the maximum walking distance is three blocks or more will be negligible, and for two blocks or more will

TABLE 22

INCREMENTAL UNIT COST FOR RESIDENTIAL COLLECTION SYSTEM SERVICE WITH HIGH AND MEDIUM RESIDENTIAL DENSITY AND VARYING WALKING DISTANCES (10-MILE ROUTE LENGTH AND 30,000 HOURLY PASSENGERS)

Residential Density Condition	Maximum Walking Distance (blocks)	Incremental Passenger Trip Costs ($)		
		Separate Feeder Bus Service	Combined Feeder-Express Bus Service	All Auto Travel
Medium	3	0.079	0.080	0.036
Medium	2	0.091	0.118	0.036
High	2	0.038	0.012	0.007

be insignificant. In fact, even for a 30,000 volume level and a three block walking distance, a headway increase will produce immaterial cost reductions. On the other hand, for volumes even as high as 20,000 hourly passengers, increases in the walking distance do make differences worth noting. And, as previously pointed out, at lower volumes, they will be significant.

The previous analyses for residential collection systems, and for combined residential and line-haul systems, assumed feeder bus stop headways of 10 min and a maximum walking distance of two blocks. Table 22 gives the cost effects of increasing just the walking distance—under conditions of medium residential density—while holding the 10-min headway constant; they were computed only for the 30,000 hourly volume level. Approximately the same cost effect would result from increasing the maximum headway, although it is felt that increasing the walking distance as done here would increase the passenger discomfort and inconvenience less than increasing the headway.

These data show that increasing maximum walking distance just one block (and thus increasing the average walking distance by one-half block and travel time by about 1 min) reduces the incremental separate feeder bus costs by slightly more than 10 percent and the combined feeder-express bus costs by more than 30 percent; the auto travel costs remain unchanged. The net reduction to the overall residential and line-

TABLE 23

UNIT COST FOR RESIDENTIAL COLLECTION SYSTEM TRAVEL AND FOR RESIDENTIAL AND LINE-HAUL SYSTEM TRAVEL FOR 10-MILE ROUTE LENGTH AND VARYING DENSITIES AND WALKING DISTANCES

Res. Density	Max. Walking Dist., w (blocks)	Cost per Passenger Trip ($)					
		Incremental, Res. Collection System[1]			Total, Res. Collection and Line-Haul Systems[2]		
		All Auto	Sep. Feeder Bus	Comb. Feeder-Express Bus	All Auto	Sep. Feeder Bus with Line-Haul Exp. Bus	Comb. Feeder-Express Bus
(a) 10,000 Passenger Volume[1]							
Medium	3	0.018	0.090	0.115	0.914	0.421	0.439
Medium	3	0.018	0.125	0.250	0.914	0.458	0.563
High	2	0.004	0.042	0.029	0.904	0.378	0.370
(b) 30,000 Passenger Volume[1]							
Medium	3	0.036	0.079	0.080	0.983	0.275	0.276
Medium	2	0.036	0.091	0.118	0.983	0.290	0.314
High	2	0.007	0.038	0.012	0.958	0.234	0.213

[1] Volume base is passenger volume that does not walk directly to line-haul station, thus varies for each volume, density and walking distance. Also, for auto travel, all passengers incur costs and are included in base volume.

[2] Line-haul rail transit combined with feeder bus not included because it was more expensive than both bus transit modes and offered inferior service.

haul trip costs will be smaller, however, providing a net reduction of about 5 percent for the separate feeder and line-haul express bus mode and about 12 percent for the combined or integrated feeder-express bus operation.

As the volume level decreases, the cost reduction resulting from an increase in maximum walking distance from two to three blocks will be even greater, and more significant. Table 23 summaries the results of an analysis for the 10,000 hourly passenger level, along with those data for the 30,000 level. For the lower volume level, the increase in maximum walking distance from two to three blocks produces for residential system travel a $0.134 reduction per passenger trip for the combined feeder-express bus mode, only a $0.035 reduction for the separate feeder bus service, and none for auto travelers. The net effect is to reduce the overall home-to-downtown-terminal passenger trip costs by a substantial amount for the integrated bus operation, but only by a small amount for the separate feeder bus and line-haul express bus service; the former, in fact, was reduced by $0.124 per passenger trip, or by more than 20 percent. As a result, under those circumstances where the three block walking distance ($1\frac{1}{2}$ blocks on the average) seems to be a more reasonable figure, the combined feeder-express bus operation would rather clearly represent a better service than the other type bus operation, which is just slightly less costly but requires a passenger transfer and more travel time. Furthermore, even at the 10,000 hourly passenger level it would be difficult to argue that the auto travel mode is competitive with the non-transfer combined bus system, other than for a small portion of the overall travel market. The $0.475 per passenger trip cost differential between auto and combined bus seems forbidding indeed, particularly when the relative cost economies for the bus system with regard to terminal re-design, and with regard to the addition of outbound and along-the-line service, are recalled.

DOWNTOWN DISTRIBUTION SYSTEM AND OVERALL HOME-DOWNTOWN COST ANALYSIS AND EVALUATION OF TRANSPORT SYSTEM

The two preceding sections dealt with the costs of both line-haul and residential collection systems which serve to feed (or distribute) and transmit travelers destined for (or originating from) terminals located at the fringe of the downtown central business district. In this section attention is devoted to the cost analysis of systems which also provide downtown distribution service (at five downtown stations or points) and which permit buses and trains to make their return-haul journey by running through the downtown area, rather than by turning around at a fringe downtown stub terminal. In essence, a through facility has been designed which provides operation on private, reserved rights-of-way for both the line-haul and downtown portions of the total home-to-downtown passenger trip, and which links two line-haul facilities to a single downtown distribution system; also, in the overall system costing, a feeder service is provided throughout the residential area.

Schematically, the system may be envisioned as shown in Figure 1, parts 2 and 3B. For a 6-mile line-haul route length and with three through lines, for example, the regional system would consist of six "fingers" or three routes, and of some 42 miles of private, grade-separated rights-of-way, 6 miles of which would be in downtown subway. With 10-mile line-haul routes, and with four through systems or routes for an area, there would be eight radial fingers, 88 miles of private rights-of-way, 8 miles of which would be in downtown subway. For the three route lengths costed in this analysis, the subway portion as a percentage of the total through system (consisting of both line-haul and downtown distribution systems) ran 14, 9, and 6 percent of the total system length for the 6-mile, 10-mile and 15-mile line-haul route lengths, respectively.

Only two kinds or types of downtown distribution service were costed in this analysis: one, service with a 2-mile downtown subway with five local stops (or parking garage areas for auto travelers); two, for the distribution of downtown automobile traffic, service on local surface streets. Other types of downtown distribution service (such as the use of buses on downtown city streets, or passenger transfer to jitney buses or taxis at the fringe downtown terminals for the downtown journey, or use of a loop to connect the fringe downtown terminals and distribute downtown movements) were not costed, simply because of time restrictions. However, these other types of solutions are treated qualitatively in this section.

Description of Design and Service Variables

Most of the earlier assumptions regarding line-haul and residential collection system design and service were retained in computing costs for the overall through system, which consisted of two line-haul routes connected by a 2-mile downtown distribution subway and the residential feeder service. For example, the line-haul stations were spaced at 1-mile intervals; the overall travel speed on the line-haul portion for passenger carrying runs (including acceleration-deceleration and loading/unloading delays) was 35 mph; the passenger volumes were uniformly distributed along the line-haul route length; maximum vehicle and train headways at line-haul stations were set at 2 min; one seat was provided for each passenger; and the auto seating "capacity" was set at 1.6 seats (or persons) per car. For the feeder service, the maximum feeder bus headway was set at 10 min, the feeder bus stops were located at four-block intervals, and the maximum walking distance was two blocks.

For the downtown distribution portion, there were a number of important service and design restrictions, as follows:

1. Downtown transit stations (or ramps and parking zones for autos) were located at ½-mile intervals, thus providing five downtown stops.
2. Downtown bus or rail transit train stops would be at least 10 sec long.
3. For bus transit, at each downtown stop there would be at least one bus slot for each line-haul station.
4. Passengers entering (or leaving) the downtown area from a given line-haul route would be destined for (or originating at) one of the five local downtown stops on the same through line.
5. Downtown destined (or originating) passengers were distributed as follows: 16.5 percent at each of the two outside stations, 21 percent at the middle station, and 23 percent at each of the two remaining stations.
6. There were no speed or schedule frequency restrictions on the downtown subway portion.

Most of these assumptions do not affect the relative cost structure of the two transit modes materially; the exception in this respect is the item requiring at least one bus slot for each line-haul station for the bus subway. This restriction causes extra bus slots to be constructed in 14 of the 18 volume and route length combinations, thus increasing bus station length and costs. Because the width of the downtown bus stations is about five times that required for rail transit stations, and because the unit cost for bus stations (relative to rail stations) follows proportionately, and because downtown station costs range from 12 to 27 percent of total system costs for bus transit but only 3 to 14 percent for rail transit, this assumption does materially affect both the absolute and relative costs of bus transit. (Bus system costs—absolute and relative—could be cut substantially if this restriction were not held, and if passengers were inconvenienced by having buses from more than one line-haul station use the same bus slot. Another way of handling the problem would be to install an informational system for indicating to outgoing passengers precisely at which bus slot the next bus would be arriving and what its destinations were, instead of having regularly scheduled locations.)

Although only the previously noted restriction materially affects the relative downtown distribution system cost structure for bus and rail transit, some of the other service and design assumptions have a marked effect on cost comparisons between the transit modes and passenger car travel. The two major items in this regard are numbers 1 and 6, both of which are related in a real sense. For example, as the station spacing gets smaller the average overall speed of both transit systems gets lower; although auto speeds would fall somewhat as ramp spacing was reduced, it is doubtful that they would fall as rapidly. Furthermore, because transit vehicles and trains must stop at each station, the auto traveler would enjoy a speed and travel time advantage in this respect. As a result, the passenger car system would permit auto travelers to make the home-downtown trip from 1 to 3 min faster than the bus transit system and from 1½ to 4 min faster than the rail transit system. (With a total trip time of about 14 to 15 min for auto travelers, these savings amount to somewhere between 10 and 30 percent.) Of more importance is the recognition that auto travelers incur no walking inconveniences or discomforts at the home end of their trips (unlike both transit systems) and they undergo no transfers throughout the trip (unlike the rail transit system travelers); the consequence of these service inequalities will be noted after presentation of cost data for the systems.

Analysis of Additional Costs for Downtown Distribution Subway System

In the analysis of the additional costs incurred for downtown distribution service, only those costs over and above those required to provide line-haul and residential collection system service were included. Consequently, it was necessary to re-schedule and re-cost the entire system operation, fully accounting for operational and thus costing interdependencies, and then subtract out the costs incurred for line-haul and residential collection service. Construction costs for the downtown distribution subway were based on the unit costs given in Table 24. The unit cost for subway between stations includes all capital outlays, and takes into account the different dimensional requirements for transit vehicles and passenger cars. The approximate inside dimensions used to develop the basic excavation and structural costs were 13½ ft (width) by 14½ ft (height) for both bus and rail transit, and 12 ft (width) by 10 ft (height) for passenger cars; the height and vertical clearance for cars were reduced substantially over those normally provided inasmuch as only passenger car costs were involved here (and no costing was made for the additional costs for joint use by buses and trucks).

The subway station unit costs are most meaningful, of course, only when combined with data on numbers of incoming lanes or tracks, lengths of trains or number of bus slots required (and thus bus station length), etc. Most of the pertinent data appear in the Appendix.

Also, it should be noted that for those auto system travelers destined for the three inside downtown zones (about 67 percent of the total; see item 5) central downtown garage costs were used in place of the fringe downtown garage costs used earlier (see Table 5).

The additional or incremental passenger trip costs for adding downtown distribution service to the combined total of line-haul and residential collection system travel are shown in Figure 22. Also, the downtown distribution system costs as a proportion of the total home-downtown trip costs are indicated in Figure 30; more will be said about this later, but generally for the passenger car system the downtown portion accounts for 18 to 26 percent of the total, for the bus transit system about 33 to 43 percent, and for the rail transit system about 13 to 23 percent. Thus, in terms of affecting the overall system cost structure, the magnitude of downtown system bus costs is more important than that for the other systems.

From Figure 22 it is evident that the addition of downtown distribution subways increases bus costs considerably more than rail transit costs, that the resulting relative increase of bus system costs generally falls as the volume increases. Further, it is important to note that the auto cost (for adding downtown distribution subways) relative to transit modes, increases both as the volume level and the route length increase. The additional unit cost for adding downtown distribution subways for auto is always greater than that for rail transit; on the other hand, the additional unit cost for auto is always lower than that for bus at the 5,000 passenger volume level but higher at the other volume levels.

TABLE 24

CONSTRUCTION UNIT COSTS FOR DOWNTOWN SUBWAYS AND STATIONS

Travel Mode	Construction Cost	
	Subway Between Stations[1] ($ million)[2]	Stations[3] ($)[4]
Rail transit	8.750	3,600 (12½ ft)[5]
Bus transit	8.576	17,536 (128 ft)[5]
Pass. car	6.000	—

[1] Includes engineering and contingency, as well as extra ventilation for bus and auto, and trackwork and electrification for rail.
[2] Per single-track-mile or lane-mile.
[3] Mezzanine type.
[4] Per lineal foot for each incoming lane or track.
[5] Associated platform and track or lane width.

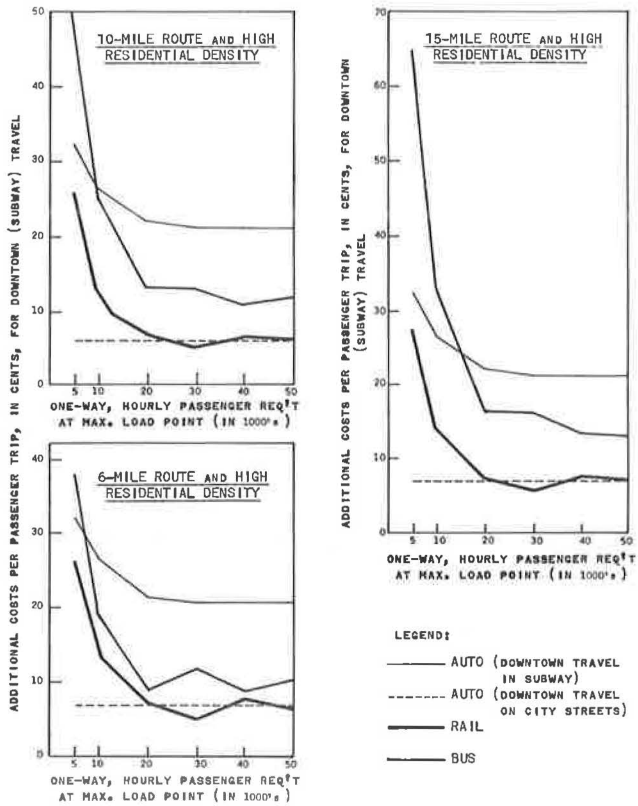

Figure 22. Additional passenger trip costs for downtown portion of trip with subway route (and autos on downtown city streets also).

TABLE 25

ADDITIONAL PASSENGER TRIP COSTS AND TRAVEL TIMES FOR DOWNTOWN DISTRIBUTION SERVICE AT VOLUMES SHOWN AND FOR A 10-MILE LINE-HAUL ROUTE LENGTH

One-Way Volume at Max. Load Point (pass./hr)	Mode of Travel for Downtown Service	Travel Time on Downtown System (min)	Approx. Add'l. Cost per Pass. Trip on Downtown Portion ($)
5,000	Rail transit	2.4	0.26
	Bus transit	2.3	0.50
	Auto, subway	1.7	0.32
	Auto, city streets	5.7	0.07
50,000	Rail transit	2.4	0.06
	Bus transit	2.3	0.12
	Auto, subway	1.7	0.21
	Auto, city streets	5.7	0.07

It is appropriate to identify the additional costs of adding downtown distribution subways separate and apart from the overall system costs for still another and perhaps more important reason; that is, to provide information which will aid in answering questions related to the general feasibility of providing downtown distribution service by subway facilities rather than providing this service on the existing street system (or by other means which have not been considered in detail, such as elevated structures, or jitney buses, or taxis). For this purpose, Table 25 summarizes the data for a 10-mile route length.

The data on auto travel are the most useful, because the alternatives and differences in service are clearly defined. For example, auto travelers might be asked whether it is worth spending an extra $0.25 per trip at the 5,000 volume level, or $0.14 per trip at the 50,000 level, merely to save 4 min in travel time and the discomforts associated with city street travel as compared to grade-separated subway travel. Because the downtown portion of the total trip was only 1 mile in length on the average, and the total trip was some 6½ miles long (from home to downtown destination point), it is difficult to expect that the answer would be positive, at least in the low volume case. (Indeed, subway travel may offer negative benefits to travelers in terms of psychological effects.) At the same time, it is legitimate to ask whether the community (consisting of travelers, shoppers, businessman, etc.) would be willing to pay the extra costs for the combined travel benefits (tangible or intangible, and if any) and environmental benefits (such as keeping autos off city streets, and hiding expressways underground).

There are other appropriate questions. For one, it is evident from Table 25 that the additional costs for rail and bus transit downtown distribution subways at the high volume level are quite low, running only $0.06 per trip for rail and $0.12 per trip for bus. Considering the various alternatives (to the rail transit subway) for providing downtown service, no reasonable and cost-feasible means come to mind. For example, if downtown jitney bus service were provided in place of the rail transit type service, at most only a $0.02 or $0.03 saving per passenger trip could be anticipated; more importantly, though, for this saving in cost the travelers would incur additional travel and waiting time delays and would have to endure an additional transfer. Thus, a fairly strong conclusion can be drawn to the effect that if high passenger volume rail transit line-haul facilities are built it is more than reasonable to build connecting downtown distribution subways as part of the overall transport system. The case is not so clear for high passenger volume bus transit, however, because the buses can operate on city streets directly from the line-haul routes and because passengers would not have to endure an additional transfer. Consequently, if the express line-haul buses provided downtown service on the existing city streets, the additional unit cost per passenger trip might go as low as $0.02 or $0.03 per passenger trip, though an extra 4 or 5 min of travel time would be required. The question then is: would bus passengers be willing to afford the extra $0.09 or $0.10 per trip to save 4 or 5 min and to have the buses travel in subways downtown rather than on city streets? It is not clear that they would. (There are a number of interesting aspects to this bus system design; for example, even with downtown bus subways, the overall bus system cost is lower than that for rail transit at high passenger volumes. And as pointed out earlier, the bus travelers would have to make no transfers whereas the rail transit passengers would have to transfer between feeder buses and the line-haul rail transit system. Thus it may be reasonable to build the line-haul system first, and to operate buses on the downtown city streets for a period, and then to raise the issue of whether or not to build the downtown bus subways.)

Analysis of Overall System Service and Cost

The more important aspects of system cost and service for the overall home-downtown trip, including residential collection line-haul and downtown distribution system service, are provided in the following. The unit passenger trip costs are shown in Figure 23 and associated data are shown in Figures 24, 25, and 26.

From Figure 23, it is evident that for 14 of the 18 volume and route length combinations the combined or integrated feeder-express bus transit system will be the most

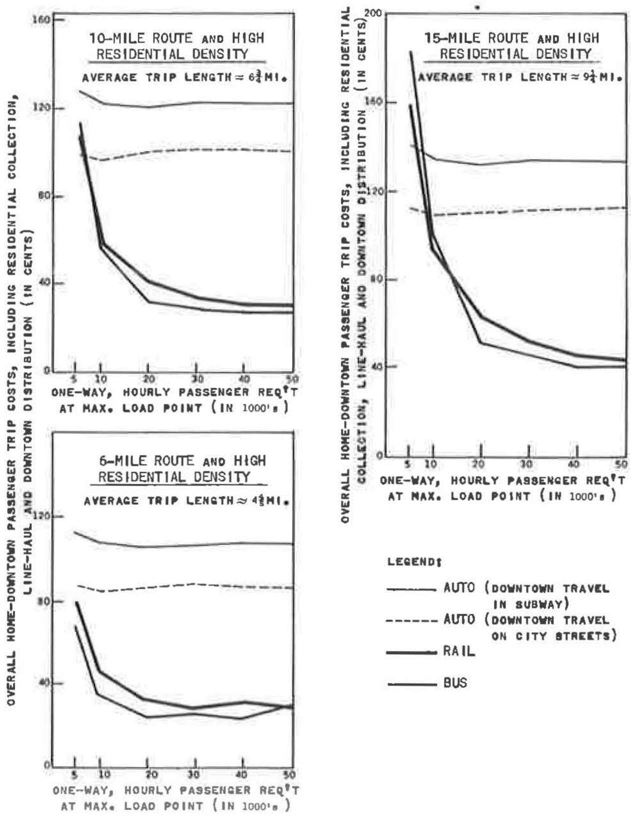

Figure 23. Overall system passenger trip costs between home and downtown (total of residential collection, line-haul and downtown distribution costs, to include all terminal and parking charges).

economic transport system for the rush-hour, home-to/from-downtown passenger movement. The major exceptions to this are (a) the low volume (5,000 hourly passengers) case for 15-mile route length where the all passenger car system, even with downtown subways, is the cheapest form of transport; and in three cases (10,000 hourly passengers and 15-mile route length, 50,000 hourly passengers and 6-mile route length, and 5,000 hourly passengers and 10-mile route length) the rail transit system is the cheapest of these three principal modes of transport.

The implications of this relative cost structure are in a sense starling, and certainly important. One, in only one urban area in the United States (New York City) are hourly passenger volumes in radial corridors so high as to sustain capacity requirements of 40,000 or 50,000 passengers per hour over 4 rush hours a day. For all practical purposes, then, the 50,000 passenger volume level case is academic and hardly applicable to areas currently considering rapid transit system proposals.

Certainly, in view of the fact that this intensive analysis demonstrates that express bus transit systems can provide downtown rush-hour service for less cost than rail transit systems in most cases, it is difficult to understand why only one urban community (St. Louis) has considered bus transit proposals in any real depth. (Others, such as Washington, D. C., have considered various types of bus transit systems, but none offering service of the high type included in this analysis. In most cases, the costs and service are examined for joint utilization of freeways with passenger cars, and with distribution on downtown streets, and with feeder bus service operating separately from the line-haul semi-express type service. Also, in most cases through express service is not offered, but rather the number of bus stops is just limited.

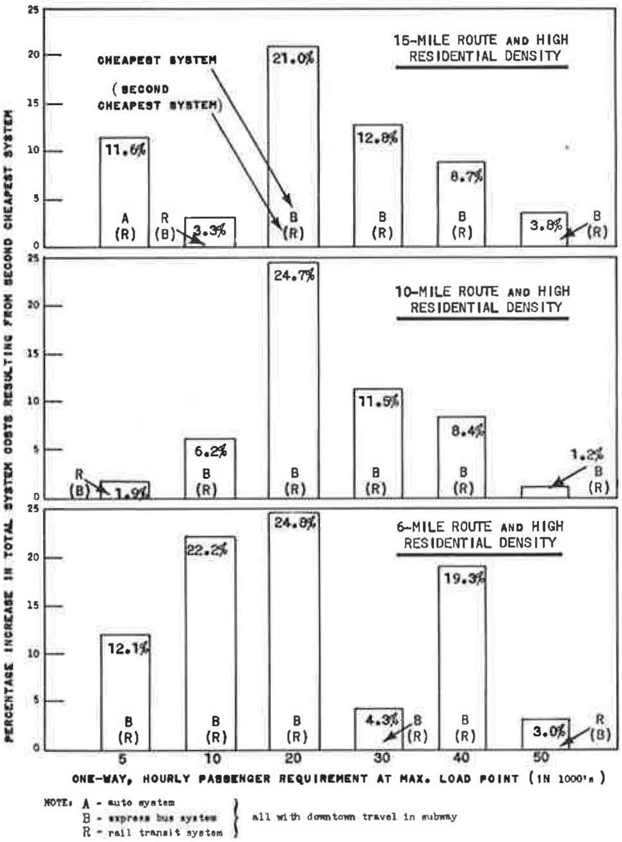

Figure 24. Increase in total system costs resulting from choice of second cheapest system.

Finally, it is important to reemphasize that this analysis is only concerned with the costs of new systems, rather than with the replacement of existing ones or conversion of existing railroad lines to rail transit facilities.)

In examining the unit passenger trip costs in Figure 23, and in comparing the costs of the modes, one might be tempted to say that the costs are almost identical and that the choice between transit modes is immaterial. However, the costs are spread to a considerable degree as indicated clearly in Figure 24, which shows the increase in unit passenger trip costs (or, for that matter, total annual system costs) that would result from selecting the second cheapest modal system instead of the cheapest one. These cost differentials range from 1.2 to 24.8 percent of the total cost of the cheapest system, with the average differential being 11.2 percent. With total annual system costs (for each through route) ranging from $10 million to $100 million, these differentials are hardly insignificant.

Before commenting on the service differentials and their implications, it will be helpful to identify the particular cost breakdown of the various systems, and the extent to which the costs are related to the design assumptions. The transit system cost breakdowns are shown in Figure 25 for the 10-mile line-haul route length.

First, at the highest volume level the costs for construction of stations and for other construction and right-of-way items (to include subway between stations and line-haul facilities) are not dissimilar for the bus and rail transit systems. However, as the volume level decreases two things are evident: (1) the construction costs for other than stations reflect the inherent indivisibility of rail transit systems and the (relative) divisibility of bus transit systems; and (2) the station construction costs for rail transit reflect considerable divisibility while those for bus transit reflect virtually no divisibility. In fact, although the

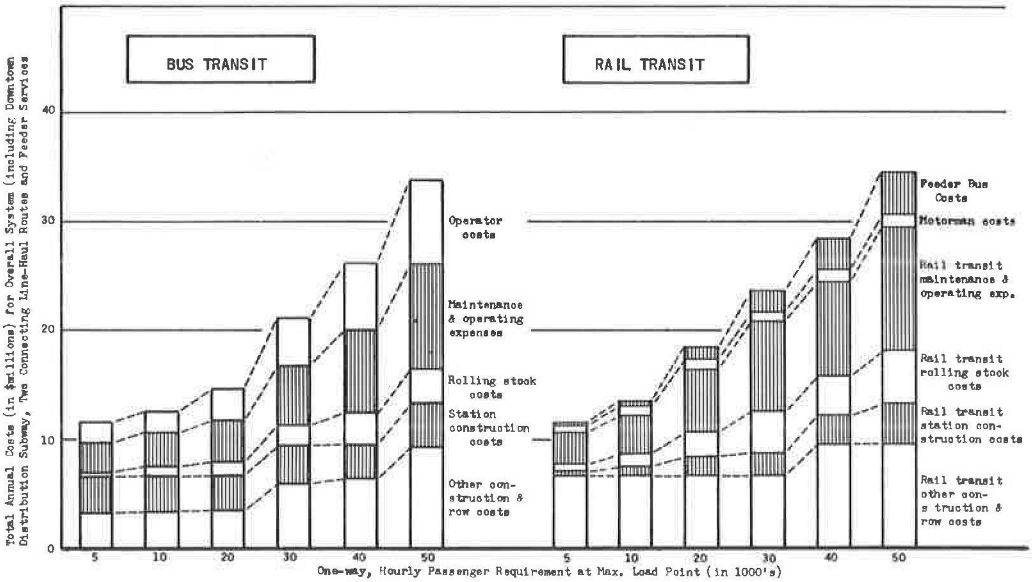

Figure 25. Cost breakdown for overall transit system: 10-mi route length and high residential density.

station construction costs for rail transit are about equal to those for bus transit at the 50,000 volume level, they differ quite widely at the lowest volume level, where the station costs for rail are only one-eighth of those for bus transit. This feature of the cost structure is important to note because of a design assumption which was made earlier for the bus transit operation. Specifically, bus stations in the downtown distribution were required to have at least one bus slot for each line-haul station (and in each direction). In other words, for the 10-mile route length case, where the downtown distribution subway provides for two-directional movement and serves to connect two line-haul routes there will be five underground bus downtown stations for each directional movement, thus a total of ten bus stations (since the bus slots and stations are unidirectional). Each of the ten bus stations, to meet the design restriction, must provide at least 10 bus slots (or one for each line-haul station). This restriction increased the number of bus slots in five of the six volume cases; the extent to which the bus station length and cost was affected by this design assumption is shown in Table 26 (for the 10-mile route length).

TABLE 26

INCREASE IN DOWNTOWN BUS SUBWAY STATION COSTS RESULTING FROM DESIGN ASSUMPTION REQUIRING AT LEAST ONE BUS SLOT FOR EACH LINE-HAUL STATION

One-Way Volume at Max. Load Point (pass./hr)	Requirement and Cost With Design Assumption			Requirement and Cost Without Design Assumption			Increase in Downtown Bus Subway Station Costs by Design Assumption (%)
	No. of Bus Slots	Length of Station (ft)	Total Cost per Station[1] ($ million)	No. of Bus Slots	Length of Station (ft)	Total Cost per Station[1] ($ million)	
50,000	4	119	2.087	4	119	2.087	0
40,000	5	147	2.578	4	119	2.087	23
30,000	5	147	2.578	3	91	1.596	61
20,000	10	287	5.033	4	119	2.087	141
10,000	10	287	5.033	3	91	1.596	215
5,000	10	287	5.033	3	91	1.596	215

[1] Per incoming lane.

It is evident that this design assumption, made for operational purposes, critically affects the absolute costs of the bus system, and thus the overall relative cost structure of the modes. For example, inasmuch as the station costs amount to 28 percent of the total bus system costs at the 5,000 volume level, 26 percent at the 10,000 level, and 22.2 percent at the 20,000 level, it is clear that eliminating this single design assumption would reduce the total bus system cost by 19.1 percent at the 5,000 volume level, 17.8 percent at the 10,000 level, and 13.0 percent at the 20,000 level.

The effect of this design assumption on the passenger trip unit costs is shown more clearly in Table 27 for the 10-mile route length. It is clear that substantial economies could have been effected if this design restriction had not been made.

Properly, one should inquire about the travel service consequences associated with changing this design assumption; that is, of not requiring at least one bus slot for each line-haul station. This restriction was made so that passengers would always know exactly where the buses for their particular destination were arriving, and that all buses arriving at any one platform or bus slot would be destined for only one line-haul station; thus riders would not have to pass up buses. (But on the other hand, a passenger destined to a particular feeder bus stop destination will, on the average, have to pass up as many buses as there are feeder bus stops.) However, if this restriction is relaxed and if the number of bus slots is tailored exactly according to needs (as shown in Table 26), then two offsetting dis-services will take place. One, the passenger loading platforms will be two to three times more crowded and uncomfortable because the platform loading space must now accommodate more people; two, they might be so crowded that additional space should be provided, thus offsetting some of the cost savings. Summarizing, the cost decreases noted in Tables 26 and 27 must be balanced against the service disadvantages which will be experienced. (Another alternative manner for handling this problem would be to install an information system which would "sense" which particular destination bus would be arriving next and then would flash this information, together with the particular bus slot where it would stop, to the passengers waiting in the bus station mezzanine. This would eliminate both the passenger crowding on the loading platform and the extra waiting time delays. However, to install such a system would obviously entail some unknown amount of capital outlay for electronic equipment and maintenance and operating expenses.) At the lowest volume level (5,000 hourly passengers) it is difficult to imagine that the extra discomfort would be valued so highly to travelers that they would be willing to pay the extra $0.22 cost per trip.

The overall travel times between home and downtown are plotted for the 10-mile route length in Figure 26. A distinction is made between running time and waiting time (the latter to include transit passenger time spent walking to and from, and waiting at feeder bus stops, or to include auto passenger time delays experienced while picking

TABLE 27

APPROXIMATE OVERALL SYSTEM COST PER PASSENGER TRIP

One-Way Volume at Max. Load Point	Approx. Cost per Passenger Trip ($): All Auto System with Downtown Subway	Rail Transit and Feeder Bus System	Combined Feeder-Express Bus System: Without Station Design Restriction	With Station Design Restriction
5,000	1.26	1.14	0.94	1.16
10,000	1.17	0.66	0.52	0.63
20,000	1.15	0.46	0.32	0.37
30,000	1.17	0.39	0.33	0.35
40,000	1.17	0.35	0.31	0.32
50,000	1.17	0.34	0.33	0.33

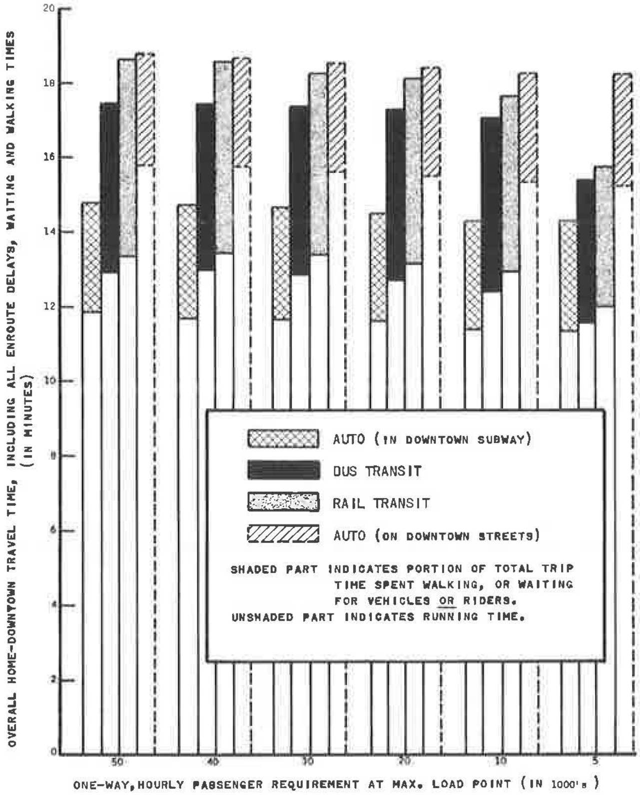

Figure 26. Home to downtown passenger travel times; 10-mi route length and high residential density.

TABLE 28

SUMMARY OF TRAVEL SERVICE AND COST DATA FOR 10-MILE LINE-HAUL ROUTE

One-Way Volume at Max. Load Point (pass./hr)	Travel Mode	% Who Must Transfer at Res. Collection and Line-Haul System Junction	Avg. Weighted Travel Time (min)		Approx. Total System Cost Per Pass. Trip ($)
			Waiting	Total	
5,000	Auto, with downtown subway	0	3.0	14.3	1.26
	Auto, on downtown streets	0	3.0	18.3	1.00
	Rail transit	10	3.8	15.8	1.14
	Bus transit	0	3.9	15.4	1.16
10,000	Auto, with downtown subway	0	3.0	14.4	1.17
	Auto, on downtown streets	0	3.0	18.4	0.97
	Rail transit	55	4.8	17.7	0.66
	Bus transit	0	4.8	17.2	0.63
30,000	Auto, with downtown subway	0	3.0	14.7	1.17
	Auto, on downtown streets	0	3.0	18.7	1.03
	Rail transit	82	5.0	18.4	0.39
	Bus transit	0	4.6	17.5	0.35
50,000	Auto, with downtown subway	0	3.0	14.9	1.17
	Auto, on downtown streets	0	3.0	18.9	1.02
	Rail transit	89	5.3	18.8	0.34
	Bus transit	0	4.6	17.6	0.33

up car poolers); also, for the passenger car system and for the combined feeder-express bus system, no intermediate passenger transfers are necessary, whereas for the feeder bus-rail transit system some intermediate passenger transfers are necessary.

For the 10-mile route length, the relevant travel service and cost data are summarized in Table 28. Of the three highest volume cases shown therein, the evidence seems quite conclusive that the combined or integrated feeder-express bus system is to be preferred over the rail transit system design. In short, not only does the bus system provide less costly transportation, but it also provides for no-transfer movement, and does so with less waiting and total travel time than rail transit. However, at the 5,000 volume level, if selecting between bus and rail transit, the choice is not as clear. On the one hand, rail transit is cheaper by $0.02 per passenger trip and would offer less waiting time; on the other hand, less passenger transfers are involved with the bus system, and the total trip travel time would be less than for rail transit. To balance these offsetting services and disservices is at best difficult and complex. Even so, one might be tempted to suggest that the waiting and travel time differences balance, thus leaving only passenger transfer and cost differentials. Consequently, a decision in favor of the bus transit system implies that travelers are willing to pay at least $0.20 per passenger trip to avoid an intermediate transfer (to/from feeder bus and rail transit). (Since the same passengers must always transfer, since they represent only 10 percent of the total passenger volume, and since the $0.02 cost differential (see Table 26) applies to the total passenger volume, the imputed value of avoiding transfers is 10 × $0.02 = $0.20.) Or, to the contrary, a decision in favor of rail transit implies that the avoidance of transfers is not worth as much as $0.20 per passenger trip.

The previous remarks only pertained, of course, to the transit modes, and thus were incomplete. For the three higher volume cases, though, the data suggest that the choice is indeed between one of the two transit systems, rather than between auto and transit. In the best of these three cases, for example, auto travel would cost $0.34 per trip more than the cheapest and fastest transit system and would not offer a faster overall trip. It seems then that the extra cost must be balanced against the service advantages of less waiting time (3.0 min by auto versus 4.8 min by transit), of more privacy, and of avoiding the discomfort and inconvenience of waiting in the cold, rain or heat. It is somewhat doubtful if these service advantages are valued that highly by the average traveler. (Certainly some travelers would value service that highly, but herein the concern is with the overall or average market and assuming no stratification.)

However, for the lowest volume case, the cost and service conditions warrant further attention. The travel conditions and costs of the different types of transit and auto systems are probably similar enough to prevent definitive conclusions regarding the "best" or even probably "best" system. As pointed out earlier, even the choice between transit modes is not clear; however, for the purpose of making comparisons between transit and auto systems, the bus transit system will be assumed to be the "best" transit system, mainly because the passenger transfer variable is eliminated, and the comparison is simplified. In this case, and comparing auto travel (including downtown subway service) with bus travel, it is found that the auto system would cost an extra $0.10 per trip but would permit travelers to avoid the discomforts of walking to and waiting at bus stops, and would save about 1 min per trip (in waiting and overall travel time). Alternatively, with a passenger car system using downtown city streets auto travelers would save $0.26 per trip over the auto system with a downtown subway and $0.16 per trip over a bus system but would find their travel time lengthened by 4 min over other auto systems and 3 min over the bus system. It is concluded from these data and conditions that auto travelers would be unwilling to afford the extra $0.26 per trip in order to have downtown (auto) subway travel and to save 4 min per trip; similarly, it is expected that travelers would also be unwilling to afford an extra $0.16 per trip to use the bus system instead of auto travel just to save 3 min per trip.

Cost Effects of Changing Design and Service Variables

In the section on performance and cost of the line-haul system, several important design and service variable changes were analyzed. Most of this earlier information

TABLE 29

SUMMARY OF OUTBOUND AND THROUGH VOLUME PER LINE-HAUL STATION

One-Way (inbound) Volume at Max. Load Point (pass./hr)	Ratio of Outbound or Through Volume to One-Way Inbound Flow (%)	Hourly Outbound Passenger Volume per Line-Haul Station (for 10-mile route length)
30,000	33	1,000
20,000	25	500
10,000	20	200
5,000	20	100

is directly applicable here, and does not require repetition. However, one aspect, that of outbound service, will be examined in more detail, and its cost and service implications explored. (It would be more accurate to use the term "minor flow direction" service, since such would apply both to morning and afternoon rush-hour service. However, for simplicity "outbound service" is used herein and thus is strictly applicable only to "minor flow direction" service in the morning rush hour).

For this purpose, it has been assumed that a certain percentage of the morning inbound (or afternoon outbound) passenger volumes will pass entirely through the downtown area and will be distributed in some fashion along the connecting line-haul facility and throughout the residential collection area; in this case, a uniform distribution along the line-haul facility was assumed. The volume levels for which the cost of adding outbound service was computed are given in Table 29, along with the through or outbound volume percentages and hourly outbound passenger volume per line-haul station. The resultant hourly passenger capacity requirements along the two connecting line-haul routes and downtown section (in each direction) would be somewhat as shown in Figure 27.

The cost of providing outbound or through service to the extent shown in Table 29 is shown in Figure 28 on a unit passenger trip basis, and is compared with the unit cost of handling the same volumes for the case where all destinations (or origins) are in the downtown area. (It should be evident that the addition of this outbound service and capacity is merely equivalent to changing the origin-and-destination pattern for the travelers, while holding the volume level, or number of passenger trips, constant.) The pattern is indeed much as one would anticiptate. Adding this service for the transit systems mainly amounts to carrying passengers over a longer distance for which the basic system facilities are already built; however, addition of the outbound service does not permit all trains or buses to operate non-stop and at top running speeds for what formerly was an empty return haul trip. Thus the utilization rates are reduced, and equipment and labor costs are increased. For the bus transit system, an interesting cost tradeoff takes place and is worth noting. On the one hand, some of the bus trips must be utilized for the longer outbound passenger-carrying trips, thus increasing the

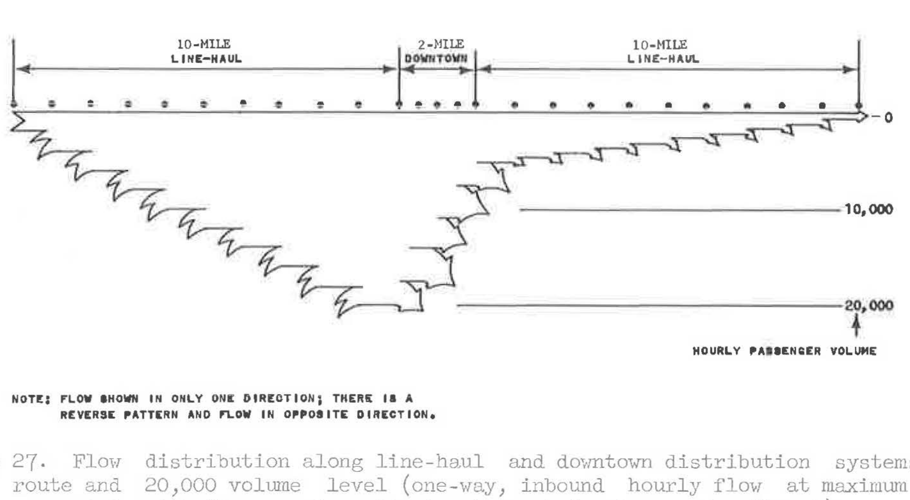

Figure 27. Flow distribution along line-haul and downtown distribution systems, for 10-mi route and 20,000 volume level (one-way, inbound hourly flow at maximum load point, with 25 percent continuing through downtown and outbound).

number of bus units required. On the other hand, for those trips originating at (or destined to) the line-haul station which is situated just 1 mile from the downtown distribution system and destined for (or originating at) the 1-mile line-haul station on the opposite or other connecting line-haul route, it is now possible to distribute the loading/unloading and acceleration/deceleration delays over a longer distance than before, thus increasing bus seating capacity.

For the passenger car system, and contrary to the transit systems, additional roadway capacity must be provided for the travelers and additional vehicular mileage will be required (thus increasing both vehicle operating and ownership costs). At the same time, however, less downtown parking garage space will be needed (by an amount equal to the percentage of through or outbound passengers), although this must be replaced by parking lot space within the residential collection area.

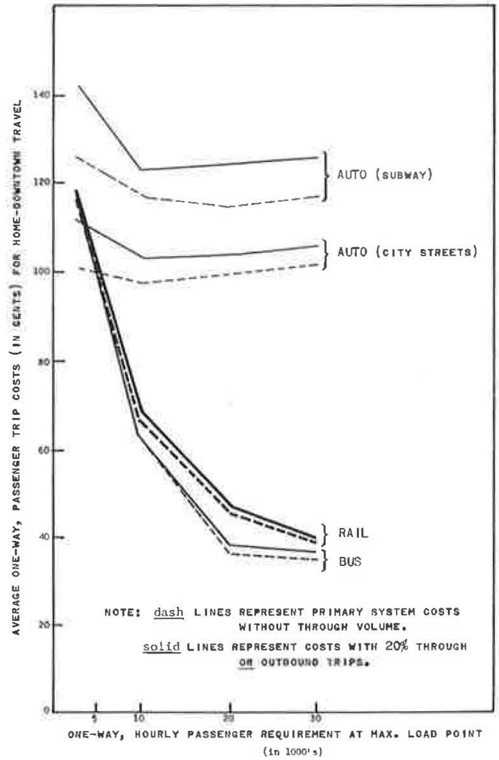

Figure 28. Overall passenger trip costs for 10-mi route and high residential density, with and without through or outbound passenger movement.

From Figure 28 it is evident that the passenger trip costs for transit travel are little affected by changing the system to accommodate outbound travel; the unit cost for rail transit travel is increased by no more than 4 percent, and for bus transit by no more than 7 percent. However, it is interesting to note that the relative attractiveness of bus transit increases at low volume levels and decreases at the higher (or 30,000 hourly passenger) volume level. For auto travel (with a downtown subway), the overall passenger trip costs increase some 5 to 12 percent. In general, then, the consequence of adding outbound service is to render the transit systems more attractive than auto travel, particularly at low volume levels.

Addition of other types of travel services will affect the overall annual system and passenger trip costs for transit systems to a far lesser extent, although in much the same manner, than changes noted in the earlier section on line-haul system costs (see Figs. 10, 11, 12 and 14). The basic reason for this is simply that the addition of other types of services generally will not affect the design or cost of the downtown distribution portion of the total system and that the downtown portion accounts for 13 to 23 percent of the system costs for rail transit and 33 to 43 percent for bus transit; at the same time, however, because a greater portion of total system costs are imbedded in the downtown section for bus transit, the addition of other types of travel services will have less effect on total costs for bus than for rail.

For auto systems, the downtown section as a percentage of the total system cost ranges from 18 to 26 percent, just slightly higher than rail but considerably lower than bus. As a consequence, addition of other types of travel services will affect auto costs more than those for bus but less than those for rail.

Examination of Figure 30, which shows the breakdown of overall system costs for the basic functions, together with Figures 10, 11, 12 and 14, will aid in visualizing these concepts.

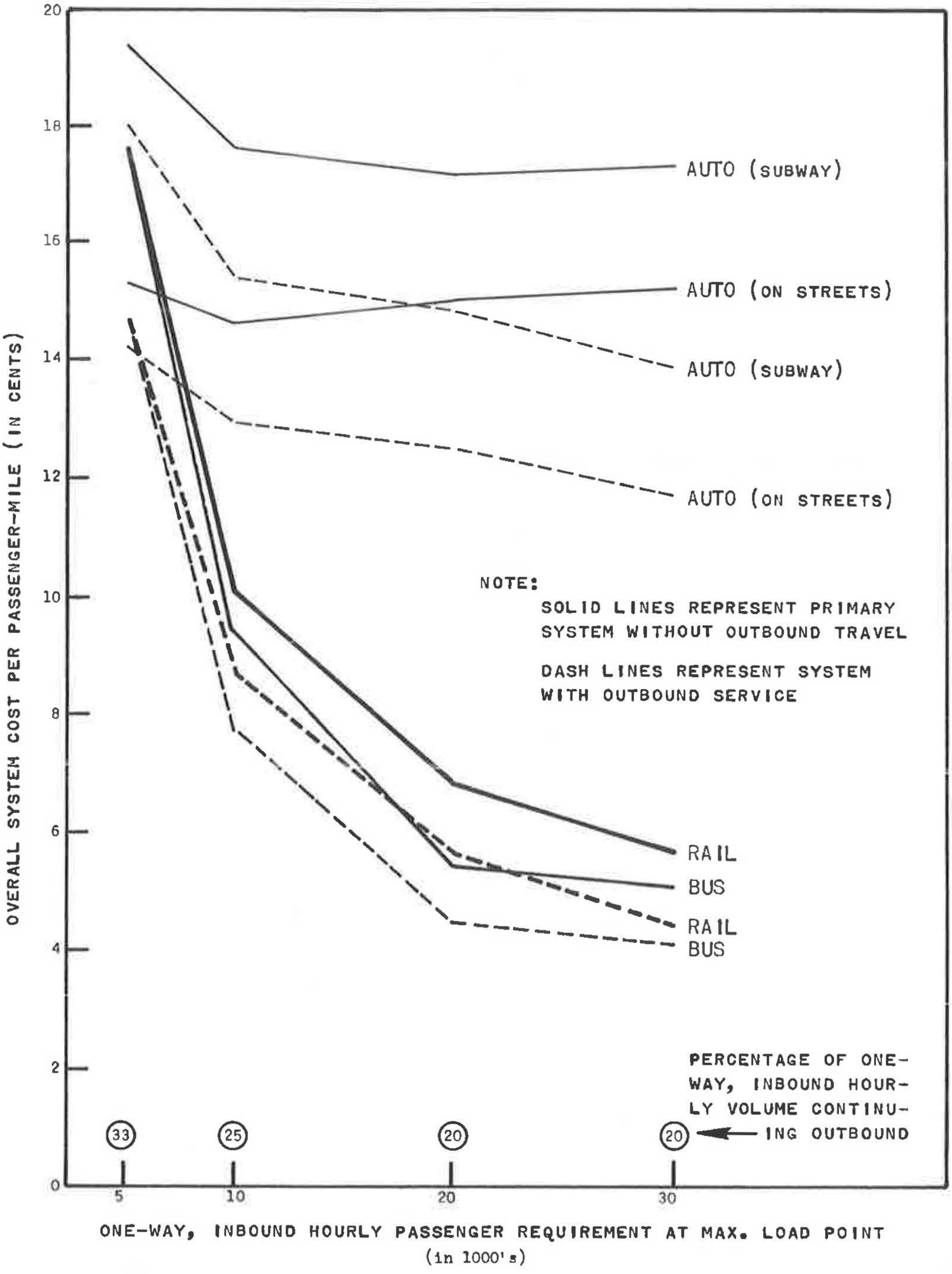

Figure 29. Costs per passenger-mi for overall system with and without outbound service; 10-mi route and high residential density.

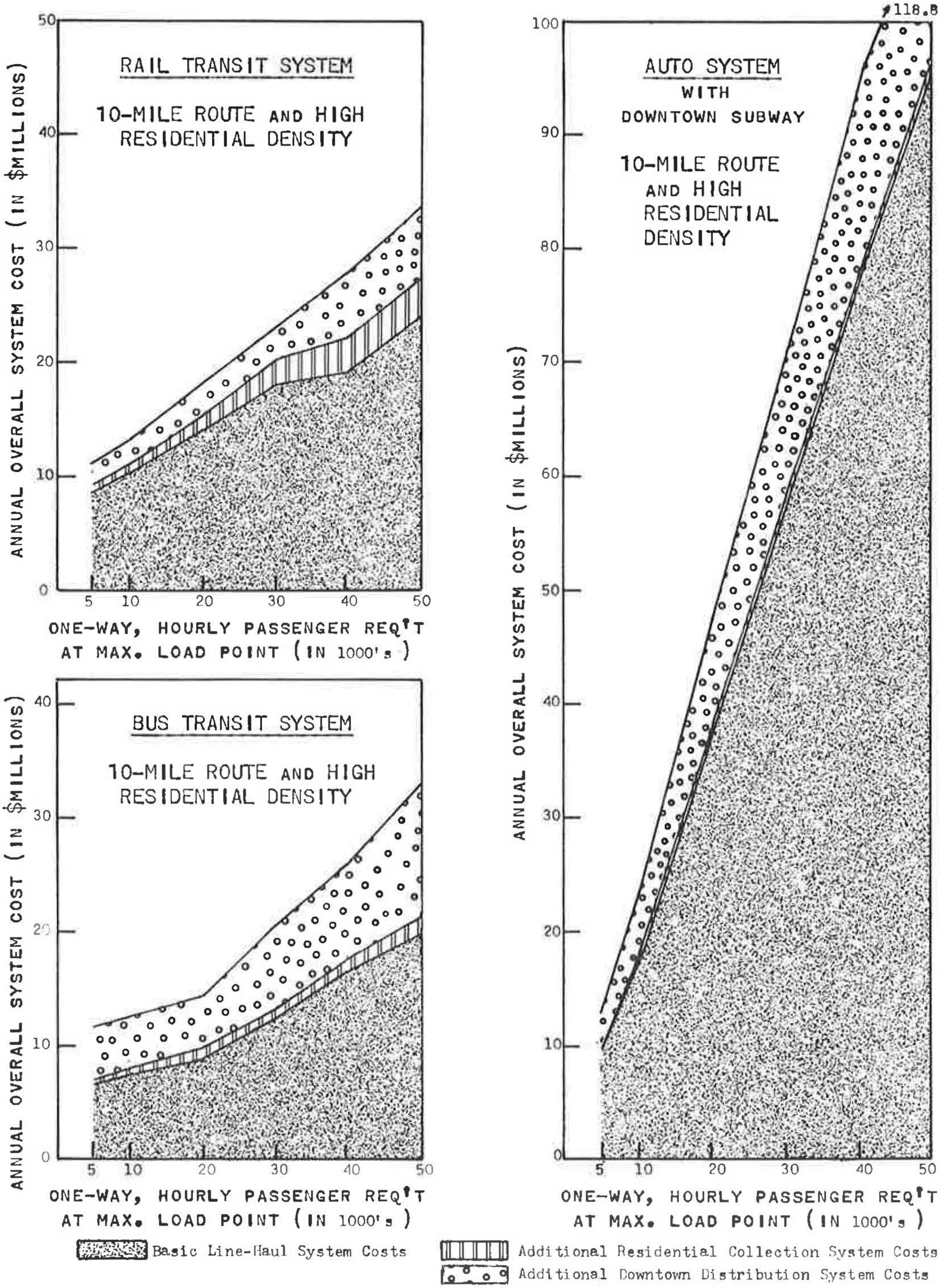

Figure 30. Overall system cost breakdown for 10-mi route length and high residential density.

SUMMARY AND CONCLUSIONS

Passenger trip costs were computed for the principal modes available for handling passenger movements between homes and downtown areas for 18 combinations of line-haul route length (6, 10, and 15 miles) and one-way, hourly passenger volume at the maximum load point (5,000, 10,000, 20,000, 30,000, 40,000, and 50,000 hourly passengers). Each system was designed to sustain these hourly volume levels for a 2-hr period in the morning and a 2-hr period in the afternoon; all costs (including 6 percent interest on capital) for constructing, maintaining, and operating the systems required to handle these flows were allocated solely to the 4-hr passenger volume. Further, and more importantly, these costs were computed for systems using private, grade-separated rights-of-way and designed to provide reasonably equivalent passenger service; thus each system was designed (a) to provide average overall passenger trip speeds of 35 mph, (b) to provide a seat for every passenger, and (c) to provide transit passengers with a bus or train headway of no more than 2 min at line-haul and downtown bus or train stations and with equal seating space standards. For residential collection system service, maximum feeder bus headways were set at 10 min, and maximum walking distance to feeder bus stops at two blocks; correspondingly, passenger car occupancy was set at 1.6 persons per auto.

The costs were first computed for basic line-haul system service (that is, for travel between line-haul station entry or exit points and the downtown stub terminal); also, these line-haul service costs included the capital and operating charges for downtown stub terminals or parking garages located at the fringe of the central area. Then, sequentially, the incremental costs for adding residential collection (or feeder) service and for adding downtown distribution service were computed and analyzed. Finally, the incremental costs and economic effects of varying certain service requirements—increasing transit headway and maximum walking distance, decreasing residential density, adding outbound and along-the-line service, increasing car occupancy, etc.—were analyzed in considerable detail.

All of the results cannot be properly analyzed in this brief summary. However, some findings can be noted, at least on a tentative basis. For situations when a connecting downtown distribution system is not to be provided, express bus operations would seem to be preferable both in terms of cost and service, at (corridor) hourly passenger volumes in excess of 5,000. However, at corridor volumes in the vicinity of or just below 5,000 hourly passengers, private automobile travel would appear to be preferable. The importance of this latter aspect can not be overstated, as hourly passenger volumes seldom exceed the 5,000 figure in specific corridors except in a dozen or so largest U. S. cities. (These conclusions, it appears, will hold true over a wide range of service and cost assumptions, although the automobile becomes cost competitive at increasingly higher volume levels as residential density falls, and as route length increases.)

Rail transit systems exhibit substantial cost economies (relative to the other modes), however, whenever it becomes necessary or desirable to place the transport facility underground. And, obviously, the cost advantage of rail transit improves as the extent or proportion of the total system in subway increases. Even so, it would not appear that the overall passenger trip cost—between home and downtown and to include residential, line-haul, and downtown service—would generally be cheapest with the provision of rail transit service. Rather, in most cases, express bus operations, operating in tunnels downtown, express on private highway for the line-haul portions, and as feeder buses in residential areas, would provide cheaper and higher quality service. It is necessary to note, however, that at low volume levels—particularly with long route lengths—or with downtown travel on city streets the automobiles again display both cost and service advantages. On the other hand, at very high corridor volume levels (such as those experienced in New York City) or with extensive subway portions, rail transit systems offer the most economic service.

ACKNOWLEDGMENTS

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Appendix

The entire analysis underlying the cost data included in this paper is far too lengthy to report. However, the unit costs and important system requirements which serve as the basis of the overall costs are outlined in the following.

I. VEHICLE CHARACTERISTICS

A. Rail Transit Vehicle

Length: 55.33 ft
Width: 9 ft
Empty car weight: 48,000 lb
Max. running speed: 55 mph (or 80.5 ft per sec)
Cost: $92,500
Service life: 30 years
Power/weight (hp/avg. loaded tonnage) ratio: 14.8
Estimated effective floor space: 400 sq ft
Seats: 79 (using bus seating space standards)
Average deceleration: 4.2 mph/sec
Average acceleration: 20 mph in 8 sec
30 mph in 14 sec
40 mph in 27 sec
46 mph in 40 sec
52 mph in 60 sec
55 mph in 80 sec

B. Bus Transit Vehicles

Two types of buses were used, depending on capacity requirements:

(1) Modified GMC-TDH 5303 bus, equipped with three doors and SDM 5303 power and transmission units.

Length: 40 ft
Max. speed: 59.5 mph
Seats: 50
Effective floor space: 254 sq ft
Gross weight (including pass.): 28,200 lb
Estimated cost: $31,200 (incl. modifications and tax)
Service life: 12 years
Average deceleration: 4.2 mph/sec
Average acceleration: 20 mph in 7 sec
40 mph in 25 sec
48 mph in 40 sec
56 mph in 60 sec
59 mph in 70 sec

(2) Modified GMC-TGH 3102 bus, equipped with three doors and slightly improved performance.

Length: 27 ft
Max. speed: 59.5 mph
Seats: 28
Gross weight (including pass.): 14,900 lb
Estimated cost: $13,100 (incl. modifications and tax)
Service life: 12 years
Average deceleration: 4.2 mph/sec
Average acceleration: 20 mph in 7 sec
40 mph in 25 sec
48 mph in 40 sec
56 mph in 60 sec
59 mph in 70 sec

C. Passenger Automobile

Compact commuting car
Estimated cost: $1,600
Service life: 60,000 miles (i.e., mileage depreciation)
Seats (or occupancy): 1.6 persons/auto where entire trip is by auto; however, for park 'n ride travel, only 1.1 persons per auto was used, and for kiss 'n ride travel, no car pooling.

II. UNIT OPERATING AND MAINTENANCE COSTS FOR VEHICLES, EQUIPMENT, WAY, SHOPS, ETC.

A. Rail Transit Systems

(1) Maintenance of way and structures:

Y_1 = Annual maintenance-of-way costs per single-track mile (in $1,000)
X_1 = Annual car-miles per single-track mile (in 1,000's)
X_2 = Gross (loaded) car weight (in 1,000's of lb)

$$Y_1 = 0.1617\ X_1 + 0.2667\ X_2 - 35.766$$

$$r^2 = 0.999$$

$$s_e = 1.95$$

(Because of the negative threshold cost, a minimum maintenance-of-way cost per track-mile of $8,500 was used. This includes maintenance of track, roadbed, electrification and signals, and a portion for roadside-slope maintenance.)

(2) Maintenance of equipment:

Y_1 = Annual maintenance-of-equipment cost per car (in dollars)
X_1 = Average car age (in years)
X_2 = Empty car weight (in 1,000's of lb)

$$Y_1 = 1022 + 69.45\ X_1 + 27.79\ X_2$$
$$r^2 = 0.73$$
$$s_e = 784$$

(3) Conducting transportation (exclusive of motormen and guards):

Y_1 = Ann. conducting trans. cost per single-track mile (in \$1,000)
X_1 = Average station spacing (in miles)
X_2 = Peak-hour passenger volume per single-track mile

$$Y_1 = 89.13 - 64.50\ X_1 + 0.007384\ X_2$$
$$r^2 = 0.73$$
$$s_e = 10.6$$

(4) Motorman and guard costs (using two-man crew per train):

Annual cost of \$17,820 for each train crew required (includes allowance for social security, relief, breaks, etc.)

(5) Power costs:

Y_1 = Kwh of power consumed per 1,000 gross ton-miles
X_1 = Hp/avg. gross ton ratio
X_2 = Average station spacing (in miles)

$$Y_1 = 59.16 + 11.02\ X_1 - 21.27\ X_2$$
$$r^2 = 0.77$$
$$s_e = 28$$

(The average rate used for this analysis was \$0.01456 per kwh.)

(6) Other operating costs (administration insurance, injuries, advertising, etc.):

Y_1 = Other annual operating and maintenance costs, as a percentage of all other costs (items 1 through 5)
X_1 = Annual revenue passengers per single-track mile (in millions)

$$Y_1 = 15.98 - 0.669\ X_1$$
$$r^2 = 0.96$$
$$s_e = 0.5$$

B. Bus Transit Systems (Including Feeder Bus Service)

(1) Bus operating costs on private rights-of-way: \$0.30 per bus-mile. Includes maintenance and garage expenses, fuel, conducting transportation (other than drivers), insurance, and administration. No gas taxes are included, inasmuch as the private right-of-way costs (both capital and operating) are fully accounted for in the line-haul and downtown distribution subway costing.

(2) Bus operating costs on residential collection area streets: \$0.325 per bus-mile. Gas taxes are included here to account for a proportion of the capital and operating costs of the residential streets.

(3) Bus highway operating and maintenance costs for private right-of-way facilities: Annual cost of $9,000 per lane-mile (of private right-of-way)

(4) Bus operator costs: Annual cost of $8,910 for each bus operator required (includes allowances for social security, relief, breaks, etc.).

C. Passenger Automobile Systems

(1) Vehicle operating and maintenance on private rights-of-way:

Item	$/veh-mile
Repairs and maintenance	0.0170
Replacement tires and tubes	0.0015
Gasoline (not including user taxes)	0.0095
Oil	0.0010
Total	0.0290

(2) Vehicle operating and maintenance costs on residential collection area streets: $0.0407 per veh-mile (includes gas taxes, and thus operating and capital costs for residential streets.)

(3) Vehicle accident insurance costs: $100 per year per auto where entire home-downtown trip is by auto. For park 'n ride auto travelers, the cost was $20 per year per auto; for kiss 'n ride travelers, the cost was set at $0.0129 per vehicle-mile.

(4) Automobile highway operating and maintenance costs for private right-of-way facilities: Annual cost of $9,000 per lane-mile (of private right-of-way).

(5) Automobile parking space maintenance and operating costs:

Type of Parking and Location	Annual Main. and Oper. Cost per Space ($)
Central downtown garage	155
Fringe downtown garage	155
Fringe lots along 6-mile route[a]	60
Fringe lots along 10-mile route[a]	60
Fringe lots along 15-mile route[a]	60

[a]Applies only to park 'n ride travelers.

III. UNIT CAPITAL COSTS AND SERVICE LIVES FOR VEHICLES, EQUIPMENT, WAY, TERMINALS, SHOPS, ETC.[1]

A. Rail Transit Systems

(1) Rolling stock costs: $92,500 per car (life of 30 years)

(2) Yards and shops costs: $8,000 per car (life of 50 years)

(3) Line-haul facility construction, track structure, electrification, and utility relocation costs: $3,625,000 per 2-track-mile (includes engineering and contingency fees, but not right-of-way or land acquisition costs) (life of 50 years)

(4) Downtown subway construction, track structure, electrification, and utility relocation costs (between stations): $17,500,000 per 2-track-mile (includes engineering and contingency fees; easement costs are assumed negligible and are excluded) (life of 50 years)

(5) Underground subway station or stub terminal costs (including mezzanine): $7,200 per lin ft for a 2-track (50-ft wide) station or terminal (life of 50 years)

[1] Annual capital charges computed using a capital recovery factor (CRF) and a 6 percent interest rate; $CRF = i/[1 - (1 + i)^{-n}]$, where n is the life (in years), and i is the rate of interest.

(6) Turnaround extension for stub terminal (underground and in subway): $1,811 per lin ft of extension plus $50,000 for each crossover (life of 50 years)

(7) Finishing costs for line-haul stations (over and above track construction costs included in item 3): $1,100 per lin ft of 2-track station and $1,550 per lin ft of 3-track station (life of 50 years)

(8) Right-of-way or land acquisition costs: Computed as a proportion of the bus transit ROW costs according to the ratio of rail transit ROW width to bus highway ROW width for the particular route length and volume level; some of the appropriate data are given in Tables 4 and 6, and the remainder are shown in the following and in subsection III.B (indefinite life). (ROW costs only apply to line-haul portion of transit system.)

TOTAL NUMBER OF RAIL TRANSIT TRACKS REQUIRED FOR EACH LINE-HAUL ROUTE AND UNIFORMLY DISTRIBUTED HOURLY PASSENGER REQUIREMENTS

Route Length (mi)	50,000 Pass./Hr			40,000 Pass./Hr			30,000 Pass./Hr		20,000 Pass./Hr		10,000 Pass./Hr		5,000 Pass./Hr	
	No. Tracks[1]	Third Track[2] (mi)	Total Track[3] (mi)	No. Tracks[1]	Third Track[2] (mi)	Total Track[3] (mi)	No. Tracks[1]	Total Track[3] (mi)	No. Tracks[1]	Total Track[3] (mi)	No. Tracks[1]	Total Track[3] (mi)	No. Tracks[1]	Total Track[3] (mi)
6	3	3	15	3	3	15	2	12	2	12	2	12	2	12
10	3	5	25	3	4	24	2	20	2	20	2	20	2	20
15	3	8	38	3	6	36	2	30	2	30	2	30	2	30

[1]Both directions. [2]Extra 3rd track where required. [3]Total single-track miles.

B. Bus Transit Systems

(1) Rolling stock costs: $31,200 for 50-seat bus; $13,100 for 28-seat bus (life of 12 years)

(2) Yards and shops costs: $4,500 per bus (life of 40 years)

(3) Line-haul facility construction costs: Cost per mile for facilities of different lane widths are given in Table 4; these were applied to the facility requirements as given in the following table (life of 35 years):

NUMBER OF MILES OF ROADWAY OF DIFFERENT LANE WIDTHS (TWO-WAY) NEEDED FOR EACH LINE-HAUL ROUTE AND UNIFORMLY DISTRIBUTED HOURLY PASSENGER REQUIREMENTS

Route Length (mi)	Roadway Needed (mi)												
	50,000 Pass./Hr				40,000 Pass./Hr			30,000 Pass./Hr		20,000 Pass./Hr		10,000 Pass./Hr	5,000 Pass./Hr
	8 Lanes	6 Lanes	4 Lanes	2 Lanes	6 Lanes	4 Lanes	2 Lanes	4 Lanes	2 Lanes	4 Lanes	2 Lanes	2 Lanes	2 Lanes
6	1	1	2	2	1	2	3	2	4	1	5	6	6
10	-	1	5	4	1	3	6	2	8	1	9	10	10
15	-	1	7	7	-	6	9	3	12	1	14	15	15

(4) Downtown subway construction (between station) costs: $8.576 million per lane-mile of bus subway (life of 50 years)

(5) Underground subway station or stub terminal costs (including mezzanine): $17,536 per lin ft for each incoming lane of bus highway; station is 128 ft wide for each lane of incoming highway. Also, $1.5 million is required for additional ventilation (life of 50 years)

(6) Turnaround loop for stub terminal (underground): $1,636 per lin ft; a 400-ft loop is required for each incoming lane (life of 50 years)

(7) Finishing costs for line-haul stations: $100,000 for each (life of 50 years)

(8) Right-of-way or land acquisition costs: The unit costs per lane-mile of facility (of given lane widths) are as given in Table 4; these were applied using the required lane widths and lengths of roadway shown in the table of subsection III B(3) above (indefinite life)

C. Passenger Automobile Systems

(1) Compact commuting car purchase cost: $1, 600; mileage depreciation over 60, 000 miles (plus interest during service life of 6 percent).
(2) Line-haul facility construction cost: See Table 4 (life of 35 years)
(3) Line-haul right-of-way cost: See Table 4 (indefinite life)
(4) Downtown subway construction cost: $6.0 million per lane-mile of roadway (life of 50 years)
(5) Construction and right-of-way costs for parking lots and garages:

Type of Parking and Location	Total Capital Costs per Parking Space ($)		Service Life (in yr)
	ROW	Constr.	
Downtown garage	1, 500	1, 600	40
Fringe downtown gar.	1, 100	1, 600	40
Lots along 6-mi route[1]	800	400	15
Lots along 10-mi route[1]	700	400	15
Lots along 15-mi route[1]	600	400	15

[1] Apply only to park 'n ride travelers.