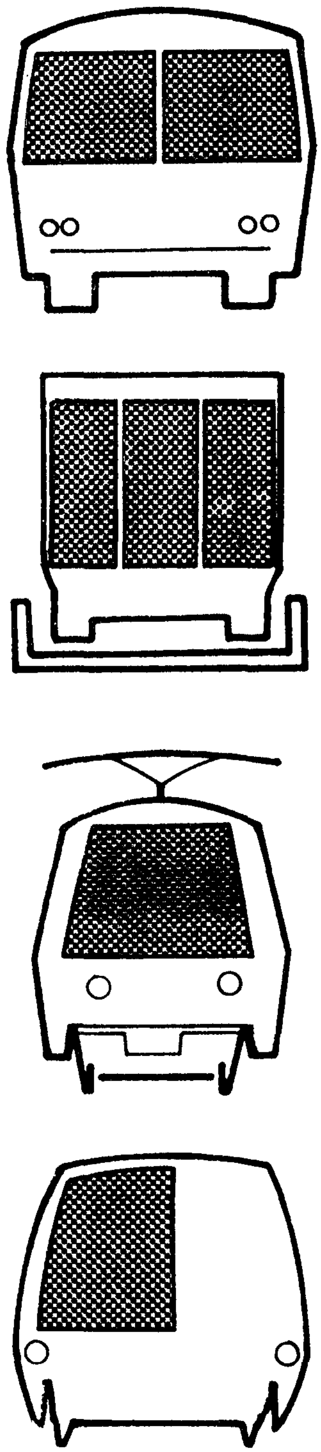
TRANSIT TECHNOLOGY SELECTION STUDY

FINAL REPORT



EVOLUTIONARY TRANSITWAYS: A CONCEPT EVALUATION

North Central Texas Council of Governments

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TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY SYSTEM

EVOLUTIONARY TRANSITWAYS: A CONCEPT EVALUATION

FINAL REPORT

FOR THE

TRANSIT TECHNOLOGY SELECTION ANALYSIS
FOR THE DALLAS-FORT WORTH INTENSIVE STUDY AREA

SUBMITTED TO
NORTH CENTRAL TEXAS COUNCIL OF GOVERNMENTS
ARLINGTON, TEXAS

BY

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY SYSTEM
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Introduction

The purpose of this study is to determine the feasiblity of developing a transitway system for initial use by buses and future conversion for use by another transit mode. This concept, if held valid, would allow the 1990 Total Transportation Plan for the Dallas-Fort Worth area to be implemented in such a way that another transit mode could be implemented at any future time. Since this advanced mode would operate on previously constructed rights-of-way and structures, the implementation costs would be substantially lower than those for a completely new system. Transitway evolution would allow the orderly development of a transit system designed for existing and near-term needs which would also have the potential to accommodate the transit demand in the region for many decades.

Although the evolutionary concept is often mentioned as a desirable way to implement public transportation, its economic and design feasibility has not previously been demonstrated. The objectives of this study are to first determine the feasibility and limitations of the concept of transitways which can both accomplish the initial requirements of transitways identified in the long-range transportation plan and evolve to accommodate other technology systems. Additionally, the pertinent tradeoffs and implications of such a concept are to be identified. Lastly, a set of conceptual transitway designs is to be developed, along with the range of hardware systems which can accommodate the staged transitway evolution. To understand the need for this analysis, it is helpful to review the planning processes which developed the existing long-range transportation plan.

Previous Studies

The 1990 Total Transportation Plan for the Dallas-Fort Worth area is a multimodal plan which calls for exclusive right-of-way transit as well as highway and bus service. The public transportation element of the long-range plan represents the culmination of several studies which began in 1971 as the Regional Transportation Study. The long-range element of this process examined three regional system alternatives: an all-bus system including separate busways, a high-speed rapid transit system, and a personalized rapid transit system using small vehicles. The Recommended Regional Public Transportation Plan, the result of the Regional Public Transportation Study; Fort Worth, Dallas, and Mid-Cities subregional studies; and an Urban Tracked Air Cushion Vehicle (U-TACV) Feasiblity Study, called for a system of exclusive guideway transit, high-level bus service, and a high-speed transitway connecting the Dallas/Fort Worth Regional Airport and the central business districts (CBD's).

Subsequent to the Regional Public Transportation Study, a multimodal planning effort was undertaken. Building from the previous study, the total transportation planning process considered five alternatives with varying degrees of investments in both transit and highway systems. The analysis of these alternatives and subsequent refinement led to the adoption, on November 23, 1974, of The Total Transportation Plan for the North Central Texas Region for 1990 (1)* by the Regional Transportation Policy Advisory Committee. The transit component of the plan is built around 12 transitways to be used by buses and, in some cases, high-occupancy vehicles.

The Dallas and Fort Worth subregional studies introduced the concept that transit corridors should have an evolutionary capability. The transitways should be able to initially accommodate buses and transfer later to use by rail rapid transit, light rail transit, or some other advanced technology. The Dallas study states, "In selecting the technology, an evolutionary approach should be used. That is, the opportunity should be created to change from existing to new innovative types in the future as they become available and as the commitment to transit becomes more certain" (2). Thus, the long-range transit plan for the Dallas-Fort Worth area is a system based largely on exclusive transitways for use by buses and high-occupancy vehicles. The concept which calls for these transitways to be capable of accepting advanced hardware types is one which should be considered in plan refinement studies.

One set of plan refinement studies has been undertaken to perform preliminary engineering for transit routes in Dallas and Fort Worth. Their scope included detailed route location studies, station location analyses, and preliminary central business district station designs. The specific purpose of the studies was to provide specific right-of-way requirements and an order-of-magnitude capital cost estimate for the public transportation system. The product of the preliminary engineering studies will potentially form the basis

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*Denotes reference number listed at the end of this report.

for reservation of future transit rights-of-way by imposing building setback restrictions on lands adjacent to proposed transit lines.

The Dallas and Fort Worth Preliminary Engineering Studies each accommodate the transitway evolutionary concept. This is accomplished by using design criteria set by buses, automobiles, and transit vehicles. The Fort Worth Commuter System was designed for initial operation of both buses and carpools during peak travel periods in one-way operation. This is to be accomplished by a 38-foot right-of-way which includes two 12-foot bus/carpool lanes and an 8-foot emergency lane. This right-of-way would accommodate a double-track rapid rail line.

The Dallas Preliminary Engineering Study assumed a transitway which would initially be used by buses only in one-way peak-hour flow and would be converted for use by a rail rapid transit system similar to those in San Francisco and Washington. This results in a 34-foot right-of-way which provides two lanes for bus operation initially; after the transition it provides two lanes for rail transit operation.

The Need for This Study

The plan development and plan refinement studies mentioned above have introduced and promoted the transitway evolutionary concept. However, there are several questions of design and economic nature about a system designed for transitway evolution. The goal of this study is to focus on the concept of evolutionary design and answer the remaining questions about its feasibility.

To set the background for considering the economic feasibility of transitway evolution, it is useful to examine certain background questions which provide insight to the concept. First, why is an advanced technology system desirable as an ultimate mode? The answers to this question involve the perceived potential of advanced systems to provide benefits over buses in terms of operating costs, system capacity, level of service, and energy. If this potential exists, then why not build an advanced technology system initially? There currently exists doubt as to the need for a rail rapid transit or similar system in view of the travel and development patterns in the Dallas-Fort Worth area. These doubts, coupled with the tremendous capital expense of advanced technology systems and the promise of large operating subsidies, reduced the viability of a rail rapid transit alternative in the 1990 transportation alternatives analysis.

Why, then, is it desirable to begin with busways and then transfer to another mode when it becomes feasible, rather than waiting until a time when the advanced mode is feasible? The first answer to this question is that long-range planning has demonstrated the need for the busway system. Other justifications are more closely related to the evolutionary concept. One of the reasons is that there is a degree of risk associated with very long-term capital investments such as transit systems. Therefore, the decision-makers will place a certain value on minimizing the risk of commitment to a large capital expense which might become outdated. An evolutionary system design would provide the flexibility to minimize this risk. Another reason for the evolutionary concept is that it has the potential of allowing the amortization of some of the expenses of the ultimate system over the operation period of the bus system. The radial, non-CBD rights-of-way and transit structure costs for the ultimate system would be justified by the benefits to be derived from the operation of the exclusive busway system. Therefore, at such time as the total ultimate system might be constructed, only the CBD system, conversion, and vehicle costs would be needed to provide a complete advanced technology system. Reviewing these questions and answers provides the following economic problem statement: Considering the probability of transferring from a bus technology to another technology, is it economical to incur a higher initial cost to avoid future costs?

In addition to the economic questions associated with the evolutionary concept, there are certain design questions which must be addressed. The paramount issue is the feasibility of constructing a transitway which will allow a conversion which will not require the operating system to be shutdown. With construction and system testing, the conversion period might last for several months. The costs of completely disrupting an operating transit system (which is carrying enough passengers to warrant an extensive system improvment) would obviously be enormous. Other design issues yet to be resolved involve transitway stations, right-of-way requirements, and the geometric design of line junctions. The resolution of these design and economic considerations will constitute a significant input to the implementation decisions of a long-range public transportation system.

Study Approach

The evolutionary guideway concept has been discussed in several previous studies. Guideway design parameters such as structural strength, maximum grades, minimum radius of curvatures, clearance widths and heights, etc. have been defined for each available transit technology. However, none of the previous studies identified in the literature survey conducted as a part of this effort (3) addressed the problems associated with the actual transition from one technology to another technology.

At the initial coordination meeting for this study, North Central Texas Council of Governments staff members, members of the Advisory Committee for this project, and study staff personnel discussed their primary concerns for this study. All participants generally agreed that it would be technically feasible to design a transitway so that it could accommodate different operational technologies; however, serious doubts were expressed concerning the following two questions.

1. Can a transitway design be developed that will accommodate continuous operation of one mode while the transition is being made to another mode?
2. If it is possible, will the evolutionary design be so complicated that it is economically impractical?

These two questions form the central focus of this study. Thus, it is an evaluation of the concept of evolutionary guideways; it is not a study in design specifics. The design approaches identified herein are intended to be conceptual in nature rather than definitive. The analyses are only as detailed as needed to address questions concerning the evolutionary transitway concept. In short, this study focuses on questions of technology attributes, system design, and operational characteristics--only as far as they affect the validity of the evolutionary concept.

Study Objectives

This study, "Transit Technology Selection Analysis for the Dallas-Fort

Worth Intensive Study Area," was designed to evaluate the feasiblity and desirability of designing transitways that can evolve from one form of mass transportation to others. The objectives of this study follow.

1. Identify logical evolutionary paths associated with various stimuli for change (capacity, labor intensity, energy considerations, etc.) from buses and evaluate the conditions under which a change in technology would be desirable.
2. Develop a set of alternative transitway designs and evaluate the feasibility and/or limitations of transition from buses to other technologies using each alternative design.
3. Identify pertinent trade-off considerations and implications associated with the evolutionary transitway concept and evaluate the desirability of this approach.

Work Plan

The detailed work plan that was developed to accomplish the study objectives included the following major elements.

1. *Literature Review and Development of Data File*
   This effort included an extensive review of the published literature as well as the collection of relevant operational data.

2. *Identification of Transitway Evolution Alternatives*
   This process included analyses of attributes of various transit technologies, a comparison of those attributes to identify logical evolutionary paths, and the development of transitway designs for each evolutionary path selected for further study.

3. *Trade-Off Analyses*
   This effort comprised the evaluation of the validity of the evolutionary transitway concept. It included analyses of operations during the transition period, estimations of the

costs for the various alternatives, present value analyses, and evaluation of decisional considerations.

In order to insure the validity of the results of this study, the North Central Texas Council of Governments formed an advisory committee comprised of transit operators, city traffic engineers, transportation planners, and various other technical experts from the Dallas-Fort Worth area to help guide the study direction. Five committee meetings were held at critical points in the study to allow the committee members to review the work to date and to suggest changes in the relative emphasis or major direction of the study.

Documentation

This report is the final report for the "Transit Technology Selection Analysis for the Dallas-Fort Worth Intensive Study Area." It is intended to be a reasonably complete documentation of the study findings without being overly burdened with details of analytical procedures, assumptions, and calculations.

Technical Memoranda were prepared at various stages of the study in order to document work performed to date in more complete detail. If the reader of this report desires more detailed information concerning the data or analyses presented herein he should refer to one of the following Technical Memoranda:

- Transitway Technology: An Annotated Bibliography (3),
- Analysis and Selection of Transitway Evolutionary Paths (4),
- Alternative Evolutionary Design Approaches (5), and
- Trade-Off Analysis Methodology (6).

This report is organized in five major sections. This first section has presented background information concerning the study. The second section presents data and analyses used in the selection of alternative evolutionary paths. Conceptual designs for the various evolutionary paths are described in the third section. Trade-off analyses that comprise the evaluation of the validity of the evolutionary transitway design concept are presented in the fourth section. Finally, the major conclusions resulting from this study are reiterated in the fifth section.

Although all analyses in this study are directed toward the conditions that prevail in the Dallas-Fort Worth area, the topic is one that is of general interest to transportation planners in many cities. Hopefully, the results of these analyses will be useful to other planning efforts around the nation.

II. SELECTION OF EVOLUTIONARY ALTERNATIVES

LABOR INTENSITY

CAPACITY

ENERGY EFFICIENCY

SAFETY

RELIABILITY

OTHER ATTRIBUTES

POTENTIAL EVOLUTIONARY PATHS

The concept of the evolutionary transitway is based on the premise that, at some future time, a reason will exist to evolve to a different transit technology. It is generally agreed that, during initial operation, buses and carpools or buses only will operate over the transitway. Previous studies have not, however, sought to identify the conditions which would need to exist to justify evolving from the bus/carpool operation to an alternative form of transit operation.

If the transitways are initially designed to accommodate buses and carpools, then supposedly a change in mode would be justified only if it resulted in significant improvement of some operational attribute. For example, a higher capacity technology will become desirable if transit demand grows beyond the capabilities of buses and carpools to serve it effectively. Accordingly, an analysis of the relative capabilities of the various mass transportation technologies seems to be an appropriate first step in identifying logical evolutionary paths.

Information concerning the relative capability of various forms of mass transportation technologies, as related to labor intensity, capacity, energy efficiency, safety, and reliability, is presented in this section. Additionally, other factors that might stimulate a desire for a change in technology are discussed. The primary purpose of this analysis of attributes is to provide information needed to select those evolutionary paths that warrant further study. The selected evolutionary paths are identified and discussed in the final portion of this section.

Labor Intensity

The labor intensity of a transit system can be evaluated in two manners. The first involves a comparison of the labor intensities associated with existing transit operations. The second approach recognizes that some transit technologies, such as rail rapid transit (RRT), perform certain functions (security, enforcement, maintenance of way, etc.) that are not performed by technologies such as bus transit. The second approach adjusts the labor intensities associated with existing transit systems in an attempt to account for this difference in functions performed.

Analysis of Existing Operations

Data presented in Figures II-1 and II-2 are from various transit systems serving large cities in the nation (7). Unfortunately, most rail transit systems in the nation are operated in conjunction with bus systems, and riders served are not reported separately. Data for those combined systems that did not report separate statistics are also plotted in these figures.

Figure II-1 depicts a labor intensity of 22 employees per million annual passengers, and Figure II-2 depicts a labor intensity of 75 employees per million annual vehicle-miles of service. These simple relationships provide a surprisingly good fit for data spanning such a broad range of operating conditions. The width of the bands superimposed on the curves is approximately ± 10 percent of the values depicted by the line.

If the curves shown are accepted as representative of all technologies included in the data, then labor intensity is the same for existing bus transit, light rail transit (LRT), rail rapid transit (RRT), and Automated Guideway (AGT) systems. If different curves are drawn for each technology, then the curve for RRT systems will lie slightly higher on the graph than the curve for bus transit systems. Such separate curves would indicate a higher level of labor intensity for RRT systems than for bus systems. With only two data points each for LRT and AGT systems, it would not be appropriate to draw separate curves for these technologies. Consequently, the single curve is considered indicative of labor intensity of all technologies.

Several factors, such as extent of peak period service provided and hours of operation per day, can affect labor intensity. Thus, it is surprising that there is such close agreement between vastly different systems. Nevertheless, the curves shown on Figures II-1 and II-2 should be regarded only as indicators of the number of employees that might be required on a new transit system. Values determined by using these curves certainly should not be considered more accurate than ± 10 percent.

Adjusted Labor Intensities

The data in Figures II-1 and II-2 are for existing operational transit systems. These data are not adjusted to account for the differences in the nature of operation of conventional bus systems and typical rail systems.

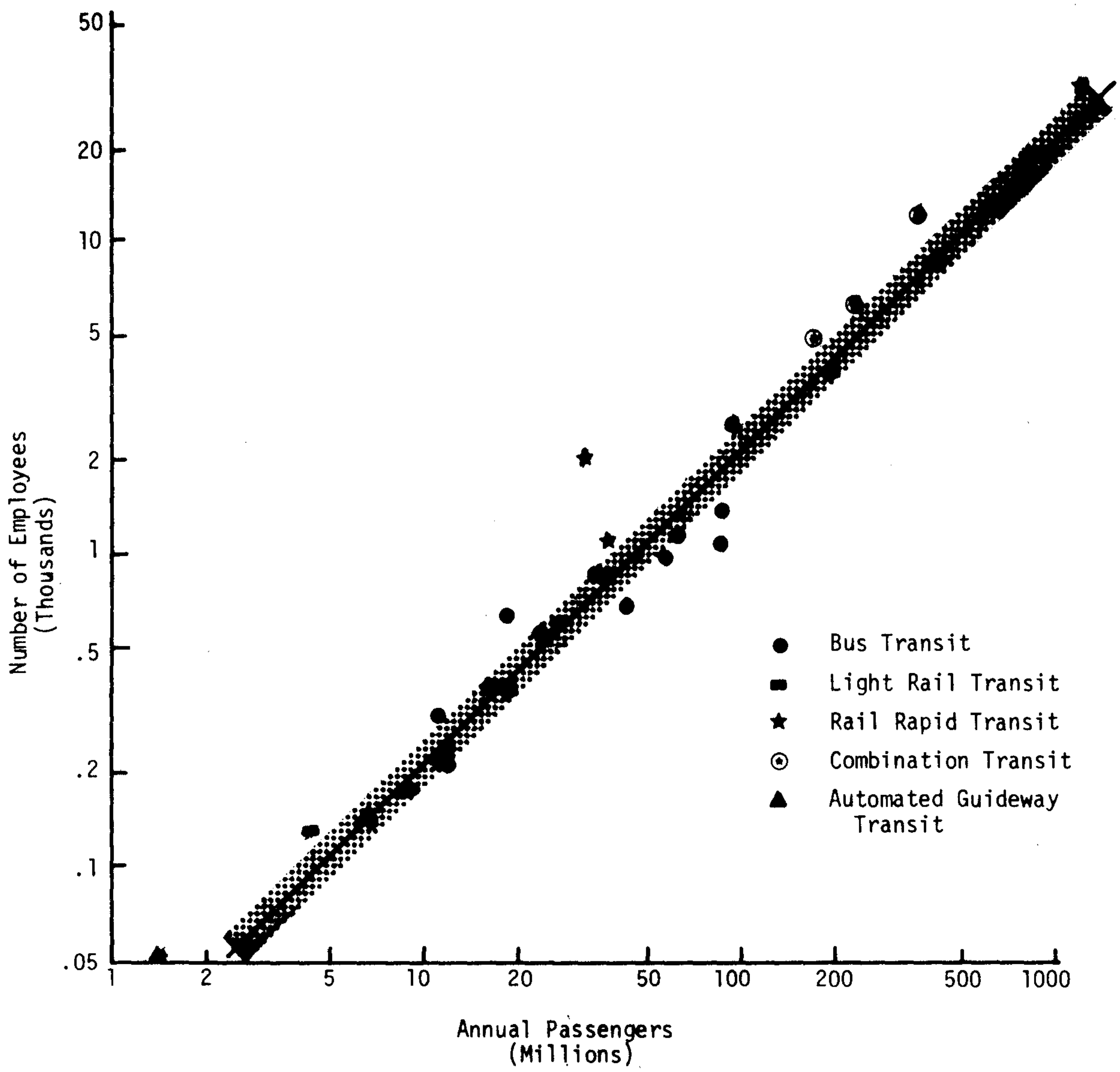

Figure II-1: Labor Intensity of Transit as a Function of Ridership

Sources: American Transit Association, 1971 Transit Operating Report; BART; University of West Virginia; and Dallas/Fort Worth Airport.

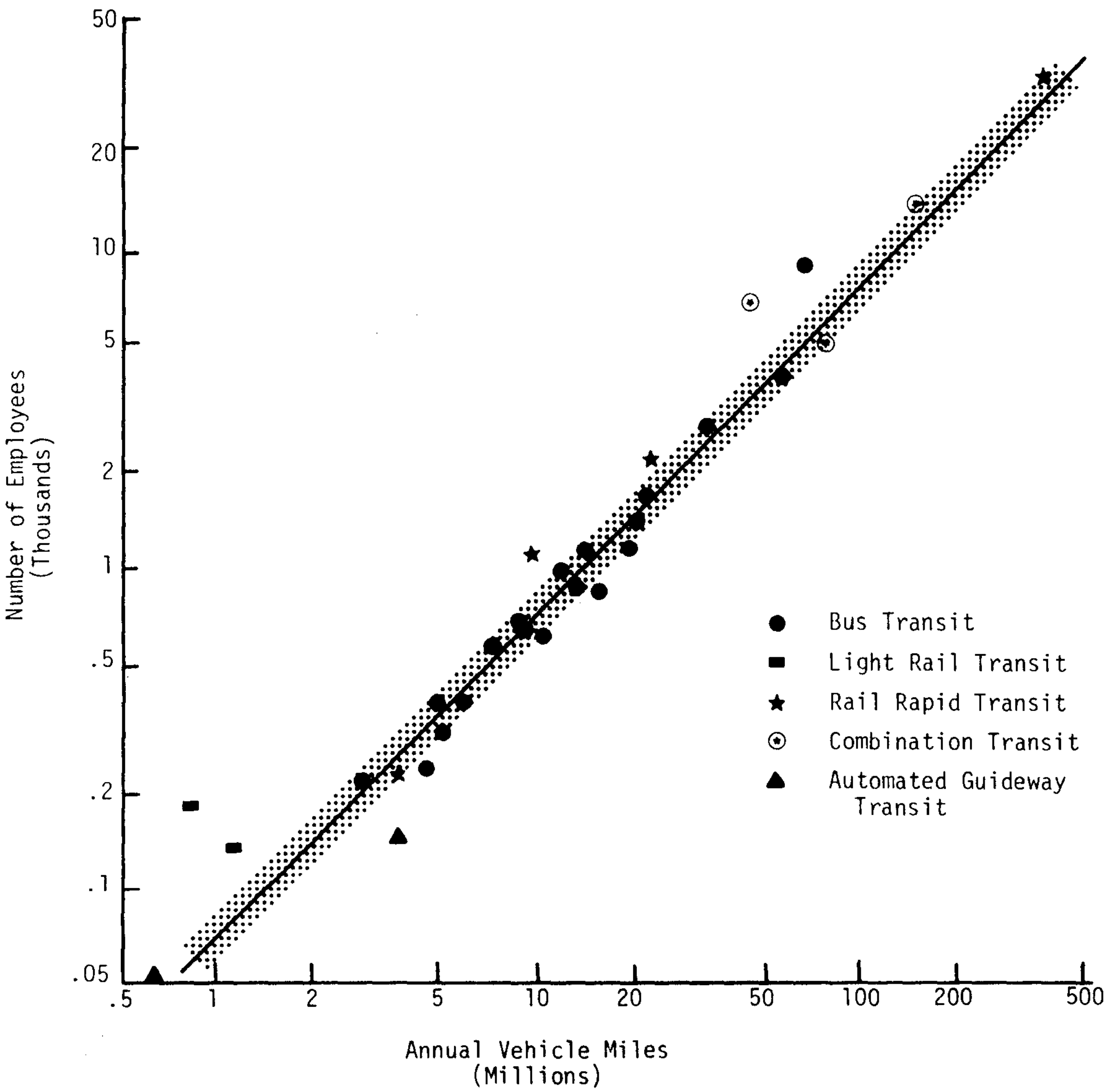

Figure II-2: Labor Intensity of Transit as a Function of Service Provided

Sources: American Transit Association, 1971 Transit Operating Report; BART; University of West Virginia; and Dallas/Fort Worth Airport.

Table II-1 compares the functions that are typically performed by the different types of transit systems included in this analysis.

A bus operation using exclusive transitways, such as that planned for the Dallas-Fort Worth area, would require some functions not performed by a conventional bus transit operation. In order to compare labor requirements of different technologies on a common basis, an analysis of representative systems for the Dallas-Fort Worth area is summarized.

Table II-1: Comparison of Functions Performed by Transit Employees

Function	Bus Transit	LRT	AGT	RRT
Vehicle Operation	X	X	X	X
Vehicle Maintenance	X	X	X	X
Management and Administration	X	X	X	X
Route and Way Maintenance		X	X	X
Station Operation and Maintenance			X	X
Security Guards				X

In The Total Transportation Plan for the North Central Texas Region for 1990, a total of 65 miles of transitways in twelve different corridors is included in addition to the proposed transitway linking the two cities and the regional airport (1). Also, on Figure 50, page 137 of that report, projected daily ridership values are presented which total 414,000. A total of 37 stations (or park-and-ride lots) are included in the plan for these twelve corridors. This system description was used as a basis for developing comparable labor intensities.

The labor intensity aspect is partially addressed by the data in Figures II-1 and II-2. As shown in Table II-1, the categories of maintain route and way, station operation and maintenance, and security, require adjustment for at least the bus transit system. Table II-2 summarized these adjustment factors.

Table II-2: Adjustment Values Used to Develop Comparable Labor Intensities

Function	Bus Transit	LRT	AGT	RRT
Maintain Route & Way	0.6 employees/ mile of transitway	*	*	*
Station Operation & Maintenance	3 employees/ station	3 employees/ station	*	*
Security	2 employees/ entrance ramp	2 employees/ station	2 employees/ station	*

*No adjustment factor is required since employees for these functions are included in the data presented in Figures II-1 and II-2.

The labor intensity relationship shown in Figure II-1 suggests that the regional system would require approximately 2250 employees. Using the adjustment factors present in Table II-2, comparable labor intensities are developed in Table II-3.

Table II-3: Comparable Labor Intensities, Total Employees

Technology	Number of Employees
RRT	2250
AGT	2324
LRT	2435
BRT*	2474

*BRT denotes Bus Rapid Transit (buses operating on busways).

The bus system would have approximately 10 percent more labor than the rail system, if all of the assumptions in this analysis are correct. However, referring back to Figures II-1 and II-2, the accuracy of the curve used to determine the initial number of employees is less than ± 10 percent. As a result, it appears appropriate to conclude that differences in labor intensity between these technologies are so small that a single relationship can be used to represent the labor intensity of all technologies. The particular relationship used for planning purposes will depend on whether projected ridership or projected service levels are considered more accurate. These relationships are as follows:

(1) 22 employees per million annual passengers,
(2) 75 employees per million annual vehicle-miles of service.

Capacity

Capacities for alternative transit technologies are difficult to define on a comparable basis. In order to compare the capacities of the various transit technologies in this study, the following conditions were assumed relevant in establishing transit capacities.

1. Capacity of a transit vehicle is equal to the number of seats available per unit of time.
2. Capacity of a transitway serving carpools is calculated for an assumed auto-occupancy ratio.
3. Operating conditions considered are based on demonstrated technical feasibility.

In addition, capacity was estimated in two manners. Since whether stations are on-line or off-line significantly influences capacity, appropriate capacity values were estimated for both of these conditions.

All of the capacity analyses performed for various technologies assumed a single lane (or track) in each direction. The capacity values calculated were for one direction of travel only. Also, the capacity values were calculated for approximately equivalent levels of service as far as speeds and seating comfort were concerned.

A comparison of the calculated capacities for the different transit technologies evaluated is presented in Table II-4. The type of system design (on-line stations versus off-line stations) that is typical for each technology is denoted by superscript numeral one, following the appropriate capacity value. To emphasize the lack of precision of these calculations, all values have been rounded off to the nearest thousand.

Table II-4: Comparison of Capacities for Single Tracks (or Lanes), (Seats Per Hour)

Technology	System Design Characteristic	
	On-line Stations	Off-line Stations
Rail Rapid Transit	29,000[1,2]	89,000[3]
Light Rail Transit	12,000[1,4]	34,000[5]
Automated Guideway Transit	10,000[6]	30,000[7]
Bus Rapid Transit	5,000[8]	39,000[1,9]
Bus/Carpool	NA	5,000-39,000[1]

[1]Denotes the typical design characteristic for each technology.

[2]40 trains/hr. x 720 seats/train = 28,800 seats/hr.

[3]123 trains/hr. x 720 seats/train = 88,560 seats/hr.

[4]based on existing operations assuming a minimum 60-second headway.

[5]176 trains/hr. x 192 seats/train = 33,792 seats/hr.

[6]60 trains/hr. x 168 seats/train = 10,080 seats/hr.

[7]180 trains/hr. x 168 seats/train = 30,240 seats/hr.

[8]120 buses/hr. x 42 seats/bus = 5,040 seats/hr.

[9]940 buses/hr. x 42 seats/bus = 39,480 seats/hr.

Energy Efficiency

Energy consumption rates used in this analysis are averages for numerous observations of typical operations within the nation. Most of the specific observations for each technology fall within a bracket of ± 20 percent of the average value used. Such a spread in specific energy consumption rates is not surprising in view of the wide range of vehicle sizes and ages as well as the variation in general traffic conditions that comprise the "average" condition.

Perhaps the largest source of disagreement in relative efficiencies calculated by various analysts concerns the conversion of kilowatt-hours to equivalent Btu's. Some analysts choose to consider the overall efficiency of the electrical power generation and distribution process when comparing electrically-powered vehicles with gasoline- or diesel-powered vehicles. Other analysts choose to ignore those losses and make the comparison on the basis of absolute energy consumed by the vehicles. A suitable compromise approach is to adjust the Btu value of gasoline and diesel fuel, in order to account for energy expended in refining and transporting the fuel; then compare the results with adjusted values for electrically-powered vehicles.

Both methods of comparison, direct conversion factors and adjusted conversions factors, were used in this analysis. The values of energy efficiencies calculated by both approaches are presented in Table II-5.

Table II-5: Energy Efficiencies of Various Urban Transit Technologies

Technology	Energy Consumption Rate	Seats Per Vehicle	Direct Conversion		Adjusted Conversion	
			Btu's Per Vehicle-Mile	Btu's Per Seat-Mile	Btu's Per Vehicle-Mile	Btu's Per Seat-Mile
Auto on Freeways	0.055 gal/mi (18.1 mpg)	5	6,875	1,375	9,790	1,958
Bus on City Streets	0.236 gal/mi (4.24 mpg)	50	32,600	652	42,244	845
Bus on Freeways	0.108 gal/mi (9.26 mpg)	50	14,900	298	19,332	387
Trolleybus	3.90 kw-hr/mi	50	13,310	266	41,730	834
Light Rail Transit	4.44 kw-hr/mi	48	15,150	316	47,508	990
Rail Rapid Transit	5.16 kw-hr/mi	55	17,610	320	55,212	1,004
Automated Guideway Transit (AIRTRANS)	3.03 kw-hr/mi	16	10,336	646	32,421	2,026

Based upon the comparative values shown in Table II-5, the energy efficiency of all transit technologies, except AGT, appears to be reasonably comparable and are decisively better than that of automobiles. The disadvantage reflected for AGT is more a factor of the number of seats per vehicle than of inherent energy requirements. Large AGT vehicles may have energy efficiencies comparable to RRT or LRT systems.

Safety

Accident records for transit systems include accidents that involve passengers only as well as those that involve vehicles. For example, the vast majority of accidents reported by rail rapid transit systems involve injuries occurring to passengers in stations rather than to passengers aboard the vehicles. Conversely, the vast majority of accidents reported by bus systems involve collisions between the buses and automobiles on city streets. Hence, comparisons of accident statistics for different transit technologies should be made only with a full realization that the types of accidents involved are totally different in nature. The data presented in Table II-6 include a breakdown of the accident rates for various types of accidents. Unfortunately, insufficient data excludes AGT systems from these comparisons.

Table II-6: Comparison of Accident Rates

Transit Technology	Traffic Accidents Per Million Vehicle-Miles	Passenger Accidents Per Million Passengers
Buses on City Street	57.5	7.7
Buses on Transitways	14.7[1]	7.7
Light Rail Transit (primarily on street)	160.3	7.1
Rail Rapid Transit	1.1	7.0 -- in stations 2.8 -- on trains

Source: American Transit Association, Comparative Operating Accident Rates, 1970-1971.

[1]Traffic Accident Rate for buses on transitway estimated by using data from Reference (8) as follows:

$$57.5 \frac{\text{bus accidents}}{\text{Mv-miles on streets}} \times \frac{\text{4.7 auto accidents/Mv-miles on freeways}}{\text{18.4 auto accidents/Mv-miles on streets}}$$

The data in Table II-5 show that RRT exhibits the lowest rate of traffic accidents but the highest rate of passenger accidents. BRT (buses on transitways), on the other hand, exhibits a reasonably good safety record on both counts. Either technology appears to be acceptable.

Reliability

Limited data are available concerning the reliability of alternative transit technologies; no such data are available for AGT. A report (9) on the state-of-the-art of light rail transit provides some data concerning the reliability of LRT, RRT, and bus transit. These data suggest that the reliability of all three of these technologies exceeds 99 percent; that is, for every 100 scheduled trips, over 99 are completed on schedule. In essence, the reliability of all these technologies is similar and high.

Combined bus/carpool operations provide an additional consideration. Current plans for the Dallas-Fort Worth area call for the construction of busways that will initially be used by both buses and carpools. Because most of these transitways will probably be elevated structures with a limited number of ingress and egress opportunities, the possible impact of stalled vehicles on overall system operation appears to be a legitimate concern.

Only two sources of data (10), (11) concerning the frequency of automobile breakdowns on urban freeways were identified. These two studies show a range of breakdown frequencies from 28 to 52 breakdowns per million vehicle miles. Using an average value of 40 breakdowns per million vehicle miles, and assuming that the "average" transitway will be five miles long, then a resulting frequency for automobile breakdowns on the transitways can be estimated at one per day during initial operation when most of the vehicles using the transitway will be carpools.

If provisions are made for stalled vehicles to get out of the traffic lane (emergency parking shoulders), the overall reliability of the system will be high. However, if these stalled vehicles must remain in the traffic lane, the resulting impact on system reliability will be tremendous. Thus, it appears that detailed consideration should be given to the methods used to handle vehicle failures on transitways used by buses and carpools.

Other Attributes

In addition to the five attributes evaluated in the preceding subsections (labor intensity, capacity, energy efficiency, safety, and reliability), numerous other attributes are important considerations in selecting a technology. Unfortunately, sufficient data are not available to make a quantitative comparison of these additional attributes; therefore, the following paragraphs discuss qualitative comparisons of additional attributes.

Overall Quality of Service - Many different factors contribute to the overall quality of service provided by a transit system. Efforts were made to hold two such factors, average service speeds and seating accommodations, reasonably constant in the comparison of capacities. Other service factors, however, vary significantly between technologies--either because of inherent design characteristics or because of normal operating practices. A subjective comparison of several other factors contributing to overall quality of service is presented in Table II-7. In this table, a value of 1 is assigned to the technology that appears to offer the best service for that factor, and a value of 5 is assigned to the poorest. No relative scale should be attached to these numbers; a ranking of 5 does not imply a quality of service only 20 percent as good as a ranking of 1, it merely implies that it is the lowest ranking of the five technologies. The assigned rankings in Table II-7 were based on observations of existing operations for the respective technologies--not theoretical capabilities.

Table II-7: Subjective Comparison of Factors Contributing to Overall Quality of Service*

Service Factor	Bus/Carpool	BRT	LRT	RRT	AGT
Headways at each location	5	4	3	1	2
Hours of Operation	5	4	3	2	1
Area Coverage	1	2	3	4	4
Minimum Transfers	1	2	3	4	4
Quality of Ride	3	4	5	1	2
Privacy & Security	1	2	4	5	2

*Note: The lowest value is best.

Public Image - Many people believe that a particular technology's public image is a very important factor in attracting new riders. Despite the fact that RRT and LRT technologies predate the motor bus, the average citizen seems to perceive them as more modern than the bus. If the image of "modern technology" is important to the success of a mass transportation system, then AGT should offer the most attractive choice since it is, in actuality, the newest technology available and could be marketed as such.

Total Costs - Probably the most important attribute to be considered in the selection of a transit technology is the total cost (capital costs and operating costs). Detailed cost studies for specific system designs would be required to compare capital costs for each technology. Labor costs are the largest component of operating costs for every transit system (ranging from 60 to 80 percent of operating costs); thus, labor intensity comparisons provide an indication of relative operating costs. However, a detailed evaluation of comparative operating costs for each technology would require an analysis of the wage scales for various job functions. Such detailed analyses are beyond the scope of this study. It is recognized, however, that relative total costs, as well as any possible differences in the availability of state or federal funds between technologies, will be primary considerations in the final selection of a mass transportation technology for the Dallas-Fort Worth area.

Labor Considerations - In addition to overall labor intensity, several other factors concerning labor are worthy of consideration. Availability of trained manpower, complexities of shift scheduling, and the ability to provide some service during a strike are all factors that are sufficiently important to influence the selection of a technology, if significant differences are found to exist between technologies.

Although each type of technology will require a different mixture of employee skills, the Dallas-Fort Worth area should have an adequate supply of all required skills. The primary differences between technologies in this regard will be the relative salaries that different skills can command in the total job market. Generally, the skills needed for the more sophisticated technologies (RRT and AGT) will command higher wages than those needed for bus operation.

All mass transportation systems experience dramatic peaks in ridership in the mornings and afternoons; however, the variation in work forces required to accommodate these peaks is significantly different. The ratio of peak-period work force to the average work force is much higher for bus systems than for the more automated technologies. The importance of this consideration will depend upon the union contract under which the system operates. If part-time employees or widely split shifts are permitted to a large extent, then bus systems can accommodate these fluctuations in work force effectively. If not, then this factor would favor the more automated systems.

In the event of a strike, transit service would be curtailed to some extent for all technologies. Very little bus service could be provided by supervisory personnel, but increased use of carpools could help to offset the reduced bus service. A larger proportion of normal service could probably be provided by supervisory personnel on the more automated systems. Thus, there appears to be little difference in the impact of strikes on the various technologies.

Fuel Availability - Relative energy efficiencies were evaluated as a separate attribute. However, the source of energy may become an important consideration in the future. If so, then the electrically-powered systems would probably be favored because of the wide variety of energy sources that can be used to generate electricity.

Emergency Operations - The ability of each technology to continue to operate under emergency or unusual conditions is also a consideration. Two such situations could be an ice storm or a power failure. Rail rapid transit would probably be least affected by an ice storm because the tremendous point-loads of steel wheel on steel rail effectively remove any ice. All rubber-tired vehicles would have greater difficulty operating during an ice storm unless the guideways were heated; however, they would probably be able to operate in conditions too severe for the average automobile. Buses would not be significantly affected by a power failure, but all electrically powered systems would be totally shut down unless an emergency power generation capability were provided.

Technology Advancement - Certainly, any dramatic advancements in technology for any of the systems evaluated (BRT, LRT, RRT, and AGT) could alter the relative attributes of these systems and stimulate a desire for a change in technology. In assessing the potential for dramatic technological advancements, the number of years of operational experience with a specific type of mass transportation is important. For instance, LRT and RRT systems have been operational since before the turn of the century. During this 75-year period, numerous technological advancements have been made; hence, the potential for some dramatic new improvements appears rather low. Similarly, buses have been used extensively in the U.S. for more than 50 years. Conversely, AGT systems have been in operation for less than five years. Certainly, the potential for dramatic technological advancement appears to be greater for AGT systems than for any other.

Potential Evolutionary Paths

It is assumed in this study that several transitways will be constructed in the Dallas-Fort Worth area by 1990 and that these facilities will be used initially by buses and carpools. Recognizing, however, that future conditions may be such that another form of mass transportation technology could become more desirable than buses and carpools, this study evaluated the feasibility and desirability of designing these transitways so that they could be modified for the transition to other mass transportation technologies.

An objective of this study is to identify logical evolutionary paths that might become desirable under various sets of probable future circumstances. Analyses of the relative capability of each technology considered for future operation (BRT, LRT, RRT, and AGT) were performed, and the results of these analyses have been presented in the preceding section. The logical evolutionary paths that might result from an effort to improve the mass transportation system's effectiveness in each of the attributes, considered individually and in various combinations, are identified in this section.

First, the logical evolutionary paths that would result if each attribute is considered independently are identified. Second, two transitway designs that will be used as a reference to compare to evolutionary design in subsequent evaluations are identified. Finally, three potential evolutionary paths are selected for further evaluation.

Attributes Considered Independently

A change in operating technology is not likely to be stimulated by a single attribute; however, a comparison of the evolutionary paths that would result if the various attributes were considered independently should prove useful in identifying probable paths that would result from various combinations of attributes. Beginning with bus/carpool operation, the evolutionary path that would result in improved values for each attribute is identified in this section.

Labor Intensity - The findings of the analysis of labor intensity lead to a conclusion that for existing operating technologies, differences in labor intensity are so small that they will not stimulate a change in technology. If labor intensity were the only factor considered, the strategy would probably be to emphasize carpools and never try to develop increased transit ridership. If the guideways were constructed and operated for the benefit of carpools only, the number of functions performed by public employees would be drastically reduced. Thus, the logical evolutionary path that would result from an independent consideration of labor intensity would be no path at all. The system would remain a bus/carpool operation.

Capacity - The analysis of capacity indicated that busways offer the highest capacity of all systems in their typical design configuration. Indeed, the only system design with a higher capacity than busways is an RRT system with off-line stations. Thus, if capacity is considered independently, the logical evolutionary path is as follows:

$$\text{Bus/carpool} \rightarrow \text{BRT} \overset{?}{\rightarrow} \text{RRT with off-line stations.}$$

The question mark is placed above the second transition because it is doubtful that a capacity greater than that provided by a busway would be needed within a single corridor in the Dallas-Fort Worth area. The second transition may not be required.

One of the primary advantages of buses over the other technologies evaluated in this study is the ability of buses to operate on existing streets as well as transitways. This attribute would be particularly attractive if it enabled a busway system to be designed that could use existing streets in the central business district (CBD) rather than requiring a system of subways under the CBD. Analyses were performed as a part of this study to determine the likely capacity constraints imposed by a CBD street system. It was found that three 4-lane streets will need to be dedicated to buses only for every two busways leading to the CBD if the streets are to handle the same capacity as the busways (4).

If the total transit capacity needed in the CBD exceeds the capacity that can be accommodated on existing streets, then some type of subway system under the CBD will be needed. This subway system, however, could be designed to serve any technology, so the CBD capacity limitation is not a major factor in selecting the technology to be used.

Energy Efficiency - The comparison of energy efficiencies reflects the energy advantages of transit over carpools; however, it does not reflect a significant difference between most transit modes if the direct conversion method of calculation is used. When the adjusted conversion method of calculation is used, buses operating on freeways or transitways are significantly more energy-efficient than other forms of transit. Thus, when energy efficiency is considered independently, the logical evolutionary path would be as follows:

Bus/carpool → BRT.

Safety - In terms of passenger accidents per million passengers, the transit technologies are generally comparable with the RRT rate being the highest. In terms of vehicular accidents per million vehicle-miles, the RRT rate is the lowest. BRT exhibits a reasonably good combination of passenger accidents and traffic accidents. Thus, it is difficult to select an optimal path. A logical evolutionary path based on safety considerations could lead to either BRT or RRT as shown below:

Bus/carpool → BRT or → RRT

Reliability - Analyses of reliability indicate that the reliability of individual transit vehicles is essentially the same for bus, LRT, and RRT. However, overall system reliability depends upon more than the reliability of individual vehicles. Probably the most significant conclusion that can be supported by the results of these analyses is that the system design should include a provision for continued operation in the event of a stalled vehicle. Thus, any one of three evolutionary paths would appear to be logical if only reliability is considered. They are as follows:

BRT
↗ or
Bus/carpool → LRT
↘ or
RRT.

Overall Quality of Service - of the six factors included in the comparison of overall quality of service, three "best" rankings went to bus/carpool, two to RRT, and one to AGT. Also, it should be noted that AGT ranked second best in three factors. Thus, if overall quality of service is considered independently, the following two evolutionary paths appear logical:

↗ RRT
Bus/carpool or
↘ AGT.

Public Image - If the apparent desire of the public for a "modern" transit system is considered independently, then the logical evolutionary path might be as follows:

Bus/carpool → AGT.

Land-Use Influences - The logical evolutionary path that would stem from an independent consideration of land-use influences would vary with the type of urban form desired. If the existing low density urban form of the Dallas-Fort Worth area is considered desirable, then the logical evolutionary path would be:

Bus/carpool → BRT.

If, however, it is deemed desirable to use the transit system to stimulate higher density development, then the logical evolutionary path would probably be:

$$\text{BRT} \rightarrow \text{RRT.}$$

In this case, carpools probably would not be permitted to use the guideways even in the initial phase.

Total Costs - Although total costs will probably be the most important single consideration, detailed comparative analyses of this factor are beyond the scope of this study. Therefore, no logical evolutionary path can be developed for this consideration.

Labor Considerations - Buses appear to be the preferred technology when considering labor costs. An AGT system would probably have the smallest ratio of peak-period work force to average work force. Either AGT or carpools appear to offer the highest potential service during a strike. Thus, when these three factors are combined, two potential evolutionary paths appear logical. They are as follows:

Bus/carpool → BRT
or
Bus/carpool → AGT.

Fuel Availability - In the event that petroleum fuels become scarce, the first major conservation effort would probably be a rationing of gasoline and a priority allotment of diesel fuel to buses. However, as the scarcity intensifies, it would become highly desirable to use a mass transportation technology that is powered by energy sources other than petroleum. Thus, the evolutionary paths that appear logical when considering fuel availability independently are as follows:

Bus/carpool → BRT → LRT
or
Bus/carpool → BRT → RRT
or
Bus/carpool → BRT → AGT.

Emergency Operations - Buses would be best able to continue operation during a power failure while RRT trains could best cope with ice storms. Hence, two logical evolutionary paths stem from this consideration:

Bus/carpool → BRT or → RRT.

Technology Advancement - The potential for dramatic technology advancements appears greater for AGT than for any other mode. Hence, the logical evolutionary path for this consideration is:

Bus/carpool → AGT.

Comments Concerning Paths - In reviewing the logical evolutionary paths that stem from independent consideration of the various attributes, several interesting observations result. These observations are as follows.

- No path involves more than three phases of operation, and bus is the interim technology in the two paths involving three phases.
- Bus/carpool is the preferred technology in one path.
- BRT is the ultimate technology in six paths.
- AGT is the ultimate technology in five paths.
- RRT is the ultimate technology in six paths, but one of those paths involves a system design with off-line stations in order to achieve a capacity that probably will not be needed.
- LRT is the ultimate technology in only two paths, and in each case LRT is just one of three possible paths with equal attractiveness.

The primary purpose for the analysis of attribute values for various technologies was to enable the identification of a limited number of probable evolutionary paths for further study. The results of these analyses form the basis for the selection of the reference designs and evolutionary paths identified in the following sections of this report.

Reference Designs

The results of the analysis of attributes indicate a strong possibility that sufficient stimuli may never develop to justify a transition from buses to any other form of mass transportation technology. Also, in order to evaluate the desirability of constructing an evolutionary design, the costs of such a design must be compared to the costs of constructing a system designed for buses only or buses and carpools, without regard to future transitions. Hence, a reference design is needed for comparative purposes.

If a transitway were designed to serve buses only, it would probably be only wide enough for two traffic lanes. Buses could continue to operate safely around a stalled vehicle by passing it in the lane for oncoming traffic, because they would have radio communication with each other; all drivers involved would be professional drivers, and the average flow rate would probably be less than 500 vehicles per hour in each direction.

If carpools were allowed to share such a facility with buses, the problems associated with stalled vehicles would be more severe. Flow rates in the primary direction would be as high as 1400 vehicles per hour; few of the drivers would be professionals, and reliable radio communication might not be available. Although the frequency of stalled vehicles might be about the same in either case, the problems appear greater for bus/carpool operations than for bus-only operations.

In view of these considerations, two different reference designs appear desirable for further study. One should be developed to serve buses only. The second should be designed to adequately accommodate both buses and carpools. Consequently, the two reference designs selected for further study are:

Reference Design #1: Narrow Guideway for BRT, and
Reference Design #2: Wide Guideway for Buses and Carpools.

These designs will serve as a basis for evaluating the designs used for each evolutionary path.

Selected Evolutionary Paths

Based upon the results of the analyses of attributes, three potential evolutionary paths were selected for further study. The following paragraphs describe the rationale for selecting each evolutionary path and identify the major concerns for further study.

Evolutionary Path #1 - Bus/carpool operation appears to be the type of operation that is best suited to the Dallas-Fort Worth area under present conditions. Furthermore, it appears that several conditions would have to change before a transition from buses to any other form of mass transportation would be justified. The changes that are considered most probable are the following:

1. Significant technological advancements in AGT,
2. Increased scarcity of petroleum, and/or
3. Increased concern over labor costs and labor problems.

Under this scenario, Evolutionary Path #1 is:

Bus/carpool → BRT → AGT with off-line stations

Evolutionary Path #2 - In the event that significant technological advancements in AGT do not occur, and if fuel availability and land-use influences become major concerns, then a logical Evolutionary Path #2 would be:

Bus/carpool → BRT → RRT with on-line stations.

Evolutionary Path #3 - If energy concerns become critical before the transitway system is developed, then serious consideration might be given to eliminating carpools from the guideway altogether. Furthermore, intense concern over energy matters could also enhance the desirability of higher density urban developments. Hence, the final evolutionary path selected to be evaluated in further studies is as follows:

BRT → RRT with on-line stations.

This path also more nearly resembles the path that is most often discussed in other studies on evolutionary designs.

Conclusion

This section of the report documents the results of analyses of various operational attributes of available mass transportation technologies. The results of these analyses formed the basis for selecting the following transitway designs for further study:

- Reference Design #1: Narrow Guideway, BRT,
- Reference Design #2: Wide Guideway for Buses and Carpools,
- Evolutionary Path #1: Bus/carpool → BRT → AGT with off-line stations,
- Evolutionary Path #2: Bus/carpool → BRT → RRT with on-line stations, and
- Evolutionary Path #3: BRT → RRT with on-line stations.

Subsequent sections of this study present the results of further evaluations of these five alternative designs.

III. CONCEPTUAL DESIGN OF EVOLUTIONARY SYSTEMS

DESIGN OBJECTIVES

SYSTEM DESIGN PARAMETERS

COMPONENT IDENTIFICATION AND ANALYSIS

DESCRIPTION OF CONCEPTUAL DESIGNS

WIDE TRANSITWAY DESIGN IN PERSPECTIVE

SPECIFIC TRANSITION PROBLEMS

TECHNICAL FEASIBILITY

Design Objectives

At the beginning of this study, it was generally agreed that it would be technically possible to design a guideway that could accommodate various operational technologies. However, the benefits of building a universal guideway design would be limited if all use of the transitway had to be discontinued for a period of 3 to 5 years while it was being converted to another mode. Thus, the primary questions that this design study is intended to answer are:

1. Can a transitway design be developed that will accommodate continuous operation of buses while the transition is being made to another mode?
2. If such a design is possible, will it be so complicated and expensive that it is impractical?

The objectives of this design study were to identify the major problems that would occur in the transition phase and to develop possible design solutions for these problems. Finally, all of these features were combined into the conceptual designs that are described in this section of the report.

In reviewing these conceptual designs, the reader should bear in mind that the total focus of this study is to evaluate the feasibility and desirability of designing transit systems that can evolve from one form of mass transportation technology to other forms. In developing these conceptual designs, every effort was made to assure that adequate provisions for essential components of each technology were included. No effort was made, however, to define design details that do not have a direct impact on the evolutionary process. Hence, the products of these efforts are referred to as "conceptual designs" rather than "preliminary designs."

The conceptual designs described in this section are not intended to represent the ultimate or optimum design for any particular set of conditions. Rather, they represent a reasonable design approach that is suitable for the purposes of this study. Hopefully, they will serve to identify numerous design considerations that must be addressed if a truly evolutionary system is to be designed. Certainly, more extensive study and design work will be required to transform these conceptual designs into usable system designs.

System Design Parameters

The Total Transportation Plan for the North Central Texas Region for 1990 (1) serves as the basis for this study. This plan calls for a total system of 65 miles of transitways radiating outward from the two central business districts (CBD's) as shown in Figure III-1. Approximately two-thirds of this mileage will be in the Dallas system, and the remaining mileage will be in Fort Worth. Thus, there will actually be two separate systems.

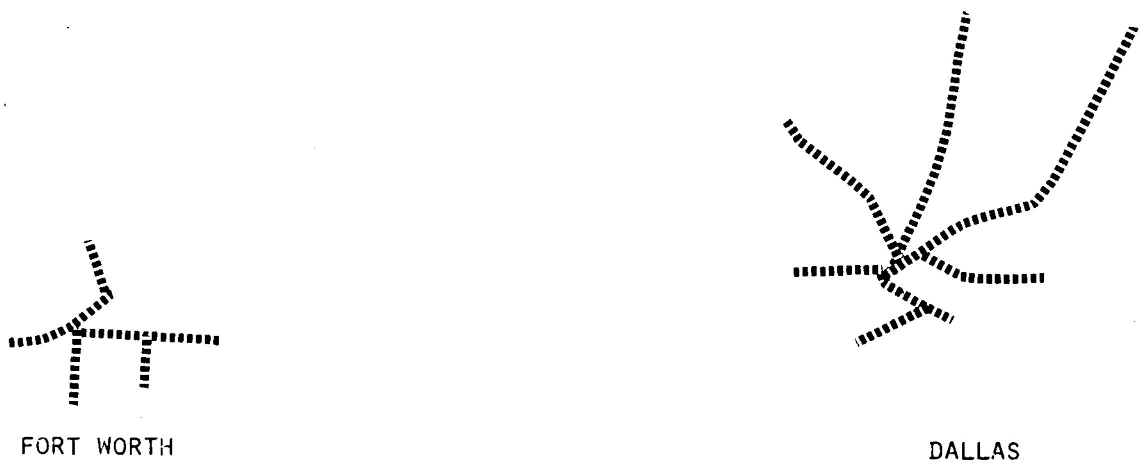

Figure III-1: Proposed Transitway System

The 1990 plan does not identify specific locations for the proposed transitways; however, most of the designated corridors generally parallel existing railroad tracks. It is expected that portions of these routes will be located adjacent to the railroad tracks so that they can be constructed at-grade.

For the purposes of this study, it is assumed that the ultimate system will include 65 miles of transitway and 37 stations distributed as follows:

- 5 miles of subway in the two CBD's,
- 7 subway stations in the two CBD's,
- 30 miles of elevated guideway,
- 30 miles of at-grade guideway, and
- 30 stations outside of the CBD's.

It is further assumed that the initial system will not include the subway segments within the two CBD's. The initial system will include 60 miles of busways (and 30 stations) leading to the edges of the CBD's. The buses will operate on existing streets within the CBD's. Then, at the time that a transition from buses to some other technology occurs, the subway portion will be designed to accommodate that technology. Thus, this study does not address the problems of evolutionary designs for subway sections.

Component Identification and Analysis

Certainly, the development of detailed designs for each component is beyond the scope of this study; however, a recognition of the need to include provisions for specific components is essential to the development of suitable conceptual designs. Thus, an effort is made to identify those components that are critical to this study.

Station Considerations and Components

Although the primary function of a station is to enable passengers to board and depart transit vehicles, several other functions are also logically located at stations. Also, several considerations influence the design of a station. These are identified in the five following subtopics.

Configuration - The function and configuration of a station varies with its location along the transitway as follows:

- Terminal Station (at end of transitway),
- Intermediate Station (along a transitway), and
- Transfer Station (at intersection of two transitways).

Transfer stations are not considered as a part of this study because the only locations shown in the 1990 plan where transitways intersect are within a CBD. It is assumed that the CBD portions of the transitway will not be constructed until a transition from buses to another technology is made; the transfer stations can be designed at that time. Typical examples of both terminal stations and intermediate stations should be considered for each design approach.

Stations can be elevated, at-grade, or subway. Again, the only subway stations planned are located within the CBD's so they are not considered as a part of this study. Typical examples of both elevated and at-grade stations should be considered for each design approach.

Systems can be designed using either on-line stations or off-line stations for each technology. However, for the purposes of this study, all bus and AGT designs will use off-line stations and RRT designs will use on-line stations.

Passenger Facilities - It is assumed that all stations, regardless of mode, will include a park-and-ride lot. It is also assumed that certain amenities (benches, telephone, litter bins, and possibly vending machines and restrooms) will be considered for all stations. However, the need for fare collection systems (turnstiles, ticket machines, change machines, etc.) and dual level structures (to reach loading platforms) will depend upon the mode.

Control and Communications Facilities - Adequate provisions should be made for equipment required to control AGT and RRT vehicles on that section of guideway assigned to the station control unit. The station control unit also must be tied into the communication network serving the guideway and the central control.

Power System Facilities - It is assumed that power substations required for AGT and RRT systems will be housed in the stations whenever feasible. All stations should also include adequate equipment room space for the machinery needed to operate the station.

Transit Vehicle Facilities - Platform lengths, switching requirements, and safety measures will vary, depending upon the transit mode using the station. It is assumed that RRT platforms will serve 10-car trains (750 ft. long), AGT platforms will serve 4-car trains (165 ft. long), and that buses will load at a transit shelter in the park-and-ride lot.

Guideway Considerations and Components

Those guideway considerations and components that are deemed critical to this study are identified in the following five subtopics.

Structural Configuration - The following factors will vary according to the transit mode in use:

- Guideway width (shoulders are required for bus/carpool operation),
- Structural load (bending moments on RRT system are approximately double those for buses and AGT), and
- Roadway deck configuration.

Also, buses and carpools require ramps for entry to and exit from the guideway. A maximum guideway grade of 4 percent and a minimum radius of curvature of 400 feet will be used for all designs.

Power Distribution - The guideway design must include provisions for power conduits and conductors as needed for the various transit technologies.

Controls and Communications - The amount of control and communication equipment needed will vary, depending upon the transit mode in use. However, considerations should be given to the need for each of the following items:

- Control cable conduits,
- Control and communications rails,
- Vehicle presence detectors,
- Control block system, and
- Miscellaneous hardware.

Vehicle Guidance System - All guideway input/output elements required in guiding the transit vehicles will fall under this category. This includes a guidance reference system and switching systems. Provisions must be made in the guideway design to accommodate the elements required for each mode that will be used.

Maintenance and Emergency Systems - Some provisions should be made to accommodate routine maintenance operations and for emergency situations. The following factors should be considered in this category:

- Maintenance/emergency walkways,
- Guideway lighting,
- Safety barriers, and
- Provisions for passing stalled vehicles.

Vehicle Considerations

Those vehicle considerations deemed critical to the transitway design are identified in the following four subtopics.

Size and Configuration - The following vehicle design characteristics influence the transitway system design and should be identified:

- Vehicle height, width, length, and weight,
- Number and location of doors, and
- Maximum number of vehicles per train.

Performance Capabilities - The geometric design of the transitway system must be compatible with the performance capabilities of all vehicles that will use it. The following items are deemed critical to the overall design:

- Maximum grade at operating speeds,
- Maximum grades for entry and exit speeds, and
- Turning radii versus speed.

Power and Steering Systems - RRT and AGT vehicles receive their power and steering from the guideway. All special requirements for vehicle power and steering systems inherent in each transitway design approach should be identified.

Special Components - All special components assumed to be available on each type of vehicle should be identified.

Description of Conceptual Designs

The following system designs were identified previously for evaluation.

- Reference Design #1: Narrow Guideway for BRT
- Reference Design #2: Wide Guideway for Buses and Carpools
- Evolutionary Path #1: Wide Guideway, Buses/Carpools → BRT → AGT
- Evolutionary Path #2: Wide Guideway, Buses/Carpools → BRT → RRT
- Evolutionary Path #3: Narrow Guideway, BRT → RRT

Conceptual designs developed for each of these systems are described in the following pages through sketches and narrative descriptions.

Again, it should be stressed that the total focus of this study is to evaluate the feasibility and desirability of designing transitways that can evolve from one form of mass transportation technology to other forms. In developing these design approaches, every effort was made to ensure that adequate provisions for essential components of each mode and all necessary operational features were included. No effort was made, however, to define design details that do not have a direct impact on the evolutionary process.

For example, the detailed design for column footing on elevated structures and for roadbeds on at-grade segments must be keyed to the soil conditions at various locations along the route. Consideration of these structural design features were not deemed essential to this study. Also, because the most constrained situation for guideway geometrics will be on elevated portions, all guideway cross-sections are shown for elevated portions.

Various structural configurations have been used for elevated guideways. Prefabricated concrete I-beams, steel I-beams, rectangular concrete beams poured in place, concrete box girders poured in place, and steel box girders have all been used in the various structural designs reviewed for this study. The prefabricated concrete I-beam design approach was selected for use in this study because specific examples of existing structures were identified to serve as a pattern for each transitway design. It should be noted; however, that more esthetically pleasing designs can be achieved using concrete box girders.

Reference Design #1: Narrow Guideway for BRT

The narrow guideway for BRT consists of a two-lane roadway without shoulders. A typical cross section of an elevated portion of the guideway is shown in Figure III-2. Each bus lane is 12 feet wide. Additional width is required to provide for a double yellow stripe down the center and parapets on each side; consequently, the total width of the guideway is 28 feet. The overall structural design is typical of that used by the State Department of Highways and Public Transportation for ramps at freeway interchanges in Texas (12).

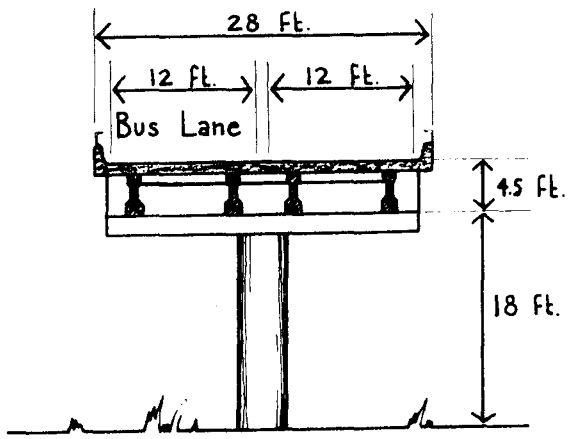

Figure III-2: Cross Section of Elevated Structure, Narrow Guideway for Buses Only

A site plan for a typical station along the transitway is shown in Figure III-3. The "station" in this instance would be a park-and-ride lot with a sheltered loading area. This design approach will permit a bus to exit the transitway from either direction and stop at the station. The bus would then return to the guideway in either direction of flow. The tie-in of ramps with surface streets would also enable buses serving local neighborhoods to enter or exit the transitway at any station. Of course, this design philosophy assumes that most of the buses on the guideway will continue past the station without exiting the guideway.

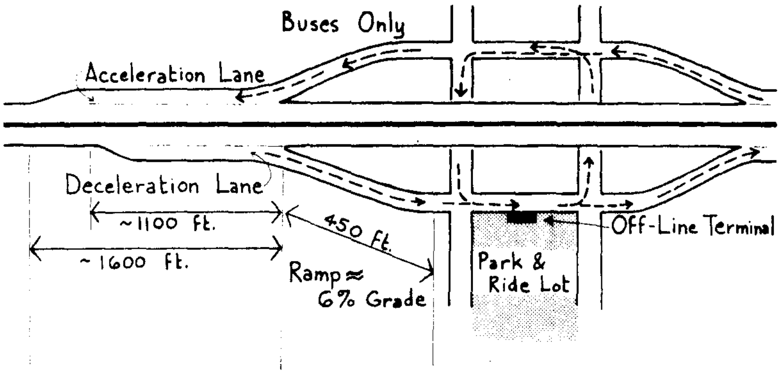

Figure III-3: Typical Site Plan at Station, Narrow Guideway for Buses Only

Acceleration and deceleration lanes are added to the basic width of the guideway at each ramp location. The length of these lanes was determined using performance specifications for the Transbus (13). Sufficient length is provided for a bus to accelerate from 30 mph to 50 mph and then merge with traffic from the acceleration lane. This length exceeds the length listed in the AASHTO "Redbook" (14) for automobiles, because even the Transbus will not have acceleration capabilities equal to the average automobile. Conversely, the deceleration lane is long enough to permit a bus to enter it at 50 mph and decelerate to 30 mph before the ramp is reached.

A maximum grade of 6 percent is considered desirable for bus operation. Thus, a minimum of 450 feet will be required for ramps to descend from the transitway level to the street level--normally a 21-foot difference in elevation.

Operational characteristics for the narrow transitway are depicted in Figures III-3 and III-4. Figure III-3 represents a typical design near a station where the guideway is elevated. Figure III-4 shows a possible ramp configuration for use along at-grade sections of guideway. Those buses not scheduled to stop at the station will continue on the transitway. Because the ramps connect with surface streets, some protective devices or police enforcement may be required to prevent automobiles from entering the ramp.

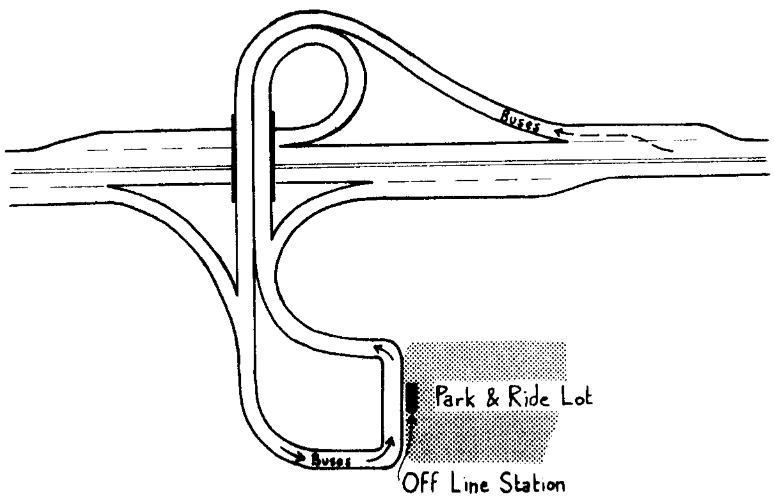

Figure III-4: Operational Plan, Narrow Guideway for Buses Only, At-Grade Portion

Another design feature that might cause some concern is that the narrow transitway does not provide shoulders for stalled vehicles or walkways for passengers to exit a bus in an emergency. Assuming that all buses will be in constant two-way radio communication, emergencies can probably be accommodated in a safe, efficient manner. However, these concerns are the primary reasons that it is considered undesirable for carpools to share a narrow guideway with buses.

Reference Design #2: Wide Guideway for Buses and Carpools

The data presented in Section II of this report concerning the frequency of stalled vehicles on freeways indicate that, unless some provision is made for stalled vehicles, the transitway could be blocked on an average of once per day by stalled cars. Such an eventuality would produce an unacceptably low level of reliability for the total system. Thus, it was decided that all designs considered in this study that are intended to serve carpools as well as buses would provide accommodations for stalled vehicles.

Once the decision was made to provide accommodations for stalled vehicles, then an evaluation of the appropriate type of accommodation was conducted. The three design approaches that were considered are summarized below:

- 2-lane roadway operated as a one-way transitway (inbound in morning and outbound in afternoon),
- 3-lane roadway with the center lane being reversible so that the peak direction of flow would have an emergency shoulder, and
- 2-lanes + 2-shoulders -- so that both directions of flow would have an emergency parking shoulder.

An evaluation of the operational and safety aspects of each of the design approaches led to the selection of the 2-lane plus 2-shoulder design. This design approach operates the same in morning and afternoons, it provides for the return flow of buses, and, if it is widened slightly more, a median barrier can be included to separate opposing directions of flow.

The wide guideway design for buses and carpools selected for this study consists of two 12-foot travel lanes with continuous 10-foot shoulders on either side. The typical elevated cross-section shown in Figure III-5 reflects a total width of 50 feet, including space for a concrete median barrier in the center and parapets on either edge.

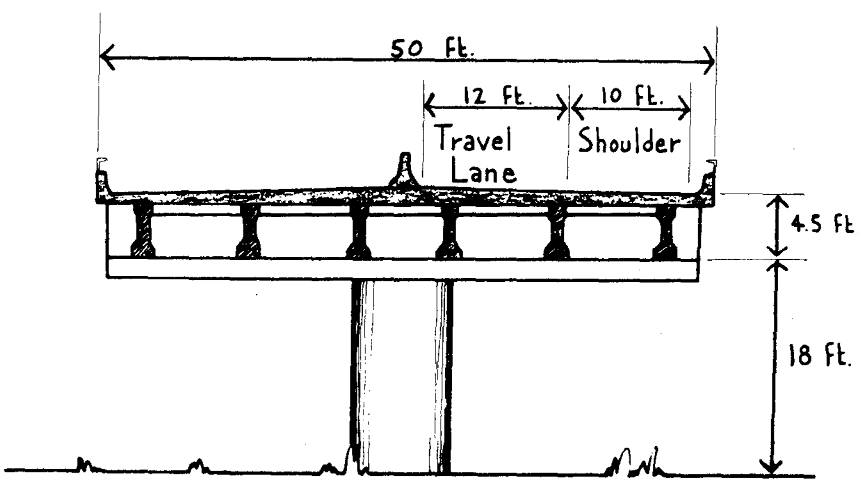

Figure III-5: Typical Elevated Cross-Section, Wide Guideway for Buses and Carpools

A concrete median barrier is shown for this design although there is some disagreement among the study team as to whether one should be constructed. A barrier would prevent possible head-on collisions on the guideway, but it would also restrict the flexibility of operation. However, in view of the fact that median barrier designs are now available that can be placed on a roadway without having to be structurally tied to the deck, the study team chose to make the structure wide enough to accommodate a barrier even though one may not be installed.

A typical site plan for an intermediate station along an elevated section of wide guideway is shown in Figure III-6. The overall layout is very similar to that used for the narrow guideway. The shoulders will be used as acceleration and deceleration lanes, but the width of the guideway will be held constant. The continuous shoulders will accommodate stalled vehicles, and the shoulders can be used as emergency walkways for the occupants of stalled vehicles to exit the guideway. Along sections where the guideway is at grade, the ramp configuration would have to be modified to permit vehicles on the lane opposite the station to reach the station without crossing a lane of guideway (see Figure III-4, page III-11, as an example).

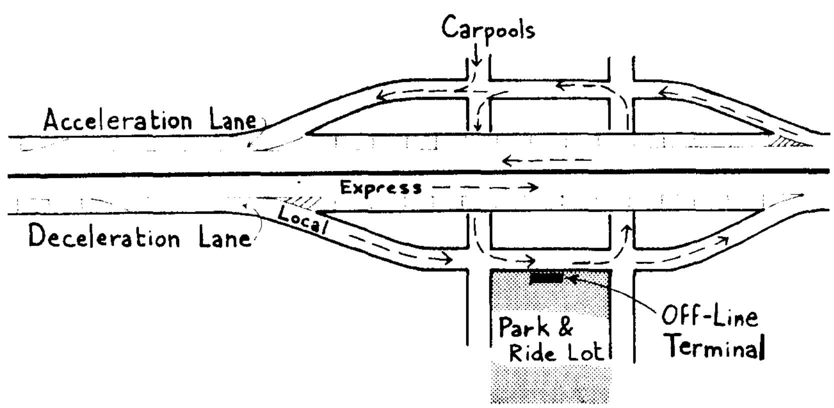

Figure III-6: Typical Site Plan at Station, Wide Guideway for Buses and Carpools, Elevated Guideway

If there is little expectation that a guideway might be extended further, operations at the terminal station can be simplified by a station design similar to the one shown in Figure III-7. If it were deemed likely that the guideway would be extended further in the future, the terminal station layout would be similar to Figure III-6 with only two ramps and the through lanes stubbed off.

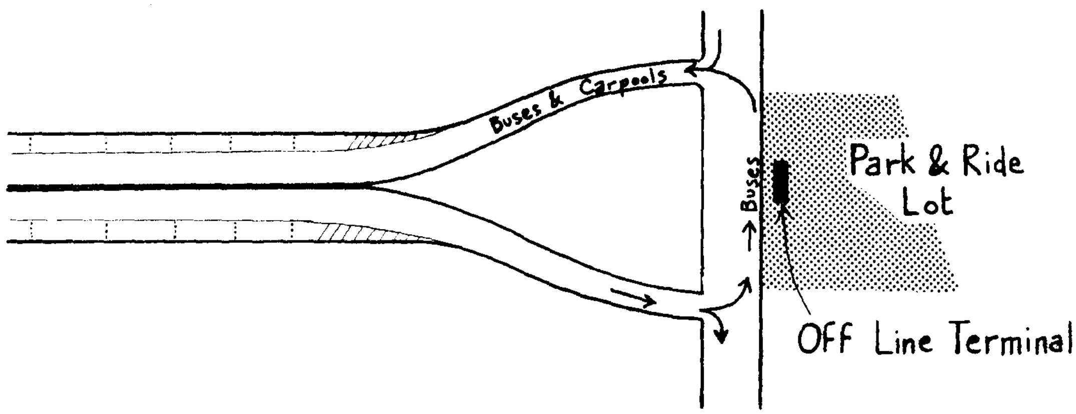

Figure III-7: Typical Site Plan for Terminal Station, Wide Guideway for Buses and Carpools

Operation of the wide guideway will be similar to that of the narrow guideway, except that carpools will be permitted to use it as well as buses. Buses and carpools will be able to enter or exit the guideway at each station (park-and-ride lot). Those vehicles not desiring to leave the guideway can continue straight through. In essence, the wide guideway will be a two-lane freeway for use by high-occupancy vehicles.

Evolutionary Path #1:
Buses and Carpools → BRT → Automated Guideway Transit

Evolutionary Path #1 utilizes a wide guideway in evolving through three types of operation. Initially, buses and carpools will share the guideway. Then carpools will be eliminated and buses will continue to use the guideway. During the transition to Automated Guideway Transit operation, buses can continue to use the shoulder portion of the guideway. Finally, the guideway will be dedicated entirely to AGT.

No significant changes in the guideway design are required to accommodate the eventual transition to AGT. As shown in Figure III-8, concrete guidewalls will be installed on the existing roadway deck when the transition is to take place. All power rails, signal controls, and guidance mechanisms can be mounted on the guidewalls. If a concrete median barrier is used during bus/carpool operation, it can be designed to accommodate power and control rails at a later date.

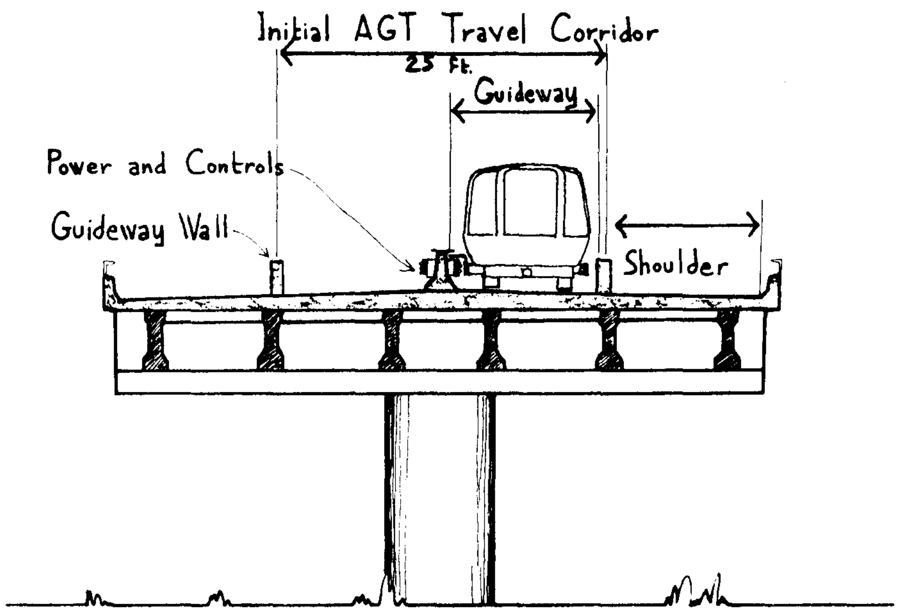

Figure III-8: Cross-section of Guideway, Evolutionary Path #1

Stations for the AGT will be constructed around the guideway adjacent to park-and-ride lots. During the initial construction phase, buses will continue to operate on shoulders as depicted in Figure III-9 (elevated guideway) and Figure III-10 (at-grade guideway). As the conversion process is nearing completion, all buses will have to exit on the ramps at each station because the shoulder portion in the AGT station will serve as the off-line bay for the AGT (see Figure III-11). Finally, after the AGT is in full operation, the bus ramps may be removed (see Figure III-12 for intermediate station and Figure III-13 for terminal station).

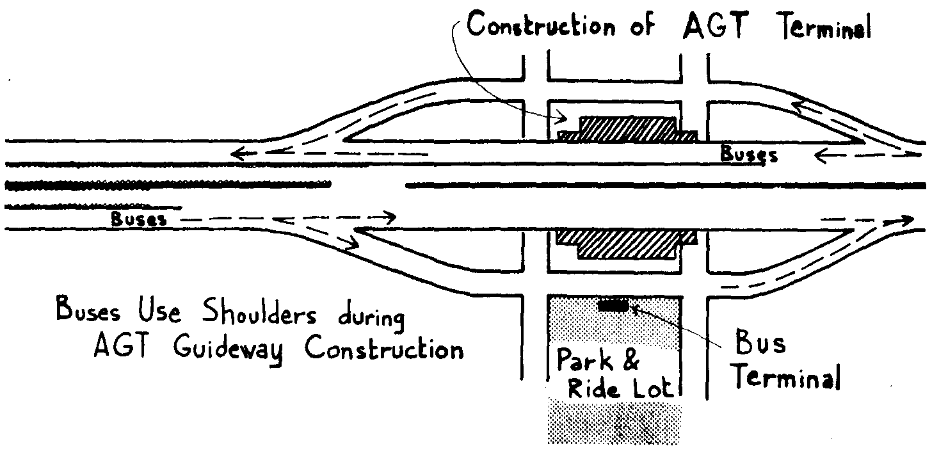

Figure III-9: Initial Construction Phase for Transition to AGT at Station on Elevated Portions, Evolutionary Path #1

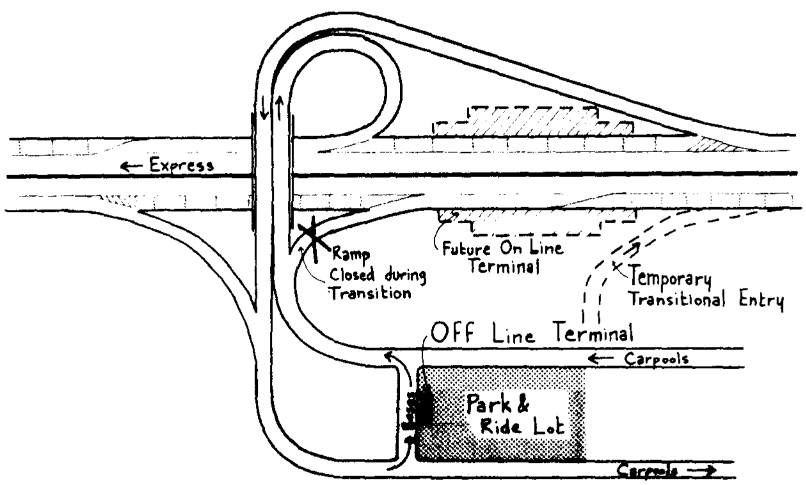

Figure III-10: Initial Transition to AGT at Station on At-Grade Guideway, Evolutionary Path #1

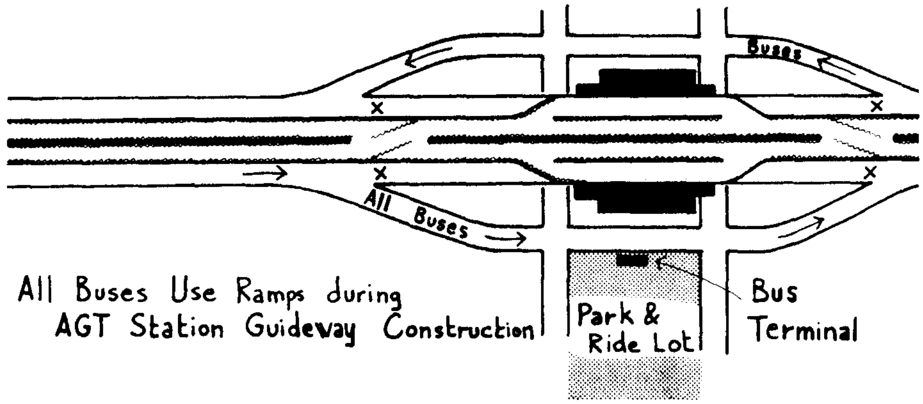

Figure III-11: Final Construction Phase for Transition to AGT, Evolutionary Path #1

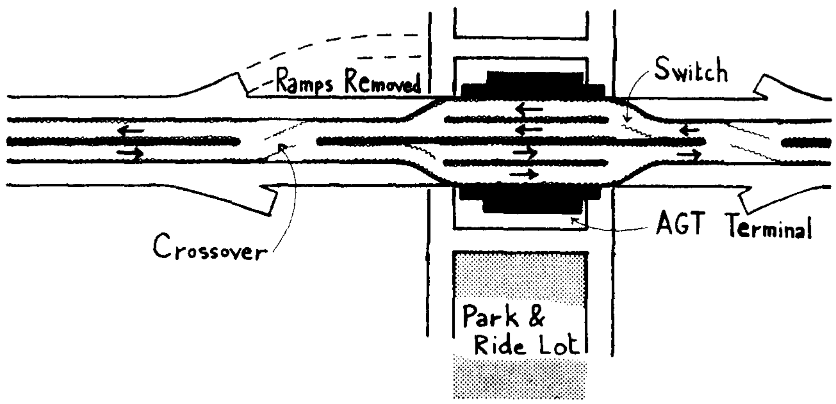

Figure III-12: AGT Operation on Guideway, Evolutionary Path #1

The resulting guideway design fully accommodates AGT operation. The shoulders remaining alongside the AGT lane can serve as maintenance platforms and emergency walkways. Hence, they will continue to provide benefits after the final transition is made. Also, the shoulders provide an opportunity for further development of the system.

The total capacity for AGT operation, as depicted in Figure III-12, is 21,000 seats/hour in each direction. Should this capacity prove insufficient at some future date, the guideway can be modified to accommodate dual tracks

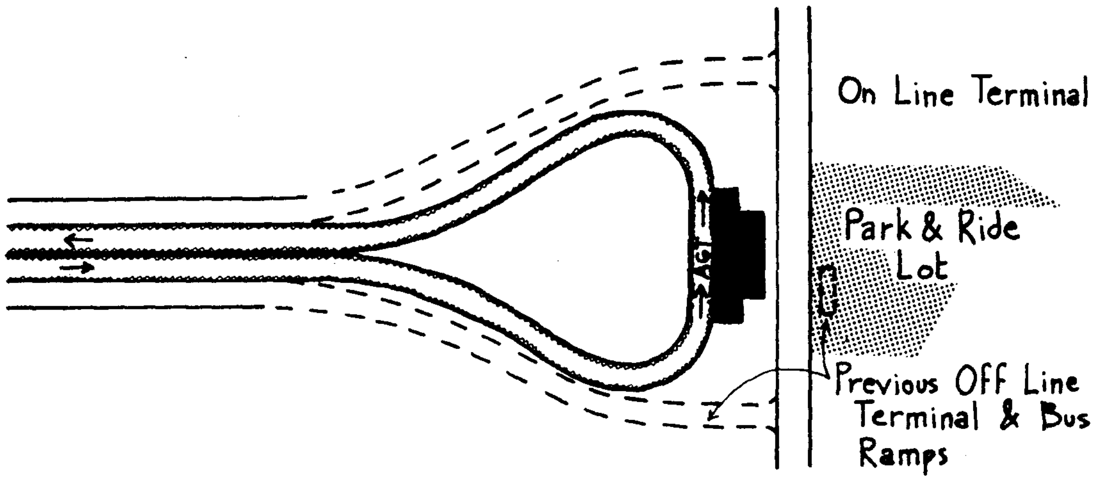

Figure III-13: AGT Operation at Terminal Station, Evolutionary Path #1

in each direction to double the capacity. Design sketches depicting how this ultimate dual track operation can be accommodated are shown in Figures III-14 and III-15. Additional guideways will be constructed at each station, but the total construction process can be completed while the AGT continues to operate on the inside track.

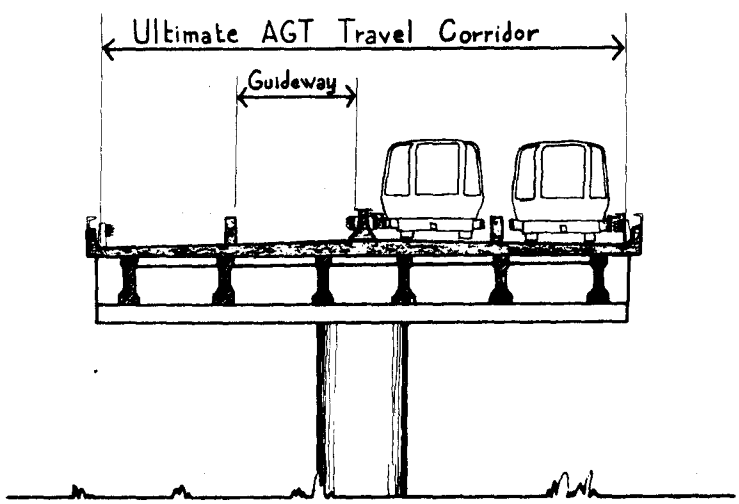

Figure III-14: Dual-Track AGT Operation, Evolutionary Path #1

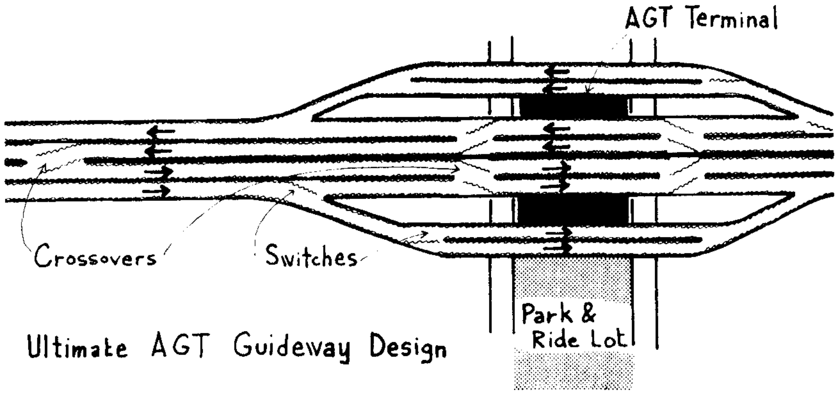

Figure III-15: Station Operation for Dual-Track AGT, Evolutionary Path #1

Evolutionary Path #2:
Buses and Carpools → BRT → Rail Rapid Transit

In order to accommodate Evolutionary Path #2, the structural design of the guideway must be modified significantly from that shown for Reference Design #2 (compare Figure III-16 with Figure III-5). However, once the heavier guideway is constructed, it will operate just as envisioned for Reference Design #2 during its initial phase serving buses and carpools (see Figure III-17). Then carpools will be banned and the facility will serve buses only. Buses will continue to operate on the shoulders of the guideways during track construction for RRT (see Figure III-18).

RRT stations can be constructed around the guideway adjacent to each park-and-ride lot. During initial construction, buses would continue to operate on the guideway shoulders as depicted in Figure III-19. Ultimately, the shoulder portion of the guideway near the stations will be used for the RRT loading platforms as shown in Figure III-20; thus, during the latter stages of conversion, all buses will have to exit the guideway at each ramp.

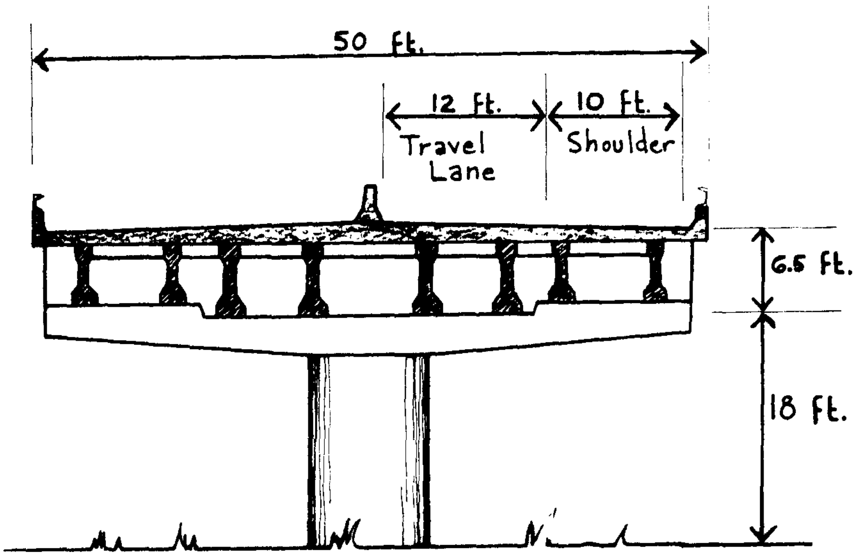

Figure III-16: Wide Guideway Designed to Accommodate RRT, Evolutionary Path #2

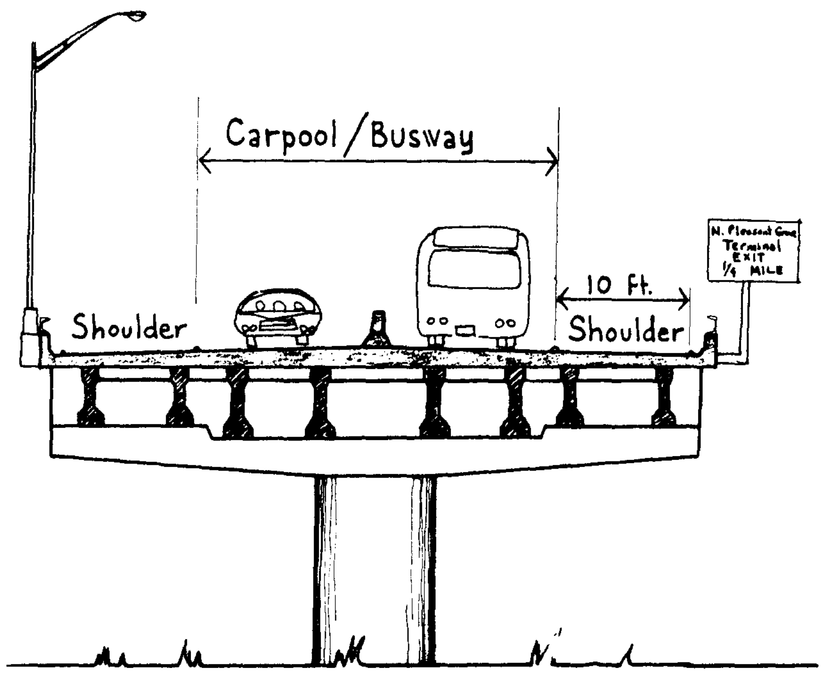

Figure III-17: Operation with Buses and Carpools, Evolutionary Path #2

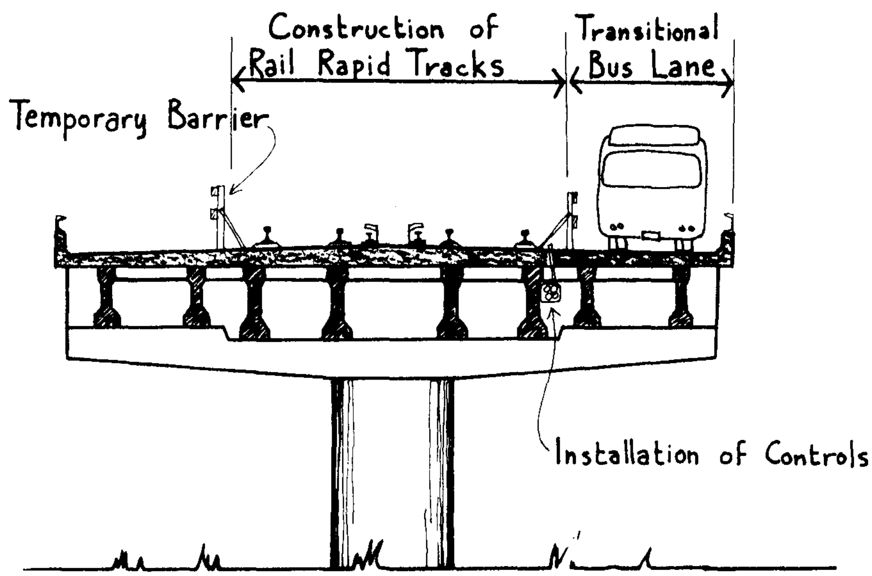

Figure III-18: Operation of Buses during RRT Evolutionary Path #2

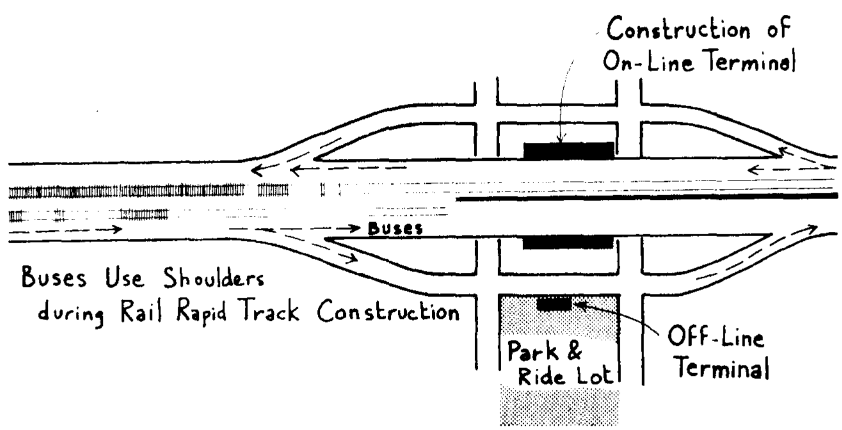

Figure III-19: Operation near Station during Initial RRT Construction, Evolutionary Path #2

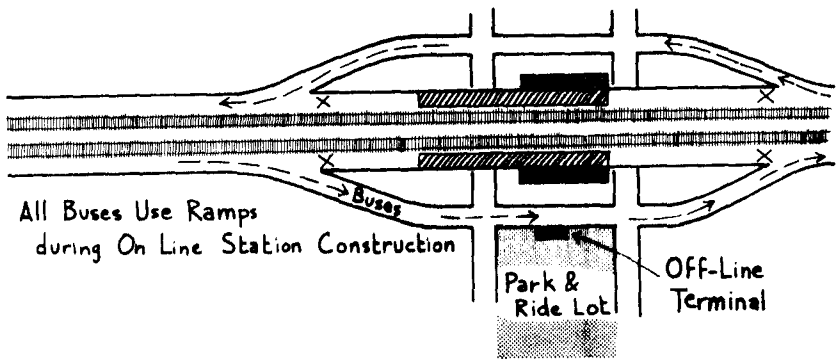

Figure III-20: Operation during Final Stages of Conversion, Evolutionary Path #2

Although most RRT systems place the power rail on the outside of the guideway, this design approach anticipates that the power rails will be located in the center portion of the guideway (see Figure III-21). Hence, the total guideway will be divided into a power corridor in the center, travel corridors on each side of the power corridor, and emergency walkways on either edge (see Figure III-22). Thus, the wide guideway, initially constructed to accommodate carpools, will be an asset to the RRT operation as a maintenance platform as well as an emergency walkway.

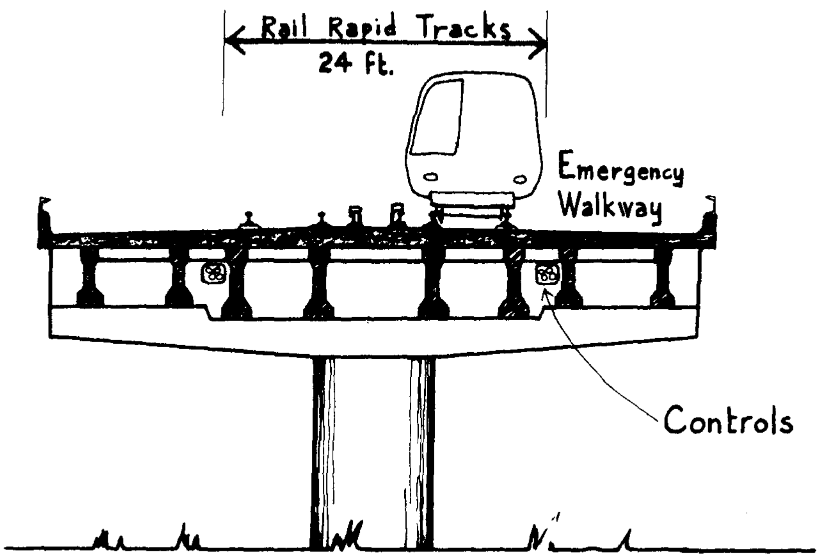

Figure III-21: RRT Operation, Evolutionary Path #2

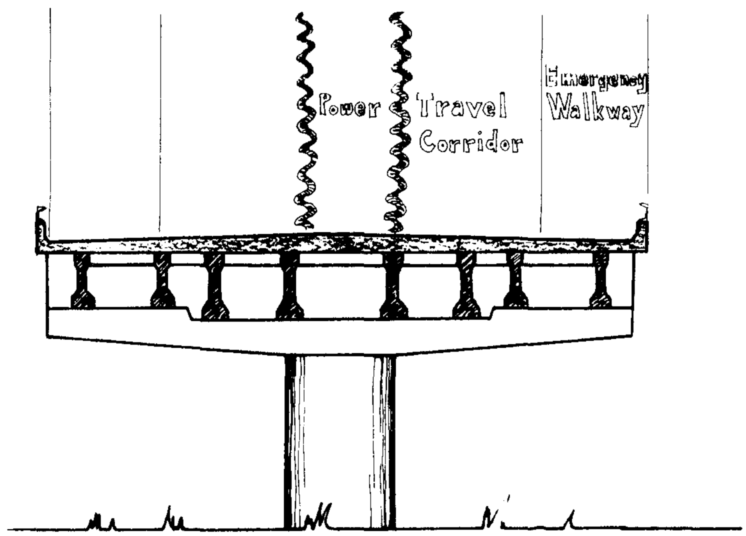

Figure III-22: Corridors along the RRT Guideway, Evolutionary Path #2

Evolutionary Path #3:
BRT → Rail Rapid Transit

Evolutionary Path #3 more nearly resembles the universal guideways mentioned in the literature. It utilizes a narrow guideway that will be used by buses inititally and later be used by RRT trains. A cross-section of the guideway design for this path is shown in Figure III-23. The thickness of this guideway is significantly greater than that shown for Reference Design #1 (see Figure III-2). Also, the column supporting the structure is larger.

The design shown in Figure III-23 is very similar to that used for the Lindenwold Line, a rail rapid transit facility (15). This particular design was selected because it is most similar to typical designs for highway structures used as a reference for busway designs. BART and MARTA use concrete box beams, while Washington, D.C. METRO uses a steel box beam to support the span between columns.

This narrow guideway cannot accommodate bus operation during transition to RRT use, even though no portions of the guideway will have to be destroyed in order to accommodate RRT. Stations will be constructed in areas reserved for that purpose adjacent to park-and-ride lots (see Figure III-24). The ramps used by buses will be removed as a part of the transition process; however, acceleration and deceleration lanes will not be removed. They will serve as safety islands for pedestrians exiting RRT trains during emergencies (see Figure III-25).

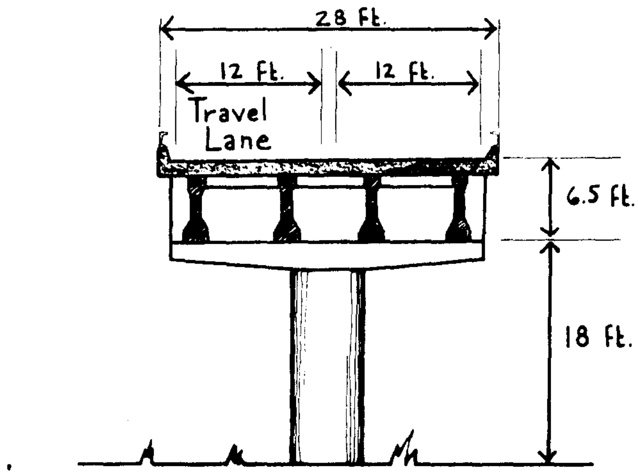

Figure III-23: Guideway Design, Evolutionary Path #3

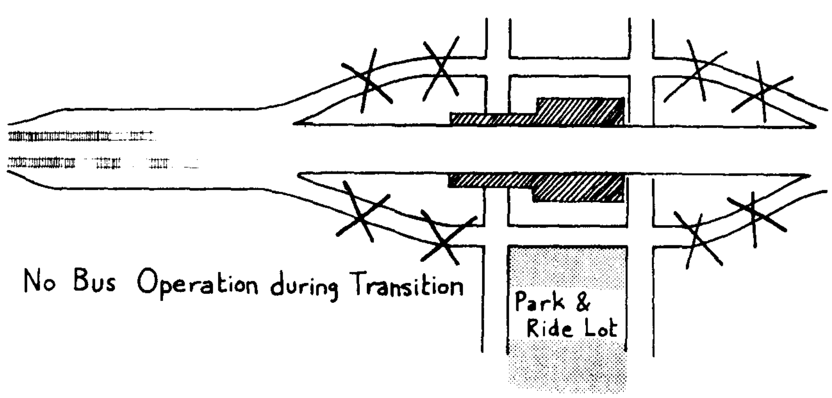

Figure III-24: Transition to RRT, Evolutionary Path #3

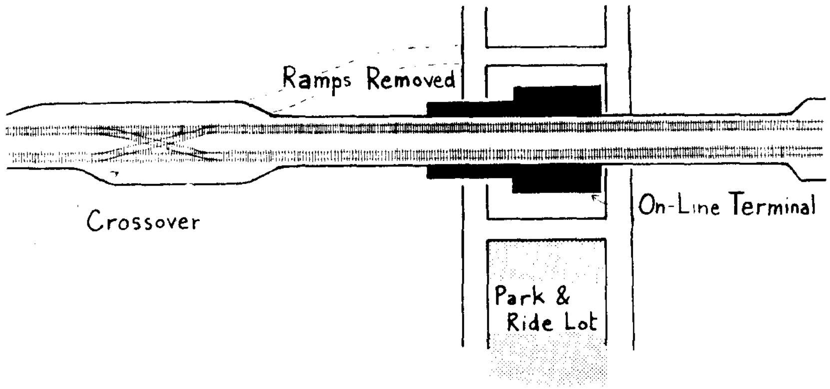

Figure III-25: Operation of RRT, Evolutionary Path #3

Wide Transitway Design in Perspective

The conceptual designs presented in the preceding pages were developed for general situations--without regard to constraints of specific site locations. Certainly, the wide guideway design is more massive than envisioned by most transitway studies. Thus, it seems appropriate to evaluate this design in perspective with its future environment.

General expectations for the Dallas-Fort Worth area are that the majority of the future transitway routes will parallel existing railroad lines. Some portions of the system will probably parallel existing surface streets and one or two segments will probably be adjacent to existing freeways.

Several such typical locations were identified in the Dallas-Fort Worth area for site-specific design studies. In each case, photographs of the existing site were taken and then a perspective drawing was developed showing how the transitway would fit into each specific location. Some of these perspective drawings are presented on the following pages--each of which portrays a wide transitway design similar to either Reference Design #2 or Evolutionary Path #1.

Hopefully, as much as half of the transitway system will be in locations where the guideway can be constructed at grade. The most likely locations for these at-grade portions are adjacent to existing railroads. The drawings in Figure III-26 show how the wide guideway might be constructed at-grade near existing rail lines. The top portion of Figure III-26 shows a segment of guideway between stations while the bottom portion shows a transit station using the "trumpet" type crossover design.

Of course, where grade-crossings that cannot be closed exist along rail lines, the guideway will need to be elevated. Figure III-27 shows two examples of elevated transitways in the vicinity of existing grade-crossings. The top portion of the figure shows how a typical transit station and park-and-ride lot can be handled. The lower portion of Figure III-27 shows a stretch of elevated guideways between stations.

Probably the most difficult situation for this transitway design will be when it parallels an existing surface street in the vicinity of a transit station. Two such examples are shown in Figure III-28. The top portion of the figure portrays an elevated guideway adjacent to a two-lane surface street. The lower portion of Figure III-28 shows an elevated section of guideway adjacent to a four-lane arterial street. In both instances, the on-and off-ramps extend over the street.

Each of these perspective drawings show the transitway in an appropriate scale with its surroundings. Next to a single railroad track or a two-lane street, the 50-foot wide guideway appears rather large. However, when the same guideway is placed next to a freeway--as shown in Figure III-29--it looks much smaller. Certainly, the visual impact of the wide guideway will be greater than that of a narrow guideway, but, it is no larger than many urban transportation facilities.

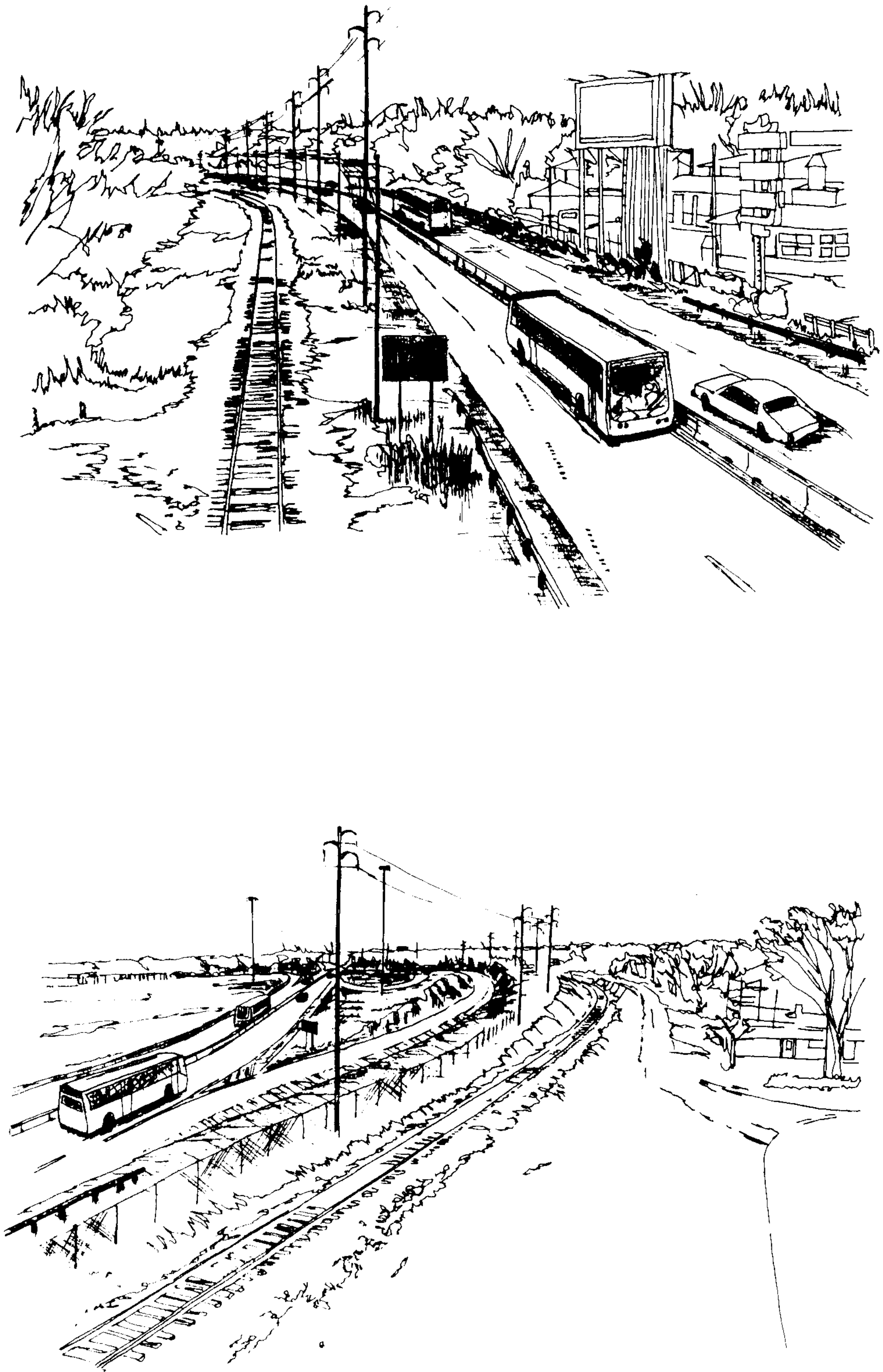

Figure III-26: At-Grade Portions of Transitway
Adjacent to Railroad Track

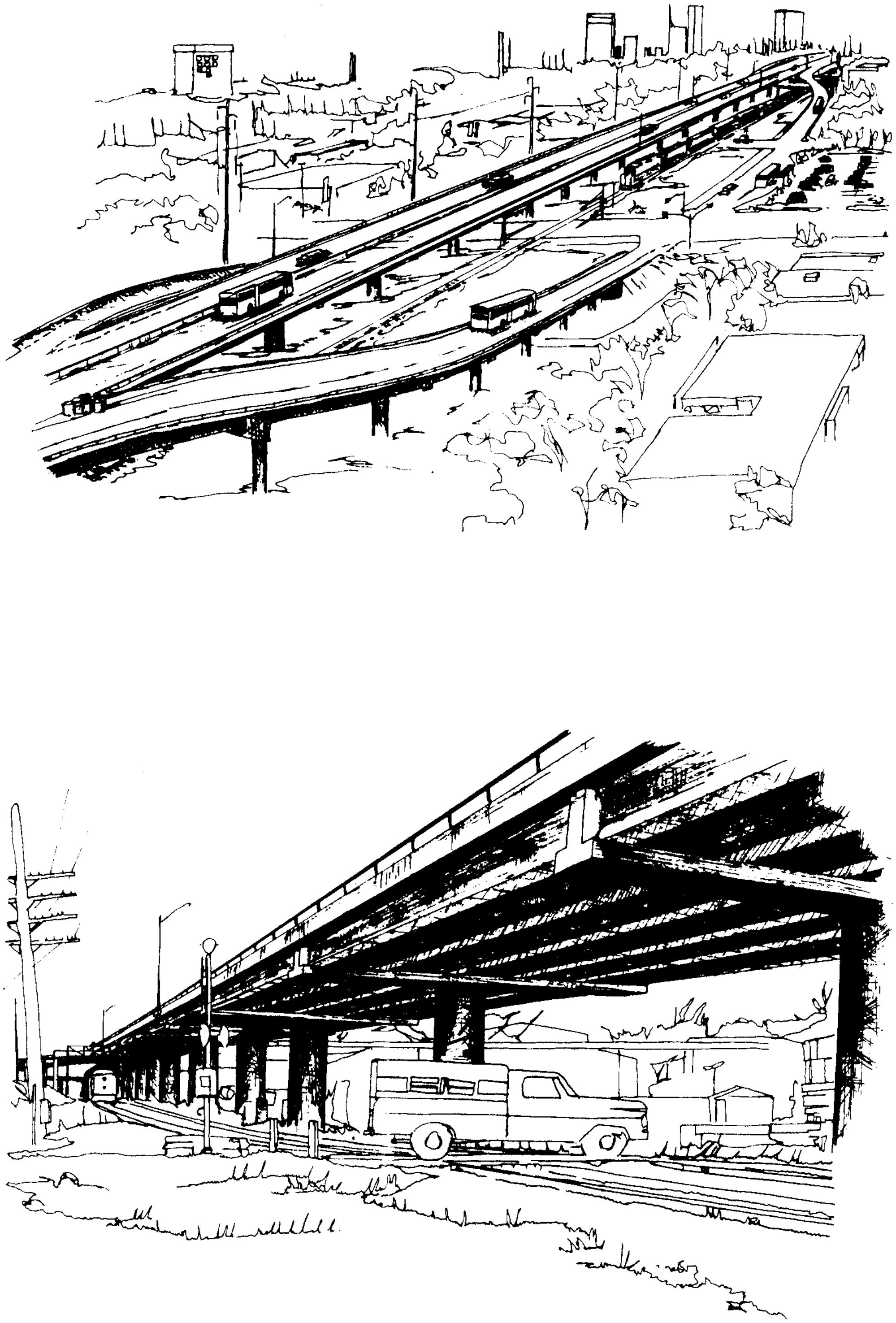

Figure III-27: Elevated Portions of Transitway Adjacent to Railroad Track

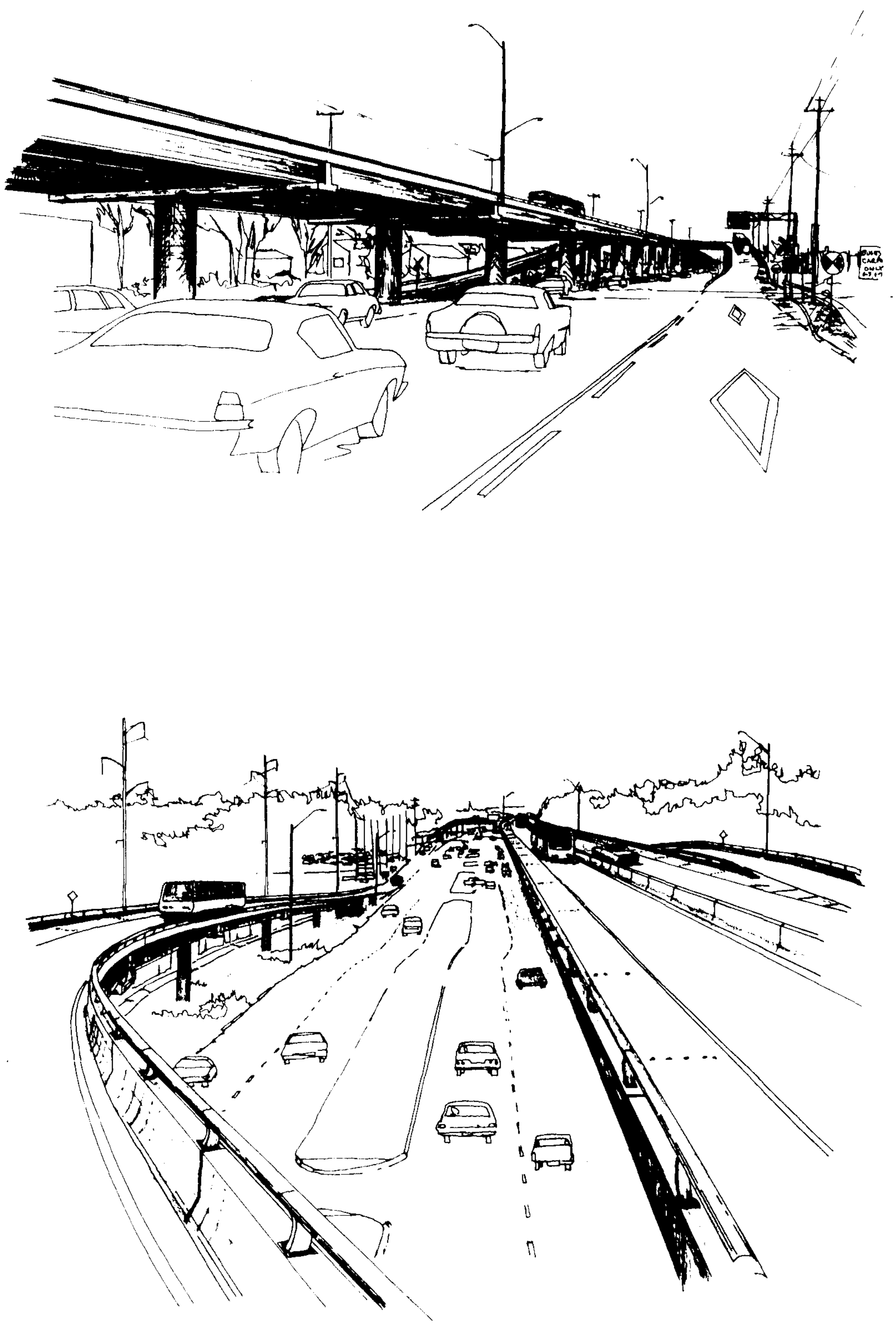

Figure III-28: Elevated Transitway Adjacent to Surface Streets

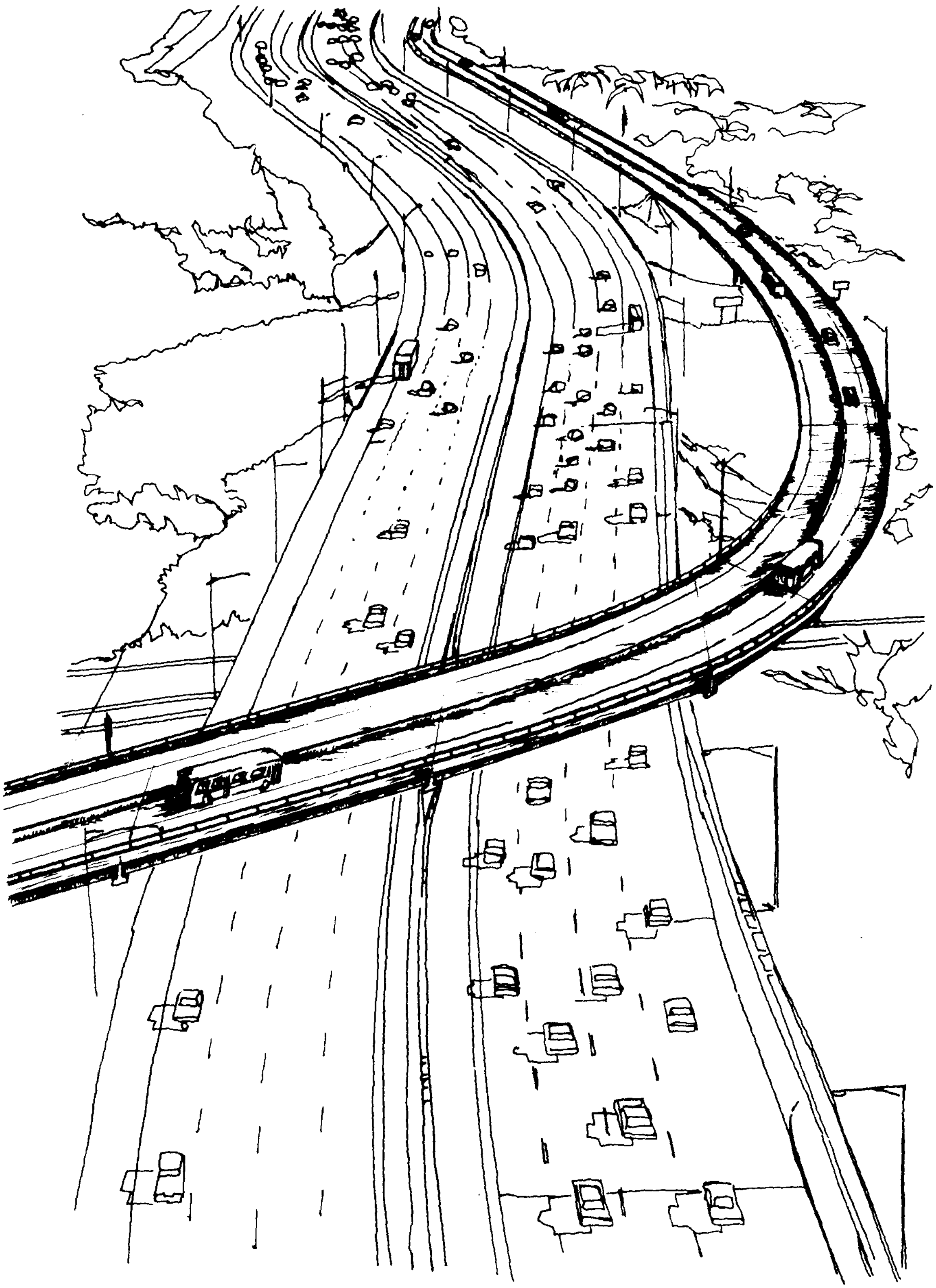

Figure III-29: Elevated Transitway Adjacent to Freeway

Specific Transition Problems

During the course of this design study several specific problems associated with the transition process were identified that warrant some discussion. Problems associated with the construction process, interchange design, and operations during transition are discussed briefly in the following pages.

Construction Process

In order to minimize the disruption to bus operations during the transition period, it appears highly desirable to plan the construction work in two phases. The first phase would include the following activities:

1. Construction of entire CBD subway system,
2. Construction of main-line guideways (rails for RRT or guidewalls for AGT), power, and controls,
3. Construction of vehicle maintenance facilities, and
4. Construction of station structures except for those elements that will block the existing shoulder.

The final phase of construction would include the following activities:

1. Construction of remaining elements of stations (station sidings for AGT and station platforms for RRT), and
2. Testing and debugging of AGT or RRT system.

Such a phasing of construction activities will enable bus operations to continue to provide a relatively high level of service during the initial construction phase by using the shoulders of the wide guideway. Additional delays will be encountered by the buses during the second phase of construction because they will have to exit the guideway at each station. However, the duration of the latter transition period will be minimized by the phasing of construction activities.

A total width of approximately 26 feet will be available for construction activities in the center of the wide guideway. This should be adequate for most of the activities associated with installing track, power rails, and control systems. After all, it is a larger work space than was available on the narrow dual-track guideways used on the newer RRT systems. Certainly, it will be far more commodious than the confines of single-track tunnel sections used on BART and Washington, D.C. Metro. Nevertheless, there probably will be occasions when materials and/or work vehicles will need to be transported across the shoulders. Surely, these occasional blockages of the shoulders can be scheduled outside of peak commuter periods.

Probably the one construction activity that would be the most difficult to accomplish without major interference to bus operations on the shoulders is the placement of the prefabricated concrete sidewalls for an AGT system. The procedure used to install similar concrete median barriers on highways involves the placement of precast sections by cranes and then the "toeing-in" of the assembled wall with a 1 1/2-inch thick layer of hot mixed asphaltic concrete (HMAC) that tapers out for a distance of about 3 feet from the barrier. If a similar installation technique is used, then the shoulder will be totally blocked while the HMAC layer is being installed on the outer side of the wall. Again, this activity can probably be accomplished at times other than peak periods.

Even though problems will occur, through careful planning and scheduling of construction activities it should be possible to accomplish the entire transition process while buses continue to operate on the shoulders of the wide guideway.

Interchange Design

The transitway system identified in the 1990 plan (refer to Figure III-1, page III-3) includes several "Y" and/or "T" intersections of guideways. A conventional interchange design, such as the one depicted in Figure III-30, will result in a blockage to some bus movements once the RRT or AGT system is installed (see insert sketch on Figure III-30).

One possible solution to this problem would be to route all buses along the right side of the "Y" and those buses that would have taken the other direction would then make a U-turn at the next station and pass back through the interchange. This solution would result in a significant time penalty

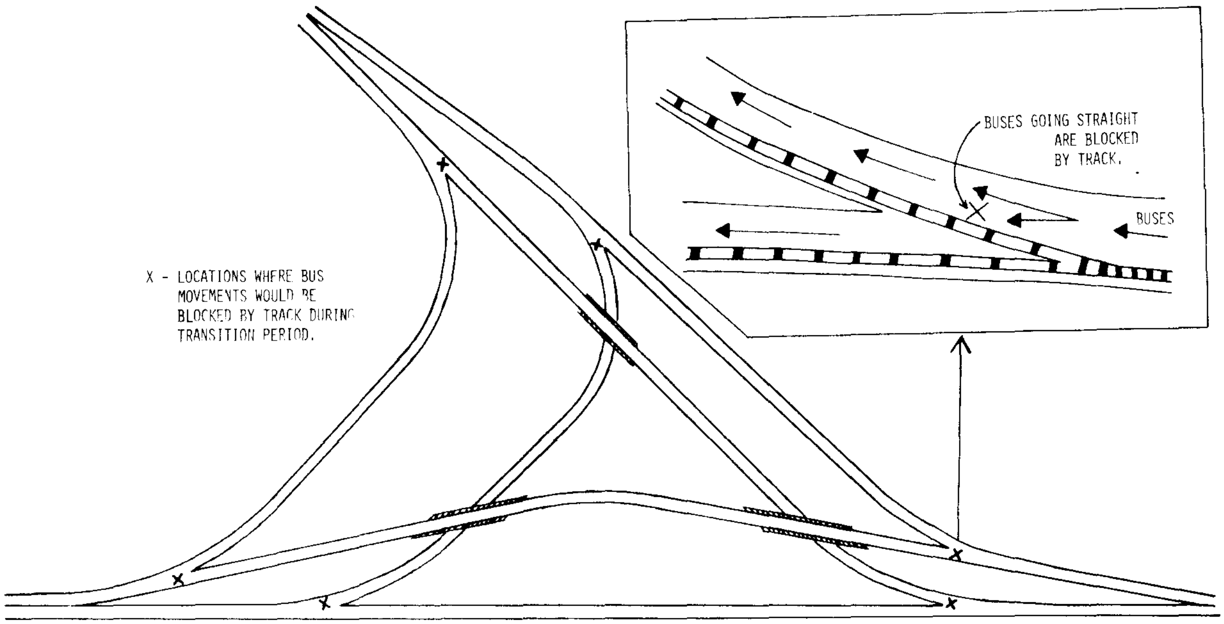

Figure III-30: Typical Interchange Design

(probably about 5 minutes) for those buses affected. Also, it should be noted that this solution is only possible if a fully-directional interchange is constructed. (Note--If only inbound/outbound movements are needed, the interchange would consist of only one grade separation rather than three.)

Another possible solution to the blockage problem would be the construction of temporary overpasses for buses to use during the transition period (see Figure III-31). Of course, the disadvantage of this solution is the cost of temporary overpasses.

A third possible solution to the blockage problem involves the use of a more complicated interchange design (see Figure III-32). Then temporary detour lanes can be provided at grade for buses to use during the transition period. The obvious disadvantage of this solution is the increased cost of the more complex interchange design.

None of these solutions appears to be particularly attractive. Some in-depth study would need to be devoted to this problem during the system design process to assure selection of the best solution.

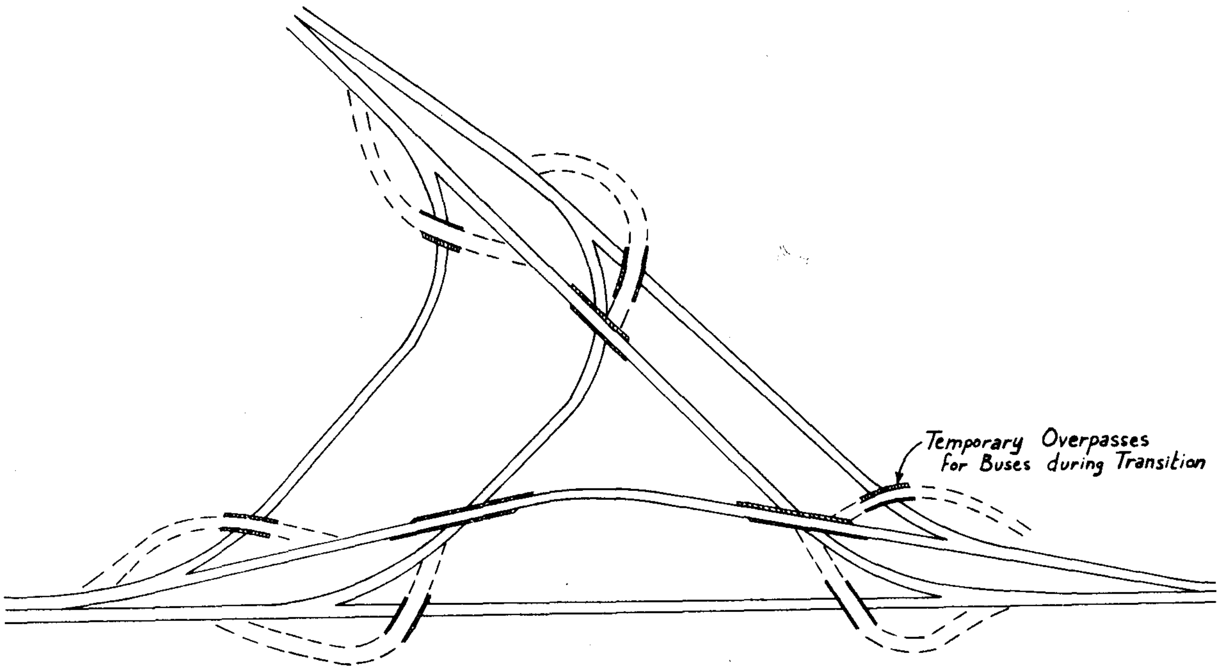

Figure III-31: Typical Interchange Design with Temporary Overpasses for Buses

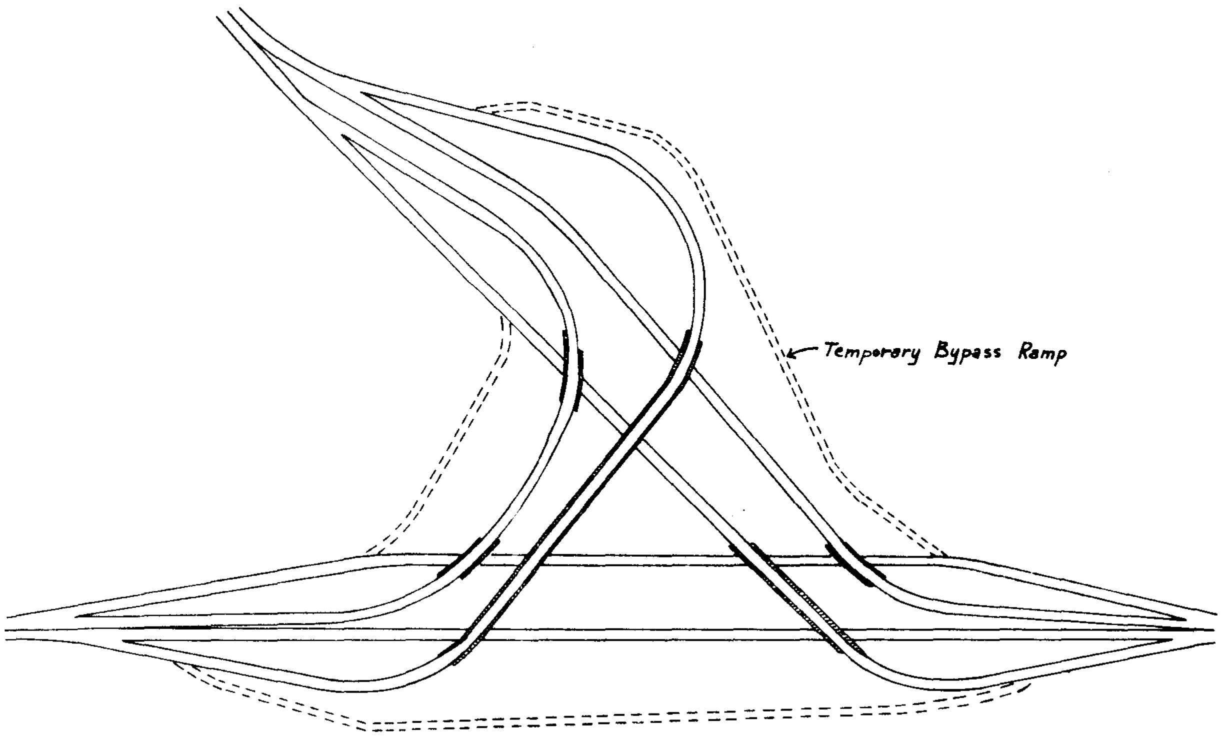

Figure III-32: Interchange Design that Permits Grade-Level Bypass Ramps to Serve Buses during Transition

Operations During Transition

All the discussion of specific transition problems so far has pertained only to a wide guideway design (Evolutionary Paths #1 and #2). No concurrent bus operation can be conducted on a narrow guideway (Evolutionary Path #3) while it is being converted to another mode. However, the construction activities could be staged by segments of the narrow guideway so that buses could use portions of it during the initial transition process.

An analysis of specific operational problems that would be encountered during the transition was conducted for each evolutionary path. For the purposes of this analysis, the following two alternative transition techniques were assumed for Path #3 (narrow guideway):

- Path #3A -- Convert entire length of guideway concurrently, and
- Path #3B -- Convert half of the length of each corridor during the initial phase and the remainder during the final phase.

The impact of the transition period on various operational parameters was estimated for each evolutionary path so that their relative ease of transition could be compared. The parameters evaluated include the time required for each transition phase, bus capacity, average operational speed, and the disruption of other traffic in the corridor.

Time Required - Estimations of time required to construct portions of a transit system are inherently inaccurate because so many factors can delay construction. Despite these inherent inaccuracies, time estimates were developed for this process. Hopefully, these estimates represent the minimum realistic time required to accomplish the various construction activities.

The CBD portion of the system will have to be constructed from scratch. The Lindenwold Line was placed into service only three years after the initial construction work began, while more than six years elapsed between the beginning of construction and the initiation of service on the Washington, D.C. Metro. The problems associated with the subway segments of this system in the CBD will probably be more similar to those encountered on the Metro system than on the Lindenwold system. So a realistic time estimate for constructing the CBD portion of the system is probably in the range of five to six years.

Construction activities in the CBD, however, will not interfere with the bus operations on the existing guideways. Thus the true transition period will be the time required to convert the existing guideways to RRT or AGT operation. If this estimated time is shorter than that required to build the CBD subway segments, then the construction of the CBD portion should precede the conversion work by an appropriate lead time.

Some typical times specified in contracts from BART and Metro for certain construction activities that will be included in the initial transition period are as follows:

- Trackwork -- 16 to 18 months,
- Power System -- 21 to 24 months,
- Control System -- 18 to 24 months, and
- Stations -- 16 to 18 months.

If these activites are staggered just enough to keep the various contractors out of each other's way, then the total package of work included in the initial transition phase could possibly be accomplished in 24 months. However, some additional time will probably be required because of the need to schedule certain construction activities around the bus operations. Thus, the estimated time required for accomplishing the initial transition phase on Evolutionary Paths #1 and #2 is 30 months.

The final transition period for Evolutionary Paths #1 and #2 involves some minor construction work (which can probably be accomplished in six months) and a period for testing and debugging the new system. The time needed for debugging is directly related to the degree of reliance on proven technology versus advanced technology. The Lindenwold Line used only proven technology and their testing/debugging was accomplished in a few months. BART, on the other hand, is still debugging after several years. For the purposes of this analysis, a testing/debugging period of 12 months was assumed for the RRT system (Path #2) and 18 months for the AGT system (Path #1).

Evolutionary Path #3A (narrow guideway, BRT → RRT) does not involve concurrent operation of buses on the guideway during transition, so the six months penalty was not added to the estimated time. Thus, the total estimated time for converting Path #3A to RRT is 42 months.

Evolutionary Path #3B is just like #3A except that half of the guideway will be converted to full RRT operation before the conversion process is started on the remaining half. Some time savings should accrue from the lesser amount of work; thus, the initial transition period is estimated at 36 months (rather than 42 months for Path #3A). The final transition period for Path #3B can probably be accomplished in only 30 months due to less time needed for testing/ debugging.

Capacity - The capacity of a busway was calculated to be 940 buses per hour in each direction at an acceptable level of service; however, various factors will combine to reduce this capacity during the transition period. For the purposes of this study, it was assumed that carpools would be excluded from the transitway before any transition would occur. Thus, the capacity calculations need only concern bus operations.

For Evolutionary Paths #1 and #2 (wide guideways), buses will continue to use the shoulder of the guideway throughout the transition. During the initial transition period, the reduced width of roadway available for bus operation (10 feet instead of 12 feet) will result in a reduced capacity. The Highway Capacity Manual (16) shows a capacity factor of 0.74 for a two-lane roadway with obstructions on either side; thus, the capacity during the initial transition period is estimated to be 940 x 0.74 = 696 ≈ 700 buses per hour.

During the final transition periods of Evolutionary Paths #1 and #2, all buses will exit the guideway at each station and travel through two intersections. Even though it is assumed that the intersecting cross streets will be collector streets rather than major arterials, it is likely that traffic signals will be needed during the final period. These intersections will probably become the bottleneck that limits the capacity of bus operation. Assuming that each intersection will have a short two-lane approach, and that the signal timing can favor the bus flow (60 percent green time), then the capacity of these intersections will be between 500 and 600 buses per hour depending upon the utilization of the added approach lane.

For Evolutionary Path #3, the buses will have to operate on facilities other than the guideway during the transition. If a freeway lane can be devoted to bus operations for each corridor, then the capacity during transition will be approximately the same as for the other paths (≈ 700 buses/hour).

However, if the buses must use a lane of a surface arterial street, the capacity will be reduced to only 330 buses per hour.[1]

Speed - During normal busway operations, average service speeds of 50 mph should be achievable with maximum speeds of 55 mph on the guideway. However, the maximum speed during transition will probably need to be limited to 45 mph for safety reasons; therefore, the average service speed will be 40 mph for shoulder operation. Delays encountered at intersections during the final transition period will further reduce the average service speed to approximately 35 mph (assuming a 30-second delay for each station) for Evolutionary Paths #1 and #2. If the buses have to use a lane of a surface arterial street during transition for Evolutionary Path #3, the average service speed will be reduced to 20 mph.

Disruption of Corridor Traffic - Another problem that needs to be considered is the disruption to normal corridor traffic that will be caused by bus operations during the transition. Detailed studies of specific corridors will be required to assess this impact in terms of delay time, capacity, speed, etc. For the purpose of this study, however, the relative severity of the disruption that will be caused by each path can probably be evaluated by considering the percentage of the corridor length that will be affected and the duration of the transition period. The disruption factor used to compare the relative impact of different paths is the product of these two parameters (percent of corridor length x months of duration).

Comparison of Paths - The total focus of this study concerns the ability of a transitway design to accommodate the transition from bus operation to another technology. Hence, it seems that a comparison of the transition period for each Evolutionary Path is appropriate. Such a comparison is presented in Tables III-1 and III-2. An inspection of the information contained in these tables reveals a clear advantage for Evolutionary Paths #1 and #2 (using a wide guideway) over Evolutionary Path #3 (narrow guideway).

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[1]From Highway Capacity Manual (16): $\frac{\text{1100 autos/hour of green}}{\text{1.5 autos/bus}}$ x 0.45 (percent of green) = 330 buses/hour.

Table III-1: Comparison of Bus Operations During Transition

Transition Parameter	Evolutionary Path Number			
	1	2	3A	3B
<u>Initial Transition Period</u>				
Time Required, months	30	30	42	36
Bus Capacity, veh/hr	700	700	330	330
Average Service Speed, mph	40	40	20	30
<u>Final Transition Period</u>				
Time Required, months	24	18	--	30
Bus Capacity, veh/hr	500	500	--	330
Average Service Speed, mph	35	35	--	20

Notes: For Evolutionary Paths #1 and #2, initial period operation is entirely on guideway, and final period operation uses ramps to bypass station construction.

For Evolutionary Path #3A, entire operation is on arterial streets.

For Evolutionary Path #3B, initial period operation is half on guideway and half on streets, while final period operation is entirely on streets.

Table III-2: Relative Disruption to Surface Traffic During Transition

Disruption Parameter	Evolutionary Path Number			
	1	2	3A	3B
Percentage of Transit Trips that Interferes with Surface Street Traffic	10	10	100	50/100
Length of Disruptions, months	24	18	42	36/30
Disruption Factor	240	180	4200	4800

Notes: Length of disruption is only that portion of the total transition period that involves operation on local streets.

The disruption factor is the multiple of the other two factors.

Technical Feasibility

The most significant findings of this design study are that an evolutionary design which accommodates continuous bus operation during transition is feasible and that the design approach is strikingly simple. The key to the whole approach is the use of a wide guideway.

Not only does the wider guideway enable buses to continue to use the transitway during the transition, but the resulting shoulders also provide significant benefits to the final operational phase (either AGT or RRT). Indeed, the only features incorporated in the initial design for Evolutionary Path #1 (Bus/carpool → BRT → AGT) that are not needed in the final phase are the entry and exit ramps and the passenger shelters located in the park-and-ride lots. It may even be desirable to retain the entry and exit ramps at a few locations to provide access to the guideway for self-propelled maintenance and emergency vehicles.

The design approach shown for Evolutionary Path #2 (Bus/carpool → BRT → RRT) could even be considered a "universal guideway" design. It is designed with the structural capability to accommodate any mode (BRT, LRT, AGT, OR RRT) and the decision concerning the specific mode could be postponed until conditions developed that stimulated a need to change modes. However, the increased structural capability is a costly feature that might never be used.

The next section of this report will address the question of costs and benefits of the five conceptual designs described in this section.

IV. ASSESSMENT OF VALIDITY OF EVOLUTIONARY CONCEPT

COST ESTIMATES

PRESENT VALUE ANALYSES

DECISIONAL CONSIDERATIONS

Cost Estimates

In order to evaluate the economic advisability of constructing an evolutionary guideway design, it is necessary to estimate the cost impacts for such designs. Of course, estimating costs for conceptual designs is, at best, an approximate process because actual costs will vary so much between different specific designs that fall within a design concept. For example, the costs for a deluxe version of a system (such as BART) can be double or triple those for a "plain vanilla" version (such as Lindenwold Line). Hence, the objective of this cost estimation effort was to accurately define the relative costs of the various designs. The resulting cost estimates should not be interpreted as valid estimates of the absolute costs for any individual design.

For the purpose of this analysis, it was assumed that the initial system for each design would consist of the following components:

- 30 miles of elevated guideway,
- 30 miles of at-grade guideway,
- 30 park-and-ride lots near future station locations,
- 1200 buses, and
- 2 maintenance yards and shops for buses.

The major cost items associated with the transition were assumed to be the following:

- 5 miles of subway system in CBD's,
- 7 subway stations in CBD's
- Conversion of 60 miles of existing guideway (i.e., track, power, control, etc.),
- 30 stations along existing guideways,
- Guideway vehicles (1200 AGT or 700 RRT), and
- 2 maintenance yards and shops for guideway vehicles.

The reference cost values used in developing these cost estimates are listed in Table IV-1. Most of these reference values came from one of the following sources:

1. Bus Rapid Transit Options for Densely Developed Areas (17),

2. Characteristics of Urban Transportation Systems (13),
3. Rail Transit System Cost Study (18), or
4. Pittsburg-Antioch BART Extension Project Final Report (19).

All of the reference cost values are based on 1973 costs. These were not adjusted to a later year because the objective of this analysis was to develop relative costs rather than planning values.

Table IV-1: Reference Cost Values

	Guideway Design	
	Narrow	Wide
Reference Designs		
Right-of-Way Costs	$1.0M/mile	$1.9M/mile
Elevated Guideway Structure	4.3M/mile	6.5M/mile
At-Grade Guideway	1.0M/mile	1.5M/mile
Ramps	$1M/station	
Park & Ride Lots & Land for Station	1M/station	
Buses	45,000 each	
Conversion Costs on Initial System		
Trackwork for RRT	$0.8M/mile	
Sidewalls for AGT	0.5M/mile	
Power System (AGT or RRT)	0.9M/mile	
Control System for RRT	0.8M/mile	
Control System for AGT	1.0M/mile	
Stations	2.6M each	
Vehicles - RRT	0.35M each	
Vehicles - AGT	0.20M each	
Other Transition Costs		
Subway in CBD's	$40M/mile	
Subway Stations in CBD's	12M each	
Vehicle Maintenance Facilities	10M each	

Note: These cost values are based on 1973 costs.

Sources of Data: References (13), (17), (18), and (19).

For the purposes of this study, it was assumed that new rights-of-way would have to be obtained for any transitway system that might be built.

Right-of-way costs were estimated accordingly, using the values shown in Table IV-1. This element of the cost estimates is probably the least accurate of all. Hopefully, much of the right-of-way will be adjacent to an existing railroad, street, or freeway and will not be as expensive as estimated. Indeed, there is some hope that portions of the transitway--particularly if the narrow design is used--could be placed within existing rights-of-way for other facilities. Thus, the final costs for right-of-way may be significantly different than the estimates used in this study.

The major differences in the Reference Designs and the designs for various Evolutionary Paths that have an impact on the initial costs are the raceways for future power and control cables and the additional structural strength required for eventual RRT operation. The costs for providing raceways was estimated to be an additional $0.2M per mile for each of the Evolutionary Designs. The procedures used for estimating the cost impact of the additional structural strength are described in the following two paragraphs.

Analyses performed by Dr. John Haynes, et al, in a previous study (20) established the relative bending moment induced by an RRT vehicle at 2.1 times that imposed by a bus. Using these relative loads, several different elevated structure designs were identified and their costs estimated. The resulting cost ratios varied from 1.75 to 2.0 with the average being 1.85. Thus, the cost impact of the increased structural strength needed for RRT systems was estimated to be 85 percent of the cost of the narrow elevated guideway for buses--or an additional $3.67M per mile of elevated guideway.

The cost impact of the increased load capability on an at-grade portion of the guideway was estimated to be 50 percent of the cost of the narrow roadway for buses--or an additional $0.5M per mile of at-grade guideway. This 50 percent increase is consistent with planning estimates used for highways and airport runways designed to accommodate vehicles weighing twice as much.

The resulting cost estimated for all five system designs are presented in Table IV-2. It should be noted once again that these estimates are based on 1973 cost data; they are not valid estimates of actual costs that would be incurred at some future date. However, the relative costs of the various designs should remain reasonably constant.

Table IV-2: Estimated Cost of System Designs

Design	Initial Cost	Transition Cost
Reference Design #1 (Narrow Busway)	390	N/A
Reference Design #2 (Wide Busway)	490	N/A
Evolutionary Path #1 (Wide: BRT → AGT)	500	770
Evolutionary Path #2 (Wide: BRT → RRT)	630	780
Evolutionary Path #3 (Narrow: BRT → RRT)	530	780

Note: Costs are in millions of 1973 dollars.

The additional initial investment required to construct a design suitable for evolving to AGT operations (Evolutionary Path #1) is negligible compared to the cost of a wide busway. As mentioned previously, the design for Evolutionary Path #2 could be considered a "universal guideway" design; however, this design costs about 30 percent more than the wide busway for the initial portion. The initial investment in Evolutionary Path #3 is 36 percent more than for the comparable narrow busway. Obviously, the major differences in the initial costs for evolutionary designs compared to a similar busway design is the added structural capability needed to support rail rapid transit vehicles.

The estimated transition costs for various evolutionary designs are virtually the same. The total estimated transition cost in each case is composed of three major components of almost equal costs as shown below:

1. Convert existing guideways ≈ $230M,
2. Construct CBD portions ≈ $280M, and
3. Vehicles and maintenance yards ≈ $270M.

Of course, these are costs that would not be incurred unless a transition from buses to another technology actually occurs.

Presumably, if such a transition ever does occur, the initial added investment in the evolutionary design would prove to be a wise investment. However, the results of present value analyses, discussed in the following section, indicate that this presumption may not necessarily be valid.

Present Value Analyses

The results of analyses of system attributes discussed in Section II of this report indicated a strong probability that a transition from buses to any other mode might never occur. Of course, if such a transition is never needed, then the additional monies expended to build evolutionary designs initially would seem to have been a poor investment. No additional economic analyses are needed to evaluate this eventuality.

If, however, sufficient stimuli should develop at some future date to justify a transition in modes, the initial investment in an evolutionary design may have been a wise investment. In order to evaluate the economic value of evolutionary design, present value analyses were performed for two possible courses of action that would yield the same final result. These two courses of action are as follows:

1. Build the evolutionary design initially and make the transition at a future date;
2. Build a busway initially and then, at some future date, do whatever is necessary to convert the system to the subsequent mode of operation (even to the extent of tearing out and replacing structures).

Each of these courses of action would require a different total investment, but what is more important is that different portions of the total investment would be required at different times. Hence, present value analyses are needed to evaluate the economic trade-offs between these various courses of action.

Present value analysis is a technique that is frequently used to evaluate alternative proposals that involve capital expenditures. The present value concept recognizes the time value of money; since money can be invested at an interest rate, one dollar received today is worth more than one dollar received five years from now.

The discount, or interest, rate involved in the analysis reflects the costs of obtaining the required monies or, in other words, the opportunity cost associated with the investment. This rate is applied to future cash flows to ascertain their present value. In theory, the alternative with the lowest present value, assuming the benefits received from all alternatives are equal, is the preferred course of action.

Whereas the discount rate establishes the cost of obtaining funds, the inflation rate establishes the magnitude of future expenditures. In effect, the inflation rate at least partially offsets the discount rate. If both the discount rate and the inflation rate are equal, there will be no reason to use the present value analysis since it will yield the same results as an analysis of total project costs, not considering the timing of expenditures. If the discount rate exceeds the inflation rate, some benefits will accrue from postponing expenditures. Conversely, if the inflation rate exceeds the discount rate, it will be beneficial to make immediate investments rather than postpone expenditures.

Thus, to an extent, the significance of using present value analysis in evaluating the evolutionary transitway concept is dependent upon the relationship between the discount rate and the inflation rate. Trends in both the consumer price index and the federal aid highway construction index are plotted in Figure IV-1. From 1945 to 1969 these two indices followed each other fairly closely, increasing at an average annual compound rate of 2.25 percent. For two years, since 1969, namely, 1969 to 1970 and 1973 to 1974, the construction index increased at a much more rapid rate than did the consumer price index. However, since this only occurred during 2 of the 30 years shown, it can hardly be considered to be a trend. From 1969 to 1975 the construction index increased by 82 percent, or an average annual compound rate of 10 percent. Thus, even during this period of the most rapid growth in the construction index, its rate of growth was only equal to the 10 percent discount rate specified by the federal government for all federal investments.

No attempt is made in this study to project either the discount rate or the inflation rate that might be appropriate in the future years. At present, the generally accepted discount rate is 10 percent. It is anticipated that inflation will continue in the future, and this inflation will, in effect, lower the value of the appropriate discount rate. As a consequence, both a 10 percent and a 5 percent discount rate were considered in this analysis.

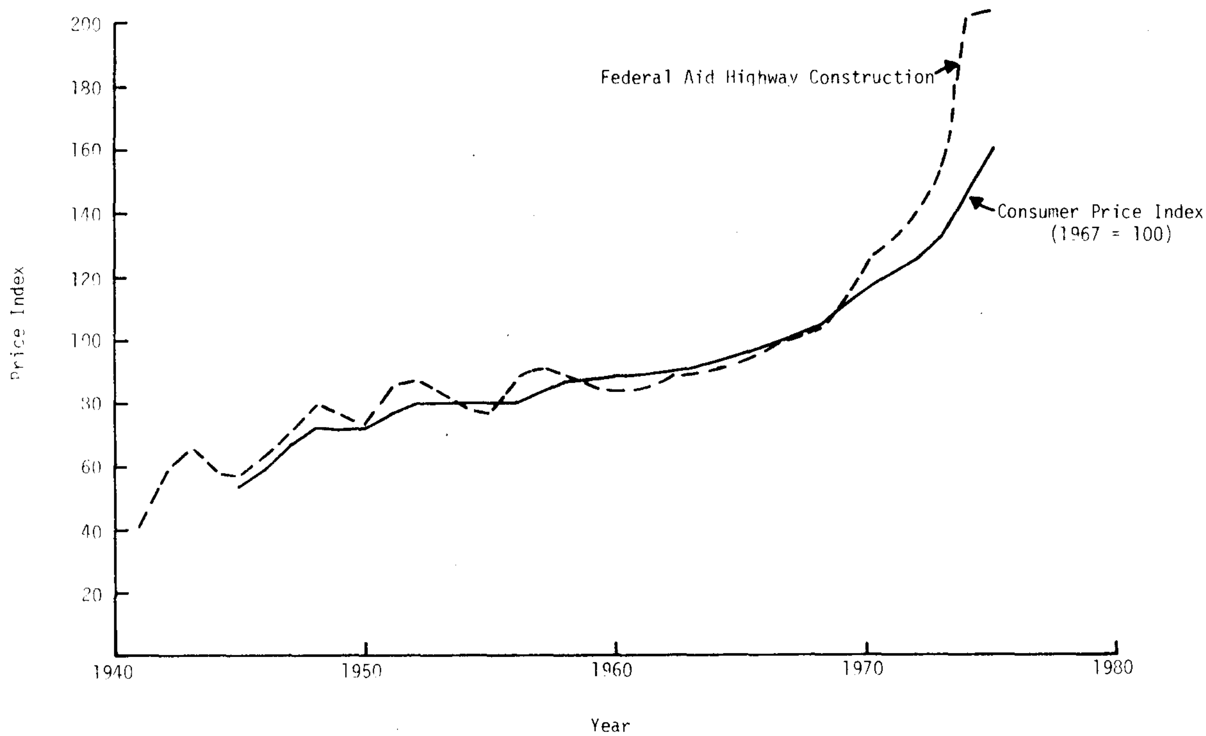

Figure IV-1: Trends in Price Indices

Evolutionary Path #1 (Wide: Bus/carpool → BRT → AGT)

If the ultimate operational technology is expected to be AGT, then the two courses of action are as identified below.

- Evolutionary Path #1 - Construct a wide evolutionary guideway and operate buses initially, with a transition to AGT at some future date.
- Alternate Approach #1 - Construct a wide busway initially and then modify it as necessary to accommodate AGT at some future date.

The estimated costs for these two courses of action are presented in Table IV-3, and the present value is presented in Figure IV-2. For this particular path, there is very little difference in costs between the two courses of action.

Table IV-3: Cost Estimates for Various Courses of Action Toward AGT Operation

Course of Action	Initial Cost	Transition Cost
Evolutionary Path #1 (Evolutionary Design)	500	770
Alternate Approach #1 (Busway Modified)	490	800

Note: Cost estimates are in millions of 1973 dollars.

Evolution Path #2 (Wide: Bus/carpool → BRT → RRT)

The two courses of action evaluated for this option are identified below.

- Evolutionary Path #2 - Construct the evolutionary guideway design (wide and strong) initially; operate buses until a transition is made to RRT.
- Alternate Approach #2 - Construct a wide busway (Reference Design #2) initially and then, when it is time for the transition, tear out the lightweight busway structures and replace them with wide RRT guideways.

The cost estimates associated with these two courses of action are presented in Table IV-4. The results of the present value analyses are presented in Figure IV-3.

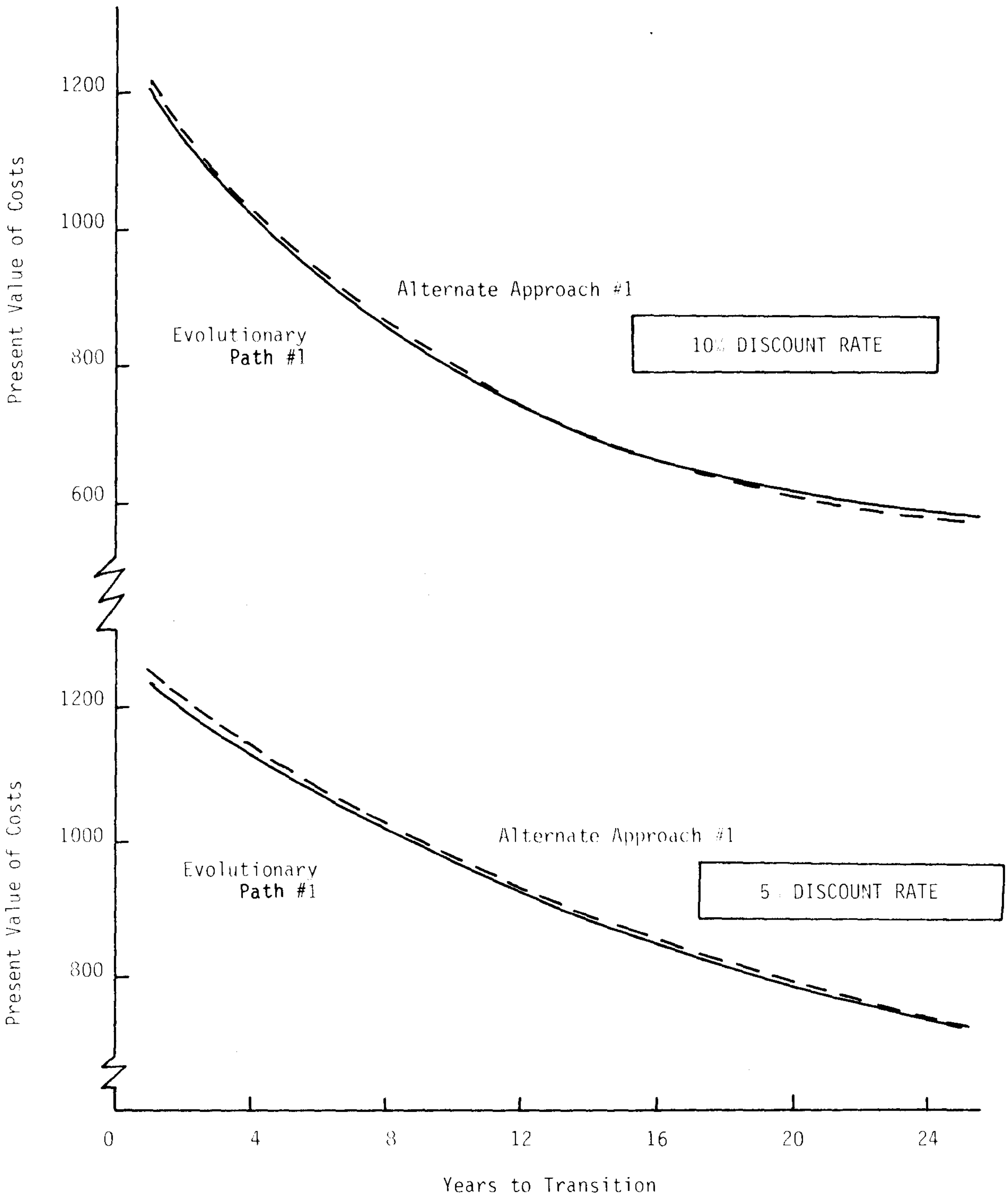

Figure IV-2: Present Value of Evolutionary Path #1 and Alternate Approach #1

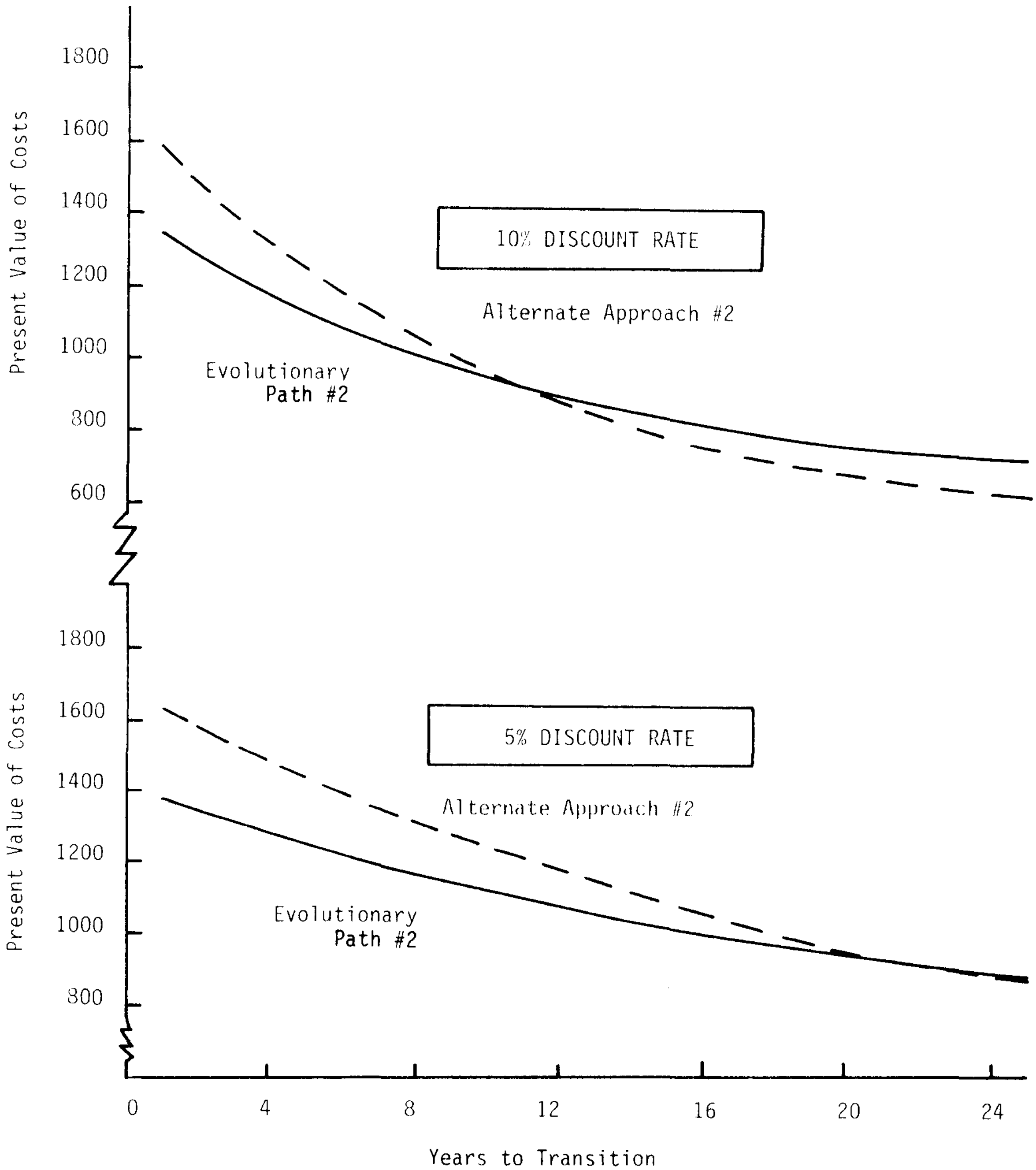

Figure IV-3: Present Value of Evolutionary Path #2 and Alternate Approach #2

Table IV-4: Cost Estimates for Various Courses of Action Toward RRT Operation Using a Wide Guideway

Course of Action	Initial Cost	Transition Cost
Evolutionary Path #2 (Wide: BRT → RRT)	630	780
Alternate Approach #2 (Busway → Rebuild Guideway)	490	1200

Note: Cost estimates are in millions of 1973 dollars

An inspection of these present value curves reveals that Evolutionary Path #2 is the lowest cost course of action for a period of years. Finally, if the transition has not already occurred, Alternate Approach #2 replaces Evolutionary Path #2 as the lowest cost option. In other words, the evolutionary approach is the lowest cost option only if the transition to RRT occurs before the 12th year if the effective discount rate is 10 percent or before the 22nd year if the appropriate discount rate is 5 percent. The significant point is that the economic advantages of the evolutionary design diminish as the transition is postponed. Eventually, the alternate approach becomes less costly in terms of present value regardless of the discount rate used in the analysis.

Obviously, this analytical technique is highly sensitive to the discount rate applied (the curves intersect at 12 years with a 10 percent discount rate or at 22 years with a 5 percent discount rate). It is not so obvious that this present value analysis technique is equally sensitive to the cost estimates used in the analysis. For example, if the cost estimates are varied within a range of ± 5 percent, the resulting intersection between the two curves will vary from 12 years to 37 years using a 5 percent discount rate. As noted previously, cost estimates are seldom accurate to better than ± 10 percent; thus, the results obtained from these present value analyses should not be considered precise--they are only indicative.

Regardless of the sensitivity of this analysis technique to the specific values used, it identifies a very significant condition--the economic benefit of the evolutionary approach diminishes with time. In other words, the longer that the transition is delayed, the less will be the savings accrued from having an evolutionary facility. Indeed, eventually the alternative approach will become the less expensive in terms of present value.

Evolutionary Path #3 (Narrow: BRT → RRT)

The two courses of action evaluated for this option are as follows:

- Evolutionary Path #3 - Construct the evolutionary guideway design (narrow and strong) initially and operate buses until transition to RRT operations at a later date.
- Alternate Approach #3 - Construct a narrow busway initially and then tear it out and replace it with a narrow RRT guideway.

The cost estimates associated with these two courses of action are presented in Table IV-5. The results of the present value analyses are presented in Figure IV-4.

Table IV-5: Cost Estimates for Various Courses of Action Toward RRT Operation Using A Narrow Guideway

Course of Action	Initial Cost	Transition Cost
Evolutionary Path #3 (narrow: BRT → RRT)	530	780
Alternate Approach #3 (Busway → Replace Guideway)	390	1120

Note: Costs are in millions of 1973 dollars.

It should be noted that the range of years to transition shown on Figure IV-4 is 50 years rather than the 25-year period plotted on the two previous figures. This longer time span emphasized an inherent characteristic of present value analyses involving two separate investments. That characteristic is that the longer the second investment is postponed, the closer the present value will approach the cost of the original investment. For example, using a 10 percent

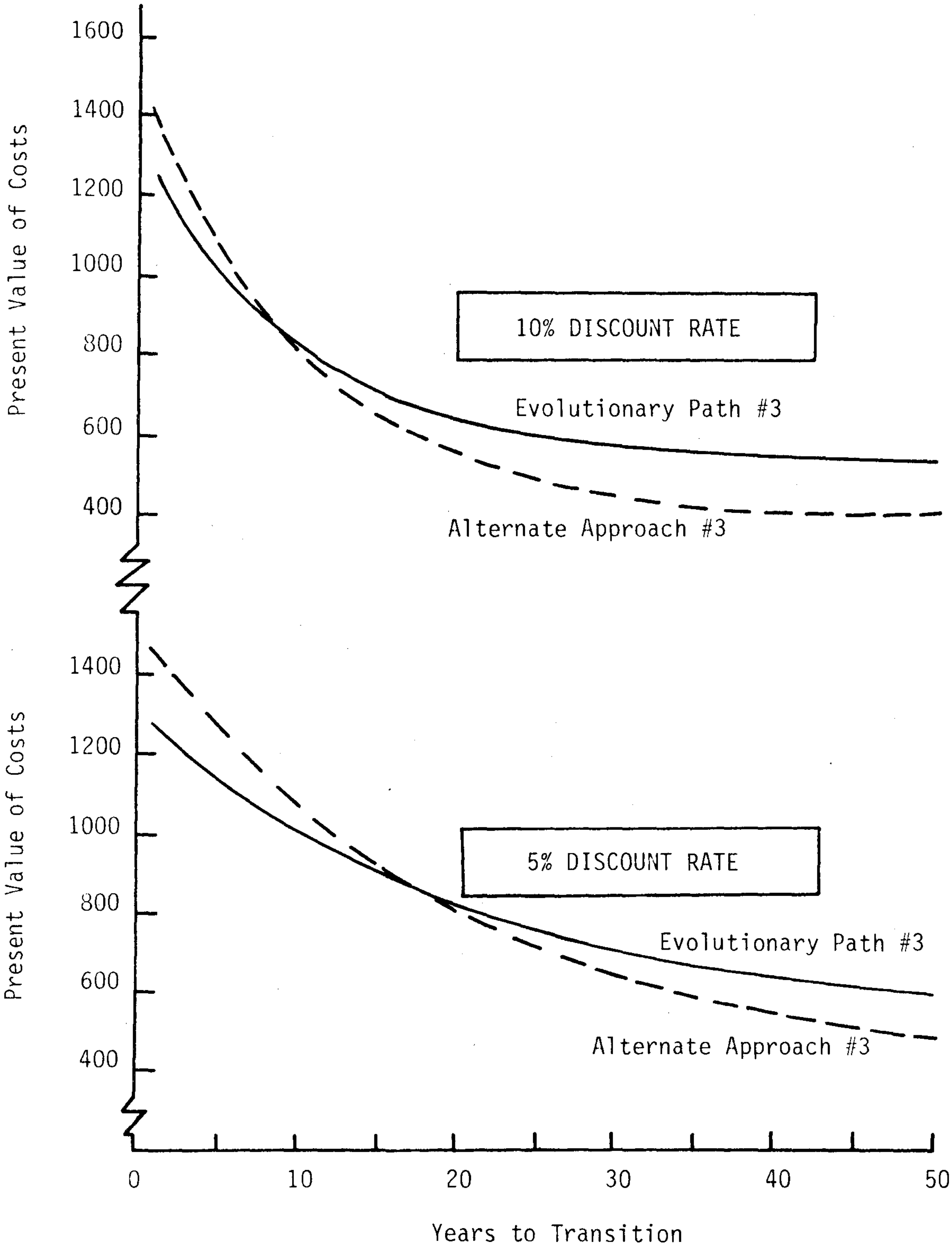

Figure IV-4: Present Value of Evolutionary Path #3 and Alternate Approach #3

discount rate, the present value of Alternate Approach #3 is only $400M after 50 years, compared to an original cost of $390M.

A significant implication of this characteristic is that, even though the alternate approach eventually replaces the evolutionary design as the lowest cost option, the present value difference in costs will never exceed the difference in initial costs. Thus, the total monetary risk associated with an evolutionary design is defined by the differences in initial costs of a busway and the evolutionary transitway.

Decisional Considerations

Thus far, the results of this study indicate that an evolutionary design is technically feasible, but that it will require a larger initial investment. Further, this higher initial investment will reap economic benefits only if a transition occurs within a specific time. Thus, it seem that several additional questions need to be addressed before a decision can be made concerning the desirability of building an evolutionary design rather than a busway.

The following questions are addressed in this section.

1. What is the probability that a transition in modes will ever be needed?
2. What are the penalties associated with building an evolutionary design and then never making a transition?
3. What are the risks associated with not having an evolutionary design if a change in mode does become desirable?
4. What other factors should be considered?

Hopefully, the discussion of these questions will identify most of the major decisional considerations concerning the evolutionary guideway concept.

Probability of Transition

The most commonly cited expected reasons for a transition from buses to RRT or AGT are to achieve an increase in capacity and a decrease in labor intensity. However, the evaluation of technical attributes presented in Section II indicates that these expectations are ill-founded--at least with today's state-of-the-art. Buses on transitways offer a higher capacity than any other existing technology. (An RRT system with off-line stations has a higher theoretical capacity, but no such system is in existence.) The labor intensity appears to be equivalent for all existing technologies.

Buses on transitways appear to be equal or superior to RRT or AGT in all other technical attributes evaluated (energy efficiency, reliability, safety, and others). Thus, it appears that a transition from buses to AGT or RRT cannot be justified for technical reasons unless dramatic technological advancements are made in AGT or RRT systems.

AGT is the newest transit technology available. Indeed, the two existing systems (the Morgantown PRT and AIRTRANS at the Dallas/Fort Worth Airport) could be considered "first generation" systems. The federal government has already made a commitment to help finance the construction of four new AGT systems. The probability that significant technologic advancements in AGT systems will be made appears high. However, before AGT will become a suitable replacement for buses, drastic improvements in reliability and modest improvements in labor intensity will be needed. Such improvements might very well accrue in future generations of this technology.

RRT systems, on the other hand, have been in operation for eighty years. Certainly, many technological advancements have been realized during that time span, but the potential for dramatic new advancements in RRT technology appears low.

Labor intensity, because of its close relationship to operating costs, is probably the most likely of all of the attributes evaluated to stimulate a desire for change. The most significant differences in the labor forces required to operate AGT and RRT systems appear to be in in track maintenance and control system maintenance. RRT systems require about three times as many people to maintain tracks as are required to maintain roadways for bus or AGT vehicles. The more sophisticated control system for AGT, on the other hand, requires more maintenance. If significant improvements can be made in either of these two areas of operation, then the labor intensity of the associated mode will be reduced.

In summary, the cost of transition from buses to AGT or RRT cannot be justified on a technical basis unless dramatic technological improvements occur. The likelihood of such progress in AGT technology appears better than RRT. Yet, the probability that a transition to either mode can be justified technically within the next twenty years appears low.

Penalties for Not Making the Transition

If additional investments are made initially to build an evolutionary design and no transition is ever justified, then the added investment represents an economic penalty. The initial investment could have been reduced or the added costs could have been applied to other areas (more miles of guideway, more amenities, etc.). The only benefit that will have accrued from the evolutionary capability is the sense of security it provided during the interim.

According to the cost estimates developed previously, the added investment required for evolutionary capability is 2 percent for AGT or 29 percent for RRT. If the evolutionary capability is considered as insurance against future eventualities, then the 2 percent additional investment would probably be considered money well spent. A 29 percent premium for insurance on the other hand, would probably be considered too high.

In any event, it will be at least 25 years before anyone can say with certainty that the evolutionary capability was not needed. Thus, the penalties associated with not making a transition are neither immediate nor severe.

Risks of Not Having Evolutionary Capability

The results of the present value analyses indicate that the economic risks associated with not building the evolutionary capability are less than those associated with not making a transition. For example, Alternative Approach #2A only costs 20 percent more than Evolutionaty Path #2 if the Transition occurs immediately. If, however, the transition is not needed for 15 years, there is little or no economic penalty associated with having to tear out the busway to build an RRT guideway.

Operational considerations, however, may preclude the option of tearing down the busway to construct an RRT system. Unless the bus system had attracted tremendous ridership, a transition to RRT would probably never be seriously considered. Thus, a heavily utilized bus operation would have to be displaced from the transitway system for four or five years in order to construct the RRT system. Such a move would be very detrimental to the system. Thus, there is a high probability that unless the original system is capable of accommodating RRT, a transition to RRT will never occur.

Converting a busway to AGT operations, on the other hand, appears to be feasible. The conversion would entail retrofitting raceways for power and control cables into existing structures. Although the retrofitting process will be more costly than including the raceways in the original design, it can be accomplished. Thus, the risks associated with not providing for AGT appear to be very small.

Other Considerations

Numerous other considerations might influence a decision of whether or not to choose the evolutionary guideway design. The following considerations are examples of the types of factors that could influence the decision.

- If a high-density urban form is desired, then RRT might be desired in the future.
- If the existing CBD street system is not well suited to heavy bus use, then the probability of a future transition is higher.
- The evolutionary capability may be a key sales point in gaining voter approval of the necessary bond issues.

The number and nature of these types of considerations that might influence a decision will vary with local conditions.

V. CONCLUSIONS

Current long-range transportation plans for the Dallas-Fort Worth area call for the development of several transitways that will initially be used by buses and carpools. The objectives of this study were to evaluate the feasibility and desirability of designing these transitways so that they could be converted to other mass transportation technologies in the future.

The methodologies and findings of this study have been described in the first four sections of this report. All of this discussion can be reduced to five major conclusions. These five conclusions are identified and discussed briefly in the following paragraphs.

1. *The evolutionary guideway concept is technically feasible.*

An evolutionary guideway design that can accommodate continuous bus operation while being converted to AGT or RRT operations was identified. The key to the whole approach is the wide guideway that was originally needed only to accommodate stalled vehicles during bus/carpool operations.

The wider guideway design developed in this study requires slightly more right-of-way than a 2-lane busway. Also, it is estimated to be about 25 percent more expensive than the narrow guideway. Initially, these were considered penalities that were entirely associated with the decision to permit carpools to use the transitway. However, further evaluation showed that the wide guideway design offered a simple solution to the problem of providing for continuous bus operation during transition. Also, the shoulders continue to provide positive benefits to the subsequent transit operation after a transition has been made. Thus, the higher costs associated with the wider guideway appear to be well justified.

It should be noted that the conceptual designs developed in this study are not intended to be interpreted as the only way to accomplish this goal. Rather, they are considered as representative of a design approach that will enable a guideway system to be truly evolutionary. Certainly, they should be sufficient to support the conclusion that the evolutionary guideway concept is technically feasible.

The design for Evolutionary Path #1 (Bus/carpool → BRT → AGT) is the simplest of the evolutionary designs. The initial cost of Evolutionary Path #1 is estimated to be only 2 percent higher than the cost of Reference Design #2 (wide busway). Certainly, if carpools are to be accommodated on the transitway initially, then the added costs of providing for future transition to AGT appear justified.

The conceptual design developed for Evolutionary Path #2 (Bus/carpool → BRT → RRT) could be considered a "universal guideway" design. It has the structural capability to accommodate any existing mode (bus, AGT, LRT, or RRT) and would probably serve any new mode that might develop in the future. The estimated initial cost of this design is only 29 percent more than the non-evolutionary wide busway design. Even though this is a relatively modest increase in cost to achieve a "universal guideway" design, other factors cast serious doubt upon the need for this transitional capability.

Evolutionary Path #3 (Narrow: BRT → RRT) is similar to the designs that are most frequently found in previous studies that are referred to as evolutionary transitways. It is designed to accommodate either buses, AGT, LRT, or RRT; however, it does not provide for continuous operation of buses during the transition.

2. *A provision for continuous operation of buses during transition is vital to the evolutionary transitway concept.*

The results of the analysis of operations during transition, performed as a part of this study, indicate the importance of providing for continuous bus operation during transition. Indeed, it appears highly unlikely that a transition would ever be made unless continuous bus operation could be accommodated. Several factors combine to support a conclusion that a provision for the continuous operation of buses during transition is vital to the evolutionary transitway concept.

First, the time that transition will require is estimated to be three to five years. Thus, any degradation in service that occurs during the transitional phase will be prolonged over many months.

Second, a reduction in the overall operating speed of buses will occur during the transition. This reduction in speed, however, will be far more severe if the buses are displaced from the transitway to existing streets during the transition. This reduction in speed has a dual impact--it will increase the cost of bus operations, and it will decrease the quality of service offered. The differences in estimated speeds during transition for

Evolutionary Paths #1 and #2 (which provide for continuous operation of buses during tranisiton) and Evolutionary Path #3 (which assumes that the buses will be displaced to the street) is a ratio of approximately 2 to 1. Thus, the impact of speed differences will be significant.

Third, the number of buses that can safely be served during the transitional period is significantly different than during busway operations. It is unlikely that a transition would be made unless heavy ridership had been developed on the bus system. Yet, the bus capacity available during transition will be less than the capacity available during normal transitway operation. Indeed, the capacity available from operations on adjacent streets is probably less (330 buses per hour) than would be needed.

Finally, the resulting disruption to other corridor traffic during the transitional period is dramatically higher if the buses are displaced from the guideway. The degree of disruption that would result from Evolutionary Path #3 would almost certainly generate strong public protests.

Service disruptions of the magnitude associated with the displacement of buses from the transitway might be justified in a program to develop a transitway system where none existed before; however, it is unlikely that they would be acceptable merely to change the transit technology from buses to something else. Hence, it appears that a provision for the continuous operation of buses during transition is vital to the evolutionary transitway concept.

3. The evolutionary capability may never be needed.

Even though an evolutionary design is technically feasible, a need to transition from buses to another mode may never develop. The analysis of attributes (labor intensity, capacity, energy efficiency, safety, reliability, and other attributes) for existing technologies (bus, AGT, LRT, AND RRT indicate that buses on transitways are equal or superior to the other technologies in almost every respect. Significant technological advancements will need to occur in the other modes before a transition from buses would be justified for technical reasons. Thus, the probability that the evolutionary capability will ever be needed appears to be low.

The implications of this conclusion tend to confuse the other findings of this study. Even though the evolutionary guideway concept has been found to be technically feasible, if the probability that the evolutionary capability will ever be needed is low, then a serious doubt remains concerning the advisability of opting for the more expensive evolutionary design. A simple busway might be all that will ever be needed.

4. *The added initial cost required for evolutionary capability must be considered as an investment risk.*

The economic analyses (cost estimates and present value analyses) indicate that the added initial investment required for evolutionary capability would definitely be cost effective if a transition is made within the limited time period after initial construction. The exact duration of the time period varies significantly with the discount rate assumed and the estimated cost values (Note--the sensitivity of the analytical procedure used to these variables is discussed in Section IV).

However, the added initial investment in evolutionary capability reaps economic dividends only if a transition occurs. If the need for a transition never develops, then the added initial investment for evolutionary capability could be considered as an insurance policy.

Evolutionary Path #1 (Bus/carpool → BRT → AGT) requires only an estimated 2 percent additional investment over a wide busway (Reference Design #2). This appears to be a modest premium to pay for insurance. On the other hand, Evolutionary Path #2 (Bus/carpool → BRT → RRT) requires an estimated initial investment 29 percent greater than a wide busway. This may be considered to be too high a price to pay for insurance purposes.

5. *Evolutionary Path #1 (Bus/carpool → BRT → AGT) appears to be the best choice for a transitway design.*

A review of the economic considerations, probabilities of technological advancements, penalties and risks, and other considerations identified in this study leads to the conclusion that--if the decision is to be made today, based upon the results of this study--Evolutionary Path #1 is the best overall choice. The major factors leading to this conclusion are as follow.

1. If carpools are to use the transitway, then some provision for stalled vehicles is needed. The wide guideway appears to be the best approach for accommodating stalled vehicles.
2. The added initial cost of Evolutionary Path #1 over the wide busway is modest (an estimated 2 percent).
3. The probability that significant technological advancements will occur appears higher in AGT system designs than in other technologies.

Certainly, the greatest unknown in this decision making process is the probability that sufficient technological advancements will occur to stimulate the need to make a transition. Forecasting future technological advancements is always a risky business. This study assessed the technology available in existing operating transit systems. Those areas that would require significant improvements were identified. Based on this assessment, AGT appears to offer the most promise for dramatic improvements in the critical areas. Even so, the inherent risks associated with forecasting future technology should be recognized.

Another qualification worthy of note concerning this study is the inaccuracies associated with assigning definitive cost values to the various conceptual designs--particularly the right-of-way costs. Preliminary cost estimates are seldom accurate to within ± 10 percent. Variations in the cost estimates for each design within this range could significantly alter their relative costs. If so, then the resulting conclusion concerning the preferred design could change.

In view of these two areas of possible uncertainty, the following studies are recommended for the selection of a preferred transitway design concept for the Dallas-Fort Worth area.

1. The initial guideway design phase for the system should include the development of detailed preliminary engineering designs for each design concept being seriously considered.

Based upon these design studies, more definitive cost and right-of-way requirements can be developed and compared.

2. An updated assessment of the state-of-the-art in AGT and RRT technologies should be made so that the probability of a future need for transition can be better defined.

After these studies are accomplished, the selection of the preferred design approach can be made with more confidence. However, unless these studies result in significantly different values, the preferred choice will be Evolutionary Path #1 (Bus/carpool → BRT → AGT).

Summation

This study has focused upon the feasibility of designing transitways that are capable of accommodating continuous operations of buses during transition to another operational technology. This concept of evolutionary transitway design has been found to be feasible and valid. However, the need for an evolutionary capability appears questionable, based upon the present state-of-the-art of transit systems.

The major objective of this study was to evaluate the feasibility and validity of the evolutionary concept. A secondary objective was to identify all major considerations in designing such a system. Hopefully, the information contained in this report is sufficient to achieve both objectives. Even if the findings of these limited studies are insufficient to permit a final decision to be made concerning the appropriate design approach for a specific metropolitan area, the methodology developed herein should prove useful.

Although all analyses in this study are directed toward the conditions that prevail in the Dallas-Fort Worth area, the topic is one of general interest to transportation planners in many cities. Perhaps the results of these analyses will be useful to other planning efforts around the nation.

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