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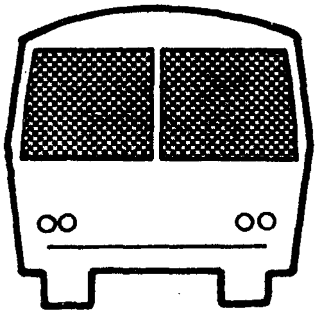
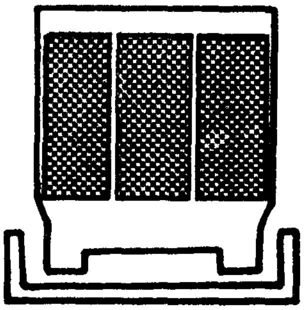
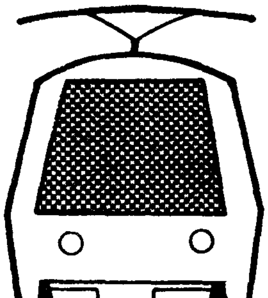
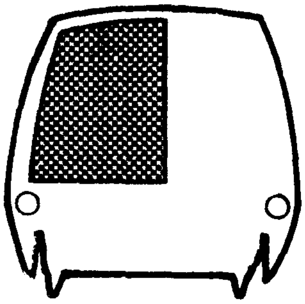
TECHNICAL MEMORANDUM NO. 2

ANALYSIS AND SELECTION OF TRANSITWAY EVOLUTIONARY PATHS









North Central Texas Council of Governments

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY SYSTEM

Technical Memorandum No. 2

ANALYSIS AND SELECTION OF TRANSITWAY EVOLUTIONARY PATHS

Submitted to
North Central Texas Council of Governments
Arlington, Texas

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by

Texas Transportation Institute
Texas A&M University System
College Station, Texas

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I. INTRODUCTION

INTRODUCTION

Current long-range transportation plans for the Dallas-Fort Worth Metropolitan Area call for the development of several transitways by 1990. These transitways will initially operate with buses and carpools; however, future conditions may make it desirable to transition from buses to some other form of mass transit along these same rights-of-way. Hence, the feasibility of designing transit facilities that can be easily adapted to various forms of mass transportation is a legitimate concern.

"Transit Technology Selection Analysis for the Dallas-Fort Worth Intensive Study Area" is a study designed to evaluate the feasibility and desirability of designing transitways that can evolve from one form of mass transportation to others. The objectives of this study are as follows:

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 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.

The purpose of this technical memorandum is to document the findings of the study concerned with the first objective listed above. The method of analysis used to determine logical evolutionary paths was as follows:

1. Several attributes were identified (such as labor intensity, capacity,

energy efficiency, etc.) which might serve to stimulate a change in technologies at some future time;

2. Data were collected and analyses were performed to determine appropriate attribute values associated with each technology; and
3. Potential evolutionary paths were identified and evaluated in accordance with the attribute values and other factors that might stimulate a change in technology.

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. ANALYSIS OF ATTRIBUTES

Previous transportation planning studies for the Dallas-Fort Worth Metropolitan Area have documented the need for exclusive facilities for mass transportation by 1990 (1)*. These studies have further documented the advisability of initially operating most of these transitways as bus/carpool facilities. An acknowledgement is made that it may become desirable, at some future date, to convert the transitways to utilize some other form of mass transportation technology. However, no effort was made in the previous studies to identify any particular set of conditions that might make a change in the form of mass transportation desirable.

If the transitways are designed initially 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 capability of various mass transportation technologies seems an appropriate first step in identifying logical evolutionary paths.

Information concerning the relative capability of various forms of mass transportation technologies in labor intensity, capacity, energy efficiency, safety, and reliability is presented in the following portions of this section. Additionally, several 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. Information developed through this analysis will also be useful in developing designs and evaluating the feasibility of those evolutionary paths selected.

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*Denotes number of reference listed at end of report.

LABOR INTENSITY

Analysis of Existing Operations

Generally, mass transportation planners have assumed that bus transit is more labor intensive than rail rapid transit (RRT). Such an assumption is entirely understandable when one realizes that buses require a driver for every 50 passengers, while RRT trains only require one motorman for every 750 passengers. However, an analysis of the manpower required to operate various types of existing transit systems fails to substantiate differences in labor intensity.

Data presented in Figures 1 and 2 are from various transit systems in the nation serving large cities (2). 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 on the curves.

The curve on Figure 1 depicts a labor intensity of 22 employees per million annual passengers. The curve on Figure 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 are approximately ± 10 percent of the values depicted by the line. Approximately half of the data points fall within the bands.

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, and rail rapid transit 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

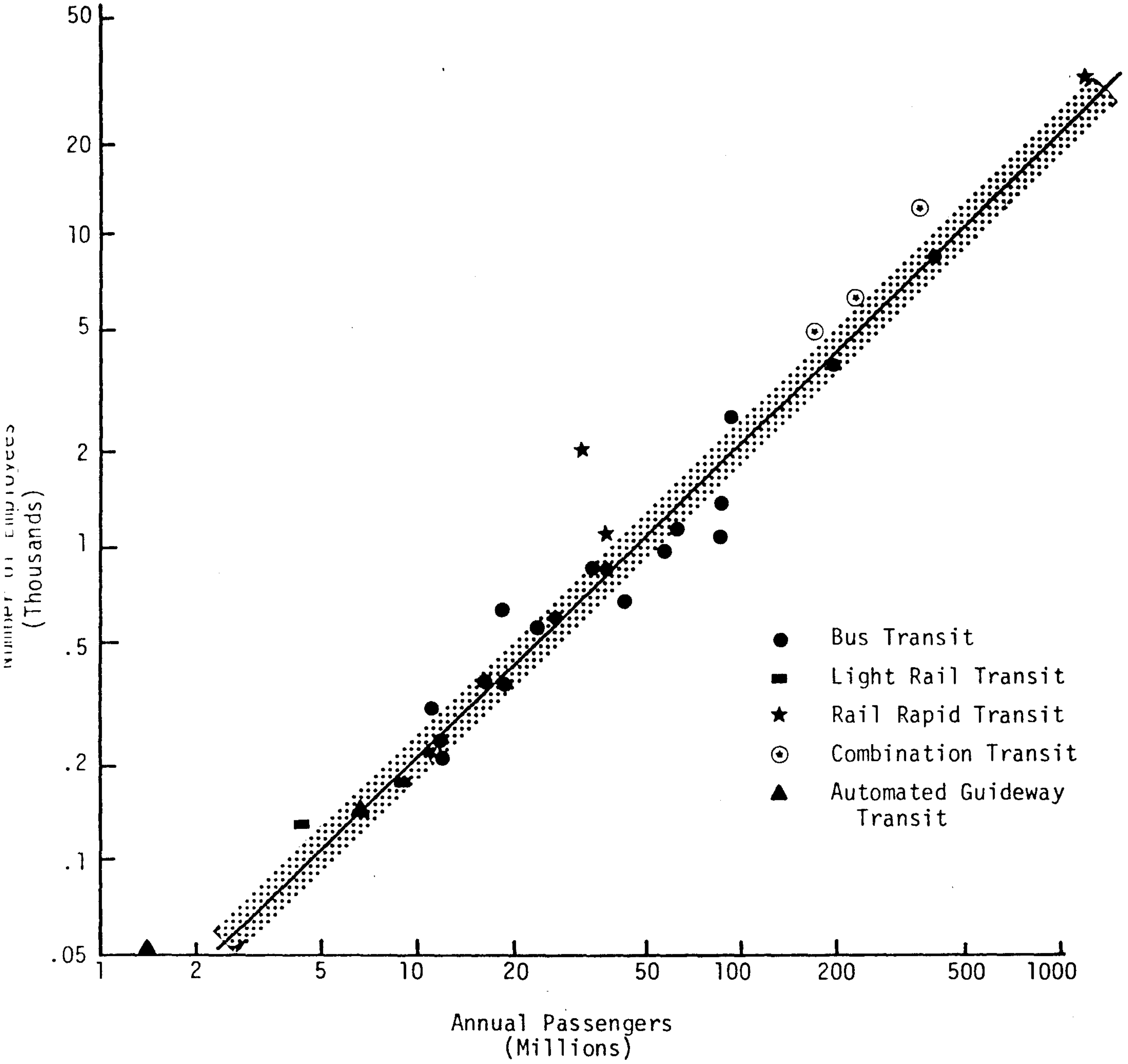


Figure 1: Labor Intensity of Transit as a Function of Ridership

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

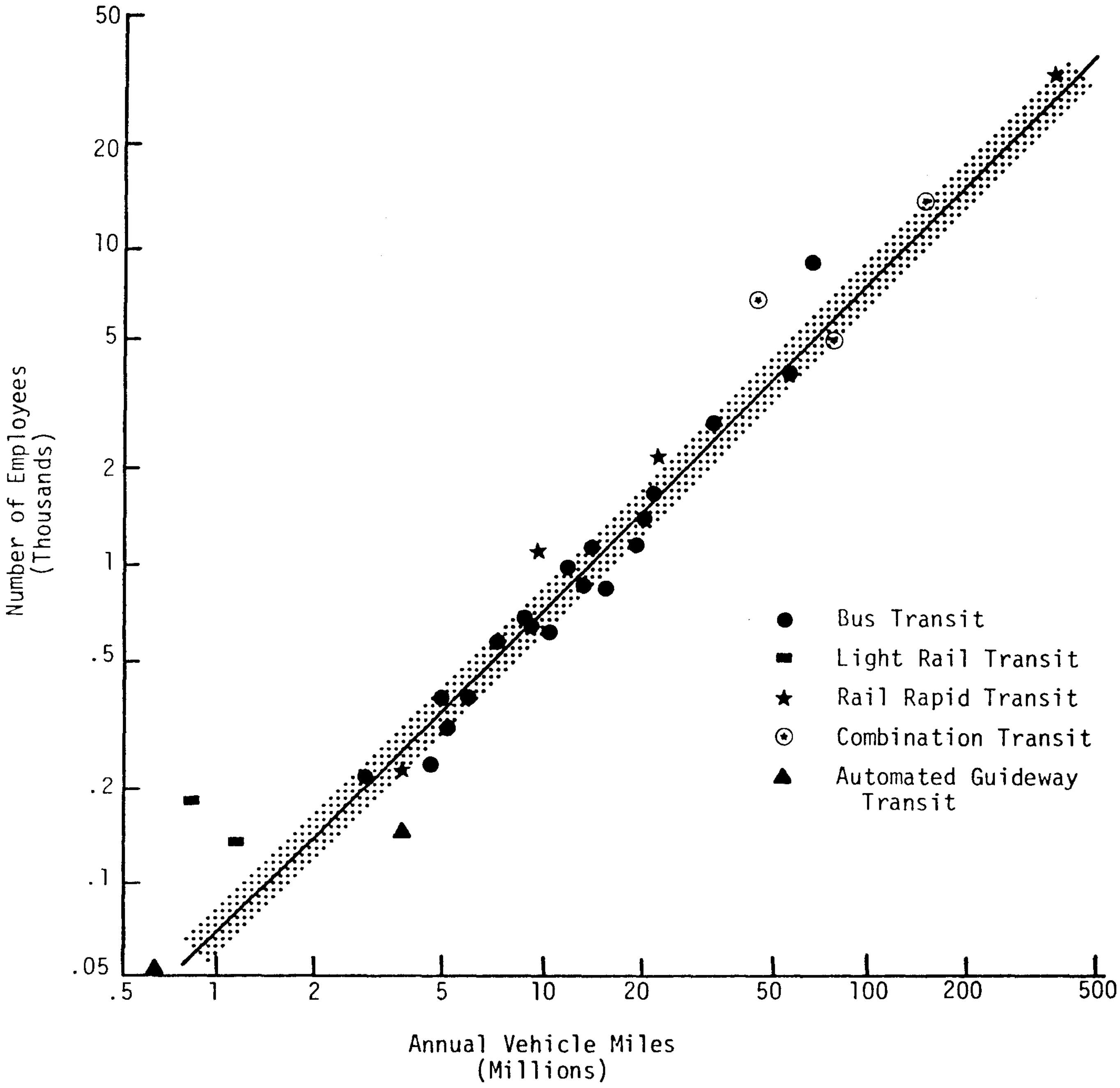


Figure 2: Labor Intensity of Transit as a Function of Service Provided

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

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 other than ridership or vehicle-miles of service can affect labor intensity. A transit system that provides dramatically increased levels of service during peak-periods will have a higher labor intensity than one that only provides moderate increases in service during peak periods. Also, a system that provides service 24 hours per day, 7 days per week will tend to have higher labor intensity than one that only operates on weekdays. Thus, it is surprising that there is such close agreement between vastly different systems. Nevertheless, the curves shown on Figures 1 and 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.

It should be noted, however, that these data are for existing operational transit systems. These data were not adjusted to account for the differences in the nature of operation of conventional bus systems and typical rail systems. Existing RRT systems perform several functions that are not performed by employees of conventional bus transit systems (i.e., maintenance of way, security guards, and station operation and maintenance). Table 1 compares the functions that are typically performed by the different type transit systems included in this analysis.

A bus operation such as planned for the Dallas-Fort Worth Metroplex, using exclusive transitways, would require some functions not performed by a conventional bus transit operation. In order to compare labor requirements of

Table 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

different technologies on a common basis, an analysis of representative systems for the Dallas-Fort Worth Metroplex is needed.

Analysis of Comparable Systems

In the plan for 1990, a total of 65 miles of transitways is included in addition to the proposed transitway linking the two cities and the regional airport (2). Also, on Figure 50, page 137, of the report, projected daily ridership values are presented which total to 414,000 daily riders using these transitways. A total of 37 stations (or park-and-ride lots) are included in the plan for these 12 corridors. These figures were used in the following analysis.

Assuming the estimated daily ridership to be representative of a typical workday, then the annual ridership would be some factor times the average daily ridership. If the system in 1990 is only operated on normal workdays, the annual ridership will be approximately 250 times the daily ridership, or a total of 103.5 million. If some service is provided on weekends and holidays, then the annual ridership will be approximately 300 x 414,000 ≈ 124 million.

The labor intensity relationship shown on Figure 1 indicates that the employment of the system would be 2250 to 2600 employees, depending upon the annual ridership figure used (103.5 million or 124 million). Recognizing that the proposed transit system will probably perform more functions than do many existing systems, it seems appropriate to evaluate whether or not these additional functions would significantly change the number of employees required for a transit system. The following paragraphs discuss the number of employees that might be added to appropriately account for the planned transit system's needs to maintain route and way, operate stations, and provide security or enforcement.

<u>Maintain Route and Way</u> - None of the bus systems shown on Figures 1 and 2 maintain their own route and way as do all other technologies; therefore, only the employment value for bus system need be adjusted for this function. A two-pronged approach was used to determine the appropriate number of employees needed to maintain 65 miles of busway. First, employment information was obtained from two representative RRT systems to determine the number of employees assigned to maintenance of routes and way in these systems. Second, information was obtained from an urban district of the State Department of Highways and Public Transportation to determine the number of employees needed to maintain urban freeways. These two numbers were then compared and an appropriate value selected.

The Port Authority Transit Corporation (PATCO), which operates the Lindenwold Line, and the Bay Area Rapid Transit District were contacted concerning a breakdown of employees by assigned functions. These two RRT systems were selected for several reasons, including the following:

(1) They are both totally RRT systems and do not operate other forms

of transit so that the employment breakdown was simple.

(2) They represent the two ends of the existing RRT spectrum--with Lindenwold being the most Spartan (fewer frills) operation in the nation and BART being the newest and fanciest in full operation.

Data concerning the grouping of employees by assigned function for these two systems are presented in Table 2 and Table 3. Employment information for bus systems in Dallas and Fort Worth is presented in Table 4 for comparison purposes only. It should be noted that employee totals for both RRT systems are carried by position codes rather than functions shown in these tables. However, the personnel department of each system provided the breakdown shown in these tables using their "best guess."

Dividing the number of employees assigned to way and power maintenance by the miles of route in each system, the following values are obtained:

	Employees/ Route-Mile	
PATCO:		
Track	1.8	
Power and Signal	2.3	
Total		4.1
BART:		
Total		4.2

District 12 (Houston) of the State Department of Highways and Public Transportation has had a "Maintenance Management" program in operation for several years in which they allocate manpower to the maintenance section in accordance with a formula involving the number of miles of various types of facilities to be maintained. The formula is adjusted periodically in accordance

Table 2: Lindenwold Line (PATCO) Employment Information
(as of January 1976)

Assigned Function	Number of Employees	
(1) Train Operations		46
(2) Station Attendants		18
Supervisors	5	
Maintenance	5	
Revenue Collection	8	
(3) Equipment Maintenance		71
Supervisors	6	
Equipment (general)	37	
Electrical	28	
(4) Facility Maintenance (Way and Power)		59
Supervisors	5	
Maintenance (general)	7	
Track	19	
Power and Signal	28	
(5) Security		21
(6) Management and Administration		29
(7) Miscellaneous (Purchasing, Traffic, etc.)		39
TOTAL		283

Source: PATCO

with the resulting level of maintenance. This past year, their formula allocated a high of 0.6 employees per mile of urban freeway compared to 0.45 employees per mile of rural freeway, and 0.09 employees per mile of rural two-lane farm-to-market roads, with several values in between for other types of facilities.

Table 3: Bay Area Rapid Transit (BART)
Employment Information
(as of October 31, 1976)

Assigned Function	Number of Employees
(1) Train Operations	165
(2) Station Agents	150
(3) Maintenance of Vehicles	300
(4) Maintenance of Track and Way	316
(5) Security	87
(6) Management and Administration	112
(7) Miscellaneous*	952
TOTAL	2082

*This category includes many engineers and technicians involved in "debugging" and system development.

Source: BART

Table 4: Employment Information for Dallas and Fort Worth Bus Systems (as of November 1976)

Assigned Function	Number of Employees	
	Dallas (DTS)	Fort Worth (CITRAN)
Transportation Functions:		
Supervision	62	12.5
Support Personnel	12	4
Vehicle Operators	520	136
Maintenance of Vehicles:		
Supervision	19	4.5
Support Personnel	49	2
Mechanics	27	20
Body Maintenance	15	--
Vehicle Servicing	47	9
Administration & Office	55	19
Miscellaneous	10	--
Part-Time Employees	42	--
	858	207

Sources: DTS and CITRAN

Because the average urban freeway in Houston has between 10 and 12 lanes (including frontage roads), the allocation of 0.6 employees per mile seems a bit high for two-lane, or even four-lane, busways. However, comparing this value to the number of employees required to maintain a mile of RRT (4.1 per mile total or 1.8 per mile for track only) raises some questions as to the validity of the number. In an effort to determine if rail lines require a higher level of maintenance manpower than freeways, the following data were collected. The Association of American Railroads provided information showing that on a nationwide basis, Class I railroads use 0.43 route maintenance employees per mile of route. The State Department of Highways and Public Transportation (SDHPT) estimates their current manpower assigned to maintenance at 7586 employees statewide, which results in a ratio of 0.108 employees per mile of highway. However, railroads tend to perform all maintenance jobs with their own crews, while SDHPT contracts major maintenance efforts such as overlays, etc. Estimates received from SDHPT and the Association of General Contractors indicate that somewhere between 1500 and 3000 contractor employees are engaged in maintenance activities on Texas highways on an annual basis. Thus, the adjusted ratio for maintenance of the 70,000-mile highway system in Texas is approximately 0.15 employees per mile.

The comparison, then, for railroads nationwide is 0.43 employees per route mile to 0.15 employees per mile of highway in Texas. This reflects a ratio of approximately three times as many employees required to maintain a mile of railroad as are required to maintain a mile of highway. This is similar to the ratio between the Houston District (0.6 employees per mile of urban freeway) and the Lindenwold Line (1.8 employees per route-mile devoted to track maintenance).

Although the reasons for the difference in maintenance manpower required for rail lines and highways cannot be explained at this time, it appears appropriate to use a value of 0.6 employees per mile of transitway in this analysis. Thus, for a 65-mile system of transitways, a bus system would need 39 additional employees for route maintenance.

Station Operation and Maintenance - In a bus/carpool system for the Dallas-Fort Worth areas, park-and-ride lots with shelters and terminals would probably constitute the "stations." These stations would probably be attended during normal hours of operations. Thus, some number of employees should be assigned to a bus system for station operation and maintenance. Also, the two light rail transit systems included in the data from Figures 1 and 2 do not operate stations, so a similar value will be added to LRT employment for this function.

A look at the data from the two RRT systems shows the following number of employees engaged in station operation and maintenance:

PATCO	1.5 employees/station
BART	4.4 employees/station

PATCO uses the barest essentials in its station design and operation, while BART has extensive landscaping, beautification, restrooms, and information booths associated with its station operation. The proposed Dallas-Fort Worth system would probably operate somewhere between these two extremes. An average of three employees per station is assumed to be appropriate for this analysis. Thus, a total of 111 additional employees will be needed on both the bus and LRT systems for station operation and maintenance.

Security - RRT systems typically employ their own security forces to police station areas and trains. None of the other technologies typically have their own security force. There is some question as to whether a transit system without extensive subways would need a special security force. However, if the transitways are initially used for buses and carpools, some enforcement will be needed to control the use of these facilities. For the purpose of this analysis, a total of two officers per major on-ramp is assumed to be an appropriate number of security personnel. A major on-ramp is assumed for each park-and-ride lot (a total of 37). Hence, a total of 74 employees will be added to the bus system for security and enforcement functions. A similar number of security personnel is assumed for AGT and LRT systems so that two officers would be available for each station.

Summary of Findings - In adding these additional employees to bus, LRT, and AGT systems for the Dallas-Fort Worth system the following comparison results:

Technology	Total Employees
Rail Rapid Transit	2250
Automated Guideway Transit	2324
Light Rail Transit	2435
Bus Transit	2474

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 1 and 2, it appears that the accuracy of the curve used to determine the initial number of employees is less than ± 10 percent.

In view of all of the factors discussed in this analysis, it appears appropriate to conclude that differences in labor intensity between these technologies are so small that a single relationship can indeed 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, or

(2) 75 employees per million annual vehicle-miles of service.

CAPACITY

Many confusing and conflicting values for capacities of various transit technologies are found in the literature. The confusion stems from the fact that capacity values are quoted for different sets of conditions. For example, the capacity quoted may be for maximum crush load or for seats available, based on observed operations or theoretical calculations, or for typical design configurations or special designs.

In order to compare capacities of various technologies on an equal basis for this study, the following conditions were assumed to be relevant.

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

Rail Rapid Transit

Existing rail rapid transit lines have carried more than 60,000 persons per hour (see Table 5); however, these capacities were achieved with more than two-thirds of the passengers standing. None of the operations listed in Table 5 achieved as many as 20,000 seats per hour.

Table 5: Rail Rapid Transit--Observed Peak Hour Volumes

Location	Trains Per Hour	Headway (Seconds)	Actual Passenger Load	Seating Capacity			% Seated	Average Speed
				Per Car	Per Train	Total		
NEW YORK	32	112	61,400	60	600	19,200	31	24.5
NEW YORK	31	116	44,510	40	360	11,160	25	19.6
NEW YORK	30	120	62,030	60	600	18,000	29	28.7
TORONTO	28	128	35,166	62	496	13,888	39	17.6
CHICAGO	25	144	10,376	49	294	7,350	71	24.5
NEW YORK	24	150	36,770	40	360	8,640	23	19.5
CLEVELAND	20	180	6,211	53	318	6,360	100	28.0

SOURCE: Capacity and Limitations of Urban Transportation Modes, Institute of Traffic Engineers (1965).

Because they use "on-line" stations, the constraining factor in all existing RRT operations is the time required for a train to enter a station, off-load and on-load passengers, exit the station and provide sufficient time before the next train enters to ensure safety. The shortest average time between trains shown in Table 5 is 112 seconds. However, most experts agree that headways as short as 90 seconds are technically achievable.

BART was designed to achieve a 90-second headway between trains. At capacity operation, each BART train will have 10 cars with 72 seats each. Thus, the design capacity for BART is:

$$40\ {}^{\text{trains}}/_{\text{hour}} \times 720\ {}^{\text{seats}}/_{\text{train}} = 28{,}800\ {}^{\text{seats}}/_{\text{hour}}.$$

Although BART has not yet achieved this design capacity, it seems appropriate to use this design value as the capacity of RRT systems with on-line stations.

If a rail rapid transit system were designed with off-line stations of sufficient capacity, the constraining factor for capacity would become the spacing between trains required to ensure safety in the line-haul portion.

For the purposes of this analysis, an automated block system, in which the power is shut off in the block behind a train, is assumed.

If a BART type system is assumed, train lengths would be 750 feet and emergency stopping distance from 70 mph would be 875 feet. (Note: BART has now reduced their maximum speed between stations from 80 mph to 70 mph in an effort to reduce vehicle maintenance). Hence, a 1000-foot block length would be about the shortest appropriate length.

The requirement for one "dead" block between trains results in a minimum of two empty blocks between trains. The resulting minimum distance between the front of one train and the front of the following train would then be 2750 feet. However, such close spacing would result in jerky operations for the trailing train, because it would often encroach the "dead" block moments before the power was restored. Hence, an average space-headway of 3000 feet seems appropriate.

At 70 mph (102.67 feet/second), the time-headway between trains is 29.2 seconds, resulting in a flow-rate of 123 trains per hour. The ultimate capacity of an RRT system with off-line stations then becomes:

$$123 \ {}^{\text{trains}}/_{\text{hour}} \times 720 \ {}^{\text{seats}}/_{\text{train}} = 88{,}560 \ {}^{\text{seats}}/_{\text{hour}}.$$

Incidentally, such a system would require six parallel tracks (three in each direction) in each station.

Light Rail Transit

LRT systems also typically operate with on-line stations, and the headway through a station is the constraining factor in determining capacity. Due to their shorter lengths and slower speeds, however, LRT trains should be able to achieve shorter headways at stations. The authors of a recent report on a review of LRT state of the art imply that 60-second headways are feasible (3). Using vehicle information contained in this report and assuming 60-second headways, the capacities shown in Table 6 were calculated.

Table 6: Capacities for LRT Systems With On-Line Stations*

Vehicle	Length, Feet	Seats/ Vehicle	Maximum Vehicles/ Train	Capacity, Seats/ Hour
Bremen 4 Axle	115	93	2	11,160
SLRV	71.5	68	2	8,160
Economy LRV	47.5	48	4	11,520

*Assumes 60-second headways at stations.

Based upon information contained in Table 6, it appears reasonable to assume a maximum capacity of 11,520 seats/hour for LRT systems with on-line stations. Of course, LRT systems could also be constructed with off-line stations as was discussed for RRT systems. Indeed, some European systems do have isolated instances where two or more routes converge and operate on a single track over some physical barrier (river, etc.). Some observed capacities over these line-haul segments are shown in Table 7 which is lifted directly from page 204 of Reference 3.

It should be noted that the capacities shown in Table 7 are observed volumes and not necessarily limiting cases. The highest number of vehicles per hour listed is 92 which corresponds to an average headway of 30 seconds. If an analysis similar to that performed for RRT systems is conducted for LRT

Table 7: Line Capacity for Selected Light Rail Systems

City	Private* Right-of-Way (Percentage)	Maximum Frequency (Vehicles per Hour)	Maximum Achieved Capacity (Passengers per Hour)
Brussels	N/A	51-72	9,600**
Cologne	77	56-62	13,600
Dusseldorf	36	92	14,000
Frankfurt	65	23	8,200 11,000***
Stuttgart	58	40	12,000
Hannover	46	80	18,000
Gothenburg	84	88	7,200 12,000****
Bielefeld	48	24	4,300
Basel	N/A	60	14,500

*Right-of-way categories A and B
**With equipment presently on order
***Rate for 15 to 30 minute interval
****Rail rapid line with modified LRT vehicles

Source: V. Vuchic, "Light Rail Transit Systems, A Definition and Evaluation," 1972 PB-213447 with updated percentages from Dr. Friedrich Lehner.

systems, assuming 400-foot blocks and an average speed of 40 mph, the calculated capacity for LRT systems with off-line stations is as follows:

$$176\ ^{\text{trains}}/_{\text{hour}} \times 192\ ^{\text{seats}}/_{\text{train}} = 33,792\ ^{\text{seats}}/_{\text{hour}}.$$

Again, such a system would require six parallel tracks at stations.

Automated Guideway Transit

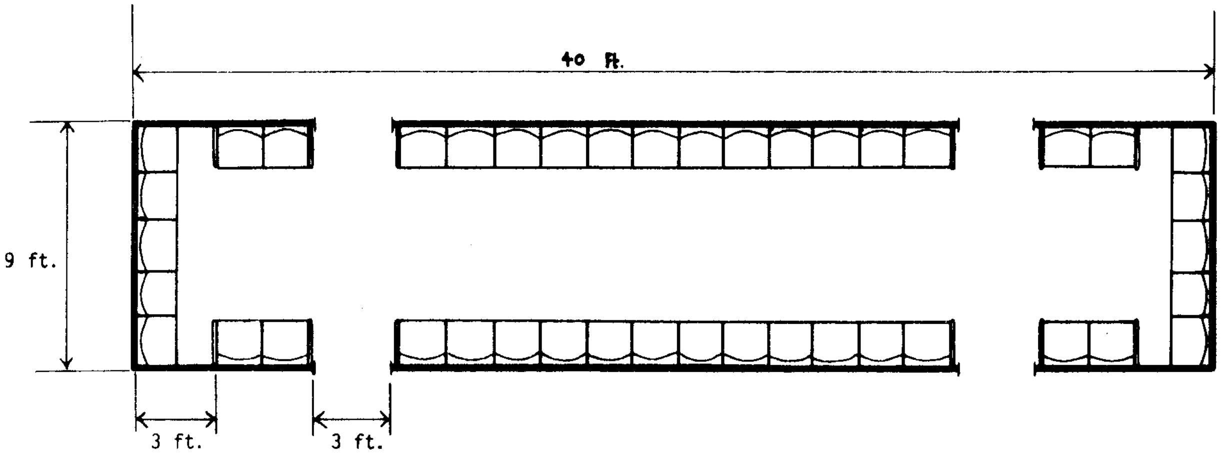
Automated Guideway Transit is the newest form of mass transportation technology being considered in this study. Indeed, no such systems are yet in operation serving commuter work trips. Data shown in this report for AGT systems are from the personal rapid transit system in Morgantown, West Virginia and the internal circulation system (AIRTRANS) at the Dallas-Fort Worth Airport. Neither of these two systems are configured as an AGT system would be if it were designed to serve commuter work trips. The Westinghouse "Skybus" system tested at Pittsburg and the airport shuttle system at Tampa, Florida more nearly match the configuration that would be used in this application; yet, they do not match it closely enough to be used as the basis for calculation. Consequently, a total new system design was assumed for the purpose of comparing capacity.

The AGT design assumed for this study has the following design characteristics:

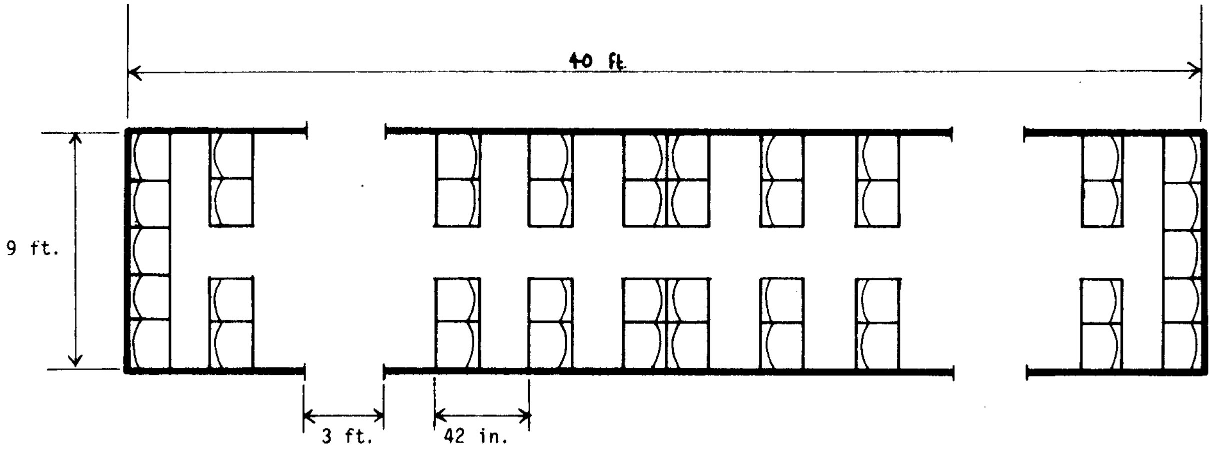
- rubber-tired traction,
- ability to switch,
- four-car trains with each car being 40 feet long and 9 feet wide with double doors on each side,
- maximum speed of 50 mph between stations, and
- an automated block system of control.

Each four-car train of this design configuration would be capable of carrying 168 seated passengers.

Seating arrangements for the vehicles mentioned above can vary depending on design philosophy. As many as 50 seats can be provided in the space available (Note - A 50-passenger bus is 40 feet long by 8 feet wide); however, a 42-seat plan provides more comfortable seating. Two possible seating plans, each with 42 seats, are shown in Figure 3. One plan is a perimeter seating arrangement that maximizes the room for standees. The other plan uses all perpendicular seats that maximize the feeling of privacy. For the purposes of this analysis, the number of seats is the only concern--not the arrangement. A capacity of 42 seats per vehicle is assumed for this analysis.



Perimeter Plan



Perpendicular Plan

Note: Each seat is at least 21" wide.

Figure 3: Possible Seating Plans for AGT Vehicles

If the AGT system is designed with on-line stations, the capacity will be determined by the time required in stations. Although a station headway of 60 seconds seems very optimistic (it would provide only about 20 seconds of doors-open time), if it can be achieved by LRT systems it should be possible for this AGT design. Hence, the estimated capacity of this AGT system with on-line stations (assuming 60-second headways at stations) is as follows:

$$42\ {}^{\text{seats}}/_{\text{car}} \times 4\ {}^{\text{cars}}/_{\text{train}} \times 60\ {}^{\text{trains}}/_{\text{hour}} = 10{,}080\ {}^{\text{seats}}/_{\text{hour}}.$$

The design configuration actually assumed for an AGT system in this study includes off-line stations. Under this configuration, the system capacity is constrained by the safe spacing required between trains on the line-haul segments. Each train will be approximately 166 feet long and emergency stopping distance from 50 mph will be 460 feet. Hence, a 500-foot block length would be the shortest appropriate length.

As noted in the analysis of RRT capacity, the requirement to maintain one "dead" block between trains results in a spacing from the front of one train to the front of the next equal to approximately three block lengths or 1500 feet. This represents a 20-second headway at about 50 mph. Thus, the capacity of this AGT system with off-line stations is as follows:

$$42\ {}^{\text{seats}}/_{\text{car}} \times 4\ {}^{\text{cars}}/_{\text{train}} \times 180\ {}^{\text{trains}}/_{\text{hour}} = 30{,}240\ {}^{\text{seats}}/_{\text{hour}}.$$

Bus Rapid Transit

Several values for observed and theoretical capacities for busways are presented in Table 8. This table is reproduced from page 3-3 of a United States DOT report on the Characteristics of Urban Transportation Systems (4).

The first entry in Table 8 refers to a test conducted by General Motors in which an actual throughput of 1450 buses/hour was achieved on a single-lane busway under carefully controlled conditions. In this particular test, all drivers were asked to maintain a constant speed of 30 mph. In normal vehicle flow situations, speeds tend to decrease as volumes increase. The second entry in Table 8 (from the Highway Capacity Manual for Level of Service D) recognizes this trend and provides a value of 940 buses per hour that would result in average speeds of 40 to 45 mph.

For the three technologies discussed previously (RRT, LRT, and AGT), speeds do not decrease as capacity conditions are approached. Each of these three technologies would be able to achieve an overall service speed of 30 to 40 mph, including stops at stations, in the configuration envisioned for Dallas/Fort Worth. In order for buses to achieve a comparable overall service speed, they would need to operate at 40-45 mph on the transitway. Thus, a capacity value of 940 buses/hour seems more appropriate for this comparison.

A vehicle similar to the newer bus designs (Transbus, RTS, etc) is envisioned for this application. These vehicles are 40-feet long by 8.5 feet wide. Approximately 50 seats are typically placed in these vehicles for normal city transit service. Such high seating densities do not provide a comparable level of comfort as the seating arrangements typically used in newer fixed-way transit systems. Therefore, it seems appropriate to use a reduced seating density for buses for the purpose of this comparison.

Because the bus would only need two doors instead of four doors, as assumed for AGT vehicles, a total of 42 seats can be provided with only a slight reduction in comfort levels (bus vs AGT). The bus seats would have to be slightly narrower than the AGT seats (20 inches vs 21 inches) and the aisle width reduced because of the narrower vehicle width (8.5 feet vs 9 feet). A

Table 8: Bus Service Volume Per Lane
Theoretical and Observed

Type of Condition	Number of Buses (per hour)	Headway (seconds)	Number(1) of Persons (per hour)	Theoretical or Observed
Uninterrupted Flow on test track[a]	1450	2.5	72,500	Observed(2)
Highway Capacity Manual Freeway - Level of Service D[a]	940	3.8	47,000	Theoretical
DOT - Cherniack ITE (1963)[a]	720	5.0	36,000	Theoretical(3)
Highway Capacity Manual Freeway Level of Service C[a]	690	5.1	34,500	Theoretical
I-495 Exclusive Bus Lane (New York - New Jersey)[a]	490	7.4	26,350	Observed
Arterial Bus Lane[b]	170	21.2	8,500	Observed(4)
CBD Curb Bus Lane[b]	160-120	23.0-30.0	8,000-6,000	Observed(5)
Bus Lane - On Line Stops[b]	120	30.0	6,000	Theoretical(6)
Highway Capacity Manual Arterial Bus Lane[b]	120	30.0	6,000	Theoretical
CBD Bus Streets, Contra Flow, Median Lanes[b]	100	36.0	5,000	Observed(7)

(1) Assuming a capacity of 50 persons per bus.

(2) Observed at the General Motors proving grounds under ideal conditions; no traffic fluctuation and perfect geometrics, 1964.

(3) Theoretical policy established in 1963.

(4) On Hillside Avenue, Queens, New York.

(5) Highest recorded to date.

(6) 20 second on-line stops, 10 second station clearance, perfect headway geometrics.

(7) Highest recorded to date.

(a) These operations do not include on-line bus stops.

(b) These operations include on-line bus stops.

Note: Above data represent one lane only.

Source: U. S. Department of Transportation, Characteristics of Urban Transportation Systems.

seating arrangement that only has three seats abreast on buses would yield 32 seats per vehicle at a superior comfort level. For the purpose of this comparison, a value of 42 seats per bus seems more appropriate.

The capacity of one lane of busway with off-line stations can be estimated as follows:

$$42 \ ^{\text{seats}}/_{\text{bus}} \times 940 \ ^{\text{buses}}/_{\text{hour}} = 39{,}480 \ ^{\text{seats}}/_{\text{hour}}.$$

This capacity value should be achievable at a quality of service comparable to that of the other technologies evaluated in this analysis.

The theoretical value of 120 buses/hour for a busway (as shown as the eighth entry on Table 8) with on-line stations appears reasonable. Thus, for a busway system using on-line stations, the capacity would be as follows:

$$42 \ ^{\text{seats}}/_{\text{hour}} \times 120 \ ^{\text{buses}}/_{\text{hour}} = 5040 \ ^{\text{seats}}/_{\text{hour}}.$$

It should be noted, however, that one of the primary assets of buses as a mass transportation vehicle is their ability to operate on surface streets as well as transitways. Hence, the design of a busway system with on-line stations seems highly unlikely.

Bus/Carpool Lanes

If an exclusive transitway is to be initially operated with both buses and carpools using it with a gradual transition to the exclusive use of buses, then the capacity of the transitway will vary as the transition occurs. Consequently, analyses were conducted to determine the actual capacity of such a facility under different operating constraints.

The first question to be addressed is the number of occupants a vehicle would need to qualify as a carpool. Data presented in Table 9 indicate that only a small percentage of the automobiles traveling a freeway in Dallas or

Table 9: Summary of Dallas-Ft. Worth Vehicle Occupancy Percentages*

	Percent of 1 Occupant Vehicles	Percent of 2 Occupant Vehicles	Percent of 3+ Occupant Vehicles	Percent Total
Dallas				
I.H. 35 E (North)	87	11	2	100
I.H. 35 E (South)	80	16	4	100
I.H. 30	80	17	3	100
U.S. 75 (North)	82	15	3	100
U.S. 75 (South)	73	21	6	100
Dallas North Tollway	86	13	1	100
Ft. Worth				
I.H. 35 W	78	18	4	100
I.H. 30	82	16	2	100
U.S. 377	77	18	5	100
U.S. 287	80	17	3	100
S.H. 199	80	17	3	100
S.H. 121	84	13	3	100
Lancaster Blvd.	83	13	4	100
Averages	81	16	3	100

*Percentages based upon peak-flow direction, 7-9 A.M. during 1976.

Source: SDHPT Regional Planning Office, Arlington.

Fort Worth during peak hours have as many as three occupants. This situation is not peculiar to the Dallas/Fort Worth area as the data in Table 10 reflects. Accordingly, the transitways would probably begin operation by permitting cars with two or more occupants to share the facility with buses and then later limit the use to cars with three or more occupants. The next step could be either to permit cars with four-plus occupants to use the facility or to exclude carpools altogether.

Another major consideration is the level of use, or congestion, that justifies a more restrictive set of operating rules. It would seem that a transitway should provide a relatively high level of service if it is to stimulate increased usage of high occupancy vehicles. Few individuals will be persuaded to switch to a higher occupancy vehicle in order to qualify to use the transitway if their vehicles experience the same congestion that is typical of freeways. Thus, it seems appropriate for the total traffic using the transitway to be limited to that which will yield average speeds of about 45 mph. This condition corresponds to a level of service "D+"--or a flow rate of about 1400 automobiles per hour.

In calculating the total number of mixed vehicles, buses and automobiles, that would yield this level of service at different mixture ratios, an equivalency of 1 bus = 1.5 automobiles was used. A total of 1400 equivalent vehicles was maintained, while the number of buses using the facility was increased. Table 11 shows the range of capacities that would be achieved for bus/carpool operation as the number of buses is increased.

Of course, a more restrictive qualification for carpools would have to be imposed anytime the total number of vehicles using the facility exceeds an equivalency of 1400 automobiles per hour. Each corridor would probably follow a slightly different path through the possible sets of conditions. At some

Table 10: Summary of Vehicle Occupancy Percentages Nationwide

	Percent of 1 Occupant Vehicles	Percent of 2 Occupant Vehicles	Percent of 3+ Occupant Vehicles	Percent Total
FREEWAY OCCUPANCY COUNTS				
Banfield Freeway - Portland (Peak Hours, Nov.-Dec., 1975)	77.6%	20.6%	1.8%	100%
Sunset Freeway - Portland (Peak Hours, Mar.-Sept., 1976)	78.7%	18.9%	2.4%	100%
Minneapolis Freeway - Portland (Peak Hours, Mar.-Sept., 1976)	72.8%	21.4%	5.8%	100%
Santa Monica Freeway - Los Angeles (Peak 7 Hours, March, 1975)	-	-	2.0%	-
North-South Freeway - Miami	-	20-23%	5-7%	-
Freeway Averages	76 %	20 %	4 %	100%
CORDON COUNTS				
Houston CBD (1971)				
Daily Average	69.8%	22.9%	7.3%	100%
Peak Hour Average	68.2%	25.4%	6.4%	100%
Nationwide (1969-1970)				
All Purposes	50.9%	27.3%	21.0%	99.2%
Work Trips	74.5%	17.6%	7.3%	99.4%
EFFECTS OF PRIORITY TREATMENT ON FREEWAY VEHICLE OCCUPANCY				
Banfield Freeway - Portland				
Before (Nov.-Dec., 1975)	77.6%	20.6%	1.8%	100%
After (Jan.-Sept., 1976)	76.3%	17.8%	5.9%	100%
Santa Monica Freeway - Los Angeles				
Before (March, 1975)	-	-	2.0%	-
After (Jun.-July, 1976)	-	-	5.4-6%	

Source: References (5), (6), (7), and (8).

Table 11: Combined Bus/Carpool Capacities on One Lane Per Hour

Assuming: L.O.S. "D+," Carpool Occupancy = 3.5 Persons/Vehicle, 42 Passengers Per Bus

Number of Buses	Number of Cars	Number of People in Buses	Number of People in Cars	Total People	Percent People in Carpools
0	1,400	0	4,900	4,900	100%
100	1,250	4,200	4,375	8,575	51%
200	1,100	8,400	3,850	12,250	31%
300	950	12,600	3,325	15,925	21%
400	800	16,800	2,800	19,600	14%
500	650	21,000	2,275	23,275	10%
600	500	25,200	1,750	26,950	6%
700	350	29,400	1,225	30,625	4%
800	200	33,600	700	34,300	2%
900	50	37,800	175	37,975	0.5%
940	---	39,480	---	39,480	0%

level of bus volumes, however, the transitway should be reserved for the exclusive use of buses.

The elimination of carpools from the transitway would be justified once the share of people carried by carpools becomes small compared to the share of problems created by carpool vehicles. This condition probably would be reached by the time that the percentage of persons carried by carpools had dropped to

10 percent. On the other hand, carpool drivers would probably be inclined to avoid the transitway as the percentage of buses in the traffic stream increases. Very few automobile drivers would likely consider a mixture of one bus for every car to be a desirable travel condition. The dashed line on Table 11 is drawn at the increment where the number of buses equals the number of automobiles. It is interesting to note that the share of people carried by carpools has dropped to less than 10 percent by the time that the number of buses equals the number of automobiles.

Buses in the CBD

One of the primary advantages of buses over the other technologies being considered in this study is the ability of a bus to operate on existing streets as well as on transitways. This attribute would be particularly important 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 transitways to be constructed below ground. Certainly, traffic control measures can be implemented to accommodate some number of buses on existing streets in the CBD; however, the number of buses that could be accommodated on existing CBD streets is a matter of concern.

The following analyses were performed to identify the measures that would be necessary in order to provide a capacity in the CBD equal to the capacity of a busway system. The following three basic approaches to providing bus capacity in the CBD are discussed in the following paragraphs:

(1) Reserved Curb Lanes,
(2) Bus-Only Streets, and
(3) Construction of Bus Terminals.

The first two approaches assume that existing facilities will be utilized, but that buses will be given priority assignment of these facilities. The third approach requires new facilities to be constructed.

Although a total of eight transitways are shown radiating outward from the Dallas CBD in the 1990 Plan, the individual legs split off after leaving the CBD so that only four separate transitways actually enter the CBD. For the purposes of these analyses, it is assumed that the desired bus capacity in the CBD is equal to the combined capacity of four single-lane busways (940 buses/hour/busway x 4 busways = 3760 buses/hour).

Reserved Curb Lanes - As noted in Table 8 (page 29), as many as 160 buses per hour have been observed using a CBD curb lane for movement and loading. However, the lower value of 120 buses per hour seems to be a more appropriate capacity value for an application where each bus lane would intersect several other bus lanes so that preferential signal timing could not be accorded to any one bus lane.

If each curb lane reserved for buses in the CBD can handle a total of 120 buses per hour, then 8 curb lanes will be required to match the capacity of one busway (940 buses/hour). A total of 32 curb lanes would be needed in the Dallas CBD to handle all of the buses that could enter the CBD from 4 busways. This would require the dedication of both curb lanes on sixteen different streets for bus use only. Any other use of the curb lane (such as cars entering or leaving parking garages, trucks loading and unloading, etc), except at intersections, would diminish the capacity of the lane to serve buses.

The Dallas CBD currently only has about 8 east-west streets and 10 north-south streets that would be suitable for reserved curb lane operation of buses.

All other CBD streets are either discontinuous or are too far from the core of the CBD. Hence, virtually every available street in the CBD would be required if sufficient capacity were provided using reserved curb lanes. Certainly, this is beyond the realm of feasibility.

An accurate evaluation of the number of curb lanes that could feasibly be reserved for buses in the Dallas CBD is beyond the scope of this study. Four such lanes are already in use during peak periods (one-side each of Commerce and Elm and both sides of Main), possibly four more could be dedicated to bus use without severe impacts on other essential traffic functions in the CBD. If so, then a total of eight curb lanes would be available--enough to handle only one-fourth of the ultimate capacity of a busway system.

Bus-Only Streets - The final listing on Table 8 (page 29) cites an observed volume of 100 buses on a CBD Bus Street. Certainly if a single curb lane can serve 120 buses per hour, a bus-only street could serve more than 100 buses per hour. The method used in developing an estimated capacity for a bus-only street is described in the following paragraph.

Although some of the major CBD streets in Dallas are 5 lanes wide, most of them are only 4 lanes wide. Therefore, a typical bus-only street was assumed to be 4 lanes wide which would permit buses to use one moving lane and one loading lane in each direction. In this instance, the moving lane is assumed to have similar operating characteristics to an outside lane adjacent to a parking lane. The Highway Capacity Manual cites a capacity of 1100 automobiles per hour of green time for such a situation. Adjusting this value for CBD signals ($\sim$ 45% green time) and bus equivalences (1 bus = 1.5 autos) yields a capacity of 330 buses per hour for the moving lane. Ignoring any small capacity gains that might be achieved from the outside lanes used for loading and unloading buses, the capacity of a bus-only street in the CBD is estimated to be approximately 660 buses per hour (half in each direction).

In order to equal the capacity of four busways, a total of 6 streets in the CBD would need to be dedicated to bus-only use. For example, the following streets might be selected as bus-only streets:

- North-South Streets
    - Lamar,
    - Ervay, and
    - Harwood
- East-West Streets
    - Pacific,
    - Main, and
    - Jackson.

Although it could probably be done, dedicating six of the 18 major streets in the Dallas CBD to bus-only use would cause severe impacts on other necessary traffic operations. Four such streets would probably be a more realistic upper limit. If so, then this technique could provide a CBD capacity equal to two-thirds of the capacity provided by four busways.

It should be noted that the operational scheme assumed for both curb-lanes and bus-only streets is that buses would enter the CBD from a busway on one side, travel through the CBD off-loading or picking up passengers, and then exit the CBD outbound on another busway. Twice as many lanes would be required if buses were to make a loop in the CBD and return to the same busway.

Construction of Bus Terminals - New off-street terminals can be constructed in the CBD to handle the buses using transitways. Certainly if new facilities are required, they can be designed for whatever capacity is required. The purpose of the following analysis is to identify the approximate size of bus terminals that would be required to match the capacity of a busway. Under the operating conditions envisioned, each busway would terminate at a terminal on the fringe of the CBD and buses would return on the same busway that they entered on. In other words, the four terminals would not be interconnected by busways.

The following assumptions were made concerning the terminal design:

(1) one level would be used for all loading and unloading of buses,

(2) another level would be needed to permit passengers to reach the appropriate platform without crossing bus lanes,

(3) both unloading and loading operations would occur on a single platform,

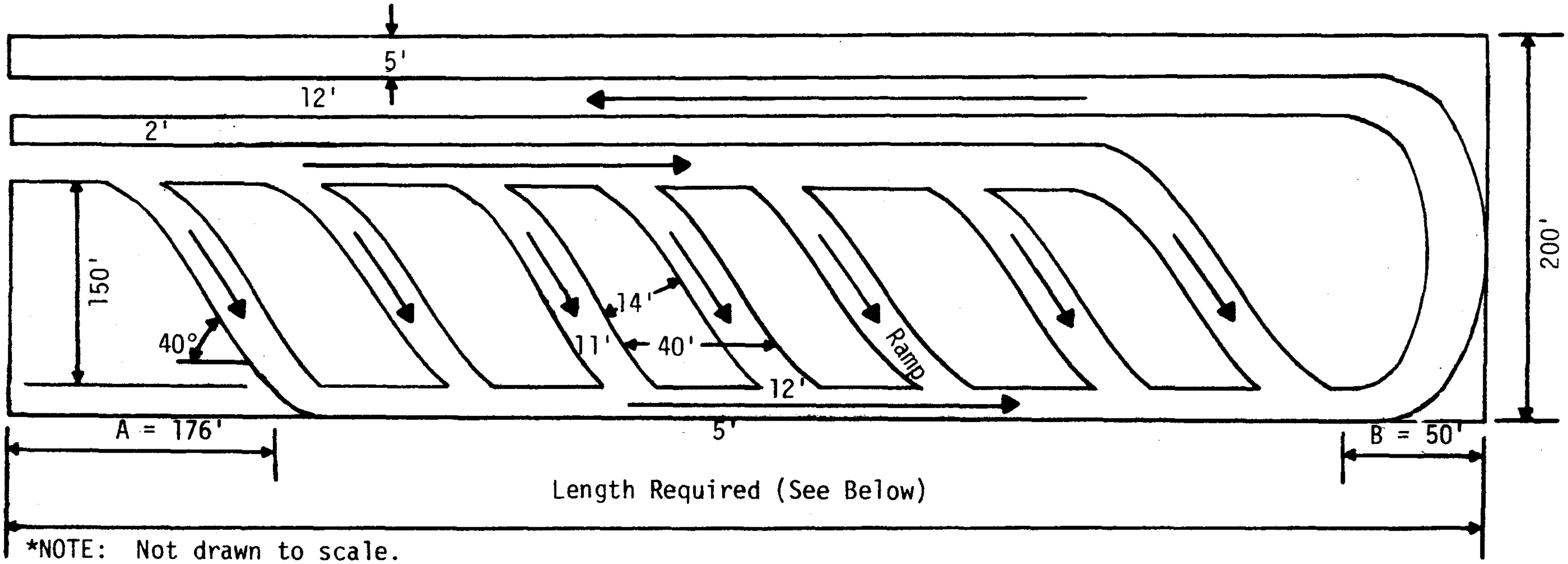
(4) a minimum berth-type arrangement is desired to minimize size requirements, and

(5) that a width of approximately 200 feet would be desirable to conform to land parcel patterns in the CBD of Dallas.

Using the assumptions listed above, a generalized layout of the bus-level of such a terminal was developed (See Figure 4). Each bus lane in this configuration will accommodate five buses in a minimum berth arrangement.

The overall length of the terminal will vary with the number of bus lanes (or platforms) needed. The required number of lanes in this application will depend upon the number of buses that each berth can handle in an hour. These two relationships are defined for a range of berth capacities in the table included in Figure 4.

For this type of commuter operation, a berth capacity of 20 buses per hour seems feasible. If so, then a plot of land at least 200 feet by 600 feet



*NOTE: Not drawn to scale.

Capacity of Berth	No. of Ramps	Length Required
10	19	986
15	12	706
20	9	586
25	7	506
30	6	466

Figure 4: General Layout of CBD Bus Terminal

will be required for each of four terminals in the Dallas CBD. In other words, four typical blocks in downtown Dallas would be required.

Of course, these bus terminals would only consume two levels, both of which could be below ground level. Thus, other uses of the land area would be possible.

Comparison of Corridor Capacities

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, either inbound or outbound. Also, the capacity values are calculated for approximately equivalent levels of service as far as service speeds and seating comfort are concerned.

Rail rapid transit (RRT) and light rail transit (LRT) systems typically use on-line stations. Some existing automated guideway transit (AGT) systems have on-line stations while others have off-line stations. All existing busways use off-line stations, and certainly all bus/carpool lanes use off-line stations for the buses. Yet, capacity values were calculated for each technology except bus/carpool for both types of system design--on-line stations and off-line stations--in order to make a fair comparison of their relative capacities.

A comparison of the calculated capacities for the different transit technologies evaluated is presented in Table 12. The type of system design (on-line stations versus off-line stations) that is typical for each technology is denoted by an asterisk following the appropriate capacity value. To emphasize the lack of precision of these calculations, all values have been rounded off to only two significant digits.

Table 12: 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*	89,000
Light Rail Transit	12,000*	34,000
Automated Guideway Transit	10,000	30,000
Bus Rapid Transit	5,000	39,000*
Bus/Carpool	NA	5,000-39,000*

*Denotes the typical design characteristic for each technology.

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, ages of vehicles, and general traffic conditions making up 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. The direct conversion value is: 1 kilowatt hour = 3413 BTU's. However, 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 these losses and make the comparison on the basis of absolute energy consumed by the vehicles. A suitable compromise approach might be to adjust the Btu values of gasoline and diesel fuels to account for energy expended in refining and transporting the fuels and then compare the results with adjusted values for electrically powered vehicles.

Both methods of comparison, direct conversion factors and adjusted conversion factors, were used in this analysis. Information concerning the adjusted conversion factors is presented in Table 13. The resulting values of energy efficiencies calculated by both approaches are presented in Table 14.

Table 13: Adjustments for Energy Conversion Factors

Gasoline:		
Btu's per Gallon	125,000	
Refining Efficiency	÷ 74%	
Distribution Efficiency	÷ 95%	
Adjusted Value	≈ 178,000	BTU/Gallon
Diesel:		
Btu's per Gallon	138,000	
Refining Efficiency	÷ 81%	
Distribution Efficiency	÷ 95%	
Adjusted Value	≈ 179,000	BTU/Gallon
Electricity:		
Btu's per Kilowatt-hour	3,413	
Generation Efficiency (coal)	÷ 35%	
Distribution Efficiency	÷ 91%	
Adjusted Value	≈ 10,700	BTU/Kilowatt-hour

Source: References 10, 11, 12, and 13.

Buses operating on transitways should achieve energy efficiencies comparable to those achieved in freeway operation. Based upon the comparative values shown in Table 14 (regardless of the conversion method used), the energy efficiency of all transit technologies except AGT appears to be reasonably comparable and decisively better than that of automobiles. The disadvantage reflected for AGT is more a factor of the number of seats on each vehicle than inherent energy requirements. Larger AGT vehicles will probably have energy efficiencies comparable to RRT or LRT systems.

Table 14: Energy Efficiencies of Various Urban Transportation 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

Note: See Table 13 for Adjusted Conversion Factors

Sources: References 1,3,4, and 14; University of West Virgina; and Dallas/Fort Worth Airport

SAFETY

Accident records for transit systems include accidents that involve passengers as well as transit vehicles. For example, the vast majority of accidents reported by rail rapid transit systems involve injuries occurring to passengers in stations rather than on-board vehicles. Conversely, the vast majority of accidents reported by bus systems involve collisions between buses and automobiles on city streets. Hence, comparisons of accident statistics for different transit technologies should only be made with a full realization that the types of accidents involved are totally different in nature. The data presented in Table 15 include a breakdown of the accident rates for various types of accidents. Unfortunately, insufficient data are available for AGT systems to include them in these comparisons.

The accident rate for buses on transitways shown in Table 15 was estimated assuming that passenger accidents would be the same as for street operation, but that traffic accidents would be reduced by a ratio similar to that experienced by automobiles operating on freeways rather than streets. A similar estimate might be made for trolleybus and LRT operations shown in this table.

Apparently, rail rapid transit is the safest of all existing forms of transit; however, buses operating on transitways will probably be equally safe. About all that can be said about trolleybus and light rail data shown in this table is that perhaps 1971 was a bad year for the limited number of these systems included in the survey.

Table 15: Comparison of Accident Rates

Technology	Accidents Per Million Vehicle-Miles
Automobile Collisions	
On City Streets	18.4
On Freeways	4.7
Buses on City Streets	
Passenger Accidents	21.03
Traffic Accidents	57.46
Total	78.49
Buses on Transitways (Estimated)	
Passenger Accidents	21.03
Traffic Accidents	14.68
Total	35.71
Trolleybus	
Passenger Accidents	36.11
Traffic Accidents	107.85
Total	143.96
Light Rail Transit*	
Passenger Accidents	62.60
Traffic Accidents	160.30
Total	222.90
*Primarily Street Operation	
Rail Rapid Transit	
Passengers in Stations	27.30
Passengers on Trains	9.94
Traffic Accidents	1.13
Total	38.36

Sources: References 4 and 15.

RELIABILITY

Transit Operations

Available data concerning the actual reliability experience of various transit technologies were not adequate to permit a comparison of reliability as a part of this study. However, the report on the state of the art of light rail transit contains a comparison of schedule reliability (3). Their comparison is reproduced herein as Table 16. The data used to develop this comparison are not included in the light rail transit report (a Pittsburgh Study is referenced), but one check concerning the values listed for buses appears to corroborate the values.

A mean time between failures of 420 hours is listed for bus systems. Assuming an average speed of 13 miles per hour for buses in typical operation, this value translates to one equipment failure every 5500 vehicle miles. Data received from Dallas Transit System documents an average rate of about one equipment failure every 8000 vehicle miles (16). The data from Dallas is categorized by bus age and reflect a range of rates from one breakdown every 6000 miles for older buses to only one breakdown every 16,000 miles for some of the newer buses. Thus, the value shown in Table 16 appears to be reasonable for bus systems with a less intensive preventative maintenance program than that practiced by Dallas Transit System.

The reliability for AGT systems shown in Table 16 is significantly lower than the other technologies. It should be noted, however, that the two AGT systems used for reliability analysis are first-generation AGT designs. Indeed, the one at Morgantown, West Virginia is still being modified to improve reliability. Surely the ultimate reliability of future AGT systems will be much better than indicated by these data.

Table 16: System Reliability

	LRT	RRT	Bus	AGT
Single Vehicle MTBF (hours)	426	424	421	60
Single Switch MTBF (hours)	3,600	3,600	-	
System Power and Wayside Equipment (hours)	10,000	10,000	10,000	NA
Schedule Reliability (trips completed on schedule per 100 trips)	99.5	99.7	99.6	NA

Source: Light Rail Transit: A State of the Art Review. Data for AGT from University of West Virginia and Dallas/Fort Worth Airport.

Bus/Carpool Operations

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. Consequently, an effort was made to estimate the frequency of vehicle breakdowns that might occur on the transitway.

Only two sources of data were identified concerning the frequency of automobile breakdowns on urban freeways. One source was a brief study conducted by Texas Transportation Institute in Houston that was never documented in a formal report. Pertinent information concerning this study is presented in Exhibit A. The second source of data stemmed from a two-year motorist aid program in Boston. Again, the results were never

EXHIBIT A

Disabled Vehicle Study

In November and December 1970, the Texas Transportation Institute conducted an interview type survey of motorists who were forced to stop on the main lanes or emergency shoulders of an urban freeway because of a vehicle malfunction. The most common causes of malfunctions were tire failures, out of fuel, cooling and fuel system breakdowns, and mechanical failures. Vehicles involved in collisions were not included in the survey.

The survey was conducted over five miles of a six-lane freeway that carried an average of 100,000 vehicles per day. The interviews were conducted during daylight hours on weekdays by city policemen. The policemen also provided emergency services or communications to aid the motorists.

The disabled vehicles were located by use of a closed circuit television system and freeway patrol units. Surveillance of the five-mile section was extensive, and it is estimated that more than 98 percent of all disabled vehicles were included in the survey.

The results of the survey were as follows:

Length of Survey	-	35 days
Vehicle Miles Traveled	-	13,335,000
Total Mandatory Stops	-	371
Vehicle Miles/Stop	-	35,900

The traffic data were collected on an electronic detection system for each day of the study. Data were also collected on all vehicles that were stopped on the shoulders. This information is not as complete as that of disabled vehicles because the time that the motorists used the emergency lane was often too short to dispatch an interviewer. The results of the survey including all stopped vehicles interviewed were:

Total Stops	-	483
Vehicle Miles/Stop	-	27,600

documented in a report; but, pertinent information concerning the study is presented in Exhibit B.

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 are 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.

EXHIBIT B

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

Department of Public Works

100 Nashua Street, Boston 02114

STALLED VEHICLES ON FREEWAYS
SOUTHEAST EXPRESSWAY

October 21, 1976

Mr. Charles Fuhs
Texas Transportation Institute
Texas A & M
College Station, TX 77843

Dear Mr. Fuhs:

In response to your telephone conversation with Mr. Charles Sterling of my staff regarding stalled vehicles on freeways, we do not keep records on this data at the present time.

However, the Automobile Legal Association in conjunction with a local radio station, WBZ, provided a tow truck to service breakdowns within an approximate 8 mile stretch on one of our major commuter corridors (Southeast Expressway) for over a two year period. This tow truck coverage ran for two and a half hours during both the morning and evening peak hours.

The Automobile Legal Association has informed us that this breakdown service aided an average of nine breakdowns in both the morning and evening rush hours (total 18 per day). The morning traffic volumes (two way) was about 8,500 vehicles per hour or 21,250 vehicles for the two and a half hour period. Thus the morning "breakdown" rate is approximately 419 breakdowns per million vehicles or 52.3 per million vehicle miles.

The evening traffic volumes (two way) was about 9,500 vehicles per hour or 23,750 vehicles for the two and a half hour evening peak. Therefore the evening breakdown rate is 379 breakdowns per million vehicles or 47 breakdowns per million vehicle miles.

This data is generalized and aggregated, but I hope it can be of some value to you.

Very truly yours,

L T Perkins

L. T. Perkins, P.E.
Traffic Engineer

CFS/smm

cc: District 8

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 comparison of several other factors contributing to overall quality of service is presented in Table 17. In this table, a value of 1 is assigned to the technology that offers the best service for that factor, and a value of 5 is assigned to the poorest; however, no relative scale should be attached to these numbers. In other words, a ranking of 5 does not infer a quality of service only 20 percent as good as a ranking of 1; it merely infers that it is the lowest ranking of the five technologies. The assigned rankings in Table 17 were based on observations of existing operations for the respective technologies--not theoretical capabilities.

Public Image - Many people believe that the image that the public has of a particular technology is a very important factor in attracting new

Table 17: Comparison of Factors Contributing to Overall Quality of Service*

Service Factor	Bus/Carpool	Bus	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.

riders. Terms such as "modern" or "new technology" are often used by laymen in describing the type of mass transportation system that they envision for their city. 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.

Land-Use Influences - Urban planners have long recognized an interrelationship between the type of urban transportation available and the type of urban development that occurs. An intensive two-year study of "Urban Densities for Public Transportation" was recently completed which documents this interrelationship (17). Bus systems are better suited for lower density urban development (3000 to 6000 persons per square mile) while RRT systems are better suited for higher density cities (15,000 to 25,000 persons per square mile). If one of the objectives of a mass transportation system in the Dallas-Fort Worth area is to influence the nature of urban development, the interrelationship between each technology and its associated land-use influence will be an important consideration.

Certainly any major transportation facility will influence the location and type of land development along its route. Some planners, however, believe that a new RRT system would exert a more dramatic influence than a bus system. Perhaps this belief is why the "value capture" concept is usually associated with new RRT systems. Under the "value capture" concept, the public agency constructing the RRT system would buy land adjacent to station locations prior to construction and then sell it at a higher price and use the "profit" from the land to help finance the construction project. However, many questions concerning the "value capture" concept need to be answered before it is used as a major influencing factor in the selection of a specific technology.

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% 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 pay-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 operate some service during a strike are all factors that are important enough to influence the selection of a technology if significant differences exist between technologies in these matters.

Although each type of technology will require a different mixture of employee skills, the Dallas/Fort Worth Metroplex should have an adequate supply of all skills required. 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 pay scales than those needed for bus operations.

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 are 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 will be curtailed to some extent no matter what technology is being used. Very little bus service could be provided by supervisory personnel, but increased use of carpools could help to offset the reduced bus service. A higher portion of normal service can probably be provided by supervisory personnel on the more automated systems. Thus, there appear to be little differences 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 automobiles. Buses would not be significantly affected by a power failure, but all electrically powered systems would be shut down totally unless an emergency power generation capability were provided.

Technology Advancement - Certainly, any dramatic advancements in technology for any of the systems evaluated (bus, 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.

III. POTENTIAL EVOLUTIONARY PATHS

The premise for this entire study is that the Dallas-Fort Worth Metropolitan Area plans to construct several transitways 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 was commissioned to evaluate the feasibility and desirability of designing these transitways so that they can easily transition to accommodate other mass transportation technologies.

The first objective of this study is to identify logical evolutionary paths that may become desirable under various sets of probable future circumstances. In order to accomplish this objective, analyses of the relative capability of each technology considered for future operation (bus, LRT, RRT, and AGT) were performed, and the results of these analyses are discussed in the preceding section of this report. 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 the evolutionary design in subsequent evaluations are identified. Finally, three potential evolutionary paths are selected for furhter 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 the following paragraphs.

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 labor intensity considerations will not stimulate a change in technology. An inspection of Figures 1 and 2, pages 7 and 8, reveals that relatively few data points lie below the band-width (denoting ±10%) superimposed over the curve. Of those existing transit systems that are below the curve, all but one are bus systems.

AIRTRANS, the AGT system serving the Dallas/Fort Worth Airport, provided almost four million vehicle-miles of service with only 141 employees last year. Thus, AIRTRANS has the lowest level of labor intensity of any system when measured as a function of vehicle-miles of service. Considering that AIRTRANS is a "first generation" AGT system, it could be argued that future AGT designs could offer a significant reduction in labor intensity.

Actually, 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. Indeed, the labor intensity of a carpool-only system would probably be less than six employees per million annual users--less than 30 percent that of transit systems.

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 resulted in the comparative capacity values shown in Table 12, page 42. 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:

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

The question mark is placed above the second transition because it is doubtful that this transition would ever be required. Previous analyses of traffic patterns into CBD's have revealed that approximately 40 percent of the workers enter the CBD during the peak-hour (18); thus, each busway could serve a total of about 100,000 CBD workers--the existing work-force in the Dallas CBD. 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 Metroplex.

Energy Efficiency - The comparison of energy efficiencies shown in Table 14, page 45, clearly 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 → Bus.

Safety - As surprising as it may seem, analyses of accident rates for various transit technologies and automobiles show that carpools are safer than any form of transit (See Table 15, page 47). Thus, the logical evolutionary path stemming from an independent consideration of safety would be no path at all--carpools would be best.

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:

$$\begin{tikzcd} & \text{Bus} \\ & \text{or} \\ \text{Bus/carpool} \arrow[uur] \arrow[r] \arrow[ddr] & \text{LRT} \\ & \text{or} \\ & \text{RRT.} \end{tikzcd}$$

Overall Quality of Service - Of the six factors included in the comparison of overall quality of service (Table 17, page 54), 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:

$$\begin{tikzcd} & \text{RRT} \\ \text{Bus/carpool} \arrow[ur] \arrow[dr] & \text{or} \\ & \text{AGT.} \end{tikzcd}$$

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

Bus/carpool → Bus.

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

Bus → RRT.

In the latter 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 manpower availability. 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:

$$\begin{tikzcd}
 & \text{Bus} \\
\text{Bus/carpool} \arrow[ur] \arrow[dr] & \text{or} \\
 & \text{AGT.}
\end{tikzcd}$$

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:

$$\begin{tikzcd}
 & & \text{LRT} \\
 & & \text{or} \\
\text{Bus/carpool} \arrow[r] & \text{Bus} \arrow[uur] \arrow[r] \arrow[ddr] & \text{RRT} \\
 & & \text{or} \\
 & & \text{AGT.}
\end{tikzcd}$$

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:

$$\begin{tikzcd} & \text{Bus} \\ \text{Bus/carpool} \arrow[ur] \arrow[dr] & \text{or} \\ & \text{RRT.} \end{tikzcd}$$

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:

$$\text{Bus/carpool} \rightarrow \text{AGT.}$$

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 final technology in two paths.
- Bus is the ultimate technology in five paths.
- AGT is the ultimate technology in five paths.
- RRT is the ultimate technology in five 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 sub-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 or buses and carpools only 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--without regard to the needs of carpools. The second should be designed to adequately accommodate buses and carpools. Consequently, the two reference designs selected for further study are:

Reference Design #1: Narrow Guideway for Buses Only, 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 analysis 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
3. Increased concern over labor costs and labor problems.

Under this scenario, the logical evolutionary path is:

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

Hence, this path was selected as Evolutionary Path #1 for further study.

The areas of primary concern to be addressed in the further studies include the following:

1. Developing a design configuration that can accommodate this path,
2. Evaluating transitional capabilities, and
3. Evaluating the costs of this approach compared to Reference Design #2.

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 would be:

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

This path was selected as Evolutionary Path #2.

The areas of primary concern for this path are the same as those identified for Evolutionary Path #1. Particular emphasis should be placed on the evaluation of transitional capabilities, however, because of the greater dissimilarity between these two technologies.

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:

Bus → RRT with on-line stations.

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

The areas of primary concern to be addressed in further studies of this path include the following:

1. Developing a design configuration that can accommodate this path,
2. Evaluating transitional problems and possible solutions to those problems, and
3. Evaluating the costs of this approach compared to Reference Design #1.

CONCLUSION

This 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 design requirements for further study:

- Reference Design #1: Narrow Guideway for Buses Only,
- Reference Design #2: Wide Guideway for Buses and Carpools,
- Evolutionary Path #1: Bus/Carpool → Bus → AGT with Off-Line Stations,
- Evolutionary Path #2: Bus/Carpool → Bus → RRT with On-Line Stations, and
- Evolutionary Path #3: Bus → RRT with On-Line Stations.

Subsequent reports issued as a part of this study will present the results of further evaluation of these five design requirements.

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