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16. Abstract

In order to make impartial yet informed decisions relative to certain transportation alternatives it is necessary to have an understanding of the characteristics and unique features as well as the opportunities of a range of options. The objective of this study was to perform an investigation of Light Rail Transit (LRT) tracing its evolution up to recent trends. The end result was to provide information of sufficient detail and scope to facilitate an assessment of the suitability of LRT as an alternative (or complement) to the bus in Texas cities.

This report provides a critique of the literature of LRT, both recent and past. A lengthy discussion of LRT design and operations covers vehicles, route network, track and structures, power supply, stations and platforms, fare collection, signalling and traffic control, and operations. A review of LRT suitability encompasses a look at cities with LRT, including those which have proposed and retained LRT systems; the subsequent application of a modelling analysis, assessing city and LRT characteristics, results in prediction of LRT viability.

Identification and assessment of important factors relevant to an evaluation of LRT are provided. These factors include monetary costs, land use, socioeconomic and political impacts, energy and environmental implications, and safety. A general comparison of LRT with other modes, specifically bus options and Automatic Guideway Transit, is included.

The implications of LRT for Texas cities, an historical review of urban rail transit in Texas, a discussion of current plans and proposals, and pertinent guidelines for consideration of LRT in an alternative evaluation process are discussed.

17. Key Words

transit, light rail, LRT, planning, design, operations, vehicles

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AN EVALUATION OF THE APPLICABILITY OF LIGHT RAIL TRANSIT TO TEXAS CITIES

by

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Technical Study Report Number 1058-IF

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Conducted for

Texas State Department of Highways and Public Transportation
and
Urban Mass Transportation Administration
U.S. Department of Transportation

by the
Center for Transportation Research
The University of Texas at Austin

August 1980

EXECUTIVE SUMMARY

One of the new concepts that has been much discussed in the last few years is called Light Rail Transit (LRT). The Urban Mass Transportation Administration (UMTA) arranged for the development of a new transit vehicle, the Standard Light Rail Vehicle (SLRV), which was designed and built by the Boeing-Vertol Corporation and has been purchased by Boston and San Francisco. UMTA also sponsored two national conferences on Light Rail Transit. As yet, there is no completed LRT system anywhere in the United States, but there are two lines currently under development in Buffalo, New York and San Diego, California.

Texas cities are experiencing to one degree or another all of the contemporary urban transportation problems of major cities. Some of the problems particularly traffic congestion, have been aggravated by the very rapid growth of the largest cities in Texas, resulting in part from the well publicized Sun Belt phenomenon. Consequently, public and mass transit have achieved a renewed respectability in Texas, and there is serious consideration of major transit improvements in many quarters. Because LRT may be one of the options that should be considered, the State Department of Highways and Public Transportation sponsored this study to assess the potential applicability of Light Rail Transit to Texas cities.

In the spring of 1976 the Transportation Research Board Committee on Light Rail Transit wrote a simplified definition of the characteristics of light rail:

> Light rail transit is a mode of urban transportation utilizing predominantly reserved but not necessarily grade-separated rights-of-way. Electrically propelled rail vehicles operate singly or in trains. LRT provides a wide range of passenger capabilities and performance characteristics at moderate costs (Ref 1).

Modern light rail systems are sometimes considered an evolutionary form of the street and interurban railways. An exploration into the past will not only uncover the roots of the light rail concept but may prove helpful in analyzing what might happen in the future.

The report provides an historical overview of the development of the light rail transit concept from the early electric streetcars, a review of the current status of LRT systems around the world, and a discussion of the recently emerging trends in the planning, design, and operations of LRT. In the United States, interest in LRT varies considerably from city to city; on a national basis, it can be fairly said that there is a moderate interest in the role of LRT in addressing the urban transportation problem. This role is seen to be that of a medium-capacity mode that is well integrated with various other transportation modes and with compatible land uses.

In North America, the majority of recent LRT projects involve the rehabilitation and modernization of the few streetcar systems which were retained. Newly constructed or proposed LRT lines show some similarities in right-of-way locations and network designs. Operating procedures in the U.S. are making less than full use of the operating advantages for which LRT is lauded and which European systems have adopted. The trends in the current LRT planning and operations can be readily traced to the trends in government policy.

In reference to principal physical and operational characteristics of LRT, particular attention is given to issues which should be addressed in either the preparation or evaluation of a specific LRT for a city in Texas. Most of the items in the following eight categories will have a direct bearing on the total costs and efficiency of an LRT system:

1. Vehicles: considerations in choosing an appropriate vehicle, along with descriptions of "state-of-the-art" technology;
2. Route Network: considerations in laying out a fixed guideway;
3. Track and Structures: descriptions of track facilities, guideway structures, and construction procedures;
4. Power Supply: characteristics of the distribution network and considerations for overhead wiring;
5. Fare Collection: descriptions of the various options available;
6. Stations and Platforms: a discussion of the wide range in possible locations and configurations;
7. Signaling and Traffic Control: control of both light rail vehicles and other traffic; and
8. Operations: descriptions of matters not covered in detail in the above categories, such as fare elasticity, the relationship between average speed and number of stops per mile, and innovative techniques.

Whether an LRT operation is viable or successful depends equally upon the situation or environment in which it is placed. One objective of this study was to examine this aspect: where has LRT been successful, or where is it likely to be successful? A summary is provided of some of the pertinent characteristics of U.S. cities that have retained their streetcar/LRT systems and of those that are seriously contemplating LRT proposals. Also included is a comparison of LRT with other transit modes using a mathematical optimizing model for transit system design. Finally, the study takes up the question of why the streetcar has survived in a few American cities, but disappeared in most of them.

Some city characteristics which relate to the viability of various transportation modes are population size, population density, automobile availability, current transit use, and the concentration of trip destinations (in this case, for employment purposes). These characteristics are reviewed for two groups of cities: 1) U.S. cities which retained their streetcar systems, and 2) U.S. cities which have proposed new LRT lines. The purposes of this review are to determine whether there are characteristics in common among the cities in each category, and whether city characteristics are different in "retained" cities and "proposal" cities. Later, the same characteristics are suggested to analyze the largest Texas cities to see how they compare with the "retained" and "proposal" cities.

Some advocates of Light Rail Transit (LRT) claim that one reason for its attractiveness as an urban transportation alternative is the existence of its proven technology. However, there are few existing systems in the U.S. which are examples of the new concept of LRT. In a search to determine monetary costs for new LRT systems, one finds the only recent cost figures are for new vehicles for old systems, refurbishing and upgrading costs for old systems, preliminary studies for construction of new systems, and some foreign experiences which are difficult to convert and compare to U.S. experience. What one does learn from the current cost reports is that the concept of LRT can be applied to such varied situations that no single costs are typical, but rather that "you get what you pay for."

The hope for LRT is that it can provide the advantages of a fixed guideway transit system at lower costs than conventional rapid transit and to cities whose densities and population do not merit conventional rapid transit. The advantages of LRT, which distinguish it from streetcars and make it comparable to conventional rapid transit, are the faster speeds obtained by running faster vehicles in separate rights-of-way and the reduced operating costs which should result from operating in trains. In an examination of current and projected costs, there are necessary tradeoffs between the performance advantages and the anticipated lower costs of an LRT alternative.

A highlight is provided of factors identified as relevant to assessing the utility of LRT as a suitable option for cities in Texas. The overall characteristics of the largest Texas cities are summarized and compared with the characteristics of those American cities that have retained or are actively considering the streetcar/LRT mode.

Each of the larger cities in the state have at one time or another, passively or actively discussed LRT. A brief "pulse taking" was conducted over the life of the project and the findings for the largest seven cities are provided.

By way of conclusion, guidelines are suggested which are intended to summarize the findings of the study for the benefit of state and local policy-makers. These guidelines are specifically oriented to large Texas cities, since the object of the study was to determine the applicability of Light Rail Transit to the Texas situation. The guidelines follow:

1. It is unlikely that a <u>citywide</u> Light Rail Transit <u>system</u> will be warranted in any Texas city under present conditions or those foreseeable in the near future. That is, a comprehensive LRT network, consisting of many routes, does not seem indicated.
2. An LRT line may be suitable in individual corridors of Texas cities under particularly favorable conditions, such as:
    - a. a high density of travel demand estimated to produce at least 8,000 LRT passengers in the peak direction in the peak hour;
    - b. location of one terminal of the line in the Central Business District (i.e., a radial line);
    - c. location of the outer terminal of the line at a major activity center and trip generator, such as a shopping center, university, airport, hospital complex, or amusement park. LRT must be fed by an excellent, integrated bus system and have park and ride support facilities.
3. An LRT line would be most attractive in a situation where the alignment can utilize an existing right-of-way, because:
    - a. There would be little or no land acquisition cost.

b. There would be little or no displacement of homes or other buildings.

c. Most of the guideway could be constructed at ground level, which is the least expensive vertical alignment.

4. The necessity for constructing an underground or elevated LRT guideway makes such a route very unattractive economically.

5. Location of an LRT line within or alongside a freeway may be satisfactory, but this depends on the characteristics of the freeway. Freeway routings often avoid major activity centers where there are concentrations of transit demand. Further, pedestrian access to an LRT stop located in the median strip of a freeway is usually poor. Hence, there should be no particular preference given to freeway alignments. Radial railroad corridors are proving to be the most desirable candidate for joint use of ROW.

6. Street running of LRT vehicles is permissible in the Central Business District, where alternative alignments would be the most costly and where frequent stops are desirable for effective passenger collection and distribution. However, the majority of any LRT route should be on separate right-of-way in order to achieve the high average speed needed to attract passengers away from competing transportation modes.

7. The spacing of stops on an LRT line should be more like that of a heavy rail system (conventional subway-elevated) than that on ordinary streetcar lines. This generally means a spacing of one-half to one mile between stops. The CBD is an exception, since close spacing of stops (every two or three blocks, depending on block length) is desirable.

8. The stops on an LRT route (outside of the CBD) should be designed as transfer points, with feeder bus service and extensive parking facilities to attract park-and-ride travelers. Demand responsive operations may be a suitable feeder mode in suburban areas.

9. Federal regulations mandate that any new transit system be accessible to elderly and handicapped travelers, including those who use wheelchairs. This suggests that an LRT line should be designed for high-level loading, and the stations should have platforms with ramps or elevators.

10. One marked advantage of LRT over bus systems is the ability to run vehicles in trains, which permits flexible allocation of capacity and economies in operating costs. This advantage makes LRT an attractive option for corridors with heavy peak-period demand. However, much of this advantage is lost if it is necessary to have a fare collector on each car of a train. This suggests that there should be fare collection at stations or self-servicing operations when multi-car trains are to be used.

11. If one objective of a transit facility is to promote intensive land development in a corridor or at certain points, then an LRT line is more likely to accomplish this than bus options. However, experience with recent rail transit projects indicates minimal land use

impact, except where there are already strong land development pressure and effective land use regulation.

12. A phased transition from busway to LRT in the same corridor in concept requires further examination in regard to both technical aspects and federal policies.
13. Any worsening of the petroleum supply situation in the United States will make LRT a more attractive option, because the power supply can be obtained from non-crude oil sources.
14. As discussed in Chapter 3, there are many technical and engineering issues that must be resolved in the design of an LRT line. It is not appropriate to make broad generalizations on these issues, since the answers will depend on local circumstances. Many of the issues involve tradeoffs between higher capital costs and lower operating costs or better service, so there are policy implications. Thorough planning and engineering studies should be conducted, and the results published, before making any final decision to proceed with an LRT line.
15. In the evaluation of alternatives Tables 6-24 and 6-25 provide information which may be useful. A form of goal achievement matrix has often been used successfully in facilitating the identification of tradeoffs, and performance measures, with respect to local objectives. It has proven to be useful at the preliminary stage of evaluation, prior to detailed engineering studies.

Given the rapid growth of Texas cities and a difficult energy situation that now appears to be a continuing feature of American life, it is clear that major transit improvements are going to be considered in several Texas cities in the next few years. Following the "alternatives analysis" procedure that has been stipulated by the Urban Mass Transportation Administration, it is probably that Light Rail Transit will be examined as one alternative. It is hoped that the information amassed in this report, and summarized in the guidelines above, will prove useful in this process.

PREFACE

This is the final report on Technical Study 3-10-78-1058, "An Evaluation of the Applicability of Light Rail Transit to Texas Cities." This study was intended to facilitate an impartial assessment of the applicability of light rail transit (LRT) as an alternative to the bus in Texas cities. This study is an attempt to provide an evaluation and documentation which will assist State and local officials in determining whether LRT proposals should be given serious and detailed investigation. It is not intended to develop specific LRT proposals for individual cities, and it is definitely not intended to present a biased view either in favor of organized LRT or against it. The purpose is to provide an objective, technical assessment of the attributes and pertinent factors which should be considered in evaluating the potential viability of LRT in Texas cities.

The authors wish to acknowledge and extend their appreciation to the many individuals who have provided information and contributed knowledge to this effort. Special recognition is extended to Mr. Don Dial of D-10M of the State Department of Highways and Public Transportation and Mr. Russell Cummings of D-10M (now D-18S) for their guidance and critique during the span of the study. To all of these individuals we are greatly indebted.

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Alan Black

Study Supervisors

ABSTRACT

In order to make impartial yet informed decisions relative to certain transportation alternatives it is necessary to have an understanding of the characteristics and unique features as well as the opportunities of a range of options. The objective of this study was to perform an investigation of LRT tracing its evolution up to recent trends. The end result was to provide information of sufficient detail and scope to facilitate an assessment of the suitability of LRT as an alternative (or complement) to the bus in Texas cities.

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The implications of LRT for Texas cities, an historical review of urban rail transit in Texas, a discussion of current plans and proposals, and pertinent guidelines for consideration of LRT in an alternative evaluation process are discussed.

KEY WORDS: transit, light rail, LRT, planning, design, operations, vehicles.

SUMMARY

With the changing problem of urban transportation in Texas cities, fostered by expanding growth and development, resultant traffic congestion, and exploding costs of gasoline (and diesel fuel), public and mass transit systems have achieved a renewed respectability. Light rail transit (LRT) is one mode for which there is increased attention yet limited understanding by many from layperson to professional engineer. The overall purpose of this study was to assess the potential applicability of LRT to Texas cities and to prepare a readily understandable report documenting the scope of the study in terms of general historical aspects to engineering details.

A historical overview of the development of the LRT concept from the early electric streetcars, a review of the current status of LRT applications from around the world and the U.S., and a critique of the findings are presented. LRT was found to be used as a medium capacity mode which is generally well integrated with various applications of other modes which serve as a complementary operation, thus enhancing the system utility. In North America the recent LRT projects tend to be concerned with rehabilitation and modernization of existing systems, except in Buffalo and San Diego. Newly constructed or proposed LRT lines show similar trends in right-of-way locations and network designs. Government policy is found to have a direct effect on the trends of current LRT planning and operations.

The physical and operational characteristics of LRT which affect total cost and efficiency are structured into eight categories. These eight categories, which are described in moderate detail, include vehicles, cost networks, tracks and structures, power supply, fare collection, stations and platforms, signaling and traffic control, and operations.

Knowing the kinds of cities and situations in which LRT has been used in U.S. cities, as well as foreign cities, is of value in a first level assessment of potential LRT opportunities in Texas cities. A mathematical model for optimizing active urban transit system applications was applied in a comparison of LRT with bus systems. Incorporated in this section of the report is a

discussion of those identifiable factors that led some U.S. cities to retain their streetcars in contrast to those which abandoned them.

An evaluation of the utility of LRT in general, which is then applied to the findings for cities in Texas, is provided in an attempt to foster that process. The characteristics of candidate Texas cities are summarized, and the report concludes with recommendations in the form of guidelines that may be useful in considering LRT as a possible transit alternative for Texas cities.

IMPLEMENTATION STATEMENT

This report documents the proceedings of a study to evaluate the applicability of light rail transit to Texas cities. The study was conducted in three phases which relate to levels of implementation possibilities.

A major section of the report contains a background critique of the evolution of LRT up to recent trends. A list of references is included to offer the reader an opportunity to seek further elaboration on a variety of topics.

The report is useful to laypersons and engineers since it provides pertinent information concerning LRT design and operations, LRT operations in example cities, and past and present LRT activities in Texas cities.

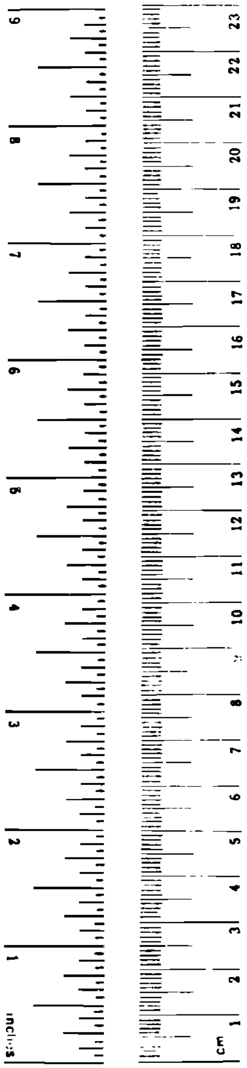
In an attempt to reach a wide audience, the format and language of the report have been prepared with care.

It is recommended that this report, along with others, be considered for use by public officials, private citizens, and others who wish to gain a basic, first level appreciation of LRT. It is intended as a basic reference, and to that end this report is submitted.

METRIC CONVERSION FACTORS

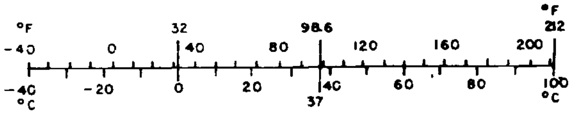
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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CHAPTER 1. INTRODUCTION

PURPOSE OF THE STUDY

Americans are currently more aware than ever before of the price they are paying for their dependence on the private automobile for intraurban transportation. Shortages of gasoline, rationing in some areas, and rapidly rising prices have aroused a public consciousness matched only by that during the Arab oil embargo of 1973-74. The reaction has been predictable: a strong demand for fuel-efficient cars, some reduction in travel, and a shift to public transportation.

The gasoline situation is not the only problem associated with the long historical shift to automobile transportation in the United States. Other facets that have received increasing attention in recent years include air and noise pollution, accidents, visual blight, decay of older urban neighborhoods, and a nagging problem that is a direct result of the popularity of the automobile——persistent traffic congestion. In addition, the life-styles and living arrangements of most Americans have changed to accommodate the automobile, resulting in a dispersed, low-density pattern of settlement (of which Texas cities provide excellent examples).

These problems have led to a revival of interest in urban mass transit in the past decade. The national total of transit passengers, which had been declining for almost 20 years, turned the corner in 1973 and has been rising steadily since then. Political attitudes towards transit have also changed drastically: most large transit systems have been taken over by public agencies, and transit is no longer expected to pay for itself out of the farebox. Federal aid to local transit, which started on a very modest scale in 1961, now exceeds one billion dollars a year. Many states have supplemented this with their own programs; for example, the State of Texas will pay 65 percent of the non-federal share for any transit capital improvement.

One result of these efforts has been to halt the wave of transit system abandonments that swept the country during the 1950's and 1960's.

Another has been the construction of some major new facilities, most notably the BART system in the San Francisco area and the Metro in Washington, D.C. There have also been considerable research and experimentation with new hardware and new systems concepts. Two well known examples of the latter are the Personal Rapid Transit line in Morgantown, West Virginia, and the Dial-A-Bus system that was tested in Haddonfield, New Jersey.

One of the new concepts that has been much discussed in the last few years is called Light Rail Transit (LRT). The Urban Mass Transportation Administration (UMTA) arranged for the development of a new transit vehicle, the Standard Light Rail Vehicle (SLRV), which was designed and built by the Boeing-Vertol Corporation and has been purchased by Boston and San Francisco. UMTA also sponsored two national conferences on Light Rail Transit. As yet, there is no completed LRT system anywhere in the United States, but there are two lines currently under development in Buffalo, New York and San Diego, California.

Texas cities are experiencing to one degree or another all of the contemporary urban transportation problems of major cities. Some of the problems particularly traffic congestion, have been aggravated by the very rapid growth of the largest cities in Texas, resulting in part from the well publicized Sun Belt phenomenon. Consequently, public and mass transit have achieved a renewed respectability in Texas, and there is serious consideration of major transit improvements in many quarters. Because LRT may be one of the options that should be considered, the State Department of Highways and Public Transportation sponsored this study to assess the potential applicability of Light Rail Transit to Texas cities.

Background

Light Rail Transit is a direct descendant of one of the oldest transit modes, the electric streetcar or trolley car (known as the tram in Europe). The streetcar was invented by the German Werner von Siemens, and the first commercial service opened in a suburb of Berlin in 1881. The first extensive streetcar system in the United States was developed by Frank J. Sprague and opened in Richmond, Virginia, in 1888. The streetcar was so much superior to the horsecar in speed and comfort that city after city converted during the 1890's and early in this century. The streetcar became the dominant mode of urban transportation (in Texas as elsewhere), and national ridership totals climbed to a peak of 13.6 billion passengers in 1923.

Trouble for the streetcar industry (then almost always in private ownership) began in 1914 with competition from jitneys, but within a few years these were outlawed in most American cities. More serious difficulties arose after the end of World War I, when a combination of mismanagement, over-capitalization and over-extension led to a wave of bankruptcies. A period of retrenchment and consolidation followed in the 1920's, at the same time that automobile ownership became significant and the motor bus appeared as a serious competitor for transit users.

The Great Depression in the 1930's reduced all transit riding markedly and accelerated the decline of the streetcar. Many of the original installations reached the ends of their useful lives, and much of the rolling stock also became dilapidated, a situation aggravated by a common practice of deferred maintenance. When it came time to rebuild and replace, many transit operators opted to convert to buses, which required a much smaller capital outlay. First buses were used on the low-patronage lines, with streetcars retained on the busier routes, but as time went by, entire urban transit systems were converted to bus.

This trend was suspended during World War II, when the manufacture of private automobiles ceased for three years, gasoline and tires were rationed, and the national speed limit was set at 35 mph. Of necessity, the American people turned back to transit, and national ridership totals reached record levels, exceeding even those of the 1920's. The streetcar participated in this revival; all large American cities and most of the medium-size ones relied heavily on streetcars during the War. Some cities were fortunate to have the excellent Presidents' Conference Committee (PCC) car, developed by a committee of transit operators in 1934 in an attempt to standardize equipment.

Following the war, the decline in transit riding resumed at an even greater pace. The conditions were quite different than before the War: now prosperity was the rule, automobile ownership increased tremendously, and millions moved to single-family homes in the suburbs. During the 1950's and early 1960's, all but a handful of American cities wiped out the last vestiges of their streetcar systesm: New York and Detroit in 1956, Chicago in 1958, Washington in 1962, and Los Angeles in 1963. The last American order for a PCC car was placed in 1952, after which more than 20 years passed before an American city again brought a new streetcar.

The abandonment of the streetcar was not total, however. Seven American cities have retained at least one streetcar line up to this time, and in three cities——Boston, Philadelphia, and San Francisco——streetcars still carry a significant number of passengers. (The details of these seven cases are discussed in the following chapters.) Two short streetcar lines have been built in recent years——one in Fort Worth, opened in 1963, and one in Detroit, in 1976——but these are both special-purpose lines that do not qualify as major transit service.

The situation has been quite different in other countries, as indicated by the fact that today about 300 foreign cities have streetcar or LRT systems. The majority of these are in Communist countries, where automobile ownership is very low, but the streetcar has also remained popular in many parts of Western Europe and Japan. There has been a steady demand for new rolling stock, which has been continually modernized, so that foreign equipment is a far cry from the PCC car and its predecessors. While street running was originally the rule in Europe, some of the new lines built since World War II have incorporated long stretches of separate rights-of-way, making relatively high average speeds possible. This was the origin of the Light Rail Transit concept.

The Situation in Texas

The historical record of the streetcar in Texas was roughly parallel to that in the rest of the United States. While it may be hard for many Texans to imagine, it is a fact that at one time the electric streetcar was the backbone of urban transportation in Texas. (Details of this history are given in Chapter 2.) According to the census reports on electric railway transportation (conducted by the U.S. Census Bureau every five years from 1902 to 1937), the peak number of companies was 39 in 1912; the peak mileage in the state was 1,024 in 1927, and the peak ridership was 187.5 million fare-paying passengers in 1922. The last figure is about 50 percent greater than the total number of annual transit passengers in Texas today.

The decline of the streetcar came somewhat earlier in Texas than elsewhere, as San Antonio abandoned its system in 1933, and Houston in 1941. During World War II, there were only three Texas cities (Dallas, El Paso, and

Waco) that still had electric railway service. Dallas abandoned its last line in 1956. El Paso continued to operate one streetcar line across the border to Ciudad Juarez until 1973. Current plans call for a return of this operation today since it was a viable and economical service.

Initially most of the Texas cities converted to bus service, and during the 1940's and 1950's, all of the larger cities in the State had bus service. Some of these systems were eventually abandoned, while those that remain have all changed to public ownership. Today there are 18 metropolitan areas in Texas that have public transit service (all provided by buses). Since there are 25 Standard Metropolitan Statistical Areas designated in Texas by the Census Bureau, this means that there are seven metropolitan areas without any regularly scheduled transit service.

The Case for LRT

The idea of Light Rail Transit was based on some of the modern installations in Europe. As mentioned earlier, the concept has been actively promoted by the Urban Mass Administration. Perhaps the principal motivation for UMTA officials stemmed from the billion-dollar costs for constructing what now must be called "heavy rail" systems——such as BART in San Francisco, METRO in Washington, and MARTA in Atlanta. While the federal allocations for transit investment aid have risen rapidly, the amounts are still far short of what would be necessary to build conventional subway-elevated systems in all the major cities (particularly Los Angeles). Thus UMTA has favored LRT as a cheaper alternative as far as rail systems are concerned.

At the same time, many transit advocates favor rail transportation over the bus, and there is a reluctance by some to make a total commitment to the bus for all future transit improvements in the United States. The bus does not enjoy a good image or the overall respect of the public. The low average speed and high average travel times of most conventional bus operations does not make it much of a competitor with the private automobile. The image of buses may be enhanced with various types of preferential treatment of buses which are currently being widely tested. It is widely felt that large and medium-size cities that do not have heavy rail need some transit facility that is "better" than possible with buses only.

Thus, Light Rail Transit is typically seen as a kind of intermediate mode between heavy rail and bus. It is generally compared with heavy rail, on one hand, and with bus, on the other. It is presumed that it might be suitable for corridors of medium density where a medium level of capacity is needed. This might well apply to such Texas cities as Houston, Dallas, El Paso and San Antonio.

The main advantage cited for LRT over heavy rail is lower costs, particularly for construction of guideway. Since LRT vehicles are lighter and top speeds are lower, savings can be achieved in track construction, power distribution, and signaling. The greatest savings are possible, though, from running LRT vehicles in existing streets, so that no new rights-of-way are needed. This would presumably only be done where tunneling or overhead guideway would be exorbitant.

As discussed later, the prices for new LRT vehicles recently purchased by American cities have been very high, so it is questionable whether they are any cheaper than heavy rail vehicles. There is little information on LRT operating costs, and no reason to think they would be much lower than those for heavy rail.

When compared with conventional bus service, the principal advantage of LRT is that is runs on a separate right-of-way; it is thus free from traffic interference and capable of much higher average speed. (Note that LRT proponents want to eat their cake and have it too: LRT is cheaper than heavy rail because it can run in mixed traffic, and faster than buses because it runs on a separate right-of-way. Obviously both advantages cannot be achieved simultaneously, but LRT is intended to be a flexible mode that gives more opportunity for compromises. This really underscores its position as an intermediate mode between heavy rail and bus.)

LRT does share the other advantages of rail transportation over the typical bus: The ride is generally conceded to be smoother. The vehicles do not produce any air pollution on site. The power need not be generated with petroleum-based fuels. The vehicles can be grouped in trains, which creates some operating economies in heavy demand situations. The permanence of the guideway is more likely to induce land use impacts. And finally, rail transit may generate more public and political acceptance.

Thus, LRT is widely regarded as filling a gap in the spectrum of transit alternatives that should be considered by American cities. Presumably heavy rail will be indicated for some cities, and bus systems for others, but in between there may be some cities for which LRT will be the optimal mode. Just how big the gap is, and how many cities are involved, will only be determined by further analysis and experience. However, the fact that so many foreign cities consider LRT to be a viable transit mode suggests that this assessment has some validity.

Outline of This Report

The objective of this report is to assemble information on the development and current status of Light Rail Transit, and on its operations, economics, and impacts, in order to assist State and local policymakers in deciding whether it is a reasonable alternative to consider for public transportation development in Texas cities. It was assumed that the only cities in Texas where LRT might be suitable (if at all) would be the larger cities——specifically, those with a population of at least 200,000. While specific proposals advanced for individual Texas cities are reviewed, no attempt is made to develop any specific plans or to determine that City X is suitable for LRT and City Y is not. These are matters that require site-specific studies and decisions by the appropriate public officials.

Throughout the study, the participants attempted to maintain an attitude of objectivity about the feasibility of Light Rail Transit. Hence this report is not a brief for the LRT cause, any more than it is a condemnation of LRT and advocacy of only highway-based public transportation for Texas. The purposes of the study were considered to be exploration, information gathering, and general analysis.

The remaining section of this chapter discusses the definition of Light Rail Transit and distinguishes it from other transit modes. Chapter 2 covers the evolution of LRT, including its historical development from the earliest streetcars (with particular discussion of Texas experience), the current status of LRT operations and plans in the United States and foreign countries, and recent trends in the planning and operations of LRT systems. Included is discussion on each of the American cities that has retained the streetcar, along with recent proposals for new LRT systems in other cities.

Chapter 3 delves into the details of the design, engineering, and operations of LRT systems. Among the topics discussed are vehicles, track and structures, power supply, stations, fare collection, and signaling. The chapter pinpoints particular issues that must be settled in developing any specific LRT proposal.

Chapter 4 focuses on the kinds of cities and situations where LRT appears to be a viable option. It describes the characteristics of cities that currently have streetcar/LRT systems and those that are actively considering building LRT lines. A mathematical model for optimizing urban transit systems was applied in a comparison of LRT with bus systems, and the results are summarized. Finally, there is a discussion on the factors that led some American cities to retain their streetcars, in contrast to the majority that abandoned them.

Chapter 5 takes up the factors which would be important in evaluating any LRT proposal. Costs would obviously be crucial, and recent data on vehicle prices, construction costs, and operating costs are presented. Other factors are also discussed, and there is a comparison of LRT with other transit modes.

Chapter 6 attempts to relate the general findings of the study to the Texas situation. The characteristics of candidate Texas cities are compared with those of other cities that have or are considering streetcar/LRT systems. Past proposals for particular Texas cities are summarized. The final section presents recommendations in the form of guidelines that may be useful in considering Light Rail Transit as a possible transit alternative for Texas Cities.

DEFINITION OF LRT

In the spring of 1976 the Transportation Research Board Committee on Light Rail Transit wrote a simplified definition of the characteristics of light rail:

> Light rail transit is a mode of urban transportation utilizing predominantly reserved but not necessarily grade-separated rights-of-way. Electrically propelled rail vehicles operate singly or in trains. LRT provides a wide range of passenger capabilities and performance characteristics at moderate costs (Ref 1).

The guideway consists of two steel rails with power collection normally from an overhead wire. The term "light rail" was coined to describe those rail systems designed to handle lower passenger volumes than the conventional rapid ("heavy") rail transit systems. A double meaning has evolved since light rail vehicles are usually lighter in weight per foot of length than heavy rail cars partly because they are narrower. Other terms for the light rail mode include:

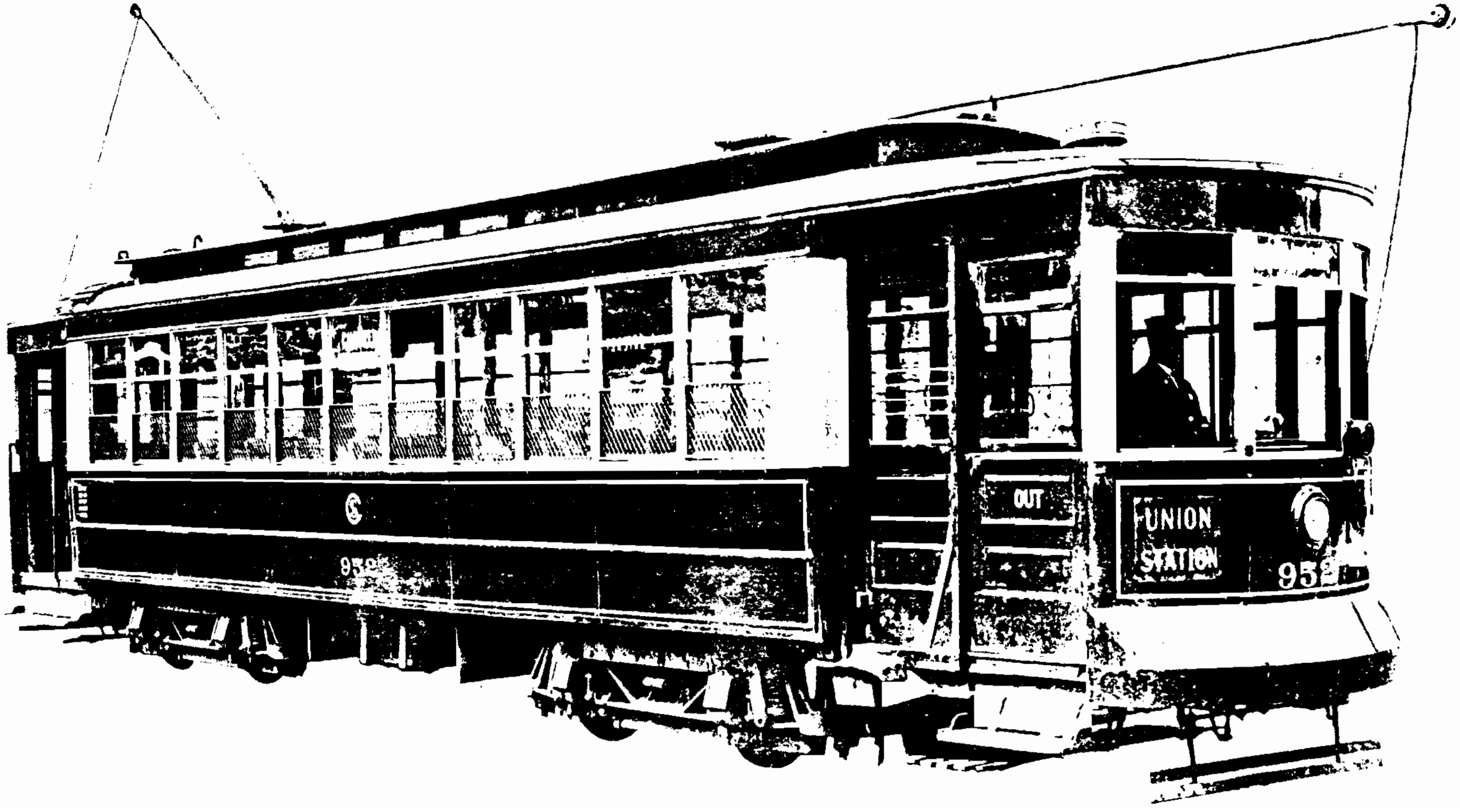
- modern trolley,
- intermediate capacity rapid transit,
- rapid tramway, and
- semi-metro.

LRT vehicle technology is similar to the old electric streetcar (sometimes referred to as trolley, tram, or electric street railway). Figure 1-1 shows a "typical" streetcar that was used in many U.S. cities starting about 1910, while Figure 1-2 depicts the Presidents' Conference Committee (PCC) car that was last built in 1952 and is still widely used today. Newer light rail vehicles (LRV's) have been designed to take advantage of "state-of-the-art" technology, resulting in faster, safer, and more comfortable cars. Figures 1-3, 1-4, and 1-5 depict some modern LRV's.

The major difference from the conventional streetcar mode lines in a systems concept: the streetcar (almost by definition) typically operates on city streets competing with other traffic while light rail systems utilize private rights-of-way for a large portion of their routes. Even if streetcars are used on such a system, the reduction of conflicts with regular traffic should result in higher operating speeds and greater safety.

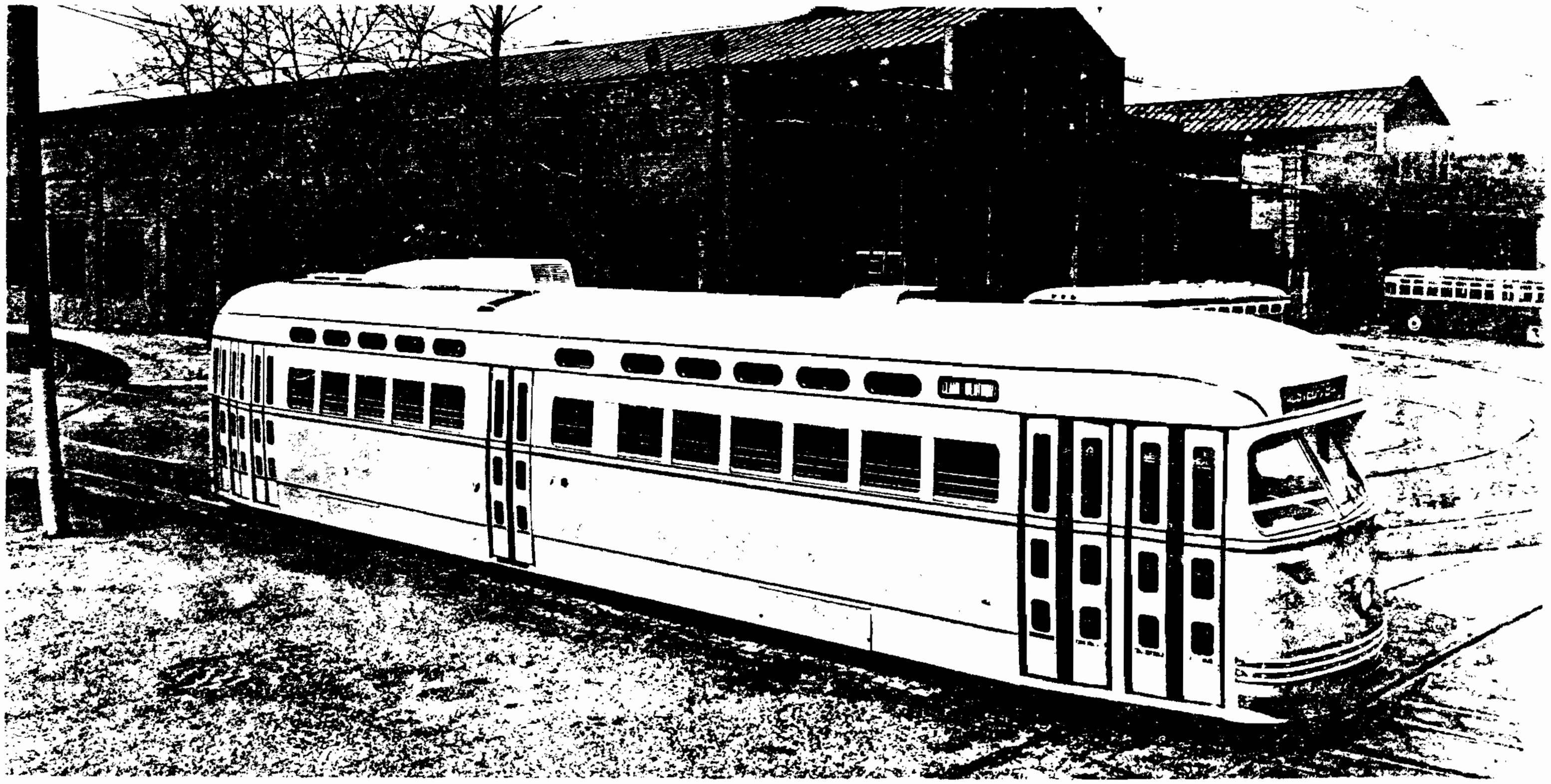
A search of the literature revealed no clear definition indicating when a streetcar system could be classified as light rail. This is partly because many streetcar systems are being gradually upgraded to light rail systems. One such example is in Pittsburgh where plans are being made to upgrade the existing trolley system by increasing the amount of private rights-of-way and modernizing grade-crossing signal protection (Ref 2). It appears that one reason for the common American use of the new term "light rail" is to signify a departure from some of the street railway practices of the past.

FIGURE 1-1. "PAY-AS-YOU-ENTER" STREETCAR BUILT BY PULLMAN-STANDARD, ABOUT 1910.



Source: William D. Middleton, The Time of the Trolley, 4th ed. (Milwaukee: Kalmback Publishing Company, 1975), p. 226.

FIGURE 1-2. PRESIDENT'S CONFERENCE COMMITTEE CAR BUILT BY PULLMAN-STANDARD IN 1947.

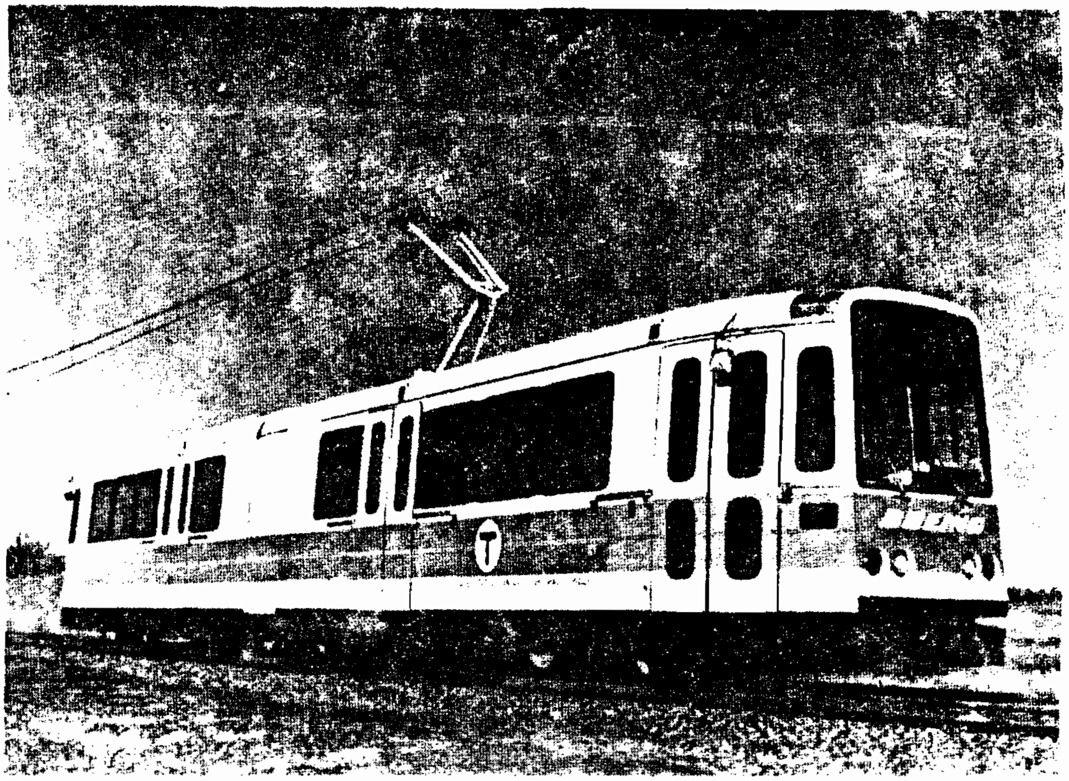


Source: Time of the Trolley, p. 134.

FIGURE 1-3. URBAN TRANSPORTATION DEVELOPMENT CORPORATION'S CANADIAN LIGHT RAIL VEHICLE.

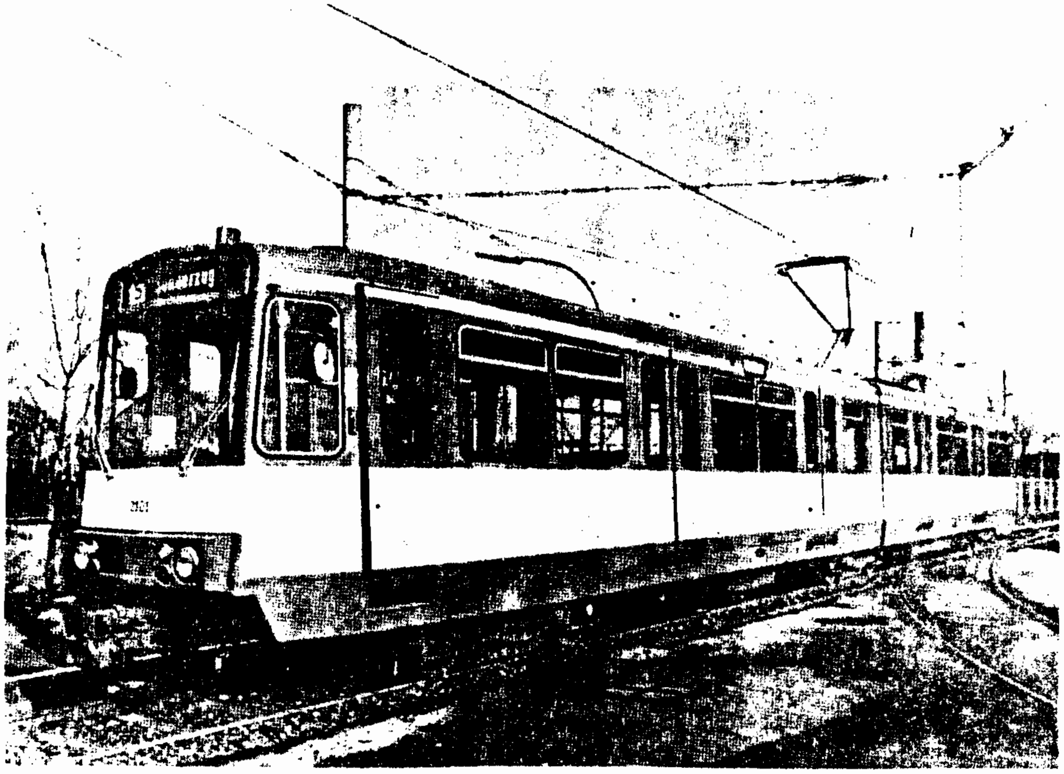
Source: U.S. Department of Transportation, <u>Light Rail Transit: A State of the Art Review</u>, prepared by De Leuw, Cather & Company (Washington, D.C.: GPO, 1976), p. 142.

FIGURE 1-4. URBAN MASS TRANSPORTATION ADMINISTRATION'S STANDARD LIGHT RAIL VEHICLE, MANUFACTURED BY BOEING VERTOL COMPANY.



Source: Light Rail Transit: A State of the Art Review, p. 145.

FIGURE 1-5. DUWAG TYPE B CAR, WIDELY USED IN GERMANY.



Source: Light Rail Transit: State of the Art Review, p. 151.

A technology similar to light rail was the electric interurban railway Interurbans (trolleys) were heavier, faster, and usually more comfortable than the old city streetcars, following routes that interconnected many fairly distant cities. While operation was on streets in cities, in rural areas the interurban operated on the sides of highways or on private rights-of-way. Figure 1-6 depicts a typical American interurban car built over forty years ago.

The trackless trolley is also called "electric bus," "trolley bus," or "trolley coach." Since there are no rails to guide the vehicle, the trolley bus must be steered, usually with rubber tires on regular pavement. The vehicle requires two overhead wires for operation whereas streetcars need only one. This is because the streetcar is able to make its ground connection through the contact of steel wheel with steel track (thus completing a circuit), while the rubber-tired bus must use an extra wire. Figure 1-7 shows a typical trolley bus.

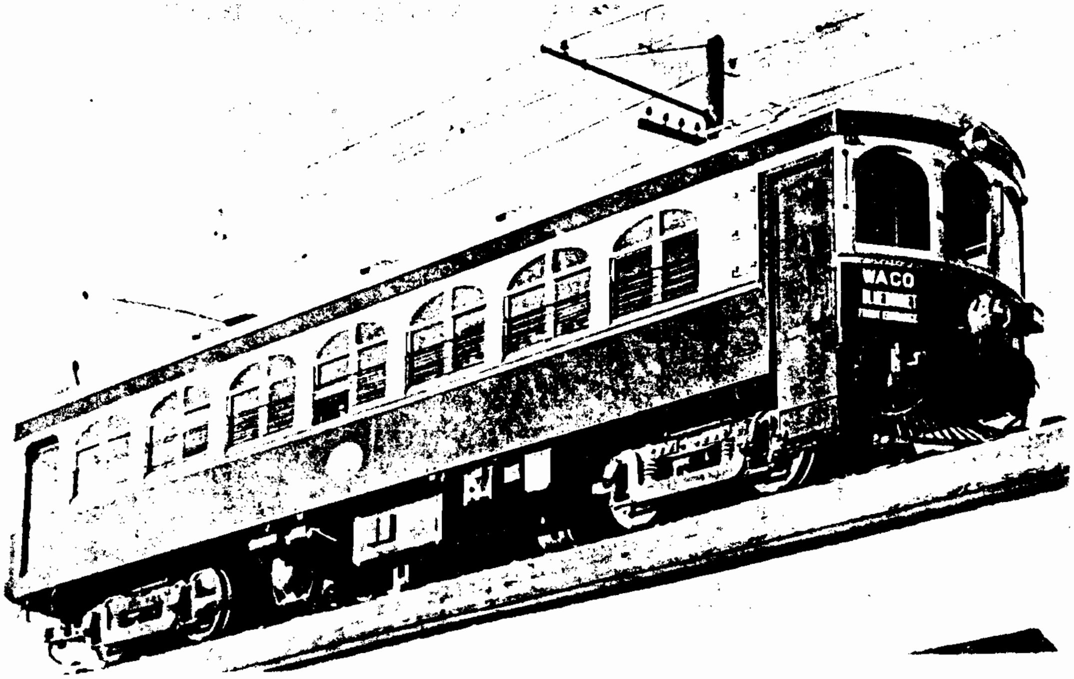
The commuter railroad ("regional rail") refers to a service that transports passengers on a daily basis from suburbs and nearby towns to the downtown areas of large cities. Peak period work trips to and from the Central Business District (CBD) are primarily served.

While light or heavy rail could operate in a similar manner, a distinction can usually be made through the differences in technology. A commuter railroad normally has conventional unpowered passenger cars pulled by heavy diesel or electric locomotives. Electric locomotives use overhead catenary wiring instead of a third rail since the right-of-way (ROW) is not fully protected. Amtrak operates as a type of electricity commuter railroad on privately owned track. Some commuter railroads are now using specially designed equipment such as double-deck passenger cars. Toronto is using the double deck (bi-level) commuter cars, built by Hawker Siddely.

An LRT system is usually distinguished from conventional rapid rail transit (Figure 1-8) in that it does not always require private, grade-separated rights-of-way; that is, at-grade crossings with other traffic, while not desirable, may occur in places. This usually results in lower operating speeds and greater accident hazards compared to rapid rail but with a reduction in:

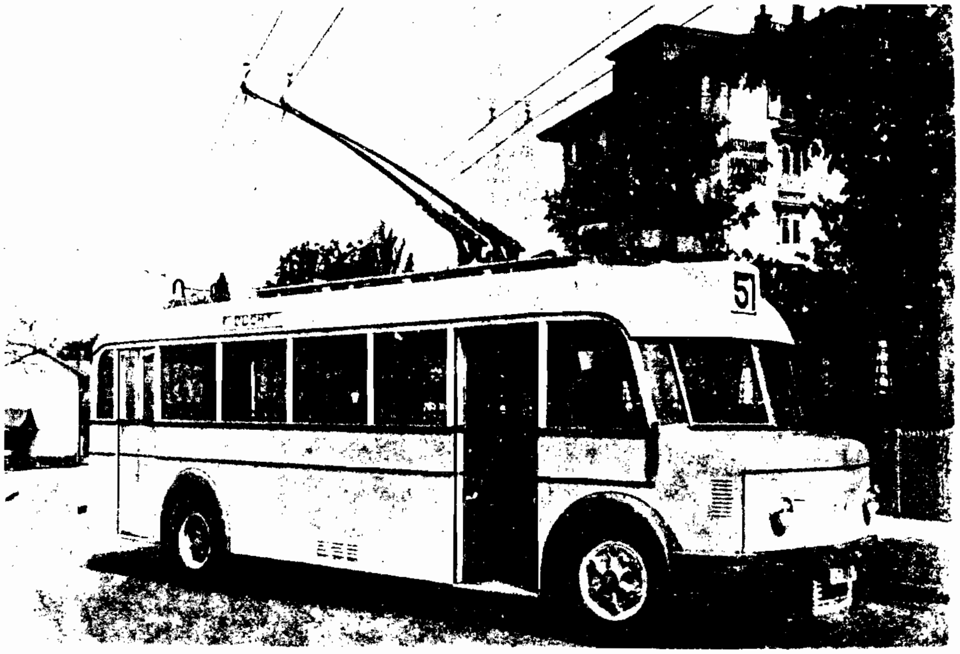
- construction costs, due to less need for expensive subway and/or elevated tract sections,

FIGURE 1-6. INTERURBAN VEHICLE IN OPERATION ON THE WACO-DALLAS-DENISON ROUTE IN THE 1930s AND 1940s.



Source: Rod Varney, *Texas Electric Album* (Claremont, California: Interurbans, 1975), p. 26.

FIGURE 1-7. SWISS TROLLEY BUS, BUILT ABOUT 1940.



Source: Charles S. Dunbar, Buses, Trolleys, and Trams (Feltham, England: Hamlyn Publishing Group, 1967).

FIGURE 1-8. BAY AREA RAPID TRANSIT (BART) TRAIN IN SAN FRANCISCO, CALIFORNIA.

Source: Lyndon Henry, Texas Association for Public Transportation, CARTRANS: High Speed Transit for the Texas Capital (Washington, D.C.: Rail Foundation, 1973), p. 52.

- the lag time between initial construction and operations since at-grade track can be constructed more quickly.

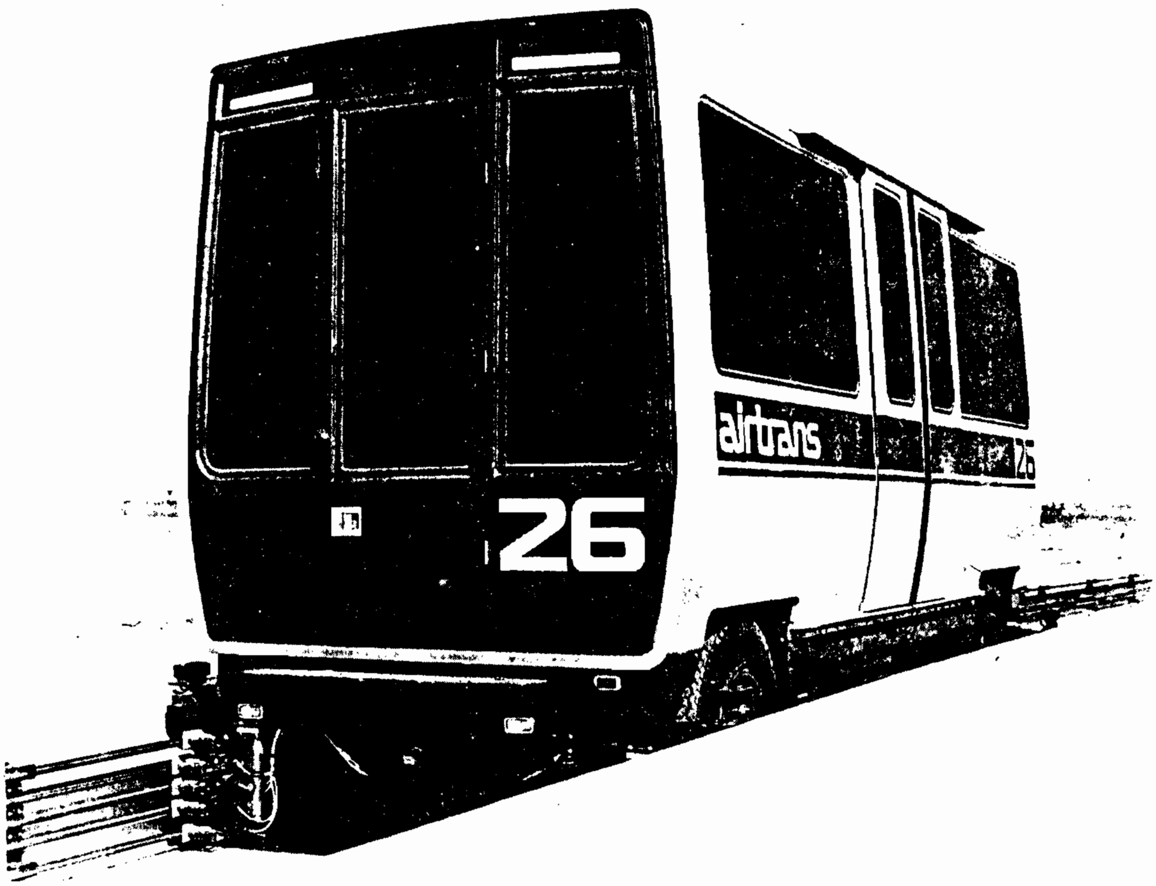
While the narrower LRV's have lower passenger capacity per foot of length, they are able to operate on sharper curves. With less restriction on horizontal alignments, it may be possible in some cases to substantially reduce the costs of right-of-way purchases.

Group rapid transit (GRT) and personal rapid transit (PRT) are classified separately from both light and heavy rail technology (Ref 3). GRT (also known as light guideway transit) operates singly or in trains over an exclusive guideway, generally under automatic control but incorporates an unconventional vehicle suspension and guideway design. The vehicles are usually the size of a small bus, and stations can be on-line or off-line. During peak periods, service may be demand-activated. PRT generally uses small vehicles (2-6 seated passengers) that operate over an exclusive guideway with total automatic control. Stations are off-line and services can usually be demand-activated. Both GRT and PRT are commonly classified as "Automated Guideway Transit" (AGT). Figure 1-9 depicts an AGT vehicle with rubber tires that can hold about 20 passengers.

Sometimes a light rail system is designed as a predecessor rapid rail transit. The concept is to upgrade the system as more construction funds become available and as passenger capacity requirements increase. Such a system is commonly termed "pre-metro." Compared to regular light rail, the track requirements are for a greater horizontal radii of curvature, less steep grades, and an ability to eventually convert to a fully controlled right-of-way (no at-grade crossings). With this concept many of the cost advantages of regular light rail over heavy rail cannot be realized, even at the initial construction stage. Since some of the track may need to be relocated to ensure an exclusive right-of-way, the total cost of first constructing light rail and later converting to full rapid transit would be much higher than to construct a rapid transit system at the outset (Ref 4).

The term "light rapid transit" refers to a system that uses light rail vehicles but has fully controlled right-of-way. A portion of the line is usually under some form of automatic train control with average operating speeds approaching that of conventional rapid rail transit.

FIGURE 1-9. "AIRTRANS" AUTOMATED VEHICLE OPERATING WITHIN THE DALLAS/FORT WORTH AIRPORT



Source: <u>CARTRANS</u>, p. 99.

Table 1-1 compares "typical" streetcar, LRT, and rapid rail transit systems based on 22 components. Many planners now consider a streetcar operation simply to be at the lower end of a light rail transit performance spectrum (Ref 5).

The following chapter of this report will describe in greater detail these characteristics, the past experience in Texas, and provide a basis for future considerations.

TABLE 1-1. COMPARISONS BETWEEN STREETCAR, LIGHT RAIL, AND RAPID RAIL TRANSIT MODES

Planning Components Mode	Streetcar	Light Rail Transit	Rapid Rail Transit
Capital Cost/Track Mile	Low	Middle	High
Operating Cost/Passen. Mile	High	Middle	Low
Right-of-Way	Shared	Partially controlled	Exclusive
Area Coverage	CBD coverage and dispersed lines	CBD coverage and radial lines	Predominantly radial
Track Location	At grade	Predominantly at grade	Subway/elevated structures frequently needed to ensure a fully controlled right-of-way
Track Alignment	Sharp curves and steep grades common	Sharp curves and steep grades possible	Smoother curves and less steep grades needed for higher speeds
Single/Multiple-Unit Operation	Mostly 1 vehicle	1-4 vehicles	2-10 vehicles
Loading	Street level	Low or high level platforms commonly used, with street loading possible	High level platforms only
Fare Collection	On-vehicle	On-vehicle or at-station	At-station
Station Spacing	Under 800 feet (250 m)	800-2500 feet (250-800 m)	1600-6500 feet (500-2000 m)

TABLE 1-1. COMPARISONS BETWEEN STREETCAR, LIGHT RAIL, AND RAPID RAIL TRANSIT MODES (CONTINUED)

Planning Components / Mode	Streetcar	Light Rail Transit	Rapid Rail Transit
Signalling	Visual	Visual/block signalling	Automatic block signalling
Traffic Control	No vehicle priority in mixed traffic	Vehicles usually given some priority at crossings	No at-grade crossings allowed
Passenger Access	Pedestrian feeder	Auto, pedestrian, and bus feeder	Auto, pedestrian, bus, and perhaps light rail as feeder
Power Collection	Overhead, with trolley pole	Overhead, usually with pantograph	Third rail
Power Supply	500-650 volts DC	600-900 volts DC	600-1500 volts DC, or high-voltage AC
Safety and Reliability	Poor, due to traffic conflicts, careless pedestrians	Moderate, depending on amount of controlled right-of-way	Very good
Vehicle Length	45-70 feet (14-21 m)	50-100 feet (15-30 m)	50-75 feet (15-23 m)
Vehicle Weight per Unit Length	550-900 lbs/ft (820-1115 kg/m)	750-950 lbs/ft (1120-1420 kg/m)	750-1200 lbs/ft (1120-1790 kg/m)
Seats/Vehicle	15-40	20-90	30-90
Total Passengers/Vehicle	75-180	100-200	100-300
Capacity/Track	Under 5000 passengers per hour	5000-20,000 passengers per hour	10,000-60,000 passengers per hour
Operating Speed	6-15 mph (10-24 kph)	10-30 mph (16-48 kph)	15-45 mph (24-72 kph)

REFERENCES

1. Statement by the Transportation Research Board Committee on Light Rail Transit, Spring 1976.

2. Parsons Brinckerhoff-Gibbs & Hill, LRT in Pittsburgh (pamphlet, 1977).

3. "Reference Guide," in Lea Transit Compendium, Vol II No. 1, 1975 (Alabama: N. D. Lea Transportation Research Corporation).

4. Robert J. Landgraf, Greater Cleveland Regional Transit Authority, "Pre-Metro: Conversion Now or Never," in Transportation Research Board Special Board Special Report #182, Light Rail Transit: Planning and Technology (Washington, D.C.: National Academy of Sciences, 1978), pp 62-67.

5. "Editorial," in Passenger Transport, November 11, 1977.

CHAPTER 2. EVOLUTION OF LRT

HISTORICAL DEVELOPMENT

Modern light rail systems are sometimes considered an evolutionary form of the street and interurban railways. An exploration into the past will not only uncover the roots of the light rail concept but may prove helpful in analyzing what might happen in the future.

The first section of this chapter provides information as to why the electric railway developed; what effect it had on urban areas; and why it declined, especially in the United States. The remaining two sections include Texas experience and foreign experience with electric railways.

General History

Animal-Powered Railways. Before the development of electric streetcars, horse-drawn railways existed in hundreds of American cities and towns. These railways offered a service far superior to that attainable by horse-drawn omnibuses. A major disadvantage of the omnibus was that the wooden or cast-iron wheels had to travel over the rather poor, unpaved street surfaces that existed in the 19th century (Ref 1). Even paved streets tended to slow wheel rotation because rough materials such as gravel, cobblestone, and wooden or stone blocks were commonly used to provide a good walking surface for the horses.

Only seven northeastern cities had tracks laid in the streets before 1860. The large increases in urban population after the Civil War, due to the rapid rate of both industrialization and immigration, led to the wide-scale implementation of horsecar lines (Ref 2). Workers were now able to live beyond the acceptable walking range from their places of employment without increasing travel time. While real estate promoters of suburban land advocated horse railways, so did social reformers, since the lines helped to relieve overcrowded housing conditions in the city center (Ref 2). In 1881 the United States had 3,000 miles (4800 km) of track, 18,000 cars, and 100,000 horses and mules among 415 private companies (Ref 3).

Figure 2-1 shows a typical horsecar. Both the car body and the longitudinal seats along each side were constructed of wood. These 4-wheeled, single-deck cars could seat about 10-15 passengers, with a total capacity anywhere from 20-30 individuals.

Horsecars were always rather expensive to operate. Seldom was a cost lower than 25¢ per vehicle mile (16¢/vehicle km) achieved by a company (Ref 4), and this was a substantial amount in the 1870's and 1880's. Average speeds were only 5 or 6 mph (8-10 kph). Even though the vehicles were small, both a driver and an onboard fare collector (conductor) were commonly used.

About half of the costs to operate a horsecar were attributable to the traction power——the horses or mules (Ref 5). Not only were they voracious eaters, but the useful working life of a horse was 3-5 years, with only 2 or 3 hours of daily labor. Most companies kept about 5 to 10 horses for each horsecar.

What tended to wear out horses quickly was the frequent starting from a dead stop and the strain to pull a fully-loaded car up steep grades. Various "solutions" were to limit the weight of a loaded horsecar to fit the terrain, the use of horse teams, and/or the use of horse relays along a steep hill. In some cases, passengers had to get off and walk up particularly steep hills before getting on again. To relieve the strain from frequent starting from a dead stop, some operators would merely slow down and make agile male passengers get on and off while the car was in motion.

Horses and mules also suffered from diseases. This vulnerability of street railway systems became evident in 1872, when the "Great Epizootic" killed thousands of horses and mules in the larger cities of the eastern United States. Pollution was another significant problem, for it was estimated that each street railway horse deposited about 10 pounds (4.5 kg) of manure in the streets daily, in addition to wastes in the stables (Ref 3).

Steam- and Cable-Powered Railways. Both the rather slow speeds and the high passenger fares kept the horsecar lines from significantly altering city development. As an alternative, operation of steam railroads on regular streets was tried. The steam locomotives were usually enclosed in car bodies similar to horsecars to give them a less frightening appearance (Ref 3). Figure 2-2 shows such a vehicle (called a "steam dummy") pulling a

FIGURE 2-1. TWO MULE "BOBTAIL" CAR OPERATING IN LOUISVILLE IN 1883

Source: <u>Time of the Trolley</u>, p. 29.

FIGURE 2-2. STEAM DUMMY BUILT IN THE 1870s FOR STREET RAILWAY SERVICE IN PHILADELPHIA

Source: <u>Time of the Trolley</u>, p. 33.

regular horsecar. However, complaints of the excessive noise and smoke, plus an inability for steam engines to operate efficiently with a great deal of starting and stopping, kept the steam dummy from ever being very successful.

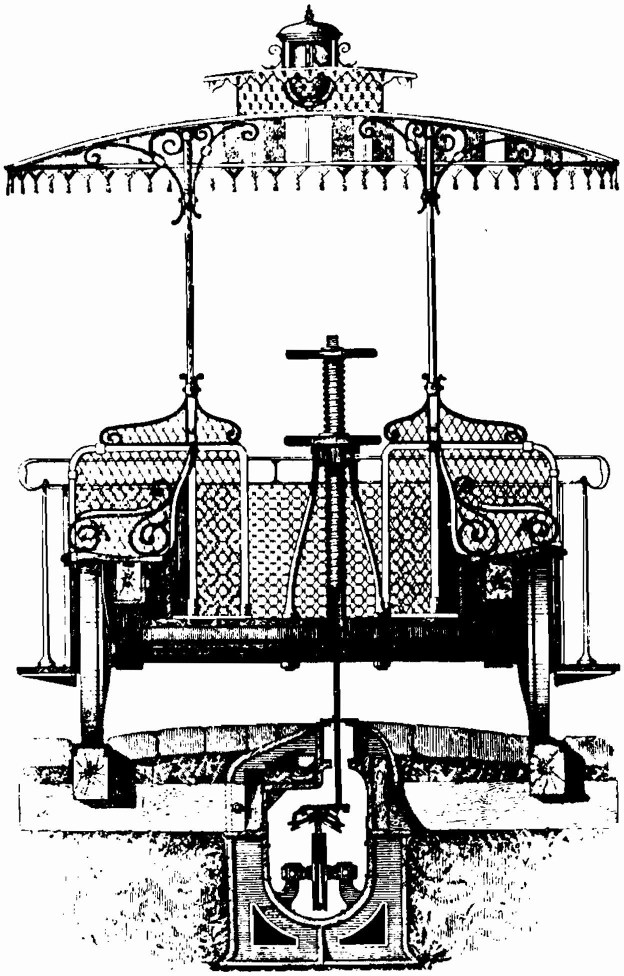
Cable railways were first tried in the 1870's. Figure 2-3 shows a cross-section view of the screw-type grip developed by Andrew S. Hallidie for the first cable railway in San Francisco. The closing of the grip would allow the cable car to be pulled along by the underground steel cable. Cables ran in loops around pulleys for several miles and were operated by a central steam power plant. Due to the expensive construction costs, cable railways were limited to operation in well-developed areas where high traffic demand already existed. However, in 1894 there were nearly 5,000 cable cars running in 28 American cities over 662 miles (1065 km) of track (Ref 3).

The Early Electric Railway. In early 1888, there were 21 private electric railway companies operating some 172 cars over 86 miles (138 km) of track. All the lines, however, were plagued with frequent breakdowns. The first successful electric railway was opened later that year by Frank Julian Sprague at Richmond, Virginia (Figure 2-4). It was soon followed by widespread electrification of America's animal-powered street railways, along with substantial new track construction.

By 1890 there were over 1222 miles (1930 km) of track operated among 200 companies. Over 100 of these were actually equipped by Sprague's firm, while fully 180 used his basic idea (Ref 6). By 1902 electric track mileage had increased to 22,000 miles (35,400 km), with about 750 companies operating 50,000 electric cars. In constrast, between 1890 and 1902 (the years of Census reports), the length of animal-powered track went from 5,660 to 260 miles (9110 to 420 km), cable track from 490 to 240 miles (790 to 390 km), and steam track (on city streets) from 710 to 170 miles (1140 to 270 km).

It was generally about as expensive to construct new tracks as it was to electrify the former horsecar lines. The lightweight rails were not entirely adequate to handle the loads of the heavier electric vehicles. Since one of the rails was commonly used as a return circuit for electrical current, better electrical bonding was needed at joints. Tracks frequently had

FIGURE 2-3. CROSS SECTION OF HALLIDIE'S SCREW-TYPE GRIP.



Source: Time of the Trolley, p. 35.

FIGURE 2-4. ONE OF FRANK SPRAGUE'S FORTY RICHMOND TROLLEYS.

Source: <u>Time of the Trolley</u>, p. 69.

curves too sharp for safe operation of electric vehicles at speeds greater than those attainable by horse-drawn cars.

About 97 percent of all the electric mileage in 1902 consisted of power coming from overhead wires (Ref 7). A trolley pole on top of each powered vehicle was usually used to get the 500 to 650 volts direct current (vDC) to the onboard vehicle motors.

The remaining three percent utilized either a third rail or underground conduit system. With a third rail operation, power was received from an electrified rail located either between or outside the two track rails. This system usually required less maintenance than overhead lines. However, initial construction costs were higher, and the rails could cause serious injury if touched by people or animals. Thus use of third rail was limited to lines where the right-of-way was fully protected, such as in tunnels or on elevated structures.

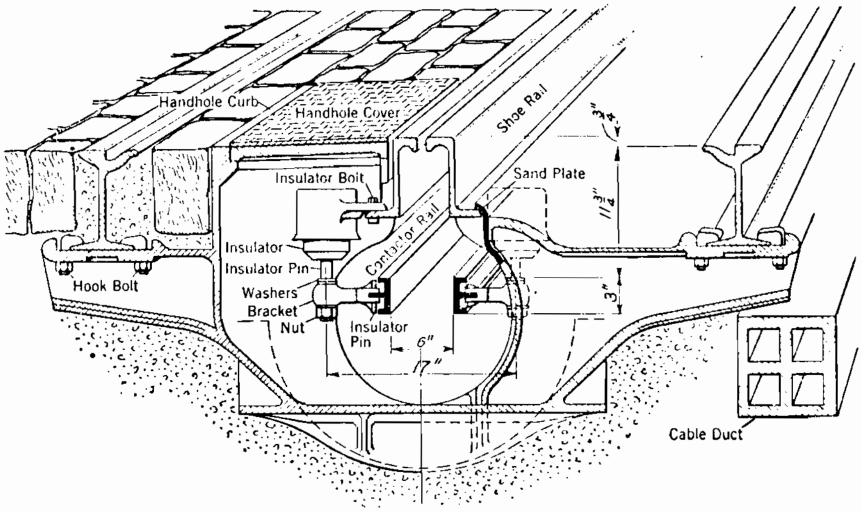
The underground conduit system (Figure 2-5) was developed in an attempt to eliminate the esthetic problems associated with overhead wiring and still have safe street operation. However, this operation never proved very successful because of some serious disadvantages, such as:

- extremely high construction costs,
- difficulties with water, snow, ice, and refuse collecting in the conduit, and
- problems with "dead spots" where tracks cross (Ref 8).

The end result was that the use of overhead wires was the cheapest method of power transmission, and most cities wanted electric street railways so badly that they were willing to tolerate a maze of wires above the streets (Ref 2).

In the 1890's, commercial power was rarely available in large enough quantities (if available at all) at the appropriate voltage for street railways. Thus many of the early streetcar/interurban companies built their own steam power plants (which used coal or oil) to generate electricity. In many instances, electric railway companies became electric power companies, and found themselves in the business of selling power to the residents of towns and rural areas (Ref 6).

FIGURE 2-5. UNDERGROUND CONDUIT SYSTEM



Source: Francis R. Thompson, <u>Electric Transportation</u> (Scranton, Pennsylvania: International Textbook Company, 1940), p 418.

Streetcar/Interurban Promotion and Development. The electric streetcar attained average speeds of 10-15 miles per hour (16-24 kph), as compared to 5-6 (8-10) for horse railways and 3-4 (5-6) for walking. With frequent service, this enabled people to live much further from their places of employment without increasing commuting time.

Although trips formerly made by horsecars were diverted to electric streetcars, the major effect was to open a huge new travel market. The rapidly increasing urban population between 1880 and 1910 due to continuing immigration and industrialization was the underlying reason for the almost phenomenal expansion of electric rail lines. Between 1900 and 1910, streetcar line expansion led to the development of the interurban rail network. Interurbans connected distant cities, often paralleling steam railroad lines, but with lower fares and a higher service frequency of 1 to 3 single-unit vehicles per hour.

As with the streetcar lines that extended beyond city boundaries, the interurbans also influenced residential development. Many interurbans ran on regular streetcar tracks within the city limits, but used track on predominantly private (exclusive) rights-of-way in rural areas (Ref 9). Since there was not always a clear-cut distinction between a streetcar operation and an interurban operation, a technical book published in 1907 used another term:

> By suburban or light interurban lines are meant those which extend a few lines beyond the limits of the city, and on one, or more, may be located a park or pleasure resort (Ref 10).

In order to encourage passenger travel, many railway companies owned and operated electric amusement parks and/or pleasure resorts that were easily reachable only by trolley. The 1907 electric railway census lists 467 such parks. These parks were common (and popular) in the medium-size and smaller cities and towns, where the downtown areas provided little social recreation. However, in the summer months and on Sundays, parks located at some distance from large crowded cities were extremely popular, mainly for the "fresh air." These parks and resorts ranged from a little land next to a car barn set aside for a picnic grove or ball park to accommodations for large theaters, dancing pavillions, and amusement parks.

This period from 1890 to 1910 led to the development of "streetcar suburbs" (Ref 11). Families followed the privately owned and operated streetcar/interurban routes out from the old city boundaries into expanded areas of vacant or unsettled land. Unlike the residences that concentrated around the isolated station stops of steam railroads, each streetcar line provided (with its frequent stops) an almost continuous strip of land for development from the suburban terminal to the downtown area. The result was that the boundaries of the built-up areas of a city consisted of "long fingers or tentacles reaching out from the more solid center, each owing its growth to a radiating street railway" (Ref 7).

Many railway companies were also in the business of selling suburban real estate, since construction of a new line meant greater accessibility to the central city and hence an increase in the desirability (and value) of the land. In some cities real estate syndicates built electric railways just to promote their land (Ref 2). In others, they subsidized construction costs of those lines built to their land and sometimes offered annual payments for several years (until their land was sold) to make up for any operating deficits. Many real estate developers served on city boards that controlled the regulatory process concerning route selection and fares (Ref 2).

The physical peak for electric railways came about 1917 with some 26,000 miles (42,000 km) of street railway trackage and over 17,000 miles (27,000 km) of interurban trackage. There were 80,000 passenger cars in operation, of which 60,000 were streetcars and 20,000 were interurbans (Ref 12). The peak year for streetcar and interurban patronage did not come until 1923 when 13.6 billion passengers were carried.

Vehicle Technology. The early electric cars were much like the horsecars they replaced, except that electrical equipment was installed. The typical single-truck trolley car of the 1890's had motorman controls on open platforms at each end ("double-ended") with little more than a waist-high dashboard to protect the operator from the elements (Ref 3). Enclosed vestibules were later added to protect the operator from bad weather. Figure 2-6 shows a typical single-truck car very popular in the 1890's and early 1900's.

FIGURE 2-6. TYPICAL EARLY ELECTRIC CAR, BUILT ABOUT 1895

Source: Time of the Trolley, p 108.

The largest of all the early electric railway car builders was the J.G. Brill Company of Philadelphia, which had switched from horsecar to streetcar building in the early 1890's. Thousands of trucks and car bodies were built by Brill, but electrical equipment came from either Westinghouse or General Electric. As a general rule, however, the railway industry was characterized in the early years by scores of car manufacturers, each building a different design.

Figure 2-7 shows a typical double-truck car of rather large capacity for the period. Figure 2-8 shows a double-truck open car built by Brill in 1906, a type very popular in summer months for excursions to parks and resorts. Double-deck electric rail vehicles (Fig.2-9) were never popular in the United States mainly because passengers complained about walking up a flight of stairs (especially while the car was in motion) and frequent height restrictions (Ref 8).

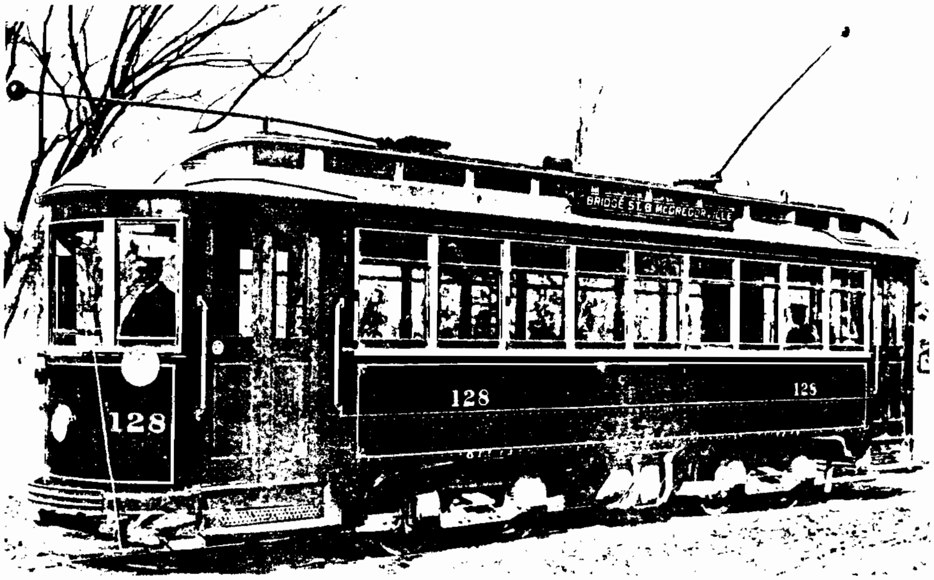
Figure 2-10 shows a typical interurban vehicle. These cars were heavier and faster than most streetcars, and were designed for greater passenger comfort at longer trip distances. Average operating speeds ranged from 20 to 30 mph (32 to 48 kph) depending on frequency of stops and maximum speeds attainable. They were usually geared for maximum speeds of about 25 to 35 mph (40-56 kph), but some interurbans were able to maintain speeds in excess of 60 mph (96 kph) in rural areas (Ref 6). Actual operating speeds were seldom this high, however, because of generally inferior track construction.

Perhaps the ultimate in interurbans was the 63-foot (19 m), 50-ton private car Alabama built by the St. Louis Car Company in 1905. It was equipped with four 200-horsepower motors and was capable of speeds approaching 100 mph (160 kph). An average speed of 80 mph (130 kph) was once achieved over the 20-mile (32 km) distance between Los Angeles and Long Beach (Ref 9).

If electrical requirements and track gauge were compatible, interurbans could operate on regular street railway track. However, since many citizens did not like to see bulky interurbans running on their streets, some companies used to "camouflage" these vehicles to look like streetcars (Ref 13).

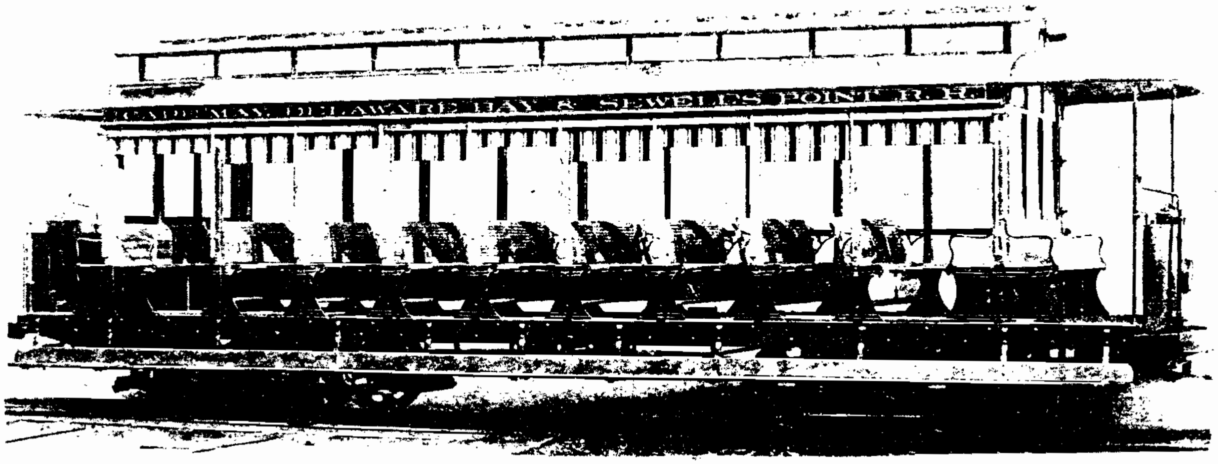
Just as the term "light interurban" was used to describe a cross between a streetcar and interurban oepration, the Electric Railway Dictionary

FIGURE 2-7. STURDY DOUBLE-TRUCK TROLLEY CAR OF THE PRE-WORLD WAR I ERA, WITH SPACE FOR FORTY SEATED AND SIXTY STANDING PASSENGERS.



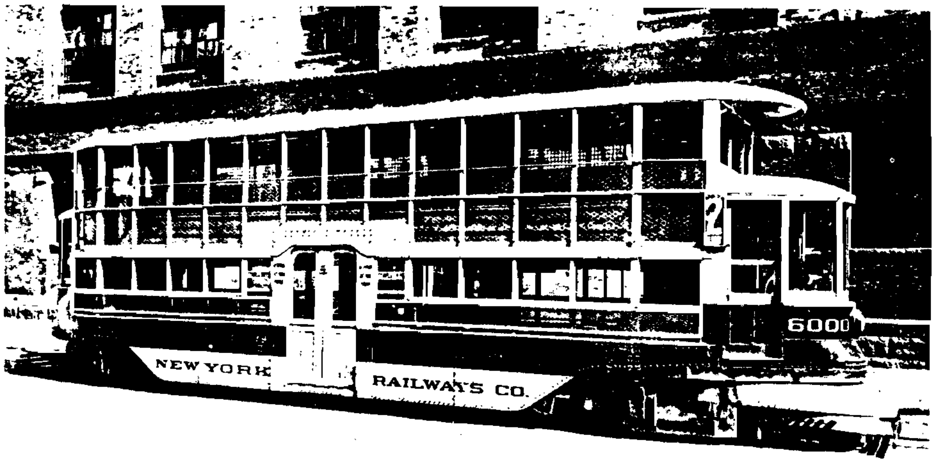
Source: <u>Time of the Trolley</u>, p 111.

FIGURE 2-8. DOUBLE-TRUCK BRILL OPEN CAR WITH TWELVE BENCH SEATS, BUILT IN 1906.



Source: <u>Time of the Trolley</u>, p. 116.

FIGURE 2-9. DOUBLE-DECK ELECTRIC VEHICLE BUILT FOR NEW YORK RAILWAY IN 1913.



Source: <u>Time of the Trolley</u>, p 123.

FIGURE 2-10. HIGH-SPEED INTERURBAN OF THE TEXAS ELECTRIC RAILWAY.

Source: <u>Texas Electric Album</u>, p. 40.

(1911) defined a new type of vehicle:

> Suburban Car. A car used for short runs into suburban and country districts. Usually fitted with cross seats and more powerful motors than city cars, but not designed for the high speed of interurban cars. No sharp lines of distinction are drawn between city and suburban cars or between suburban and interurban cars (Ref 14).

Figure 2-11 depicts a vehicle that could be classified as a "suburban" car.

Operational Improvements. Operational improvements were tried in an attempt to reduce operating costs per passenger. Multiple-unit trains and articulated vehicles were used on lines of high patronage to increase the number of riders per motorman, while small and efficient Birney cars were used on lines of low patronage.

Trains of two or more cars were introduced during rush hours or other peak periods. Instead of using multiple-unit trains consisting only of motor cars, nonpowered trailer cars were sometimes pulled. Some of the advantages of the use of trailers include:

- no motorman was needed in the second car, and
- trailers are cheaper and lighter than streetcars of the same seating capacity.

Some of the disadvantages include:

- a reduced train speed as compared to the use of two or motor cars,
- the necessity of using more powerful motors in the powered vehicles than might otherwise be the case, and
- the necessity for maintaining more than one type of car (Ref 3).

Articulated cars were introduced in Cleveland during the early 1890's, but did not achieve much importance until Boston's major railway company started building some cars in 1912. Instead of building a new long car that was jointed in the middle, a center compartment was suspended between two old 20-foot (6 m) single-truck cars. This 63-foot (19 m) high-capacity car was called the "two rooms and a bath" car by Bostonians. It was capable of negotiating Boston's sharp curves and narrow streets and permitted the

FIGURE 2-11. LIGHTWEIGHT SUBURBAN CAR
BUILT IN THE 1920s.

Source: Time of the Trolley, p 128.

Elevated Railway Company to put their old single-truck cars to a new use. Figure 2-12 shows an articulated car built about 1918 that consisted of the combination of two old double-truck cars.

On streetcar lines of fairly low patronage, Birney cars were introduced in 1916. These small cars could be operated with a one-man crew, who worked as both the motorman and fare collector (conductor) (Ref 3). The standard single-truck model (Fig. 2-13) weighed from 7 to 9 tons, was 28 feet (9 m) in length, and seated about 32 passengers. These "safety" cars weighed about half as much per seat as the heavier equipment they replaced, consumed less electricity, and were capable of higher schedule speeds. Between 1916 and 1920, 4000 Birneys were built. In 1930 when the last Birney was constructed, 6000 were in use throughout the United States as well as in a number of foreign countries. Some of the cars built after 1920 were larger, double-truck versions that retained the economics of one-man operation.

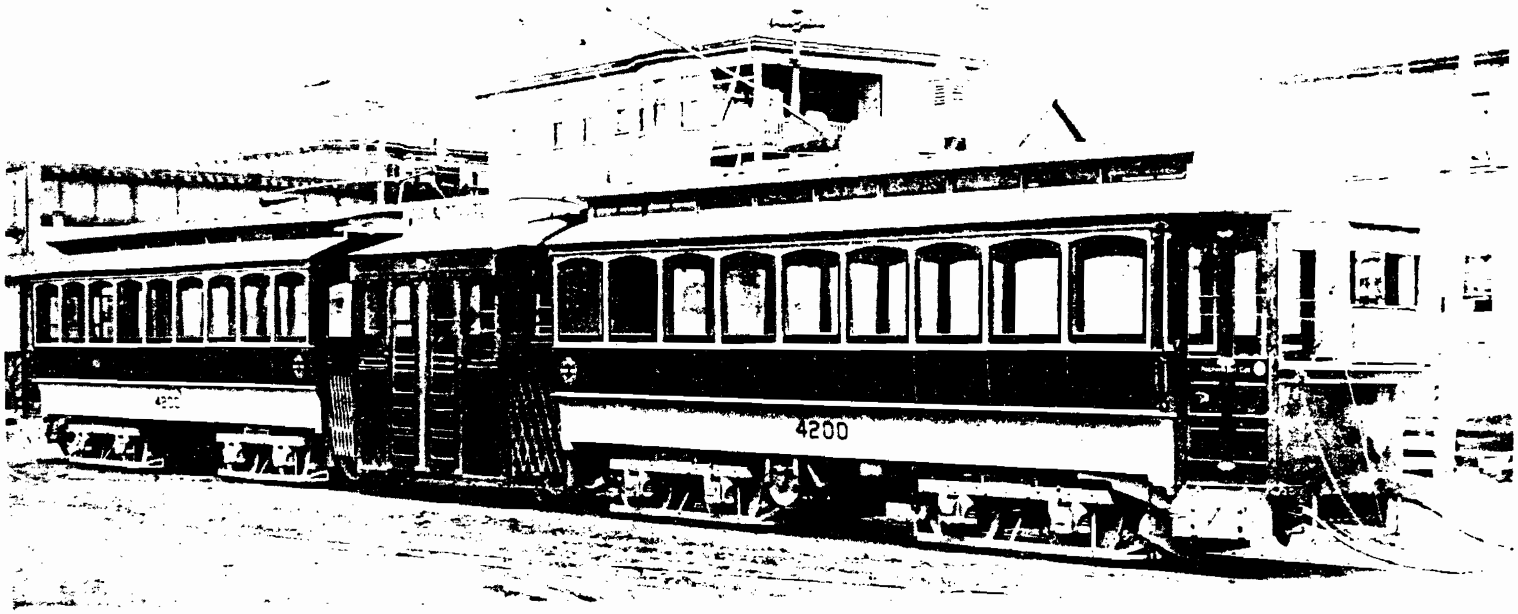
Decline of the Electric Railway. The early success of the electric railway was due to the fact that there was no transportation mode that could effectively compete with it. The families that moved out to the "streetcar suburbs" were dependent on the rail line for most of their work, shopping, and recreational trips.

Indirect and direct competition from the automobile and bus provided the first real alternatives. Figures 2-14 and 2-15 depict trends in this century. of U.S. transit ridership and number of vehicles of various transit modes.

The early electric railway industry can be characterized as one of excessive optimism that led to massive overbuilding of miles of routes (Ref 2). Most private companies had anticipated that ridership (and therefore revenue) would increase indefinitely, while operating costs would remain low and stable (Ref 15).

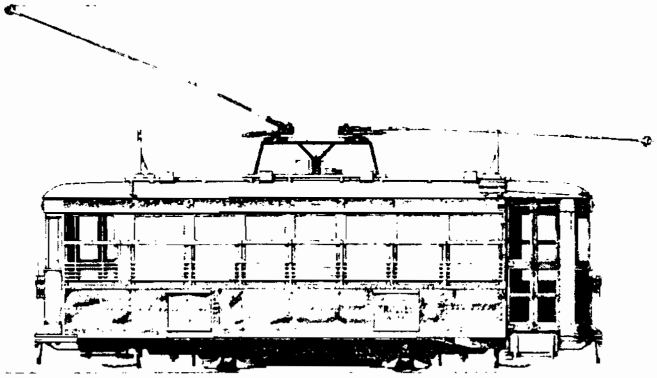
As early as 1915 a number of interurban railway companies were in serious financial trouble. The revenue from passenger fares was not adequate to cover all operating and maintenance costs and still leave funds to pay interest due on bonds and dividends to stockholders. Most interurban lines should never have been built because any serious effort of predicting daily patronage would have shown an insufficient number of fare paying riders. Fast-talking promoters managed to convince local citizens and

FIGURE 2-12. AN "ARTICULATED" BOSTON CAR, BUILT ABOUT 1918.



Source: Time of the Trolley, p. 125.

FIGURE 2-13. POPULAR SINGLE-TRUCK BIRNEY DESIGN OF 1920



Source: Time of the Trolley, p 414.

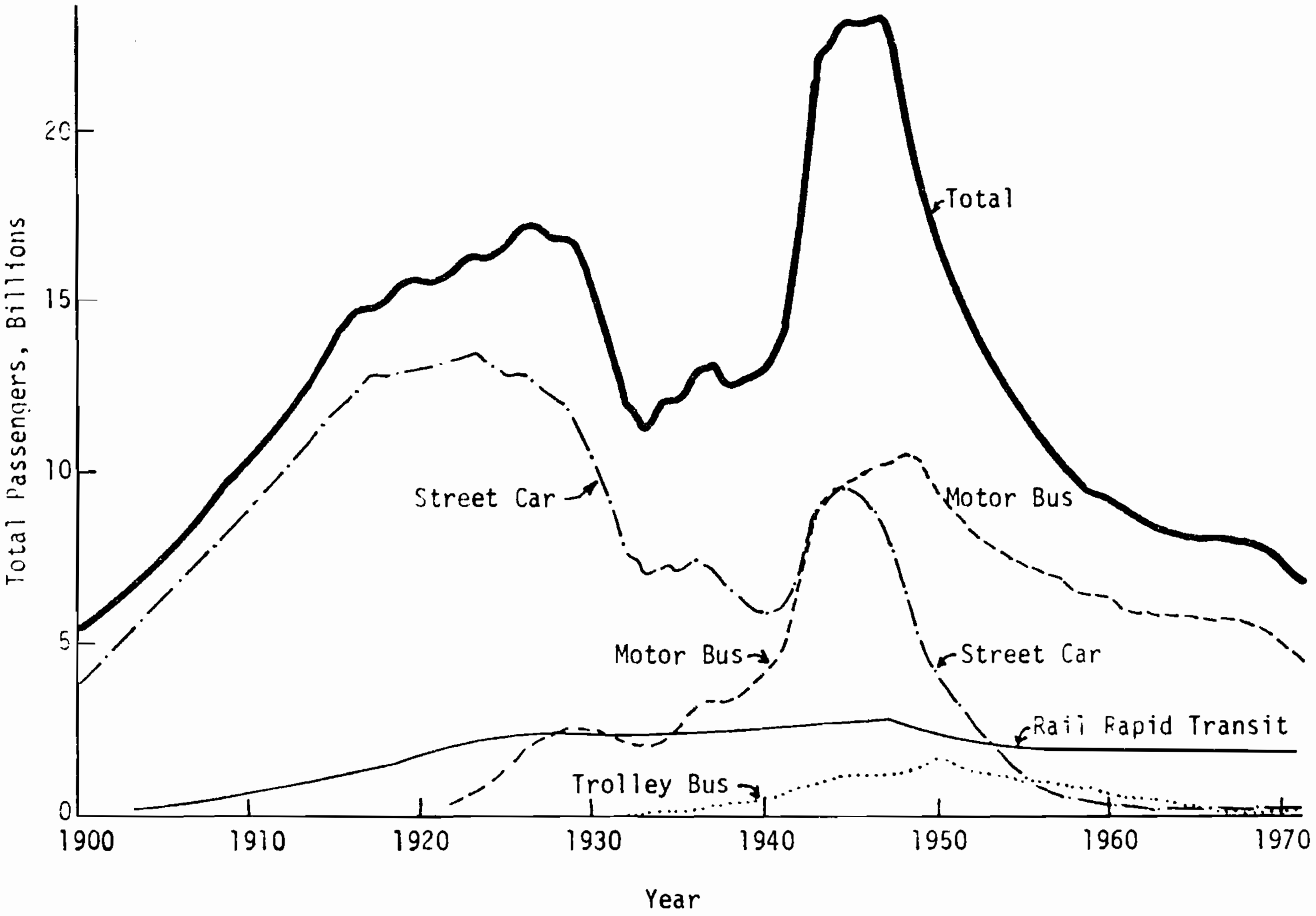


FIGURE 2-14. TRNEDS IN TRANSIT RIDERSHIP

Source: Texas Transportation Institute and Texas Highway Department, <u>Transit in the U.S. and Texas : Past, Present, and Future</u> (College Station: Texas A & M University, 1973), p. 5

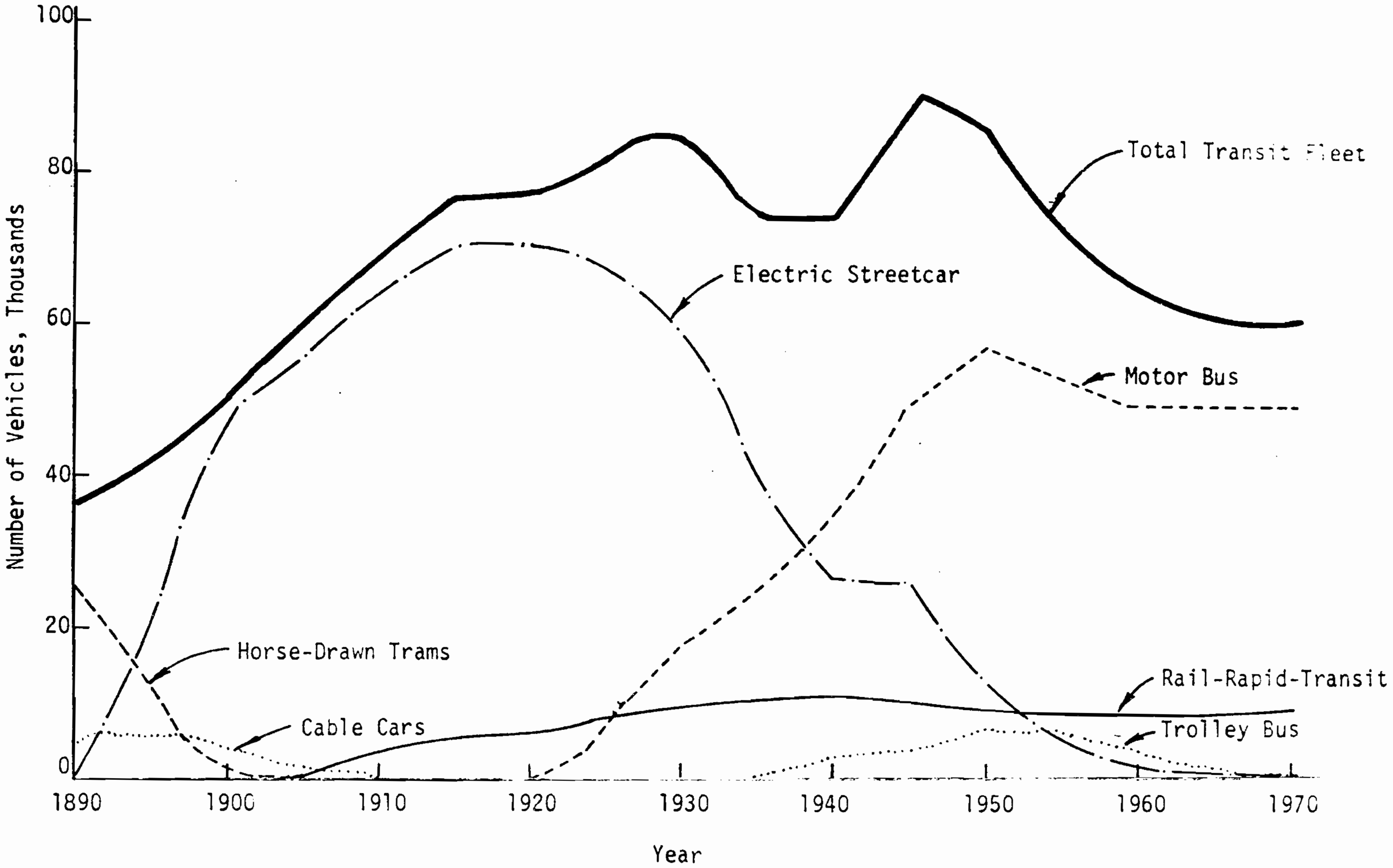


FIGURE 2-15. TRENDS IN THE TRANSIT VEHICLE FLEET.

Source: <u>Transit in the U.S. and Texas</u>, p. 6.

officials that an interurban passing through their small town was an asset:

> To strum on the melodious chords of local pride and enhancement of property values, a specialized breed of interurban promoter appeared. He could cite the magnificent benefits to practically everyone that an electric line would bring: how farmers would be free to sell milk and produce wherever it would bring the most, instead of being exploited captives of just one nearby creamery or market; or how women would be liberated from the stupefying monotony of rural or helmet life and could avail themselves of the improving opportunities of the city; how merchants could get one-day deliveries from distant warehouses, far quicker than by regular freight (Ref 3).

Local citizens were heavy investors along with real estate promoters and other business interests. Funds for capital investment were rather limited, leading to poorly constructed railways. Inadequate fare revenues led to a neglect of maintenance resulting in rapid deterioration of track quality. The only thing that kept many of the interurbans operating for several more years was the additional revenue from the handling of freight (Ref 13).

Street railways also suffered early financial troubles. Most problems stemmed from municipal regulations, increased operating costs, and irregular traffic flows (peaking).

Before they could lay any streetcar tracks, private companies had to obtain franchises from the local municipal government. If certain stated requirements were met, the company was given permission to operate a railway in a given city for a specified period of time (20-50 years). The common requirement was that the company pave and maintain the streets inside its tracks and for a foot outside. The only payment was usually an annual license fee for each car operated (Ref 2).

What hurt companies most were regulations such as fixed-rate flat fares. In the early 1900's street railway companies pushed for a fixed fare, usually set at 5¢/passenger, in an attempt to discourage other companies from charging less. However, by the end of World War I, this fare was too low due to increased labor costs and the need for extensive vehicle and track maintenance. Average trip lengths had become longer, too, since streetcar lines were extended further out into the suburban areas.

In an attempt to increase revenues, many street railway companies sought establishment of graduated fare systems in which higher fares would be charged for trips to zones further from the city. However, suburban real estate developers, who commonly sat on local regulatory boards, strongly opposed this, since some of their lands would appear less desirable (since travel costs would be increased). Retention of the flat fare basically meant that those who could afford suburban homes were being "subsidized" by those who could not (Ref 15).

Severe inflation occurred from about 1915 to 1920. Not only materials prices but wages for operators and conductors were on the increase, leaving scarce funds for maintenance. While the financial reports of street railway companies may have shown that fare revenues covered operating and maintenance costs, depreciation expenses were excluded. Replacement of worn equipment was financed through the issuing of new securities.

Large variations in passenger demand resulted in poor utilization of equipment and labor. Even though trailers were commonly used during peak hours, the vehicles were still overcrowded. But yet, at certain time of the day, hardly anyone rode the trolleys.

Since a number of private railway companies operated in each medium-size city in the 1900's, the bankruptcy of some of the companies usually led to consolidation with others that were less financially troubled (Ref 3).

The growing popularity of the automobile in the 1920's provided the first real competition because it acted to disperse businesses and residences away from the radial streetcar/interurban routes. Rising incomes and lower automobile prices made the automobile more affordable, while massive highway building by the government, starting in 1916, drastically accelerated its popularity. The decline of off-peak travel to parks and pleasure resorts severely cut into railway revenues, causing further problems with the handling of peak versus off-peak demand (Ref 16).

By 1914 thousands of automobiles were used as "jitneys." Jitneys were typically operated by unemployed motorists who picked up passengers waiting along streetcar routes for a 5¢ fare. By the middle 1920's, however, jitneys had virtually vanished, mainly because street railway companies had pressured local governments into regulating the jitney industry (Ref 3).

The suburban streetcar had started the trend of suburban living which could now be continued with the private automobile on an even wider scale. Railway companies had no money to lay fixed rail lines to these newly developed residential areas. Even if they did, the houses were much too dispersed to support adequate patronage to enable fare revenues to cover operating and maintenance costs. Since the bus could be wherever there were highways, it was more successful in making adjustments to changing demands (Ref 17).

Within the city, the streetcar was forced to compete on the same right-of-way as highway vehicles. Operating speeds were restrained by other traffic, and passenger access was at times hazardous. Unlike the bus, a streetcar could not pull over to the curb to let passengers on or off, could not maneuver around stalled vehicles, and could not be rerouted over different streets if tracks and overhead wires were not already in place. About the middle 1920's, an anti-trolleyite had this to say:

> Nuts to warm, friendly feelings. All this selectively omits the other side——the endless waiting on windy corners, the savage crowding and stale smells, the piercing squeal of the flanges on a curve, the ugly snarl of wires overhead, track all over the street, the bone-shaking ride on hard streets, the rattling windows, and above all the slowness (Ref 4).

Since most trolley systems were privately owned and operated, those lines that could not pay for their expenses through fares were abandoned. Those lines that still yielded a profit were usually used until major repairs were needed, at which time they too were abandoned.

In the pre-World War II era lines were abandoned rather than taken over by a municipality. Most cities were of very limited financial means even with their taxing power over the community (Ref 2). Those railway companies that did not go bankrupt usually started to replace streetcar routes with fleets of new buses. In 1937 there were almost 1,000 private companies that operated motor buses, and only 300 that operated electric railways.

The Great Depression hurt even the successful railway companies because there were fewer passengers willing to pay even a 5¢ fare. Massive unemployment (up to 25%) reduced the number of commuters. A significant piece of federal legislation enforced in 1938 severely undercut the financial base of electric railway companies. The Public Utility Holding Company Act of 1935 was interpreted as saying that no electric power company could also operate an electric street railway. Since a number of early street railway companies also became electric power companies for a town, they were forced to sell or abandon one of their divisions (Ref 18). The sale of electricity to residents was usually more profitable, resulting in the forfeit of the railway division.

Experimental trolley bus lines were in operation in France by 1910, but it was not until the middle 1930's that the United States started to take a strong interest in this new mode. A number of people thought the trolley bus represented a combination of the best features of electric railways and motor buses. But it was not until about 1955 that trolley buses carried more annual passengers than electric railways (Ref 19). By 1965 the number of trolley buses still in operation became virtually insignificant.

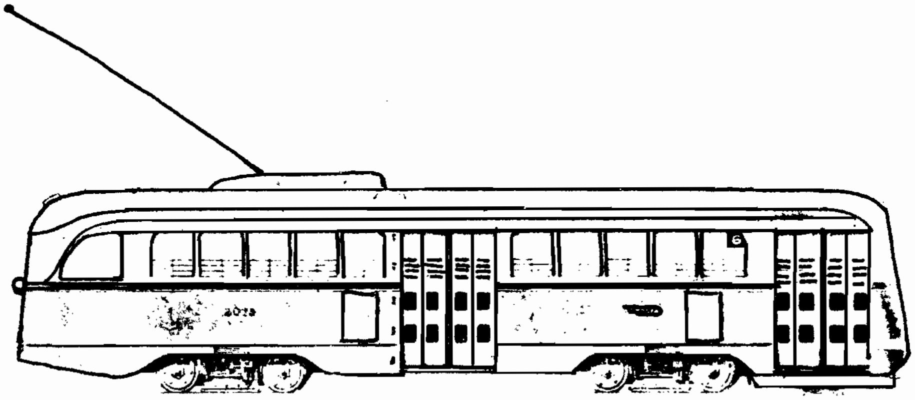
Development of PCC Cars. Along with difficulties in attracting enough ridership, there were also problems in vehicle construction. Before 1930 there was little agreement among operators in different cities as to what constituted the "best" design. As a result, most streetcars were custom made for a particular railway company based on factors such as clearance restrictions, steepness of grades, local ordinances and traditions, specialties of a particular car builder, desired passenger capacity per vehicle, maximum attainable speed, acceleration/deceleration rates desired, and length of run (Ref 13).

An attempt was made in the 1930's to stop the rapid decline in ridership and reduce operating costs by constructing a standardized streetcar known as the Presidents' Conference Committee (PCC) car. Beginning in 1929, twenty-five of the larger streetcar companies pooled their money and ideas on what should constitute the "ideal" trolley. Five years and one million dollars later, they came up with the PCC design (Fig. 2-16) which far surpassed all other streetcars in ride quality, quietness, and acceleration (Ref 8).

The St. Louis Car Company and Pullman-Standard obtained licenses in 1936 to mass produce the PCC car. By 1940 some 1400 PCC's were in service. The peak construction year was 1946 when 800 cars were built. By 1952 when the last order was delivered (25 PCC's for San Francisco), nearly 5,000 had been built.

The PCC car came along too late to help most American street railways. By 1940 some 170 cities with over 25,000 population relied wholly on motor buses. The major effect of the PCC car was to postpone street railway

FIGURE 2-16. STANDARD PCC STREAMLINED CAR.



Source: Time of the Trolley, p 414.

decline (Ref 4). Only the period during World War II led to an increase in annual passengers, due to rationing of gasoline and tires and the termination of automobile production.

There have been claims that General Motors (GM) was the principal force behind the elimination of streetcar operations in favor of GM buses (Ref 20). Companies supported by GM (United States Motor Transit in 1932, National City Lines in 1936) bought a number of electric rail transit systems throughout the country, converted them to GM bus operations, and then resold them. In 1949 General Motors, Standard Oil of California, and Firestone were convicted by a jury in a Chicago federal court of criminally conspiring to wreck electric transportation and replace it with gas or diesel buses.

However, conversion of electric railways was in full swing a decade before GM got into the picture. In fact, replacement by buses may have saved transit in many cities from total collapse.

Virtually all interurban railways were abandoned by the 1950's. Most U.S. streetcar systems that were still operating were using PCC cars. Vehicle maintenance was a major problem since no new vehicles were available for purchase. The common practice was to "cannibalize" some cars to keep others going (Ref 6).

Those American systems which have survived to the present did so largely because they operated on reserved rights-of-way, out of the regular traffic stream. The lines are usually located in high-density areas where high passenger volumes have virtually been assured.

> [There was] ... one type of service in which electric railways continued to have an advantage——the handling of suburban traffic into large cities where a private right-of-way was available and street traffic congestion could be avoided. Under such circumstances, bus service or the automobile is definitely inferior to rail service, especially for commuting to work and for routine shopping trips. As traffic congestion has grown, the relative service advantages of this type of rail operation have increased, and despite obsolete equipment the volume of business has remained almost stable, or even increased (Ref 6).

Chapter four includes information on each light rail/streetcar system that is presently operating in the United States.

Texas Experience

In the 1920's Texas had a peak of about 1100 electric rail miles (1800 km). Roughly 600 miles (1000 km) could be classified as street railway and 500 (800 km) as interurban trackage. About 1500 passenger cars were used to carry almost 200 million annual revenue passengers. However, by 1950 only Dallas and El Paso still had electric railway operations.

As with most U.S. Cities, animal-drawn railways preceded the development of electric streetcar operations in Texas. Nineteen Texas towns and cities are known to have had over one mile of track in 1889. Table 2-1 shows the nine Texas cities that had five or more miles (8 km) of horse (mule) railway track in that year. Except for Waco, mules instead of horses were the common motive power. Although they were not as fast and had a lower resale value than horses, the mules could stand up to the hot Texas sun for longer periods of time and were much cleaner.

The majority of animal-drawn railway operations were gone by 1900 although Seguin kept a 1.25 mile (2.0 km) line open until 1918 (Ref 21). Some private companies strung overhead wires along their former "horsecar" line, even though the tracks were generally not built to the standards required for the heavier and faster electric cars. Both Austin and Fort Worth could not use their former "horsecar" trackage as built because the track gauge was narrower than the standard 4'8½" (1.435 m) gauge that they adopted for their electric streetcar lines. Laredo and San Antonio got around this problem by using the narrower 4'0" (1.22 m) horsecar gauge for their electric line gauge. Both the animal and electric railway track gauge in Dallas, El Paso, Galveston, Houston, and Waco was the standard 4'8½".

The development of electric street railways in Texas basically followed the national pattern. One major difference, however, is that Texas cities never had a period of high-density residential development. In 1890 when streetcars were becoming popular in the northeast, the two largest cities in Texas were Dallas and San Antonio, each with only 38,000 population.

Table 2-2 lists those Texas cities with over 50,000 populations in 1975 and shows which had an electric street railway. From 1890 to 1910 Corpus Christi had a "steam dummy" operation. Of the ten cities without their own electric railway, at least five were served at one time by interurbans. Census data shows that these ten cities were very small in the

TABLE 2-1. TEXAS CITIES WHICH HAD FIVE OR MORE MILES (8 km) OF HORSE (MULE) RAILWAY TRACK IN 1889

City	Population, 1890	Year of Initial Operation	Track Miles (km) in 1889
Austin	14,600	1874	10 (16)
Dallas	38,100	1872	18 (29)
El Paso	10,300	1882	6 (10)
Fort Worth	23,100	1876	8 (13)
Galveston	29,100	1866	54 (87)
Houston	27,600	1868	14 (23)
Laredo	11,300	1883	5 (8)
San Antonio	37,700	1878	18 (29)
Waco	14,400	1878	8 (13)

Source: U.S. Census Bureau
Texas Division, Electric Railroader's Association (Texas ERA) Files, in San Antonio.

TABLE 2-2. ALL TEXAS CITIES WITH OVER 50,000 PEOPLE IN 1975

City (ranked by population)	Population, 1975	Once Had An Electric Street Railway	Years of Operation
1. Houston	1,357,400	yes	1891-1940
2. Dallas	822,500	yes	1890-1956
3. San Antonio	773,200	yes	1890-1933
4. El Paso	385,700	yes	1902-1973
5. Fort Worth	358,400	yes	1891-1938
6. Austin	301,100	yes	1890-1940
7. Corpus Christi	214,800	yes	1910-1931
8. Lubbock	163,500	no	
9. Amarillo	138,700	yes	1908-1926
10. Arlington	122,200	no	
11. Beaumont	113,700	yes	1906-1939[a]
12. Garland	111,300	no	
13. Irving	103,700	no	
14. Waco	97,600	yes	1890-1948
15. Abilene	96,500	yes	1908-1931
16. Wichita Falls	95,000	yes	1909-1933
17. Pasadena	94,700	no	
18. Odessa	84,500	no	
19. Laredo	77,000	yes	1889-1936
20. Brownsville	72,200	yes	1912-1935[a]
21. San Angelo	66,100	yes	1908-1916
22. Midland	63,000	no	
23. Mesquite	61,900	no	
24. Tyler	61,400	yes	1913-1917
25. Galveston	60,100	yes	1891-1938
26. Richardson	59,200	no	
27. Grand Prairie	56,800	no	
28. Port Arthur	53,600	yes	1906-1937
29. Longview	52,000	yes	1912-1920

[a] unclear when operations actually ceased

Source: U.S. Census Bureau
Texas Almanac
Texas ERA Files

pre-automobile era. For example, the population of each city in 1910 was as follows:

Lubbock	1,940
Arlington	1,790
Garland	800
Irving	not incorporated
Pasadena	not incorporated
Odessa	not incorporated
Midland	2,190
Mesquite	690
Richardson	not incorporated
Grand Prairie	990

Table 2-3 shows those Texas cities with under 50,000 population in 1975 which once had electric street railways. Table 2-4 lists all 34 Texas cities which once had electric streetcars and shows their estimated population in five different years (1902, 1914, 1925, 1933, 1939). Table 2-5 takes these same cities and years and shows miles (km) of electric street railway track for each city, excluding interurban track.

Table 2-6 shows those Texas cities with eight or more miles (13 km) of street railway track in 1924 and their approximate number of passenger cars. Most of the cars came from the top three American car builders: American Car Company, J. G. Brill Company, and St. Louis Car Company.

Between 1916 and 1922 cars of the one-man Birney design were brought (mainly from the American Car Company) as can be seen in the following figures (Ref 21):

Austin	17
Beaumont	16
Dallas	62
El Paso	35
Fort Worth	85
Galveston	18
Houston	67
San Antonio	30

TABLE 2-3. TEXAS CITIES WITH UNDER 50,000 PEOPLE IN 1975 WHICH ONCE HAD ELECTRIC STREET RAILWAYS

City (by Population)	Population, 1975	Years of Operation
Denton	43,500	1907-1918
Texas City	40,900	1912-1920[a]
Temple	39,500	1904-1926
Texarkana	33,800	1903-1934
Sherman	26,000	1892-1936[a]
Paris	23,200	1894-1935[a]
Denison	22,400	1892-1936
Marshall	21,100	1909-1927
Greenville	20,900	1910-1919
Corsicana	19,900	1903-1930[a]
Cleburne	16,000	1911-1918
McKinney	14,300	1913-1926
Waxahachie	13,800	1914-1928
Mineral Wells	13,000	1908-1920
Bonham	7,300	1892-1913

[a] unclear when operations actually ceased

Source: U.S. Census Bureau
Texas Almanac
Texas ERA Files

TABLE 2-4. ESTIMATED POPULATION IN FIVE SEPARATE YEARS FOR TEXAS CITIES WHICH HAVE ONCE HAD ELECTRIC STREET RAILWAYS

City	Estimated Population				
	1902	1914	1925	1933	1939
Abilene	4,600	9,600	16,700	24,200	26,300
Amarillo	3,100	12,200	29,300	45,700	50,800
Austin	23,800	31,900	44,000	63,600	84,500
Beaumont	11,700	28,600	49,100	58,000	58,900
Bonham	5,000	5,300	5,800	5,900	6,300
Brownsville	7,100	11,000	16,900	22,000	22,100
Cleburne	8,100	11,300	12,200	11,200	10,700
Corpus Christi	5,400	9,100	19,100	36,600	54,400
Corsicana	1,500	10,400	13,300	15,200	15,200
Dallas	52,500	118,900	209,700	270,800	291,300
Denison	12,200	15,000	15,500	14,400	15,400
Denton	4,300	5,900	8,600	10,100	11,000
El Paso	19,900	54,600	90,000	100,700	97,400
Fort Worth	36,000	86,600	135,000	167,700	176,200
Galveston	37,600	39,900	48,600	55,300	60.100
Greenville	7,300	10,300	12,400	12,900	13,800
Houston	51,500	102,600	215,300	320,000	375,300

TABLE 2-4. ESTIMATED POPULATION IN FIVE SEPARATE YEARS FOR TEXAS CITIES WHICH HAVE ONCE HAD ELECTRIC STREET RAILWAYS (CONTINUED)

City	Estimated Population				
	1902	1914	1925	1933	1939
Laredo	11,700	18,000	27,700	34,600	38,600
Longview	3,900	5,400	5,400	7,700	12,900
Marshall	8,600	12,600	15,200	16,900	18,200
McKinney	4,400	5,500	7,000	7,700	12,900
Mineral Wells	2,400	5,500	6,900	6,100	6,300
Paris	9,700	12,800	15,300	16,600	18,400
Port Arthur	2,300	13,500	36,600	49,500	46,600
San Angelo	9,900	10,200	17,700	25,500	25,800
San Antonio	62,000	122,500	196,500	238,200	251,600
Sherman	10,700	13,500	15,700	16,100	17,000
Temple	7,900	11,000	13,200	15,300	15,300
Texarkana	6,500	10,500	14,000	16,700	17,000
Texas City	1,200	2,000	3,000	4,200	5,500
Tyler	8,500	11,100	14,600	20,500	27,200
Waco	21,800	31,300	26,400	53,800	55,700
Waxahachie	4,600	6,900	8,000	8,200	8,600
Wichita Falls	3,600	21,000	41,900	44,100	45,000

Source: U.S. Census Bureau

TABLE 2-5. MILES (KM) OF ELECTRIC STREET RAILWAY TRACK IN TEXAS, EXCLUDING INTERURBAN TRACK

City	1902	1914	1925	1933	1939
Abilene	-	6.0 (9.7)	5.0 (8.0)	5.0 (8.0)	-
Amarillo	-	10.0 (16.1)	2.0 (3.2)	-	-
Austin	13.4 (21.6)	20.4 (32.8)	23.0 (37.0)	23.0 (37.0)	17.0 (27.4)
Beaumont	-	12.0 (19.3)	15.6 (25.1)	15.6 (25.1)	19.1 (30.7)
Bonham	2.6 (4.2)	3.0 (4.8)	-	-	-
Brownsville	-	3.0 (4.8)	2.2 (3.5)	2.2 (3.5)	-
Cleburne	-	8.5 (13.7)	-	-	-
Corpus Christi	-	8.0 (12.9)	9.0 (14.5)	9.0 (14.5)	-
Corsicana	-	5.0 (8.0)	5.0 (8.0)	5.0 (8.0)	-
Dallas	47.6 (76.6)	77.5 (124.7)	104.9 (168.8)	110.6 (178.0)	100.0 (160.9)
Denison	5.0 (8.0)	5.0 (8.0)	3.0 (4.8)	3.0 (4.8)	-
Denton	-	4.0 (6.4)	-	-	-
El Paso	13.5 (21.7)	31.9 (51.3)	43.1 (69.3)	43.1 (69.3)	21.2 (34.1)
Fort Worth	25.0 (40.2)	70.5 (113.4)	81.6 (131.3)	81.6 (131.3)	-
Galveston	35.9 (57.8)	37.9 (61.0)	38.4 (61.8)	38.4 (61.8)	18.5 (29.8)
Greenville	-	10.0 (16.1)	-	-	-
Houston	37.2 (59.9)	66.1 (106.4)	91.0 (146.4)	91.0 (146.4)	60.5 (97.3)

TABLE 2-5. MILES (KM) OF ELECTRIC STREET RAILWAY TRACK IN TEXAS, EXCLUDING INTERURBAN TRACK (CONTINUED)

City	1902	1914	1925	1933	1939
Laredo	2.9 (4.7)	6.0 (9.7)	2.3 (3.7)	2.3 (3.7)	-
Longview	-	1.0 (1.6)	-	-	-
McKinney	-	3.0 (4.8)	2.0 (3.2)	-	-
Marshall	-	4.3 (6.9)	4.6 (7.4)	-	-
Mineral Wells	-	7.0 (11.3)	-	-	-
Paris	5.0 (8.0)	5.5 (8.8)	5.5 (8.8)	5.5 (8.8)	-
Port Arthur	-	7.5 (12.1)	8.0 (12.9)	8.0 (12.9)	-
San Angelo	-	3.5 (5.6)	-	-	-
San Antonio	45.5 (73.2)	77.0 (123.9)	92.6 (149.0)	92.6 (149.0)	-
Sherman	5.7 (9.2)	5.7 (9.2)	3.0 (4.8)	3.0 (4.8)	-
Temple	-	5.0 (8.0)	6.0 (9.7)	-	-
Texarkana	-	14.0 (22.5)	14.0 (22.5)	14.0 (22.5)	-
Tyler	-	7.0 (11.3)	-	-	-
Waco	16.3 (26.2)	18.0 (29.0)	16.0 (25.7)	16.0 (25.7)	1.7 (2.7)
Waxahachie	-	4.8 (7.7)	5.0 (8.0)	-	-
Wichita Falls	-	10.5 (16.9)	15.5 (24.9)	15.5 (24.9)	-
TOTALS	255.6 (411.3)	561.1 (902.7)	598.3 (962.3)	584.4 (940.0)	238.0 (382.9)

Source: <u>Texas Almanac</u>

TABLE 2-6. APPROXIMATE NUMBER OF PASSENGER VEHICLES FOR TEXAS CITIES WITH EIGHT OR MORE MILES (13 km) OF STREET RAILWAY TRACK IN 1924

City	Approximate Number of Passenger Cars, 1924
Austin	45
Beaumont/Port Arthur (includes interurban	about 80
Corpus Christi	5
Dallas/Fort Worth (includes extensive interurban operations)	about 480
El Paso (includes interurban)	98
Galveston	66
Houston (includes interurban to Galveston)	about 240
San Antonio	175
Texarkana	16
Waco	28
Wichita Falls	23

Source: <u>McGraw Electric Railway Manual: The Red Book of American Electric Railway Investments</u> (New York: McGraw Publishing Company, 1924).

Individual orders for a particular car type usually ranged from two to twenty vehicles.

Figures 2-17 thru 2-23 depict the streetcar patterns that existed in seven Texas cities. The map of San Antonio's streetcar lines in 1913 most clearly shows that most lines had a radial orientation in which tracks extended from the central city area to the suburban regions. Some of the lines reached company owned parks and theaters in addition to existing residences, while others reached vacant land being promoted by a real estate firm. Figure 2-24 lists examples of the parks and subdivisions that were served by Texas electric railways in 1910.

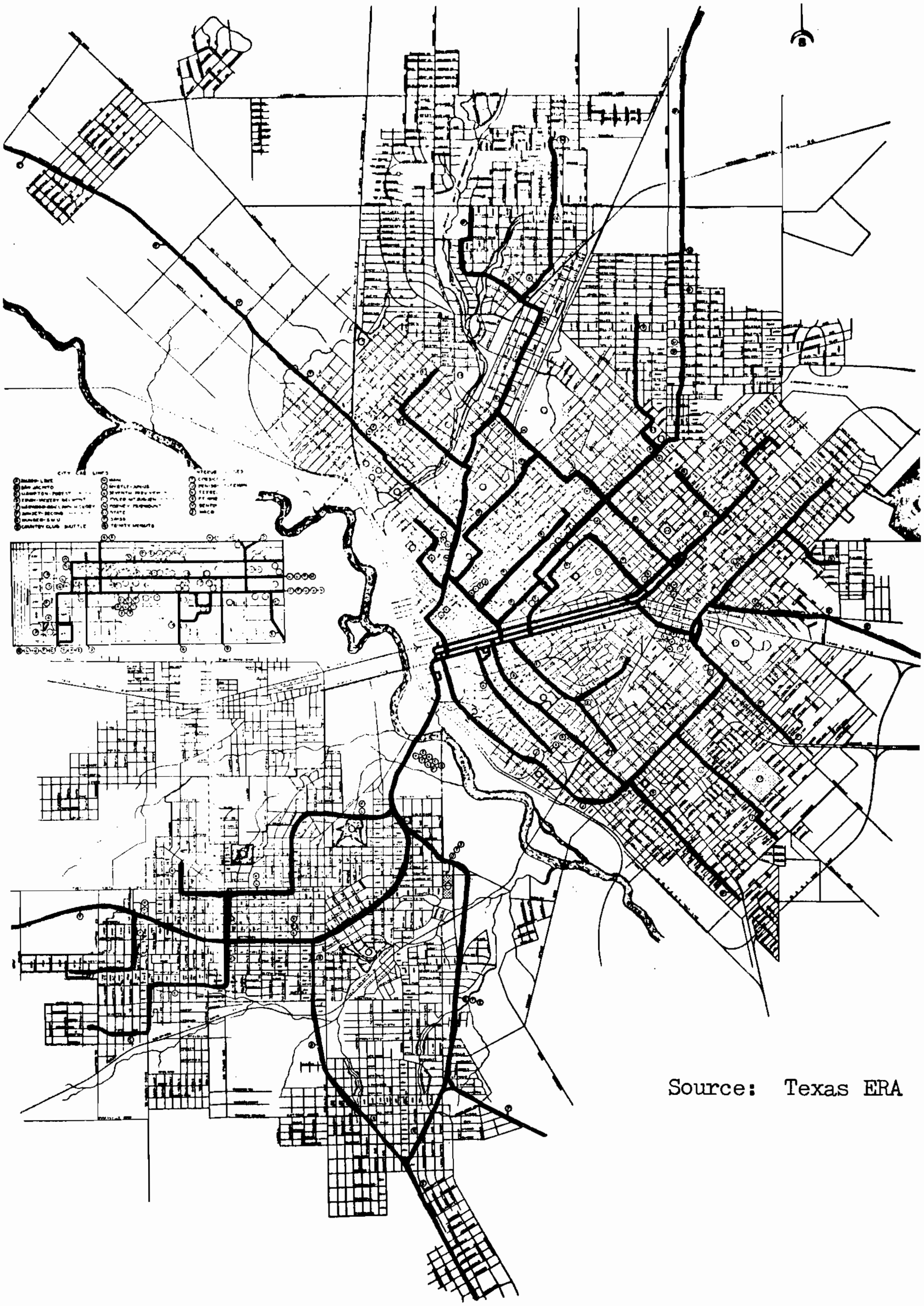
In some instances, a street railway company also acted as a real estate investor. The selling of suburban land that was recently made accessible by an electric railway was an effective way of recouping some of the costs of railway construction. When the suburban land was held by another firm, the usual practice was for the real estate investor to at least partially subsidize the construction of a line to his land.

Interurban railway construction in Texas came mostly after 1910 when construction in other states had nearly ceased. Table 2-7 shows all of the known electric interurban lines and their approximate track mileage. The usual procedure was to lay only one track between the distant cities, but build frequent sidings to allow two meeting vehicles to pass each other safely. In 1928 there were about 500 miles (800 km) of interurban track in operation. Interurban cars were capable of achieving speeds up to 60 mph (97 kph) on private rights-of-way in the rural areas along the Waco-Dallas-Denison route (Fig. 2-25). Figure 2-26 shows the route of the Galveston-Houston Interurban which was one of the most successful lines in the country. The 50-mile (80 km) run could be made nonstop at an average speed of about 40 mph (64 kph). The interurban cars were also given rights of access to the street railway systems in both Galveston and Houston.

Table 2-8 summarizes census information on street and interurban railway companies in Texas, 1902-1937. The only known city operation of an electric railway was in Amarillo. From 1920 to 1923 the City of Amarillo took over a private railway company that was forced into receivership in 1917 (Ref 22).

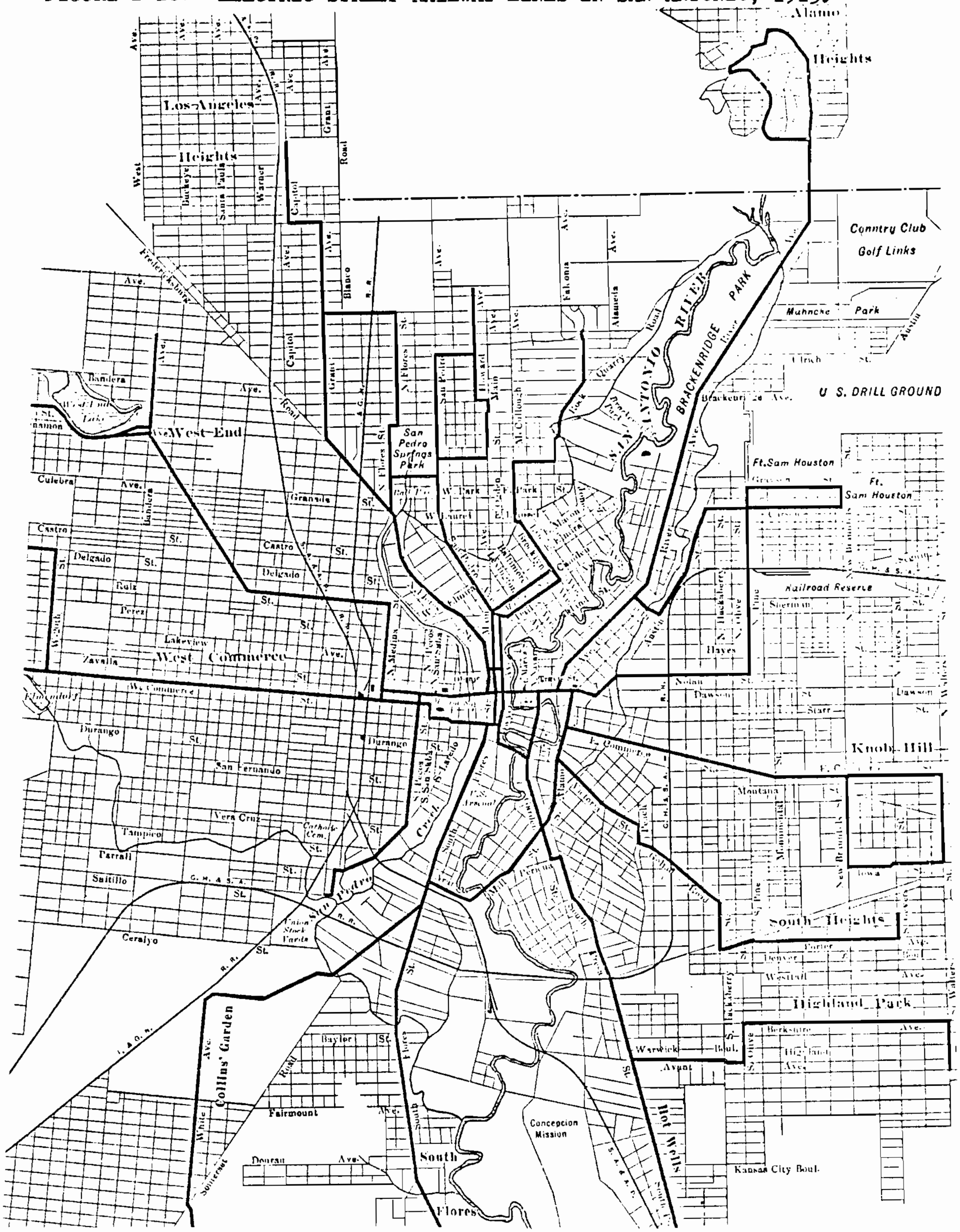
The later years of the Great Depression brought an end to most of the private street railway companies. San Antonio was one of the first major U.S. cities to convert from streetcars to an all-bus system (1933). In 1937

FIGURE 2-17. ELECTRIC STREET RAILWAY LINES IN DALLAS, 1925.



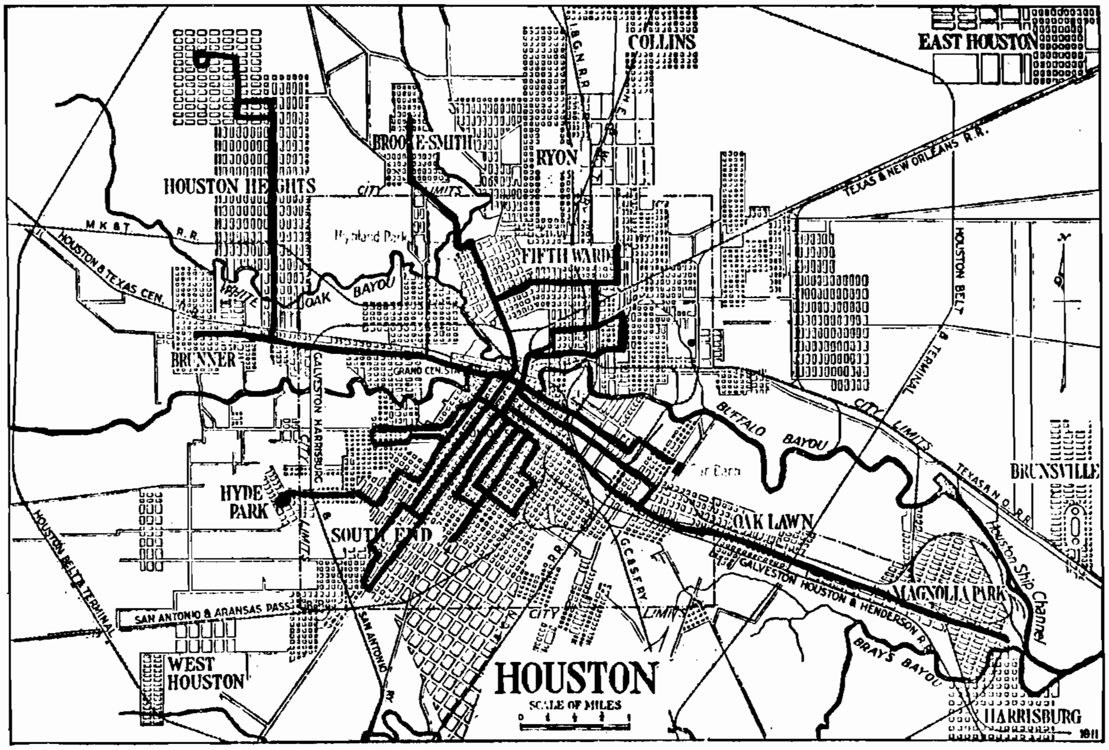
Source: Texas ERA

FIGURE 2-18. ELECTRIC STREET RAILWAY LINES IN SAN ANTONIO, 1913.



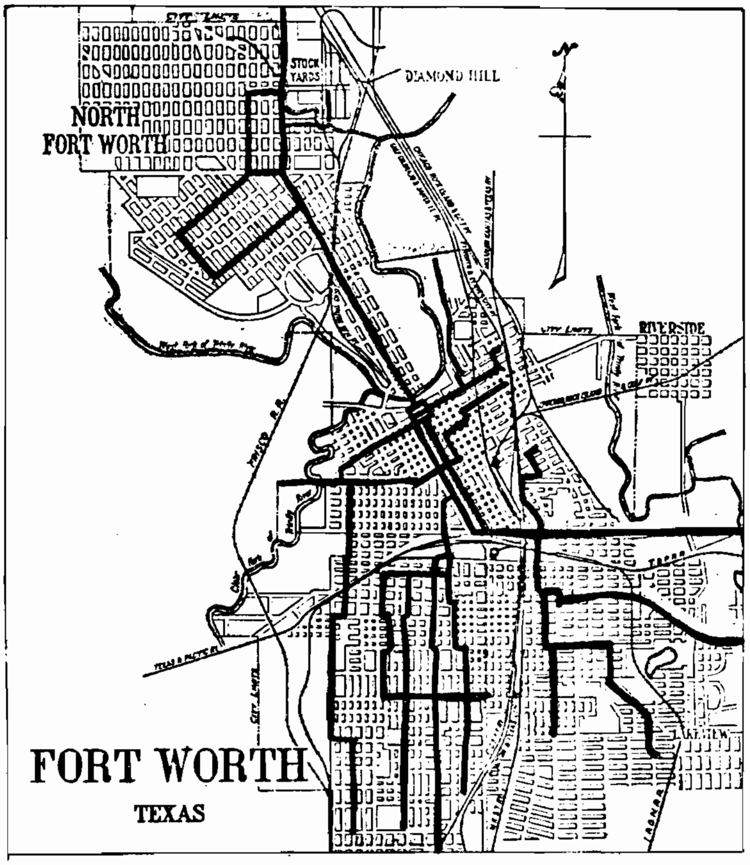
Source: Electric Railway Journal.

FIGURE 2-19. ELECTRIC STREET RAILWAY LINES IN HOUSTON, 1911.



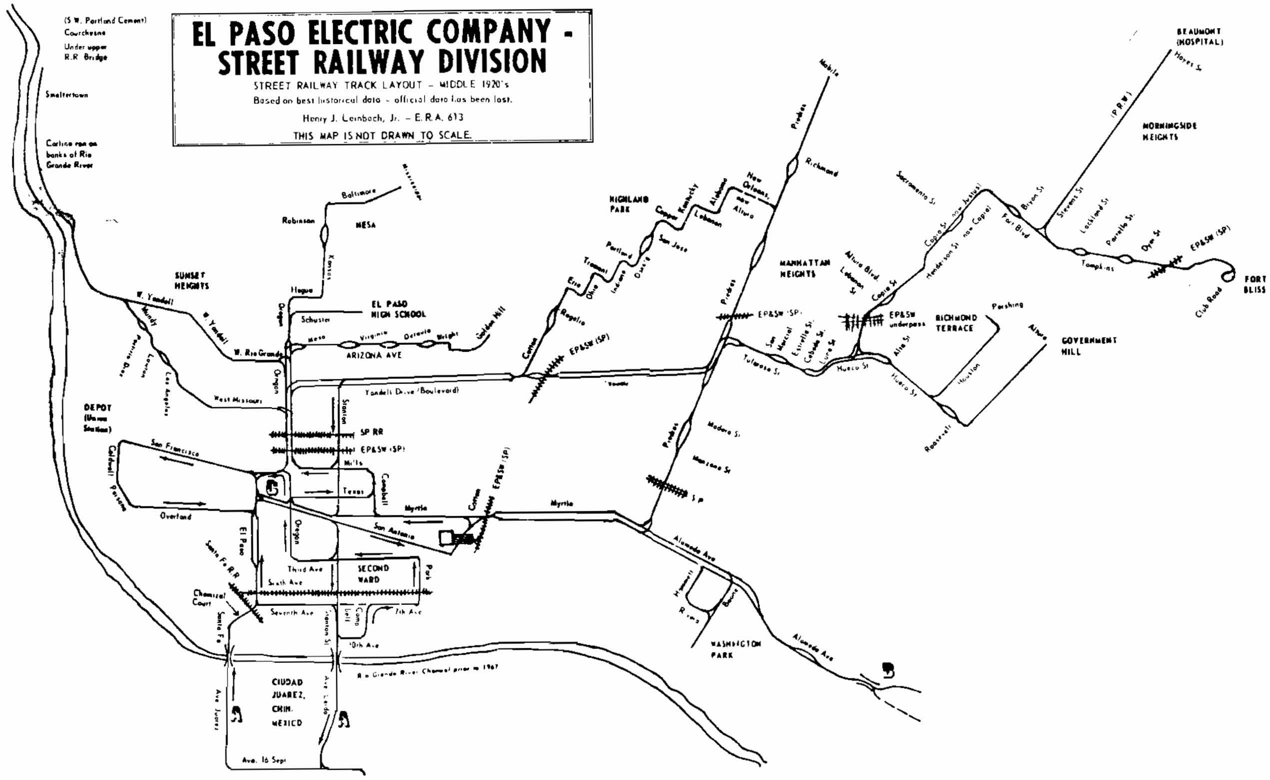
Source: Texas ERA Files.

FIGURE 2-20. ELECTRIC STREET RAILWAY LINES IN FORT WORTH, 1909.



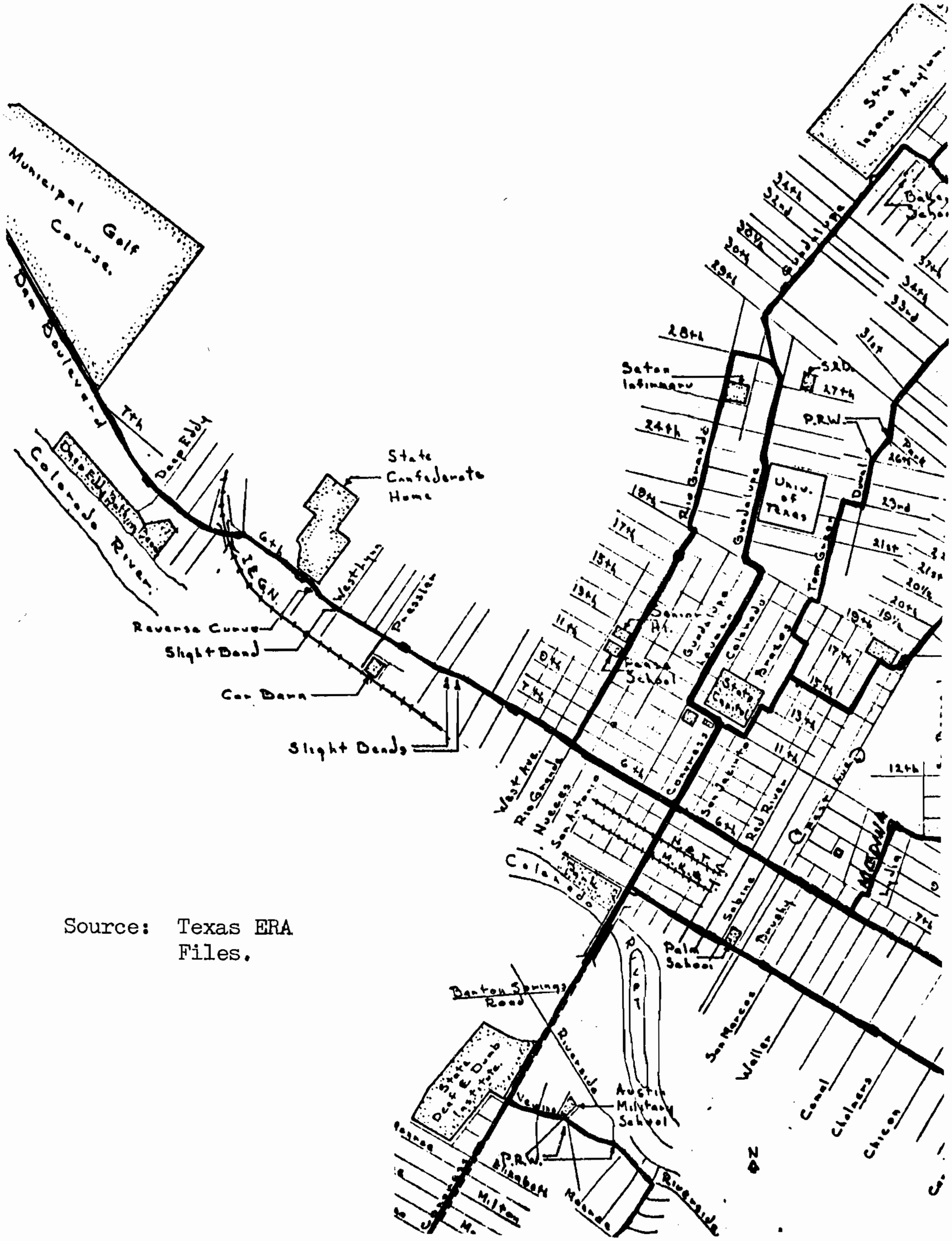
Source: Texas ERA Files.

FIGURE 2-21. ELECTRIC STREET RAILWAY LINES IN EL PASO, ABOUT 1925.



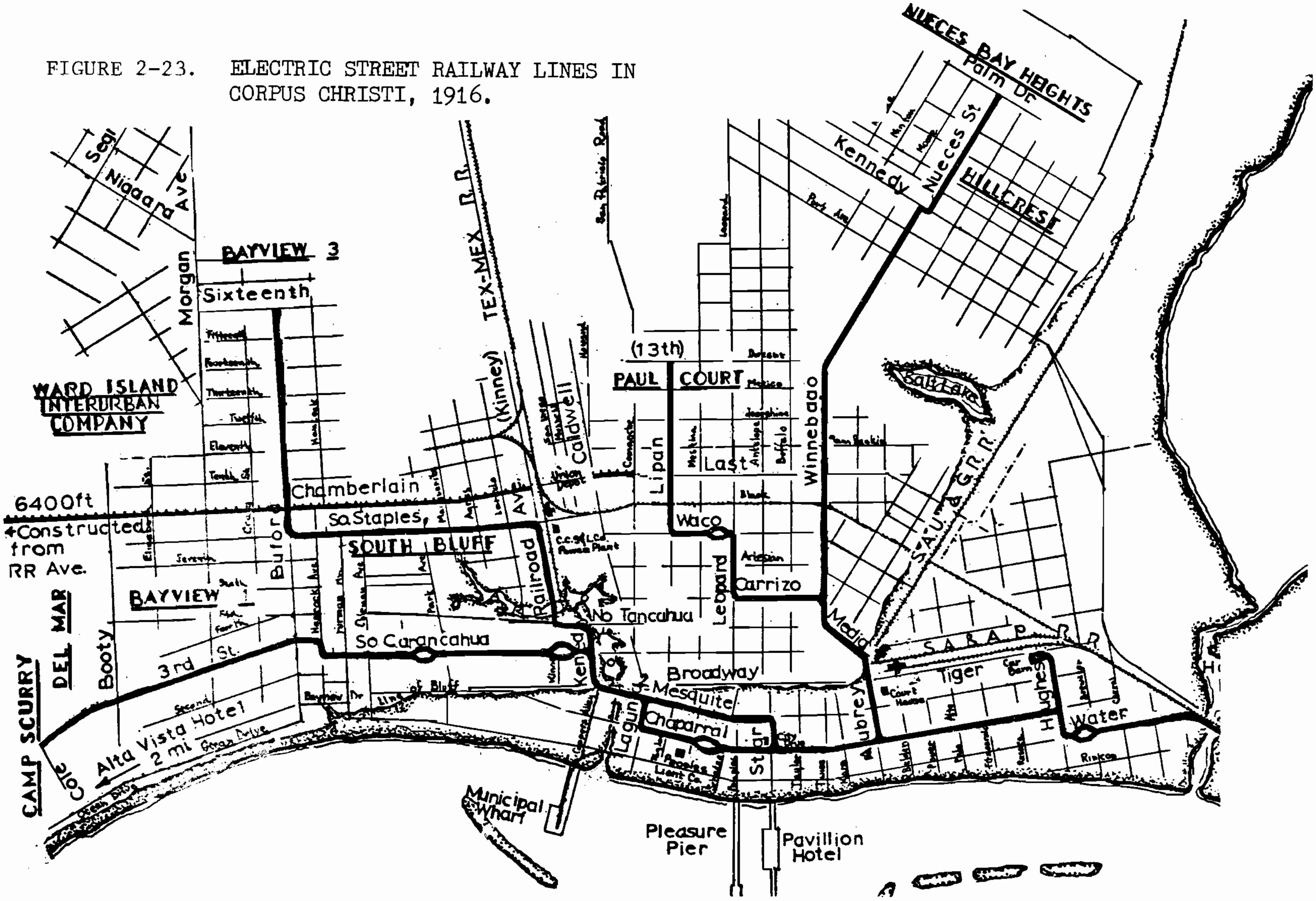
Source: Texas ERA Files.

FIGURE 2-22. ELECTRIC STREET RAILWAY LINES IN AUSTIN, 1919.



Source: Texas ERA
Files.

FIGURE 2-23. ELECTRIC STREET RAILWAY LINES IN CORPUS CHRISTI, 1916.



Source: Texas ERA Files.

FIGURE 2-24. PARKS/SUBDIVISIONS REACHED BY ELECTRIC RAILWAYS IN 1910.

Amarillo	Glenwood Electric Park
Austin	Hyde Park
Beaumont	Driving Park, Magnolia Park, and baseball grounds
Bonham	baseball park, theater, and an indoor swimming pool
Dallas	Kirkland Park, Lake Cliff Park at Oak Cliff
Fort Worth	Rosen Heights, White City, and Lake Erie Park at Handley
Houston	Highland Park, and a baseball park
Laredo	Loma Vista and League Baseball Park
Paris	Warlick Park
San Antonio	San Pedro Springs Park, Electric Park, Brackenridge Park, and International Fair Grounds
Sherman	Woodlake Park
Temple	Midway Park, between Belton and Temple
Waco	Summer Theatre

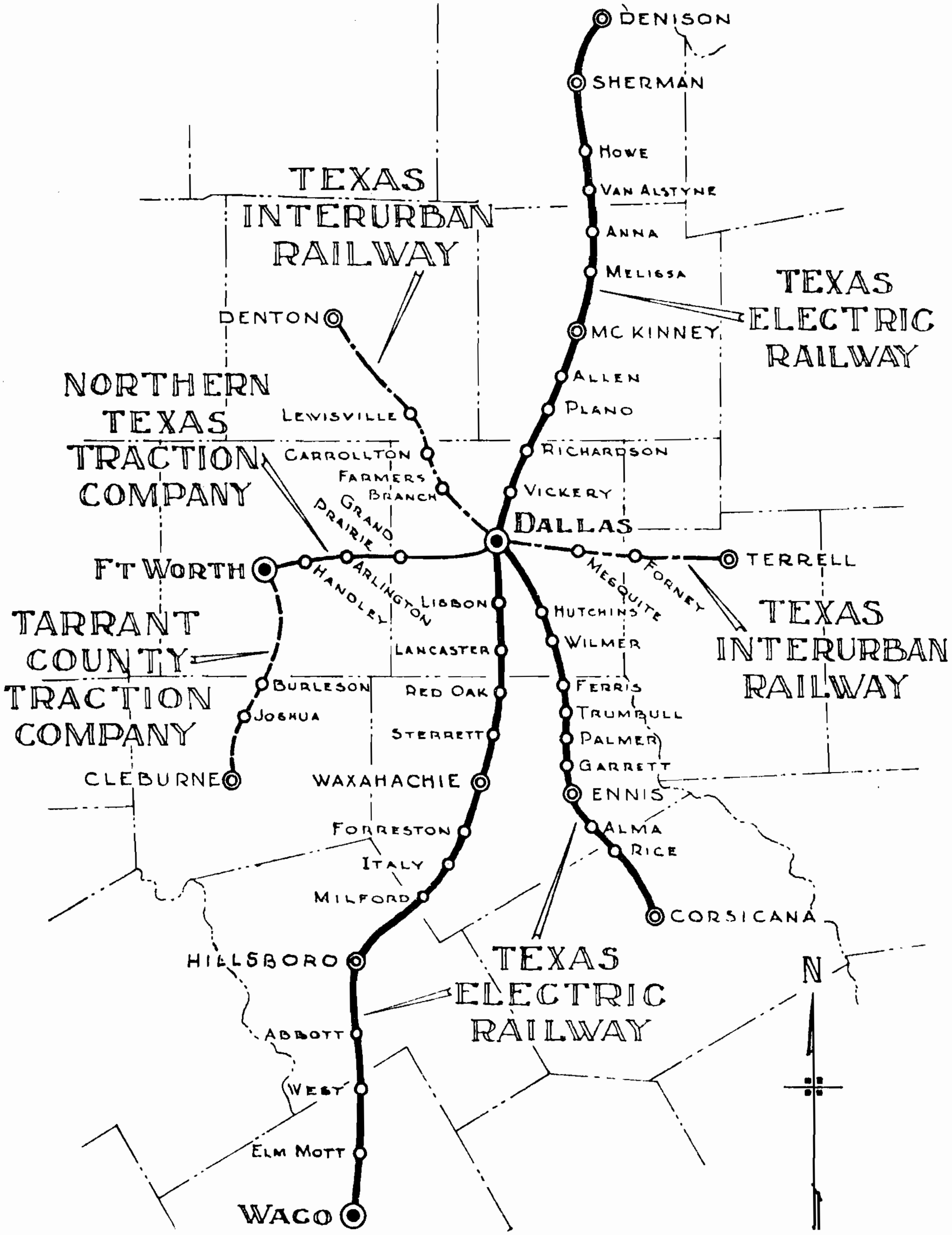
Source: American Street Railway Investments (New York: McGraw Publishing Company, 1910), pp. 295-303.

TABLE 2-7. ESTIMATED ELECTRIC INTERURBAN TRACK MILEAGE IN TEXAS.

Route	Peak Miles (km)	Years of Operation
Sherman to Denison	11 (18)	1901-1948
Dallas to Fort Worth	35 (56)	1902-1934
Temple to Belton	14 (23)	1905-1923
Dallas to Sherman	66 (106)	1908-1948
Houston to Galveston	50 (80)	1911-1936
Waco to Dallas	100 (161)	1911-1948
Fort Worth to Cleburne	32 (51)	1912-1931
Bryan to College Station	7 (11)	1913-1923
Dallas to Greenville	53 (85)	1913-1923
El Paso to Yslete to Fabens	30 (48)	1913-1932
Beaumont to Port Arthur	20 (32)	1913-1935
Dallas to Corsicana	50 (87)	1913-1941
Dallas to Terrell	33 (53)	1923-1931
Roby to Rotan	4 (6)	1923-1941
Dallas to Denton	29 (47)	1924-1931
Houston to Baytown to Goose Creek	34 (55)	1927-1941
TOTAL	568 (919)	

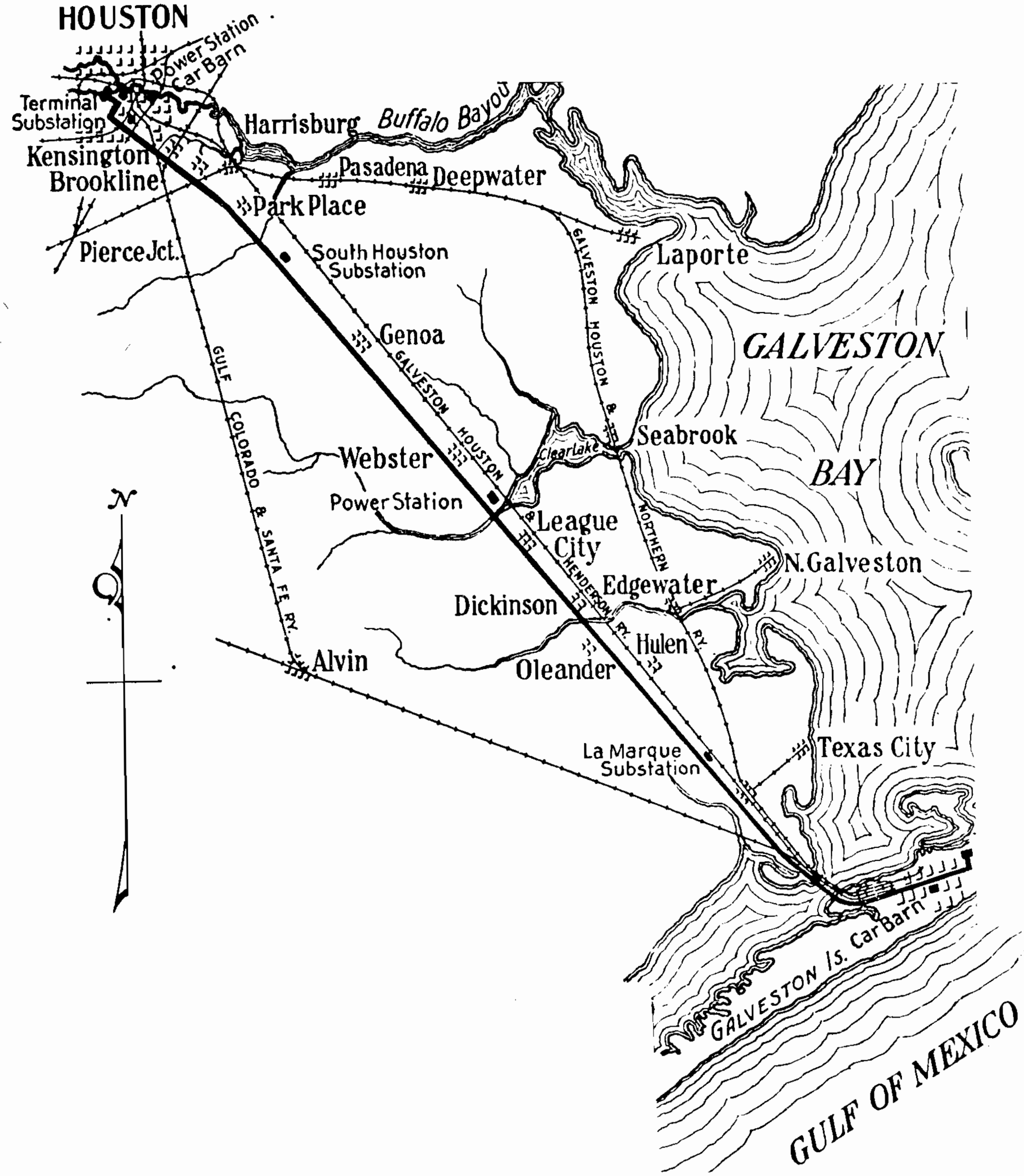
Source: Texas Transportation Institute, <u>The History of Rail Passenger Service in Texas</u>, 1820-1970 (College Station: Texas A & M University, 1970), p. 11.

FIGURE 2-25. ELECTRIC INTERURBAN RAILWAYS FOCUSING ON DALLAS IN 1930.



Source: Texas Electric Album, Inside Cover.

FIGURE 2-26. ROUTE OF THE GALVESTON-HOUSTON INTERURBAN.



Source: Electric Railway Journal.

TABLE 2-8. SUMMARY OF CENSUS INFORMATION ON STREET AND INTERURBAN RAILWAY COMPANIES IN TEXAS, 1902-1937

Year	Number of Companies	Total Miles (km) of Electric Railway Track	Total Number of Passenger Cars	Total Annual Fare-Paying Passengers
1902	17	303 (488)	449	30,038,000
1907	23	415 (668)	779	81,496,700
1912	39	717 (1154)	1058	130,268,100
1917	32	940 (1512)	1313	150,400,800
1922	24	966 (1554)	1428	187,536,300
1927	20	1024 (1648)	1376	179,354,600
1932	15	878 (1413)	1086	87,765,100
1937	8	510 (820)	506	62,350,900

Note: These figures do not report Texarkana under Texas, since the company was based outside of the state (in Arkansas).

Some of the figures include nonelectric railways:

1902 -- 6.87 miles (11 km) of horse railways
1907 -- 6.80 miles (11 km) of horse railways and 2.25 miles (4 km) of a gasoline-powered railway
1912 -- 4.70 miles (8 km) of horse railways and 7.50 miles of gasoline-powered railways
1917 -- 1.25 miles (2 km) of a horse railway.

Mileage figures for 1927 and 1932 may have undercounted the actual track mileage.

there were 25 companies operating a total of 932 buses with about 86 million annual revenue passengers. Only Dallas, El Paso, and Waco still had electric railway operations during the "transit revival" of the World War II period.

Of the interurbans only the Texas Electric Railway lines along the Waco-Dallas-Denison route were in operation during the war years. This company finally ceased operation in 1948 due to increasing operating costs and declining patronage.

Both the Dallas and El Paso systems used PCC cars in the 1950's. El Paso bought a total of 20 used PCC cars (built in 1937) from San Diego (17 in 1950, 3 in 1952). Seventeen of these PCC's were still in operation in the early 1970's, but only on a 3.1-mile (5.0 km) loop from downtown El Paso to downtown Ciudad Juarez across the Mexican border. This "international carline" carried about 10,000 to 12,000 passengers a day, but service was frequently interrupted from 1966 till the final suspension in August, 1973. The City of El Paso has purchased these old cars and placed them in storage. El Paso also now owns the streetcar facilities still in place on the United States side of the border.

Dallas bought new, double-ended PCC cars in the late 1940's, but sold them to Boston when the Dallas streetcar operation was abandoned in 1956. From 1949 till 1966 Dallas also had trolley buses with a peak of over 80 vehicles in 1960.

The only other Texas city ever to use PCC cars was Fort Worth, starting in 1963. This was the year that a local department store opened a subway line from a nearby parking lot to its downtown location. A full description of this line will be made in chapter four.

Foreign Experience

From the 1830's to the 1860's, the omnibus was widely used in some of the larger European cities. Unlike many of the fast-growing American towns these older European cities had fairly well-paved streets suitable for omnibus travel at about 5 mph (8 kph). Fares were rather high, though, so most of the riders were middle-class citizens (Ref 5).

The development of animal-powered railways in Europe followed the United States after a lag of 10 to 15 years. While very popular in the 1880's, only a few very large cities had some lines as early as 1870. Lines in the 1870's and 1880's went to various points within the city boundaries or to steam railroad stations on the outskirts. Horsecars were privately operated but regulated by municipal governments. In some cases the local government would construct the lines and lease them to private firms (Ref 5).

The boom in construction of new railway lines did not start until the mid 1890's——about five years behind the United States. While this was due mainly to slower economic growth, it was also because of the stronger aesthetic values, especially in Europe. Europeans were proud of their cities and the overhead wires and support poles characteristics of American streetcar systems were considered "visual pollution" (Ref 5).

Storage batteries and electrical conduit systems were tried on numerous occasions as alternatives to the overhead method. Over 15 percent of the 250 electric railway systems in Europe in 1898 did not use overhead wiring (Ref 23).

When environmental objections were not serious the overhead method was far superior in economic terms. Better design of overhead systems through the use of handsomely decorated steel poles were a definite improvement over the United States' "typical" wooden pole. The higher-voltage feeder cables for the trolley wires were commonly placed underground since they were not directly used by rail vehicles.

By the early 1900's electric railways (tramways) existed in Asia, Australia, South Africa, Canada, Mexico, Cuba, and at least eight countries in South America, in addition to most European countries. Germany was clearly the early leader, with over 2100 miles (3400 km) of line in 1902. As early as 1898, 69 German cities were equipped with electric railways. France had 1240 miles (2000 km) and Great Britain had 870 miles (1400 km) in 1902 (Ref 5).

By 1910 rapid growth in some European countries largely closed the gap between the quality of U.S. and European public transportation systems. Private enterprise was the major source of initiative, as in the United States. However, the underlying force came from electrical manufacturers rather than individual railway companies (Ref 5). Both General Electric and Westinghouse were deeply involved in the development of European railways, such that until 1914 about half of all European trolley cars used U.S. motors and controls. The J. G. Brill Company sold complete cars in a number of countries that did not have their own car building industry. The majority of Brill's worldwide business, however, came from the selling of the wellknown Brill trucks, or bogies (Ref 3). So evident was the influence of America's early superiority in vehicle manufacture that the 500-volt DC system commonly used in the U.S. became virtually a worldwide standard.

Except for Great Britain (which had municipally owned and operated railways), virtually all early electric railways were operated by private companies. The common procedure was for the local government to pay for track construction and lease the lines to private companies. This procedure was developed with horse railways and continued with electric railways. Public control through regulations was much stronger than in the United States. While this may have hampered innovation, the end result was to keep private companies from indiscriminately reducing service wherever deemed appropriate.

A franchise was usually written in such a way that a municipality could purchase a railway operation after a specified number of years. Public ownership had the advantage that costs could be met through both fares and general taxation. Taxation was considered a fair system since public transit service was looked on as benefitting the whole community (Ref 24).

In German cities "municipalization" of railways was in full force by the 1920's. During the 1930's when a number of street railways were being abandoned (especially in America and Great Britain), systems in German cities were actually being extended. The furnishing of railways for public transportation was considered a social service in which deficits were covered by profits from municipal utilities (electricity, gas, and water supply). Electric railways were encouraged over buses since they used electricity (generated by coal) rather than imported fuel.

By the 1960's the majority of major railway systems not abandoned in European countries were publicly owned and operated. Generous subsidies, however, were necessary to keep the railways in operation.

Foreign countries have experienced increased automobile ownership, as in the United States, but subsequent patronage decline on streetcar routes was not as great. Foreign cities, especially in Europe, are generally more dense than those in America, making ownership of an automobile less of a necessity (Ref 25).

Used streetcars from abandoned U.S. systems were sold in large numbers to Central and South American cities after World War II. The PCC design was built under license in a number of foreign countries including Belgium, Italy, and Czechoslovakia.

The extent of present operations in foreign countries will be discussed in the next chapter. The light rail concept appears to be thriving in Germany. The "solution" has been to use modern vehicles on predominantly reserved surface rights-of-way in the suburbs and in tunnels in the city center (Ref 1).

CURRENT STATUS OF LIGHT RAIL TRANSIT AROUND THE WORLD

This section opens with a review of the status of existing LRT systems in the United States, Canada, and elsewhere in the world (with the focus on Western Europe). The majority of the LRT experience involves the rehabilitation and modernization of retained streetcar systems. Only a few situations involve newly constructed lines. Ridership trends for the U.S. systems will also be examined.

This is followed by a review of the status of proposals for LRT in the United States and Canada. The planning and implementation of major transit investments in the United States are usually dependent on current federal urban transportation policy. Therefore, the section concludes with a discussion on the recent history and current status of federal policy, insofar as it affects LRT planning.

Existing U.S. LRT Systems

There are currently nine operating LRT or streetcar systems in the U.S. Seven of them were built around the turn of the century or in the early part of this century (1920 and 1935), and in this report these will be called the "retained" systems. The other two, Fort Worth and Detroit, are special purpose lines, approximately one mile each, which were constructed relatively recently.

The general characteristics of all nine systems are shown in Table 2-9 The "retained" systems include only parts of their original streetcar networks. The lines which were retained usually had some portion in a separate right-of-way.

TABLE 2-9. CHARACTERISTICS OF LRT IN NORTH AMERICA

City	Inauguration Date	Number of Lines	Length of Lines (Mi/km)	Type of R.O.W. (%)			Modern. of R.O.W.	New Vehicles
				Grade Sep.	Reserved	Street		
U.S.								
Boston	1896	5	24.6/41	48	30	22	Minor-Completed	Yes
Cleveland/ Shaker Heights	1920	2	13.05/21.75	53	47	-	Minor-Planned	Yes
Detroit	1976	1	.75/1.25	-	-	100	New	No
Ft. Worth	1963	1	1.1/1.9	100	-	-	Extension-Planned	No
Newark	1935	1	4.1/6.8	100	-	-	Extension-Planned	Plans
New Orleans	1893	1	6.4/10.6	-	88	12	None	No
Philadelphia	1892	15	108/180	23	1	76	Minor	Yes
Pittsburgh		5	24/40	3	73	24	Major-under construction	Yes
San Francisco	1912	5	18/30	36	30	34	Major-Completed	Yes
Canada								
Toronto	1892	10	68.5/114.2	-	3.5	96.5	Extension-Planned	Yes
Edmonton	1978	1	4.5/7.5	22	78	-	New	Yes

Sources: Lea Transit Compendium, Vol. II, No. 5, 1975.
GM Transportation Systems, Light Rail Transit Systems: A Compendium ..., 1975.
E.S. Diamant, Light Rail Transit: State of the Art Review, U.S. DOT, 1976.

The Boston system includes five lines, only three of which are part of the original streetcar network. Two other lines have been constructed in former commuter rail rights-of-way; the most recent was completed in 1959. Four of the lines converge in a subway in the central business district (CBD). The fifth line serves as a feeder to Boston's heavy rail subway. The major modernization effort to take place since the 1959 construction has been the purchasing of new vehicles. There has been no major effort to relocate right-of-way.

The two-branched line between Cleveland and Shaker Heights is a suburban line which shares a subway with Cleveland's rapid transit lines in the CBD. In suburban Shaker Heights the line branches and runs in boulevard medians. Since the Shaker Heights Rapid became part of the Greater Cleveland Regional Transit Authority, a contract has been let with an Italian firm to purchase new light rail vehicles.

The Detroit line is strictly a streetcar operation instituted in 1976 as a tourist attraction. Vintage vehicles were purchased to run in a downtown shuttle fashion. Detroit is one of the cities with LRT proposals which will be discussed later. However, this short line is not a forerunner to the LRT system being conceived.

The one-mile line in Fort Worth opened in 1963, is the only privately owned LRT in the U.S. outside of amusement parks or trolley museums. The completely grade-separated right-of-way runs from a parking lot to the basement of a retail/office complex. The service is provided even during hours when the stores are not open, and there is no charge for either parking or riding. There has been some discussion of extending the line further into the CBD.

Newark's City Subway is an early predecessor of the current LRT concept. The downtown portion uses a subway, and the surface portion of the line is in an exclusive right-of-way except for one street crossing. There have been several unsuccessful efforts on the city's part to obtain federal funds for both new vehicles and extensions to the line.

New Orleans has retained only one line of its original streetcar network. The St. Charles line runs in the street in the CBD but predominantly in a boulevard median outside. There are frequent crossings and all are at-grade, preventing any advantages of reserved right-of-way. The city currently prefers its antique vehicles to new ones. The 1920's era stock was refurbished in the early 1960's.

Philadelphia has the most extensive LRT/streetcar system in the country. Two different LRT transit divisions have been incorporated into the regional transportation authority, Southeastern Pennsylvania Transportation Authority (SEPTA). The City Transit Division has twelve routes which are predominantly street-running. Five of the routes are subway-surface types, all converging in the same subway in the downtown area. The Red Arrow Division (RAD) includes three high speed suburban lines which operate predominantly in separate rights-of-way. Two of the lines use at-grade street crossings, but the vehicle crossings are protected with signaling devices. The third RAD line is the Norristown High-Speed Line, a completely grade-separated line with high platform loading and third-rail power distribution. Though the description sounds more like rapid rail, the Norristown line is considered to be LRT because it operates in single cars and the fare is collected on-board by the operator. The drawback of the three RAD lines is that they terminate at a rapid rail station, requiring passengers to transfer to reach the CBD. The last major construction in Philadelphia's LRT system was an extension of the subway in 1955.

The remaining portions of Pittsburgh's once extensive streetcar, suburban, and interurban system are five routes which share a tunnel and a bridge into Pittsburgh's CBD from the South Hills area. The routes use exclusive right-of-way of former interurban trackage, median running, and street-running in the CBD portions. In recent years, plans were aborted to replace the LRT lines with the Westinghouse Skybus. Currently the South Hills corridor is undergoing major rehabilitation to continue the LRT service. New vehicles and a CBD subway will be part of the modernization effort.

San Francisco is the other city whose LRT/streetcar system is undergoing major reconstruction. The number of routes (five) is expected to remain the same. The main element of reconstruction involves a subway in the CBD area which will be shared with the new Bay Area Rapid Transit (BART), and all five LRT routes converge there. The original system includes two tunnels which pass through hills. The street trackage has been reserved for the LRT vehicles by raising the tracks three inches above the street surface and using concrete curbs to separate them from automobiles.

Canadian LRT

In Canada there are only two cities which currently have LRT, but both are particularly good examples. Toronto's system is significant because of its size, ten lines. Edmonton's system is important because it is a newly constructed one in a city of approximately 500,000 population.

Toronto, a city with over 2,000,000 population, has always been committed to public transportation, which carries approximately 70% of peak hour travel (Ref 26). The backbone of the transit system is a rapid rail subway which has continually been expanded since it opened in 1953. Streetcars, buses, and trolley buses all act as feeders to the rapid rail, though streetcar routes also pass through the downtown. Construction is expected to begin in 1980 on a light rail rapid line, the first non-street running line for Toronto. All existing lines are street running in mixed traffic except for one which has a portion in a boulevard median. There are no plans to alter the street rights-of-way. Toronto's fleet is in the process of being replaced by a newly designed Canadian light rail vehicle.

Edmonton, Alberta, has the only totally new construction of LRT in North America that is not an extension to or a rehabilitation of a previously existing system. Edmonton abandoned its original streetcar trackage in 1951. The new line uses a subway in the CBD and exclusive railroad right-of-way outside the CBD. In Canada the financing for transit investments is shared between the city and the provincial government. The Edmonton system was implemented in record time (four years) compared to recent rail transit construction in the United States.

Worldwide LRT (with an Emphasis on Europe)

LRT is quite common in many countries around the world. Appendices to this chapter include several lists of cities with LRT or trams. A selection of European cities and the characteristics of their LRT systems is found in Table 2-10. The European experience is felt to be important because U.S. and European standards of living and Western cultures are more alike than those of the U.S. and Asia or South America. The similarities are tempered by the lower rates of automobile ownership and the higher propensity to ride transit in Europe.

TABLE 2-10. THE CHARACTERISTICS OF LRT IN WEST EUROPEAN CITIES

COUNTRY/ CITY	NO. OF LINES	LENGTH OF LINES (MILES/KM)	TYPE OF R.O.W. (%)			IMPROVEMENTS	INTERFACE MODES *
			GRADE-SEP.	RESERVED	STREET		
AUSTRIA							
Wien	39	18.6/302.7		NA		YES,'69	NA
BELGIUM							
Antwerp	10	49.3/82.2		NA		YES,SUBWAY	B
Brussels	23	178.1/296.8	37	0	63	YES,'69	HR
Charleroi	15	81.4/135.7	38	0	62	YES	NA
Ghent	4	15.5/25.8	30	0	70	NA	B,CR
FRANCE							
Marseille	1	1.9/3.2	34	0	67	NO,DECREASE	B,HR
WEST GERMANY							
Bochum-Gelensenkirchen	10	103.2/172.0	25	0	75	YES,'75, SUBWAY	B,HR, CR
Braunschweig	3	17.0/28.3	35	0	65	YES	B
Bremen	6	42.3/70.5	11	21	68	YES	B
Dortmund	8	128.5/214.2	24	24	52	YES	B
Frankfurt	20	136.4/227.3		NA		YES,'61	B,HR,CR
Hamburg	4	32.3/53.8	1	22	77	NO,DECREASE	B,HR,CR
Hannover	14	114.7/191.2	100	0	0	YES	B
Heidelberg	4	18.0/30.0	17	6	77	NO,DECREASE	B,CR
Kassel	8	56.2/93.7	32	23	45	YES	NA
Kiel	1	7.1/11.8	19	0	81	NO,DECREASE	B
Koln	15	154.7/257.8	14	0	86	YES,'74	NA

TABLE 2-10. THE CHARACTERISTICS OF LRT IN WEST EUROPEAN CITIES (CONTINUED)

COUNTRY/ CITY	NO. OF LINES	LENGTH OF LINES (MILES/KM)	TYPE OF R.O.W. (%)			IMPROVE-MENTS	INTERFACE MODES *
			GRADE-SEP.	RESERVED	STREET		
WEST GERMANY							
Munchen	18	125.9/209.8	40	0	40	NO,DECREASE	B,HR,CR
Nurnberg	16	94.4/157.3	30	0	70	NO,DECREASE	B,HR
Stuttgart	11	78.0/130.0	27	27	46	YES,'76	B,HR,CR
Wuppertal	5	29.1/48.5	22	0	78	NA	B,HR
GREAT BRITAIN							
Blackpool	1	11.0/18.3		NA		NA	NA
Tyne & Wear	4	34.0/56.7	100	-	-	NEW	B,CR
ITALY							
Milan	22	163.8/273.0		NA		NA	B,HR
Rome	8	58.2/97.0	22	26	52	NO,DECREASE	B,HR,CR
Torino	14	76.8/128.0		NA		NA	NA
NETHERLANDS							
The Hague	9	52.5/87.5		NA		YES	B,CR
NORWAY							
Oslo	5	16.6/27.7		NA		YES	HR
SWEDEN							
Goteborg	10	45.9/76.5	86	0	14	YES	B
Stockholm	2	9.1/15.2	98	0	2	NA	B,HR

TABLE 2-10. THE CHARACTERISTICS OF LRT IN WEST EUROPEAN CITIES, (CONTINUED)

COUNTRY/ CITY	NO. OF LINES	LENGTH OF LINES (MILES/KM)	TYPE OF R.O.W. (%) GRADE-SEP.	RESERVED	STREET	IMPROVE-MENTS	INTERFACE MODES *
SWITZERLAND							
Basel	10	38.0/63.3	31	31	38	YES	B
Bern	3	10.9/18.2	5	5	90	YES	B

* B = Bus
HR = Heavy Rail
CR = Commuter Rail
NA = Not Available

Source: Lea Transit Compendium, Vol II, No. 5, 1975
Huntsville, Alabama: N.D. Lea Transportation Research Corporation.

Modernization of Existing Systems

Circumstances in Western Europe contributed to a different timetable of decisions to modernize streetcar transit. The destruction of cities during World War II gave governments an opportunity to reconstruct urban transportation systems with a commitment either to transit or to the automobile. Levels of automobile ownership in all European countries have always lagged behind those found in the U.S., though the gap is closing in a few countries. Therefore, during the period after the war was over and before automobiles were so pervasive as to demand the removal of streetcars, many cities and their national governments made strong commitments to LRT as a competitive alternative to the automobile for urban travel (Ref 27).

Due to these circumstances, European cities preceded U.S. cities by more than fifteen years in initiating modernization of streetcar systems to the current LRT concepts. Modernization in Europe included acquiring new cars, providing separate right-of-way wherever possible, and streamlining operations. Approximately half of the cities have since placed some portion of their streetcar lines in subways (Ref 27). Low cost methods of upgrading services were stressed in many cities, and in recent years of economic stress these types of transit treatments are increasingly popular (Ref 27). Some techniques used are self-service fare collection, increase in station spacing, single driver operation, and the replacement of lightly used lines with feeder buses to the remaining routes.

In the U.S., modernization has only gotten under way since 1970 (Ref 28). The late 1960's found the eight U.S. cities which had retained some portion of their original streetcar network (the seven cities previously named plus El Paso) with most systems so deteriorated that the decision had to be made to either rehabilitate the lines or abandon them. With the advent of federal urban transit assistance, the cities on the whole decided to rehabilitate and modernize the rights-of-way and to both replace and refurbish vehicles. The exceptions were El Paso, which abandoned its line, and New Orleans, which had refurbished its 1920's stock in the early 1960's.

The U.S. efforts to modernize have stressed new and rehabilitated vehicles. The rehabilitation of the existing stocks is being done primarily as a stop-gap measure due to the lengthy procedure of acquiring new vehicles. All of the systems have purchased or plan to purchase new rolling stock (with the exception of New Orleans, which has non-standard gauge track; Fort Worth, whose system is privately owned; and Detroit, which uses antique cars on its tourist-oriented line). As for the routes, most cities have been upgrading track, stations, and power supply and distribution. Only San Francisco and Pittsburgh are doing major reconstruction including underground sections.

The U.S. and European efforts to modernize their respective systems are not dissimilar except that the U.S. commitment to its existing rail transit has come much later in time. Major construction and vehicle purchases in Europe are basically completed, so the current emphasis appears to be low-cost fine-tuning. The U.S., with its late start, is making a commitment to modernizing its rail transit at a time when inflation is causing the effort to be extremely expensive.

Ridership Trends

In 1973 there was a turn-around in the decline of transit usage in the United States. Since that year the American Public Transit Association (APTA) reports consistent increases in total transit passenger trips (see Table 2-11). However, the same report shows that light rail transit trips have been declining continuously since 1945. Much of the decline before 1970 can be attributed to abandoned lines. The last abandonment, El Paso, took place in 1973. Even with a constant number of LRT lines since then, the patronage is shown to be declining. Another source, published in 1978, reports the number of passenger trips to be 164,950,000 in a year (compared to APTA's 103 million). This figure is higher than the APTA figures back to 1974. There is, however, no documentation for the source's data (Ref 29).

There could be several reasons for the decline of LRT in a period where transit usage in general is on the rise. During the same years, since 1970, most of the systems have been upgrading track, stations, power supply and distribution, and rehabilitating vehicles. Some have been undergoing major reconstruction. During construction, the disruption of service causes the number of passengers to drop off due to the inconvenience of transferring to temporary bus service. Data for the time since construction ended in most cities are not yet reported except in estimates. Construction is still underway in Pittsburgh. Boston, after completing its track renovation and introducing new light rail vehicles in 1977, reported increases in ridership

TABLE 2-11. TREND OF UNLINKED TRANSIT PASSENGER TRIPS*

Calendar Year	Railway			Trolley Coach	Motor Bus	Total Unlinked Passenger Trips
	Light Rail	Heavy Rail	Total Rail			
	(Millions)	(Millions)	(Millions)	(Millions)	(Millions)	(Millions)
1940	5,943	2,382	8,325	534	4,230	13,098
1945	9,426	2,698	12,124	1,244	9,866	23,254
1950	3,904	2,264	6,168	1,658	9,420	17,246
1955	1,207	1,870	3,077	1,202	7,250	11,529
1960	463	1,850	2,313	657	6,425	9,395
1961	434	1,855	2,289	601	5,993	8,883
1962	393	1,890	2,283	547	5,865	8,695
1963	329	1,836	2,165	413	5,822	8,400
1964	289	1,877	2,166	349	5,813	8,328
1965	276	1,858	2,134	305	5,814	8,253
1966	282	1,753	2,035	284	5,764	8,083
1967	263	1,938	2,201	248	5,723	8,172
1968	253	1,928	2,181	228	5,610	8,019
1969	249	1,980	2,229	199	5,375	7,803
1970	235	1,881	2,116	182	5,034	7,332
1971	222	1,778	2,000	148	4,699	6,847
1972	211	1,731	1,942	130	4,495	6,567
1973	207	1,714	1,921	97	4,642	6,660
1974	150	1,726	1,876	83	4,976	6,935
1975	124	1,673	1,810 (b)	78	5,084	6,972
1976	112	1,632	1,759 (b)	75	5,247	7,081
P 1977	103	2,133 (a)	2,251 (b)	70	5,295	7,616

P = Preliminary NOTE: Table excludes automated guideway transit commuter railroad and urban ferry boat.

* "Total Passenger Rides" from 1940 through 1976; "Unlinked Transit Passenger Trips" beginning in 1977.

(a) Data for "Heavy Rail" from 1940 through 1976 include only intermodal transfer passengers. Beginning with Calendar Year 1977, passengers transferring from one heavy rail train to another (intramodal transfer) are included

(b) Includes cable car and inclined plane.

Source: American Public Transit Association, Transit Fact Book, 1977-78 Edition, (Washington, D.C.: APTA, 1978), p 26.

of 19% over the previous months (Ref 30). The unreliability of old vehicles, a factor contributing to passenger decline, should be remedied as most systems begin replacing them with new vehicles.

Proposals for New LRT in North America

In the U.S. there are many LRT proposals in various stages of progress. Buffalo, New York is the only city which has begun construction on a new LRT line. Buffalo's 6.4 mile line is expected to be in service in 1982. The line will run 1.2 miles in a downtown transit-pedestrian mall with the remainder outside the CBD in a subway. The right-of-way is totally reserved and is of the type considered semi-metro (high platform loading, multi-unit operation, reserved right-of-way).

The most active proposal is for San Diego; it is in the process of being implemented by the Metropolitan Transit Development Board (MTDB). In California, a fund obtained from State gasoline taxes is available for transit capital investment, allowing San Diego to proceed without the approval of the Urban Mass Transportation Administration (UMTA). The MTDB is currently attempting to acquire railroad right-of-way for a line from downtown San Diego to San Ysidro on the Mexican border. The construction is expected to be completed by 1981.

The next most active proposal is for Portland, Oregon. Portland has gone through two study periods, one ending in 1973 and the other, in 1978. The original Portland study was for a five-line system, 45.5 miles in length. The second study involves a single line, 14.4 miles long, from downtown Portland to downtown Gresham. LRT has been recommended by the Tri-County Metropolitan Transit District and awaits the approval of the two city councils and the county commissions.

Detroit has been studying transit alternatives since 1975. Several options include LRT, and the Southeastern Michigan Transportation Authority (SEMTA) board has expressed preference for LRT over other options, such as bus, express bus, or a people-mover. LRT considerations include varying portions in subway and boulevard medians. Proposed lengths of the line range from 11 to 19 miles.

Denver is another large metropolitan area which ran studies on LRT in an alternatives analysis completed in 1975. Currently, Denver is in the design stage of a project in the downtown area for a transitway utilizing small, low-polluting vehicles in a shuttle fashion. There is still some discussion of a 14 mile LRT line, but no implementation plans are underway.

In Orange County, California, the Orange County Transit District hired appraisers and attorneys in 1978 to study the possibilities for acquisition of railroad right-of-way. Both heavy rail and light rail are being considered for a 34 mile route between Santa Ana and Los Angeles with 13.4 miles passing through Orange County. This project could also proceed without federal funds, relying strictly on State and local money.

In the last year, a citizens advisory committee has recommended LRT for St. Paul, Minnesota. The group, after studying other LRT systems, requested the Metropolitan Transit Commission to conduct further cost appraisals for the use of LRT in this medium-size urban area.

In Austin, Texas, a preliminary corridor plan was prepared voluntarily by a private non-profit group, the Texas Association for Public Transportation. The proposal involved the use of railroad right-of-way for the outer portion and street-running in the downtown area. The line would have used a bridge which is currently being renovated. The city did consider and test for light rail loading as part of the renovation, but has never adopted the plan for LRT. Several local officials have discussed the prospects for seeking federal funding for a feasibility study.

Dayton, Ohio, has been studying LRT alternatives since 1970. Several corridor studies and proposals call for the use of railroad right-of-way. One corridor was selected, and the city is in the process of trying to justify the proposal to obtain federal funds. The effort seems to be stymied by federal requirements, particularly the one calling for unified support (Ref 31).

Rochester, New York is a city which proceeded through the stage of estimating costs for a totally grade-separated light rail rapid transit system. The proposal is currently dormant, most likely due to federal reluctance to fund high-cost capital investments.

In Canada, an eight mile line is under construction in Calgary, Alberta. The line uses a transit-pedestrian mall downtown, and a tunnel to reach a railroad right-of-way for the remainder of the route. It is expected to be completed by 1982. Vancouver, British Columbia has studied LRT but implementation has not begun.

Federal Urban Transportation Policy

The Urban Mass Transportation Administration (UMTA) Act 1964 was the beginning of the federal government's commitment to urban mass transit. The original grants, under Section 3, were of a discretionary nature, meaning applications for grants were submitted to the federal government and judged on an ad hoc basis. Only capital expenditures were funded, and the grants were awarded on a 2/3 to 1/3 matching basis, the local or state governments paying the lesser share. These funds were predominantly awarded to rail transit projects and formed the primary impetus in the modernization programs in existing LRT systems.

Legislation in 1973 and 1974 marked a major change in federal policy. The Federal Highway Act of 1973 allowed money from the Highway Trust Fund to be used for transit projects. In 1974, Section 5 of the UMTA Act began the first assistance for transit operating costs on a 50-50 matching basis, plus capital cost on an 80-20 basis, both allocated by a formula to all states and urbanized areas. Discretionary awards under Section 3 were still available, now on the 80-20 matching basis.

The 1978 Surface Transportation Assistance Act was signed by President Carter on November 5, after some concern by transit interests that the President considered urban transit a low priority and capital-intensive investments in transit to be inflationary. The bill, however, indicates a strong commitment to transit in general. There is a trend toward the formula type funding, which showed an increased budget. However, a major share continues to be directed toward rail transit; and in fact, a minimum amount to be spent on rail modernization was included in the Section 3 discretionary program. There is no longer a limit on the transfer of interstate highway funds to transit. For the first time, highway and transit legislation was combined into one bill, indicating a trend toward the philosophy that attention to urban travel should include a comprehensive consideration of all modes (Ref 32).

The Urban Mass Transportation Administration issued definite policy toward urban rail transit investment in March 1978. Light rail transit was included. The policy indicates that in order to receive federal funding for new transit construction, the project proponent must show why grade seperation is needed over less costly options and how local policies and actions have been developed to enhance the system's viability. There will be a ceiling for federal funding on any single project. In general, the policy indicates that capital intensive rail transit will only be acceptable when it is shown to be well integrated with land use and other transportation modes, when realistic projections of use are made, and when it can be demonstrated to be superior to lower cost transportation improvements, such as buses (Ref 33). It has been stated that priority will be given to densely populated corridors and that "newer, less dense highway-oriented cities ... may be less likely candidates to receive federal rail commitments" (Ref 34).

UMTA became involved in the development of a standard light rail vehicle in 1971 when San Francisco's MUNI solicited bids for its new fleet. Since federal matching funds were to be used in the purchase, UMTA played a part in rejecting all the bids as too high. Subsequently, UMTA sponsored a committee of light rail transit operators, similar to the President's Conference Committee in 1935 which resulted in the standard PCC car. It was not easy to reach agreement on a standardized vehicle mostly because different cities felt their requirements were unique.

In the end, all the cities except Boston and San Francisco withdrew from the project. The resulting vehicle, Boeing's Standard Light Rail Vehicle (SLRV), was somewhat less expensive than the original Boeing bid for San Francisco only. However, numerous costly modifications of the vehicles resulted in the cities' receiving the vehicles at a price considerably less than it cost Boeing to produce them. Subsequent bids by Boeing have been more than twice the figure charged to Boston and San Francisco. In addition, the recent solicitations of bids in Cleveland and Philadelphia have been for vehicles which are not the "standard" LRV. For example, Cleveland's specifications were for a number of seats rather than for a number of vehicles, and Philadelphia specified a vehicle four inches narrower than the SLRV. Boeing's having produced a vehicle was to no advantage in lowering costs, as UMTA intended. American car-building companies protested the advantages accruing to foreign manufacturers because of their countries' policies and subsidization, which U.S. companies feel they do not get.

In response to this heated issue of spending federal matching money on contracts with foreign vehicle manufacturers, a "Buy American" clause was included in the 1978 Surface Transportation Act described earlier. Policy rules are currently being formulated by UMTA. The policy applies to expenditures over $500,000. The rules are expected to prescribe products that are 50% or more American-made except when buying American would raise the project cost 10% or more, when materials are unavailable in the U.S., and when the cost would be "unreasonable" or "inconsistent with the public interest" (Ref 35).

RECENT TRENDS IN LRT

This section describes some of the recent trends in the planning, design, and operations of light rail systems, both in the United States and other countries. These developments generally reflect many years of experience with LRT, hence it is important that they be considered in developing any new proposals.

Right-of-way Location

Separate right-of-way, the most important factor that distinguishes LRT from streetcars, is also the most common trend in current LRT design. In an effort to avoid congestion and competition with automobile traffic, LRT planners are giving consideration to the locating of routes in existing railroad rights-of-way, in downtown subways, and in transit-pedestrian malls.

The recently completed line in Edmonton, Alberta, makes use of Canadian National Railway right-of-way for 3.5 of its 4.5 miles, and the remaining mile is located in a subway in the downtown area. The downtown subway concept is also found in the two situations where existing systems are being upgraded, in San Francisco and Pittsburgh. The plans for Calgary, Alberta, call for all three of the right-of-way types. A tunnel section will connect the portion of the track laid in the railroad bed with a transit-pedestrian mall in the downtown section. The San Diego proposal combines the use of railroad right-of-way and a downtown transit-pedestrian mall.

In Buffalo, the line will run in a subway outside the CBD but will surface in the CBD in a transit-pedestrian mall. The predominantly underground right-of-way location, which emulates heavy rail subway in both operating procedures and construction costs, is an extreme example of the current trends. Most routes use subway only for the densest, most congested sections.

Locations of routes in railroad right-of-way can be found in the active proposals in Portland, San Diego, Orange County, several New Jersey cities outside of Newark, and also in the proposals for Austin, Dayton, and Rochester. The two California projects are in the stage of purchasing the railroad rights-of-way. Two of the above proposals, the one between Orange County and Los Angeles and another in New Jersey between Newark and Paterson, are dependent on the abandonment of the rights-of-way by the freight and passenger trains while the others propose to share tracks with trains or construct parallel transit tracks.

Locations of Stations and Terminals

Newly designed LRT routes are planned for corridors where existing or projected land uses enhance the viability of the routes. One terminal is, of course, in the downtown area. Typical locations for the outer station stops or terminals are major activity centers and the centers of other towns. Location of trip generating activities at the outer ends of a line means that ridership with destinations outside the downtown area could reduce the peak to non-peak ratio caused by the work trip commute to and from the CBD.

Major activity centers include auditoriums, sports facilities, college campuses, and large commercial or industrial centers. The Buffalo line, for example, has its northern terminal at the campus of the State University of New York and its southern terminal at the auditorium just south of downtown. The new Edmonton line has stops at the stadium, hockey arena, and exhibition grounds. The most recently planned LRT extension to the Toronto network has its terminal at the Scarborough Town Center, a place which is called a "metropolitan subcenter" (Ref 31). Pittsburgh's plans for the reconstructed South Hills line will include a shopping development at the end of the line.

Future proposals for several cities involve routes to adjacent cities. Newark is considering extensions of its one LRT line to one or more of the following neighboring towns: Paterson, Port Newark, Port Elizabeth, Jersey City, and Bayonne. The density of adjacent incorporated places in the northeast has caused a complex pattern of commuting networks. Some of the route proposals involve a connecting link to another commuter line. Another example of town linkage is the proposed line between Portland and Gresham in Oregon. Gresham is part of the Portland metropolitan area; their downtowns are approximately fourteen miles apart.

Two other route situations are a combination of the trend of towns as terminals and the trend of activity centers as terminals. They are situations where the outer town is a tourist attraction. In El Paso, a streetcar line between its CBD and that of Juarez, Mexico, was abandoned in the last decade but is currently being considered for re-opening. The San Diego proposal is for a 16-mile line running from downtown San Diego to San Ysidro, Mexico, on the border. The use of streetcars as a tourist attraction has precedents in the existing lines in New Orleans and Detroit, where local riders also make use of them for the downtown commute. San Francisco's cable cars provide another example of serving locals and tourists alike.

Network Designs and Interfaces

The designs of new, rehabilitated, and proposed LRT systems in North America and Western Europe have some characteristics which, with a few variations, are so consistent as to be considered part of LRT technology. The basis of the designs is an integration of transportation modes usually LRT with buses and automobiles, but in some of the larger cities, with heavy rail. In very few instances (none of them in North America) do rail lines attempt to provide a complete transportation network as the old streetcar systems did. Instead, the rail lines form the backbone of the network in major corridors. Bus routes are used in less dense corridors as feeder lines to rail transit stations. In the cities which have heavy rail subways, it is the LRT routes which are used as feeder lines to the subway stations. In Toronto, for example, 107 LRT, bus, and trolley bus routes make 157 connections with the subway system (Ref 30).

Integration with the private automobile is in the form of park-and-ride lots at many of the transit stations. This represents an effort to keep automobiles out of the central city and to increase the efficiency of the rail route. Some stations are designed to accommodate automobiles discharging or picking up passenger/riders, a practice known as "kiss-and-ride."

Newly constructed or proposed routes in North America consist of single lines which are viewed as part of a staged development. This method is consistent with the idea that LRT by itself will not be a complete network. Future extensions are rarely provided for in the original construction project, except in a case like Edmonton where a T-stub has been built in the subway section to accommodate a possible extension. Since most cities have considered several corridor options, the corridors not selected for construction will undoubtedly be monitored for future conversion to LRT lines that would connect with the original line. However, the single line is considered to be functional as the backbone of a rail-bus network, even if no extensions are ever built.

Operating Trends

Cities which opt for LRT as the backbone of a new transit system usually cite operating cost advantages over buses as the reason for selecting LRT. The basis for this is LRT's ability to use a single driver for a multi-unit train. This trend is part of all future LRT plans. However, the practice is currently implemented in only three of the cities with existing systems——Boston, Philadelphia (2 lines), and Cleveland. Most of the existing systems are expected to follow the practice as the new light rail vehicles go into operation and as ridership increases warrant it. In some cases, the old vehicles are unable to operate in trains.

The trend of self-service fare collection in most European systems has contributed to faster operating speeds. This method will be tried in San Diego. The U.S. trend has been toward exact change fare and passes as an effort to speed up the boarding process. Off-vehicle collection, another technique for speedier service, is being used in the subway sections of the U.S. systems.

Conclusion

The report provides an historical overview of the development of the light rail transit concept from the early electric streetcars, a review of the current status of LRT systems around the world, and a discussion of the recently emerging trends in the planning, design, and operations of LRT. In the United States, interest in LRT varies considerably from city to city; on a national basis, it can be fairly said that there is a moderate interest in the role of LRT in addressing the urban transportation problem. This role is seen to be that of a medium-capacity mode that is well integrated with various other transportation modes and with compatible land uses.

In North America, the majority of recent LRT projects involve the rehabilitation and modernization of the few streetcar systems which were retained. Newly constructed or proposed LRT lines show some similarities in right-of-way locations and network designs. Operating procedures in the U.S. are making less than full use of the operating advantages for which LRT is lauded and which European systems have adopted. The trends in the current LRT planning and operations can be readily traced to the trends in government policy.

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CHAPTER 3. DESIGN AND OPERATIONS

The initial chapters of this report have presented a background of LRT. The next stop is to consider the principal physical and operational characteristics of this transportation mode. Particular attention is given to issues which should be addressed in either making or evaluating a specific LRT proposal for a city in Texas. Most of the items in the following eight categories will have a direct bearing on the total costs and efficiency of an LRT system:

1. Vehicles: considerations in choosing an appropriate vehicle, along with descriptions of "state-of-the-art" technology;
2. Route Network: considerations in laying out a fixed guideway;
3. Track and Structures: descriptions of track facilities, guideway structures, and construction procedures;
4. Power Supply: characteristics of the distribution network and considerations for overhead wiring;
5. Fare Collection: descriptions of the various options available;
6. Stations and Platforms: a discussion of the wide range in possible locations and configurations;
7. Signaling and Traffic Control: control of both light rail vehicles and other traffic; and
8. Operations: descriptions of matters not covered in detail in the above categories, such as fare elasticity, the relationship between average speed and number of stops per mile, and innovative techniques.

Many of the items to be discussed will overlap into two or more categories; this underlines the fact that an overall planning process must treat the various categories as a whole, since the issues in one category may affect those in another.

VEHICLES

The type and final design of vehicles for a certain light rail system will depend on:

- desired level of service (operating speed, headway, comfort criteria),
- patronage levels (peak and off-peak volumes),
- area geography and climate (steepness of grades, equipment reliability in cold or wet weather),
- clearance restrictions,
- vehicle availability (both present and future),
- energy availability,
- adaptability to existing equipment and/or structures, and
- budgetary constraints.

Some of the more important technical aspects will be detailed in this section with special attention given to the implications of each.

Purchasing and Maintenance

Since any initial order for light rail vehicles (LRV's) by a city in Texas would most likely be relatively small (under forty), it would be very expensive to contract with a manufacturer for a completely new vehicle design. Not only are there high start-up costs for a new production line, but major modifications may later be found necessary. Also, a problem may exist if a few more vehicles are needed in the future (as routes are extended) and this particular design is no longer produced.

One way to obtain vehicles is by purchasing used ones from cities that are either upgrading (through acquisition of new LRV's) or abandoning their trolley systems. For example, the PCC cars in Fort Worth came from Washington, D.C. (which abandoned its system in 1962) and Boston (which has recently purchased new LRV's to partially modernize its fleet). The twenty PCC's in storage in El Paso came from San Diego which abandoned its system in 1950.

Used vehicles should be much less expensive to purchase than new ones, even after extensive refurbishment, and they have "proven" themselves in service. However, they will be expected to have larger operating and maintenance costs. If a particular type of vehicle is no longer produced, there is no certainty as to the ease of getting replacement parts or of increasing the number of vehicles on a system at some future time.

San Francisco (115), Pittsburgh (95), and Cleveland (55) plan to completely replace their PCC fleets with new LRV's in the next five years, while Boston, Philadelphia, and Toronto may soon be selling small quantities as their new LRV's replace some of the older PCC cars. The PCC cars from Pittsburgh use a track wider than the standard 4'8½" (1435 mm) gauge, but this could be changed through modifications on the truck (bogie). The newest American PCC car, however, is now over 25 years old.

Serious consideration could be given to buying used foreign-made vehicles of which a number of fairly popular designs have been produced. However, high shipping costs and difficulties in making contracts may prevent this from ever being a particularly useful concept.

A second way to obtain vehicles is to order a conventional vehicle directly from an existing manufacturer. While there are over 10 different companies that make light rail vehicles, six merit special consideration:

1. Duwag of Dusseldorf, West Germany, has been the leading manufacturer of wide variety of LRV's in Western Europe since the mid-1950's;
2. Tatra Corporation of Czechoslovakia manufactures many of the vehicles for Eastern Europe (over 1,000 vehicles each year);
3. Urban Transportation Development Corporation (UTDC) in Canada has recently supplied 190 LRV's (built by Hawker-Siddeley of Ontario) to the Toronto Transit Commission;
4. Breda Costruzioni Ferroviarie of Pistoria, Italy, was recently awarded a $31 million contract to construct 48 LRV's for the Greater Cleveland Regional Transit Authority's Shaker Heights line (first delivery in 1980);
5. Nissho Twai American Corporation (Kawasaki) of Japan was low bidder at $58 million to build 141 LRV's for the Southeastern Pennsylvania Transit Authority (in Philadelphia); and
6. Boeing Vertol located in the United States is the manufacturer of UMTA's Standard Light Rail Vehicle (SLRV) [presently out of production].

The advantages of using a standardized vehicle from a large company involve the economics of mass production. Normally, once a production line is rolling the vehicles can be produced at less cost (depending on inflation), since the initial capital investment for "start-up" equipment has already been made (Ref 1). A city utilizing such vehicles can expect relatively easy replacement of cars and parts in the future.

A third method of obtaining vehicles is to develop vehicle specifications (performance or hardware related) and then allow contract bidding by interested manufacturers. Performance related specifications define operational requirements (such as vehicle capacity and speed) while hardware related specifications usually define various technical requirements (such as number and horsepower of motors per vehicle). Specifications should be written in such a way that many existing vehicle designs would meet the criteria with only minor modifications.

Operating and maintenance costs will depend greatly on the availability of parts and vehicle age. One reason for the high initial costs of rail vehicles is that they are built sturdily enough to have an effective service life of over thirty years. Some rehabilitated cars still in use in Philadelphia and New Orleans are more than fifty years old.

Capacity

A survey of the state of the art in vehicle design reveals a wide variation in passenger capacities. The total capacity of a vehicle is equal to the number of seated plus standing passengers. Generally, given a certain floor area, the more seats there are in a vehicle, the lower will be the total capacity. The maximum allowable load factor (total capacity/seated capacity) will depend largely on passenger comfort criteria. While most people making long transit trips (over 15 minutes) will expect to have a seat available, some of the passenger making shorter trips during peak periods might not mind standing. In fact, an advantage to standing is that passengers can exit the vehicle quickly when it stops. To increase total capacity during peak periods, some heavy rail vehicles (including some in Paris) use tip-up (retractable) seats which can be flipped up to allow more space for standing passengers (Ref 2).

Table 3-1 depicts some vehicle capacities. The new single-articulated Breda LRV is designed for 84 seated passengers. A fundamental reason for the wide range in vehicular capacities is the variation in inside dimensions, especially length. Through the use of articulation, vehicles of longer length are able to safely negotiate the same curves that shorter, non-articulated cars can. This is because the body of an articulated vehicle is jointed at one or more points to permit the car to actually "bend" around a curve.

The determination of whether to use large, medium, or small capacity vehicles depends on such factors as:

- vehicles that are available for purchase,
- the initial purchase price and expected operating and maintenance costs for all vehicles,

TABLE 3-1. DESIGN CAPACITIES OF SOME COMMON LIGHT RAIL VEHICLES

Body Configuration	Examples	Total Design Capacity* (Passenger Spaces)	Number of Seats
Non-articulated	U.S. PCC Car	118	48
	Canadian LRV	131	42
Single articulated	Boeing LRV	152	52 - 67
	DuWag U2	162	64
	DuWag B Type	180	72
Double articulated	DuWag P8	170	62
	Hannover 6000	150	46

*Based on 2.7 feet^2 (0.25 m^2) per standee

Source: <u>Light Rail Transit: State of the Art Review</u>, p. 129.

- expected passenger volumes throughout the day,
- medium (peak) and maximum (off-peak) allowable service headways, and
- the use of multiple-unit operation.

The last factor, multiple-unit operation, is one reason why some planners consider LRT to be a flexible transit mode. The common practice is to couple two or more regular vehicles together to form a train. In the past, trailers were sometimes used, which could only be operated when coupled with a regular vehicle. Most systems today, however, prefer not to maintain more than one type of vehicle in their fleet (except while in the process of upgrading).

Speed, Acceleration, and Deceleration

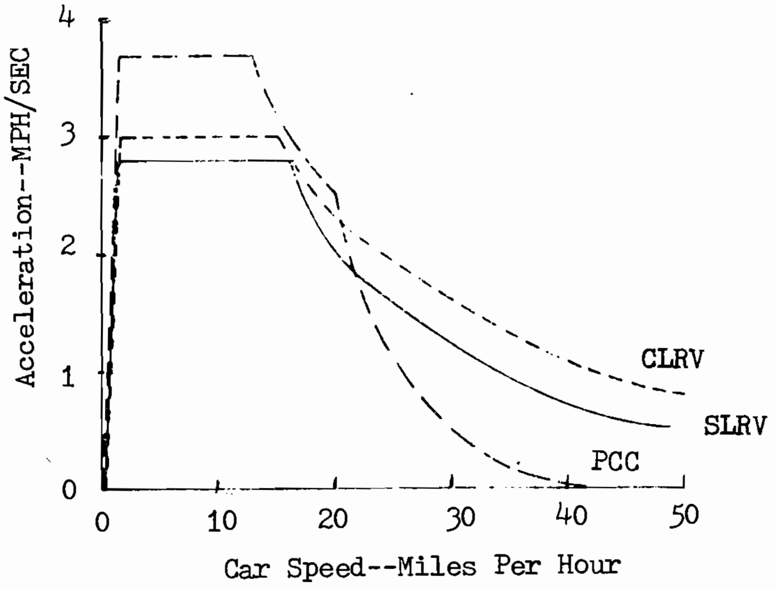
The maximum running speed for most vehicles is about 50 to 55 mph (80-88 kph). The operating speed on a particular LRT system will depend on such factors as station spacing, track alignment, safety (especially if shared rights-of-way or at-grade crossings are used) and the costs involved therewith.

Since transit vehicles must do a lot of starting and stopping, the acceleration and deceleration rates are very important. Just how important they are to the overall operating speed will depend on how closely stops are spaced. Figure 3-1 shows the approximate acceleration rates versus speed for the PCC car, the Boeing SLRV, and the Canadian LRV.

While the PCC car has a higher initial acceleration rate than the Boeing SLRV, the latter can maintain a higher average acceleration——the Boeing car can attain a speed of 50 mph (80 kph) in about the same time (37 seconds) that the PCC car could reach 36 mph (58 kph). The high-powered Canadian vehicle designed by the Urban Transportation Development Corporation can attain 30 mph (48 kph) in 12 seconds and 50 mph (80 kph) in 30 seconds.

Deceleration rates presently attainable by some LRV's are limited by rates that standing passengers can endure without losing balance. This is generally considered to be 3.0 mph/sec (4.8 kph/sec), also expressed as 4.4 feet/sec^2 (1.3 m/sec^2). Table 3-2 lists the spectrum of normal and emergency braking.

FIGURE 3-1. ACCELERATION CURVES OF THREE LIGHT RAIL VEHICLES FOR AVERAGE PASSENGER LOADING.



Source: Joseph S. Silien and Jeffrey G. Mora, Urban Mass Transportation Administration, "North American Light Rail Vehicles," in Transportation Research Board Special Report # 161, Light Rail Transit (Washington, D.C.: National Academy of Sciences, 1975), p. 97.

TABLE 3-2. SPECTRUM OF NORMAL AND EMERGENCY BRAKING

Body Configuration	Examples	Service Deceleration		Maximum Emergency Deceleration	
		ft/s2	m/s2	ft/s2	m/s2
Non-articulated	U.S. PCC Car	4.6	1.4	9.5	2.9
	Canadian LRV	5.2	1.6	10.3	3.1
Single-articulated	Boeing LRV	5.2	1.6	8.9	2.7
	DuWag U2	3.9	1.2	9.9	3.0
	DuWag B Type	3.9	1.2	9.9	3.0
Double articulated	DuWag P8	3.9	1.2	9.8	3.0
	Hannover 6000	3.9	1.2	9.8	3.0

Source: *Light Rail Transit: State of the Art Review*, p. 130.

Suspension, Propulsion, and Braking Systems

Generally most vehicles have two axles per truck. Trucks are used to carry the total vehicle and passenger weight and to control vibration caused by vehicle motion. The number of trucks used will depend on the amount of articulation: non-articulated vehicles normally have two trucks, single-articulated vehicles have three (with one truck under the articulation joint), and double-articulated vehicles generally have four. Most vehicles are designed to operate on the standard 4.708-foot (1435 mm) or 4'8½" gauge, although a number of European systems use a smaller 3.281-foot (1000 mm) gauge. Modern designs use resilient wheels for squeal reduction on curves.

LRV's are almost always electrically propelled with current coming through overhead wires. While the construction of an overhead wiring system is expensive, the major advantage is that the vehicles do not have to carry their own power source, unlike self-propelled vehicles that use either batteries or diesel. Some systems classified as light rail use a third rail for electrification (e.g., the Norristown line of the Red Arrow Division in Philadelphia), but this requires a totally grade-separated right-of-way (ROW).

An advantage of electrical motors over internal combustion engines is that they can be safely overloaded for a short period of time over their rated horsepower. This is very useful for going up steep hills. Whether to put motors on each truck will depend on the trade-off between vehicle cost and maximum speed. The absence of a powered center truck (under the articulation joint) in UMTA's SLRV may have reduced the cost, but also reduced the top speed from 65 mph (105 kph) to 50 mph (80 kph) (Ref 2).

There are basically three different and independent braking systems in wide use:

1. Dynamic brakes: traction motors supply the resistance to forward movement by acting as generators (converting mechanical energy to electrical energy) to help slow a vehicle from high speeds, much like an automobile can be slowed by putting it in low gear. If an electrical current produced by dynamic braking is returned to the overhead power supply line, it is called regenerative braking;
2. Friction brakes: this is a mechanical system consisting of disc brakes, operated pneumatically or hydraulically that can bring a rail vehicle to a complete stop, much like power brakes on an automobile;
3. Electromagnetic brakes: these consist of metal bars suspended from the truck frame, between the wheels, that will grip the track when

actuated by an auxiliary power source onboard the vehicle that is independent of the overhead line power. This system is used to prevent rollback when starting on an upgrade and during emergencies.

Electrical and Control Systems

Generally vehicles operate with a line voltage of 600 to 650 volts direct current (vDC). The overhead pick-up device can be either a trolley pole or a pantograph, both of which can extend 3 to 8 feet (0.9 to 2.4 m) from the roof of the vehicle to the overhead wire. Pressure is applied against the wire through the use of springs: the trolley pole has a U-shaped shoe (or small wheel) that slides along under the wire, while the pantograph consists of a long, flat, bar-shaped carbon shoe (3 to 6 feet or 0.9 to 1.8 m wide) that also slides along under the wire. Most modern vehicles use the pantograph although some manufacturers will offer to install either (or both). While trolley poles are less expensive, they are being phased out where possible because of the advantages of the pantograph which include:

- elimination of the need for overhead switches,
- greater current collection capacity,
- less maintenance,
- freedom from dewirement, and
- ability to be used in either direction.

Some planners have suggested that vehicles be equipped with both pantograph and third rail pick-up devices, especially if some stretches of track are fully protected from other traffic and overhead lines are considered environmentally intrusive. However, not only would this increase both vehicle and power line cost but would probably result in some operational problems of switching from pantograph to third rail and back to pantograph.

Basically, there are two power control techniques:

1. Rheostatic ("cam" controller): in this method, the power supplied to the motor is varied by changing circuit resistance in incremental amounts, thus changing the speed. PCC cam controllers have between 99 (Westinghouse) and 136 (General Electric) incremental steps; in general, as few as 25 steps will provide an accelerated rate that feels virtually "jerk free" to any passenger. The major advantages are that the cam is widely available, has proven itself in service,

and is simple to repair. The major disadvantage is that energy is wasted in the resistors. Also, it precludes the use of regenerative braking;

2. Electronic solid state: the best example of this is the recently developed thyristor chopper control. Continuous voltage control ("stepless") provides for maximum possible tractive effort. This results in smoother acceleration than rheostatic controls and can save energy (especially if regenerative braking is included). However, the equipment requires sophisticated electronic maintenance and is expensive; it can add about six percent to the purchase price of a vehicle.

Minimum Horizontal/Vertical Curvature, Maximum Safe Operating Grade

A common advantage cited of LRT vehicles over conventional rapid rail vehicles is that alignment criteria are not so strict. Tunnels and elevated structures can be shorter (due to shorter access ramps with steeper grades) and tracks can more closely follow the existing topography or street rights-of-way. There is a tradeoff, however, in that the use of very small curvature and steep grades may significantly reduce vehicle operating speed (and perhaps significantly increase braking distance on steep downgrades).

The grade climbing ability of light rail vehicles is determined by the available traction power, the weight on the drive wheels, and the coefficient of friction between the steel wheels and steel rail. Many non-articulated vehicles can operate on grades up to ten percent while articulated vehicles generally have lower capabilities, especially if the axles on the trucks located at the articulation joints are unpowered. However, grades of 4 to 6 percent are common with only moderate reductions in speed (Ref 3).

Minimum horizontal/vertical curvature is affected mainly by vehicle length and the use of articulation. Maximum horizontal turning radii usually fall in the range of 30 to 70 feet (9-21 m) while minimum vertical curvature generally range from 300 to 100 feet (90-300 m). For example, the Boeing SLRV can negotiate a 42-foot (13 m) horizontal turn and a 310-foot (95 m) vertical curve on the crest of a hill.

Loading and Unloading

The method of fare collection will determine which doors are used for boarding and which are used for exiting. Some vehicles are equipped for bi-directional operation, the major advantage being that there are easy turnbacks on simple track layouts (thus, no need for loops at the ends). Such vehicles usually have doors on each side and an operator's console at each end; this may result in a reduction of vehicle capacity and an increase in costs of both purchasing and maintenance. Single-articulated vehicles usually have three double doors per side while non-articulated vehicles normally have two double doors. If both side and center platforms are used, loading/unloading with bi-directional cars can be very rapid since instead of three double doors available with articulated vehicles, there would be six. Doors are generally one of three types:

1. Folding: these are very common and can easily be electrically operated, but take up some space inside vehicle when opened;
2. Sliding: the reliable but bulky doors run on runners and open into a recess within the double walls of the vehicle; or
3. Plug: when opened, these doors "pop" out and away from the vehicles and then slide along the outside of the car; when closed, the doors are flush with car sides.

The choice of which door type to use will depend on available space and costs involved.

There are basically two types of seating arrangements: seats can either face towards the vehicle's ends (lateral arrangement) or towards the aisle (longitudinal arrangement). Most vehicles have a lateral seating arrangement, but the UTDC Canadian LRV can be ordered either way. The vehicles on the Fort Worth line have padded, continuous seats along both sides of the interior, so that seated passengers face toward the aisle (longitudinal seating).

Most (but not all) vehicles are available with low level loading while some (including the Boeing Vertol SLRV) have an option for either high or low level loading. Low level loading means access is by steps on the vehicle with little or no need for a boarding platform. While station costs may be less, passenger boarding will be slower and access by passengers in wheelchairs is virtually impossible (unless a special lift is installed).

Legislation has made it a requirement that all federally funded transit systems be made accessible to the handicapped. For a new light rail system, three methods might satisfy this requirement:

1. Use of special lifts on all vehicles,
2. Provision of a few specially-equipped vehicles that would stop at certain stations at designated times throughout the day, or

3. Restriction to high level loading (no steps).

Present laws regarding requirements for new transit systems might, however, be interpreted as saying that equal service can be supplied with specially-equipped buses.

Dimensions and Weights

Of course, the dimensions and weights will depend on some of the considerations already discussed: capacity, track alignment, method of loading/unloading, use of articulation, and costs. Based on the vehicles described in Lea Transit Compendium, existing vehicles have the following ranges:

- widths are usually between 7 and 9 feet (2.1 to 2.7 m),
- heights from rail to roof are between 9 and 12 feet (2.7 to 3.7 m),
- lengths for non-articulated vehicles range from 40 to 50 feet (12 to 15 m), while articulated vehicles range from 55 to 90 feet (17 to 27 m), and
- weights for non-articulated vehicles are close to 20 tons, and for articulated ones between 25 and 45 tons; in other words, most vehicles range from 750 to 950 pounds per foot (1120 to 1420 kg/m) of length (Ref 4).

Passenger Amenities

Obviously, most planners want to use transit vehicles that are desirable from a passenger's viewpoint. The following are some of the comfort criteria that must be considered in vehicle design:

- availability of air conditioning and heating,
- acceptable levels of noise and riding smoothness,
- exterior appearance: modern looking, colorful, and
- interior design: seating arrangement, use of fashioned seats, carpeting, and large picture windows (the refurbished cars on the Fort Worth line even have stereo music from a tape deck).

ROUTE NETWORK

Location of Guideway

A principal of LRT over conventional rapid rail transit is the ability to use a wide variety of right-of-way (ROW) types. While anything less than a fully controlled ROW will cause a reduction in speed (mainly due to safety concerns), the costs of construction may be considerably less. There are basically three ROW categories used in the literature (Ref 5):

1. Category A: fully controlled (exclusive, private, separated) ROW, with no vehicular or pedestrian crossings at grade allowed;
2. Category B: partially controlled (semi-exclusive) ROW, with grade crossings allowed; and
3. Category C: shared ROW, with LRT operating in mixed traffic with automobiles and buses.

While category B requires more land and a higher investment cost than category C (as does A over B), there are some important advantages:

- higher speed, capacity, reliability, and comfort;
- greater productivity per unit of operating cost and greater safety,
- stronger system image and identification,
- higher passenger attraction, and
- stronger impact on urban form and land use (Ref 6).

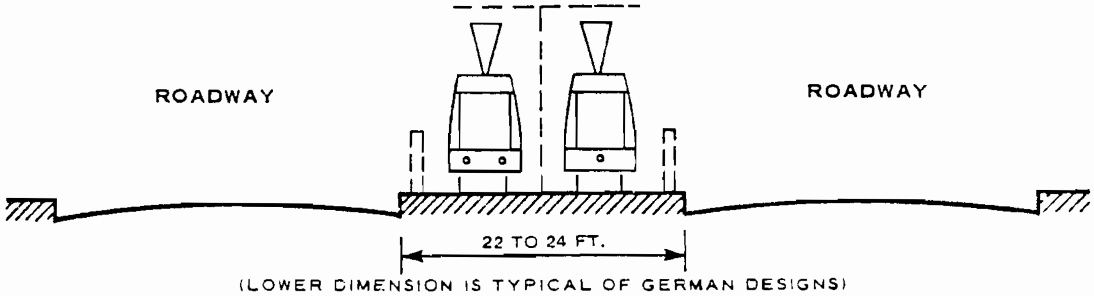
By varying the percent of ROW in each category, planners can change the relationship between system performance and investment cost. Most of the new light rail systems utilize category B. The short lines in Newark and Fort Worth, along with conventional rapid rail lines, are examples of systems using fully controlled ROW. Category C is characteristic of the old streetcar systems that operated in Texas, and is considered today only for limited uses. The flexibility of light rail is due to the fact that the system can be designed for any combination of the three categories.

Consideration must also be given to the possible vertical profiles: above grade (aerial guideways or embankments), below grade (tunnels or open cuts), and at grade. At grade construction is least expensive, but ROW costs may be high. The costs of aerial structures or tunnels can add significantly to total construction costs. If these structures are considered necessary for certain grade-separated crossings of busy streets, they are usually made as short as possible. One requirement, however, is that the access ramps to tunnels or aerial structures cannot be so steep that vehicle operating speeds are severely reduced.

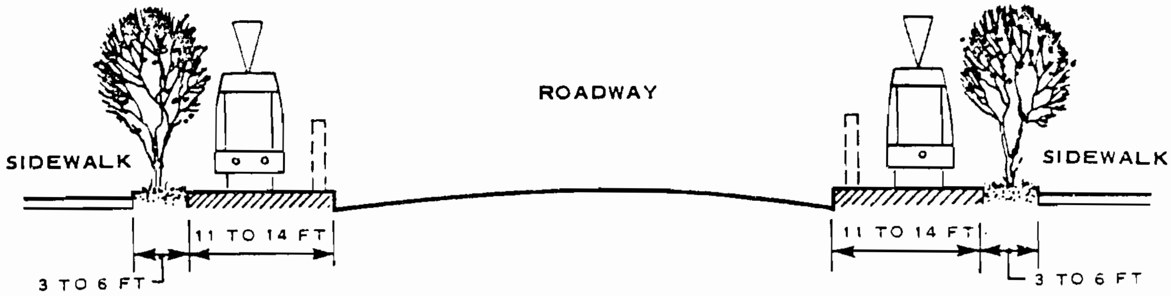
In addition to space for tracks, the total ROW should include whatever additional width is required for slopes, structures (if any), and pedestrian access facilities. For double-track railway located at-grade on level ground, ROW widths range from 20 to 35 feet (6 to 11 m) between stations and 30 to 40 feet (9 to 12 m) with station platforms included (Ref 3). Trackage locations which may be considered are the following:

1. Existing streets: may be acceptable with modern traffic management techniques; for example, street lanes could be reserved for transit vehicles during peak hours.
2. Existing roadway ROW: light rail lines could be located in the medians or on the sides of existing streets, arterials, or freeways. The first major concern, of course, is whether existing roads go where light rail is needed. For example, freeways might not pass as close to the CBD (Central Business District) as rail transit should. The problem of passenger access to a line located in a median must be considered. For lines located at the side of the road, turning movements of motor vehicles must be carefully considered. Figures 3-2 and 3-3 show possible LRT arrangements within street and freeway ROW. If a median is very narrow and no other usable ROW exists, it may be possible to use an elevated guideway with the support columns occupying the median. Figure 3-4 shows an aerial guideway in an arterial median.
3. Pedestrian malls: most of the malls in European cities were once narrow streets for automobile traffic. While the safety consideration of having pedestrians (and perhaps bicyclists) nearby may lower vehicle operating speeds, many people find the use of a transitway in a pedestrian area aesthetically pleasing, as well as very convenient.
4. Commercial property: if the owners of commercial establishments such as shopping centers, thought that LRT may help bring customers to their businesses, they might encourage the line to locate near them by offering ROW at very low prices (especially for stations). The 6.4-mile (10.3 m) LRT line being built in Buffalo will operate in the CBD down the center of a shopping mall. The short line in Fort Worth represents a situation in which a department store paid all capital and operating costs of a subway from a parking lot to the store.
5. Public parks/open space: if the only feasible way of getting from one high demand area to another (the "line-haul" portion) is through a park, light rail with its controlled guidepath can limit the environmental intrusion to the width needed for the tracks. It can blend in better with the surroundings then can multi-lane highways or "fenced-in" conventional rapid rail transit.
6. Abandoned railroad ROW: some of the LRT lines in Boston operate on abandoned ROW (e.g., the Highland Branch Line), as does much of the Lindenwold rapid rail line in the Philadelphia area. One problem

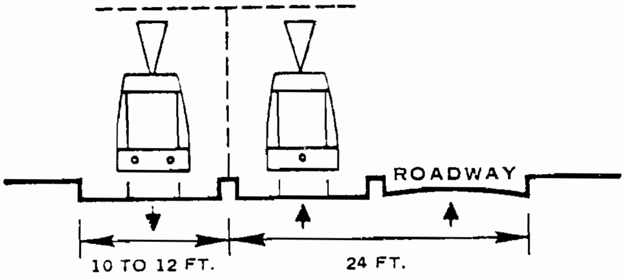
FIGURE 3-2. COMMON ARRANGEMENTS OF LRT WITHIN STREET RIGHTS-OF-WAY.



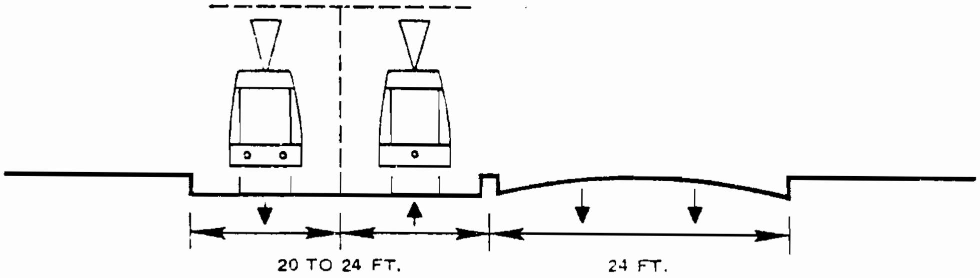
LOCATION IN MEDIAN



SYMMETRIC LATERAL LOCATION



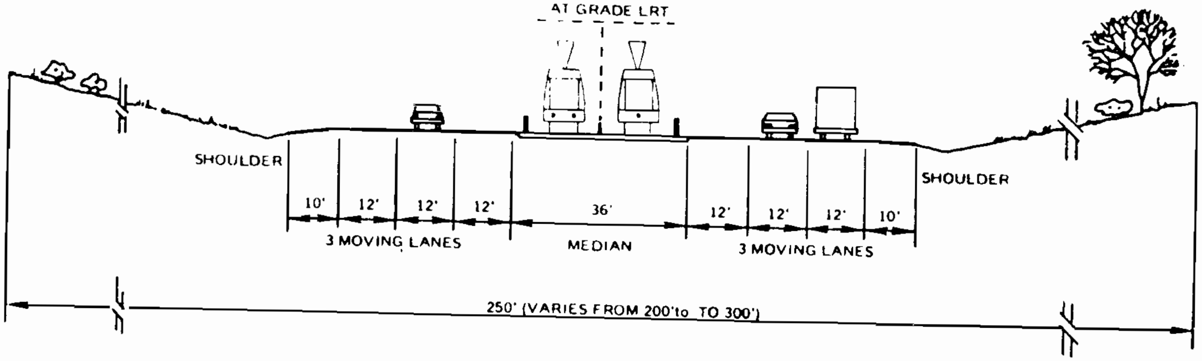
LATERAL LOCATION ON ONE WAY STREET WITH CONTRA-FLOW OPERATION



ASYMMETRIC LATERAL LOCATION

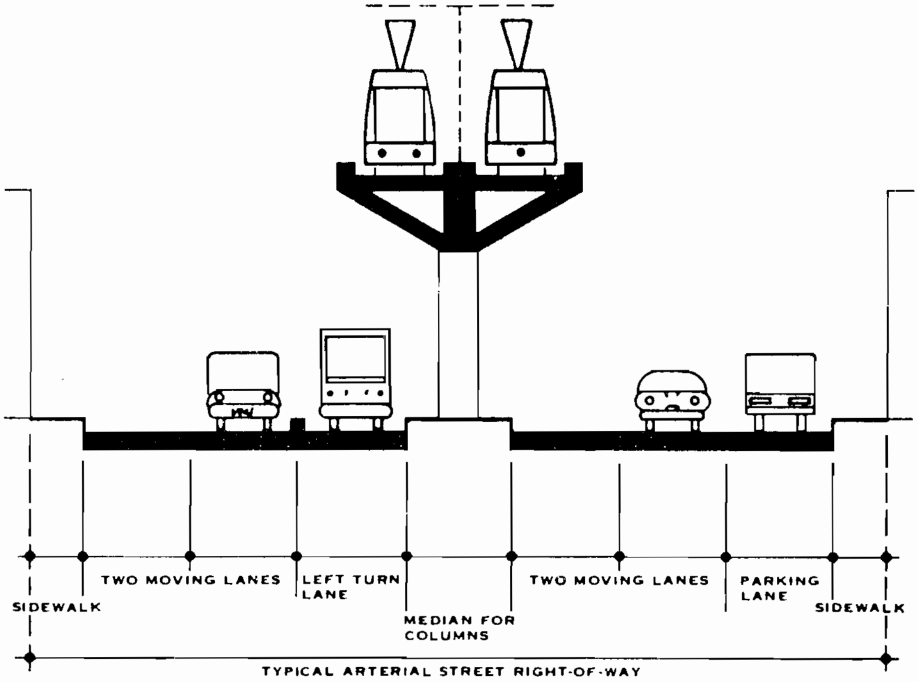
Source: Light Rail Transit: State of the Art Review, p. 90.

FIGURE 3-3. USE OF AT-GRADE RIGHT-OF-WAY ON FREEWAY MEDIAN



Source: <u>Light Rail Transit: State of the Art Review</u>, p. 104

FIGURE 3-4. AERIAL GUIDEWAY IN MEDIAN OF ARTERIAL STREET.



Source: Light Rail Transit: State of the Art Review, p. 106.

with the use of railroad ROW may be that it does not go where it is needed.

7. Existing tracks: joint use of railroad tracks with freight operations may have severe operational and safety problems unless freight movement could be confined to hours when LRT is not used. However, much of the existing railroad track on lightly used lines is in very poor condition (not up to the standards needed for smooth passenger operation). As with the use of abandoned railroad ROW, existing tracks cannot be seriously considered if they do not go where most needed for passenger service.
8. Old canal bed ROW: not a widely available option in Texas; much of the LRT line in Newark used this type of ROW.
9. Utility easement: consideration should be given to the joint use of ROW already purchased by a city, such as for electric power transmission lines or covered drainage ditches. The safety aspects of running vehicles near high-voltage lines or in areas that may be susceptible to flooding must of course be considered.
10. Purchase of new ROW: if no other options are feasible, the purchase of ROW can be done in the same way that land for urban highways is obtained. If necessary, a public body can apply the law of eminent domain to obtain developed or undeveloped land at a fair market value.
11. Use of no surface ROW: subways may require only an easement from those who own the property above the line; often, the lines go under the public streets. This may be the best option in areas of very high values (such as in the CBD).

Table 3-3 briefly summarizes the major locational opportunities. Sometimes there is a tendency to route a rail line where ROW is least expensive. But ROW cost is only a part of the picture; a major objective should be to run the line where it is most needed. Depending on the availability of funds, planners might consider the possibility of initiating light rail transit with low-cost ROW and later upgrading it if the LRT operation proves successful.

Route Configuration

A key factor in determining the type of network for a city will be the origin and destination patterns of expected passengers, both in peak and off-peak periods. The two questions "Who will use transit?" and "How many will use transit?" must be realistically considered in any transit proposal. Seven possible configurations can be identified:

1. Individual corridor lines,
2. Trunk lines with branches,

TABLE 3-3. LIGHT RAIL TRANSIT LOCATIONAL OPPORTUNITIES

Right-of-Way Location	Design Treatment	Right-of-Way Category	Relative Cost
Street	At grade – shared	C	Low
	At grade – partially controlled	B	Low/medium
	Elevated	A	Medium/high
	Depressed	A	High
Freeway	At grade – median	A	Low/medium
	At grade – beside	A	Medium/high
	Elevated	A	Medium/high
Railroad all at grade	Abandoned	B C	Low/medium
	Joint use of track	B C	Low/medium
	Separate track	B C	Medium/high
Open Space/Parkland	At grade	A B	Low/medium
	Depressed	A B	Medium/high
	Elevated	A	Medium/high
Utility easement	At grade	A B	Low/medium
New right-of-way	At grade	A B	Medium/high
No right-of-way	Depressed in subway	A	High

Source: <u>Light Rail Transit: State of the Art Review</u>, p. 86.

3. Loops,
4. Radial lines,
5. Circumferential lines,
6. Radial/circumferential lines—"cobweb" pattern, and
7. Grid pattern.

Figure 3-5 depicts these configurations. The following paragraphs will discuss possible applications and variations of the seven patterns.

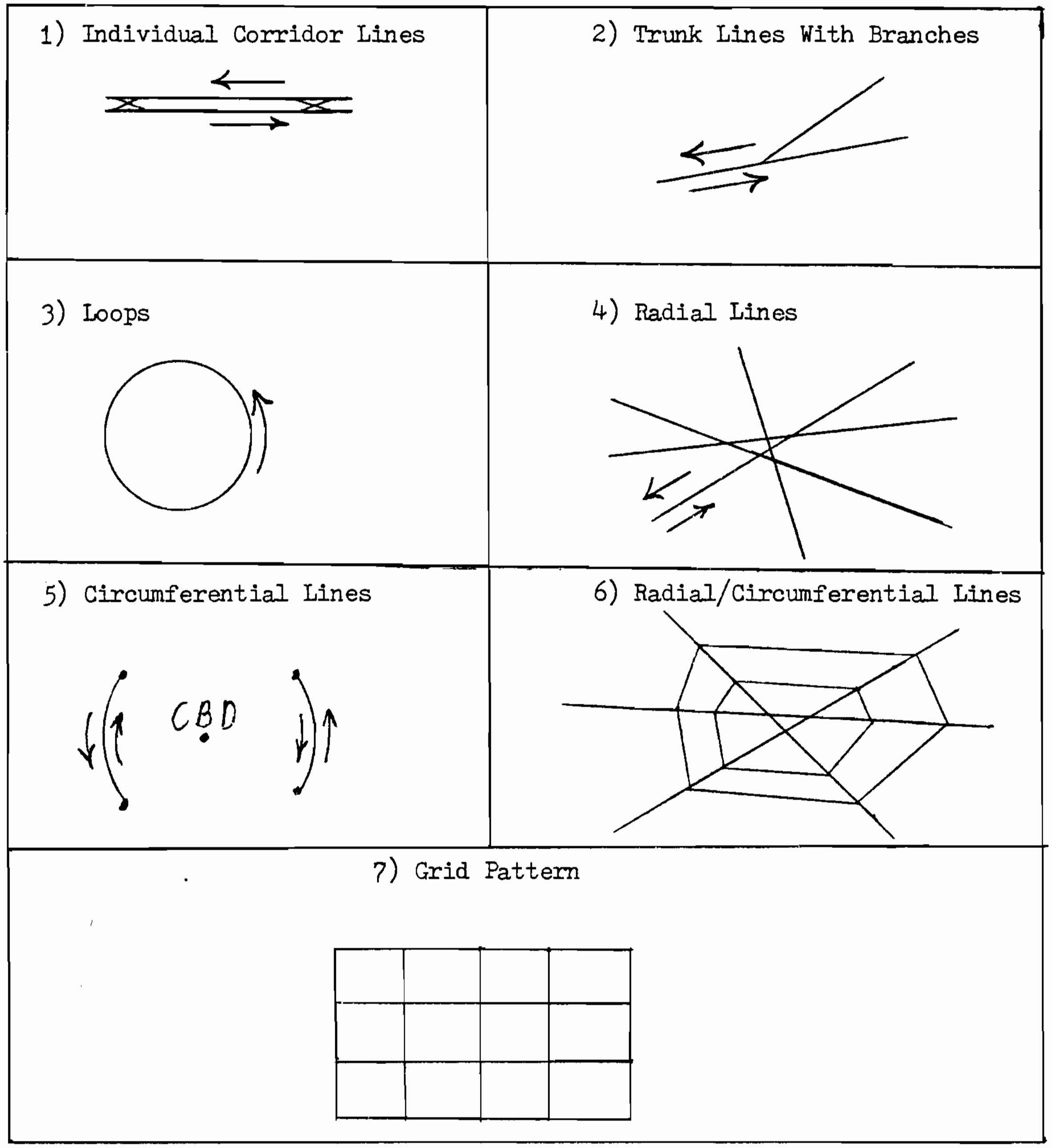
The use of individual corridor lines requires that many origin-destination pairs fall on the same route. This may exist if the line follows the strip development that has occurred next to arterial streets, with one end of the line in an area with high residential density and the other end of the line in the CBD. Single lines may also be appropriate for connecting two major activity centers, such as a line-haul connection between the CBD and a larger airport, or between an airport and a hotel/convention complex.

The use of a single trunk line with branches is an expansion of the "individual corridor" concept. The branches serve to either collect or distribute passengers. A common example in Europe is the use of branch lines in the outlying areas and a trunk (or main) line going to the CBD. However, branches could exist at each end of a line-haul route, such as with a line connecting two cities (interurban). In many cases, especially in the low density residential areas in Texas where traffic congestion is minimal, the use of buses on regular streets may be more efficient than having light rail vehicles run on branch lines. Also, branches may pose some special operational problems.

While one-way loops can cover a lot of area per mile of track, passenger trips would not compete well with the automobile in travel time. The only serious use of this configuration has been with automated guideway transit, such as "Airtrans" at the Dallas/Fort Worth Airport.

Radial lines converge on some major activity center, such as a central business district (CBD). If all of the lines converge on the CBD, to get from one outlying area to another by rail would require that a person go through the CBD. This is an especially important concern in Texas, where large activity centers (such as shopping malls, factories, or colleges) may be located outside of the CBD.

FIGURE 3-5. POSSIBLE LRT ROUTE CONFIGURATIONS



1) Individual Corridor Lines

2) Trunk Lines With Branches

3) Loops

4) Radial Lines

5) Circumferential Lines

6) Radial/Circumferential Lines

7) Grid Pattern

Source: By the Author.

For large Northeastern cities, circumferential light rail lines may act as a feeder to conventional rapid rail transit (as in Boston). Such a choice is presently not applicable to conditions in Texas.

The use of both radial and circumferential lines is an attempt to provide high quality LRT service to a majority of people in a metropolitan area. This "cobweb" is sometimes referred to as the third level of a "network approach," where the first level is good rush hour service to the CBD and the second is good service to the CBD at all times. The strong possibility exists, depending mainly on ridership levels throughout the day, that any circumferential lines in Texas could be more economically handled by buses.

A grid route layout requires a substantial amount of mileage. It attempts to put all area residents within a reasonable walking distance from a line. While this pattern works well in areas with considerable trip dispersion, it is usually confined for economic reasons to the high-density portions of cities. Unfortunately, it is in these areas that ROW is hardest to obtain at reasonable cost.

TRACK AND STRUCTURES

Location and Landscaping

Before any construction begins, careful consideration must be given to the ultimate objective of a system. For example, if ridership volumes should greatly increase in the future, how easy would it be to upgrade the system? In some cases, the ultimate goal may be conversion of the light rail system to a heavy rail (conventional rapid rail) system. If so, the light rail system should be initially designed to heavy rail standards (a pre-metro system). However, as mentioned in Chapter 2, many of the cost advantages of light rail over heavy rail will not be achieved.

The location of track will not always be determined from economic or efficiency standpoints only. Aesthetic problems, especially with arterial guideways, may come into play. While an aerial structure is usually several times cheaper than a tunnel of equal length, it might be more environmentally intrusive (Ref 2). For an at-grade railway, it may sometimes be desirable, especially in parks or residential areas, to line the edges of the ROW with trees or shrubs, even though ROW maintenance costs may increase (interference with overhead wires must be watched). Likewise, grass turf could be used as a track covering up to the railhead level, resulting in a parklike strip of green, similar to some of the LRT in New Orleans.

Roadbed and Ballast

The roadbed is the prepared subgrade on which are laid the ballast section, ties, and rails. A smooth, regular surface is provided to transmit uniform pressures (from the tracks, ballast, and passing trains) to the natural ground beneath it.

The ballast has basically four purposes for an at-grade railway:

1. It anchors the track in place against both lateral and longitudinal movement, acting as a resilient layer to absorb some of the shock from dynamic loading (a passing train);
2. It supports the weight of tracks and ties as well as the superimposed train loadings and transmits a diminishing pressure as uniformly as possible to a wider area of the subgrade;
3. It provides for water drainage away from the track and roadbed; and
4. It retards growth of vegetation around the ties (Ref 7).

The ballast is usually crushed rock; good quality is characterized by its strength, durability, stability, drainability, cleanability, and workability. Fortunately, Texas has good quality ballast material available.

Ties and Fasteners

Ties (or crossties) serve the functions of spreading the horizontal and vertical rail loadings to the ballast and maintaining the correct gauge between rails. Fasteners are used to connect the rails with the ties (rubber cushioning is sometimes used to reduce noise). Spacing of ties usually ranges from 18 to 30 inches (46 to 76 cm), depending on the weight of the rolling stock and rails. While wooden ties are widely available in the United States most new transit systems in Europe use prefabricated, prestressed concrete ties; although initially more expensive, concrete ties can significantly reduce costs of track maintenance. Metal ties are seldom used anymore due to problems with noise and electrolysis. With aerial structures, rails are sometimes placed directly on the concrete guideway with no need for the regular type of tie.

Rail

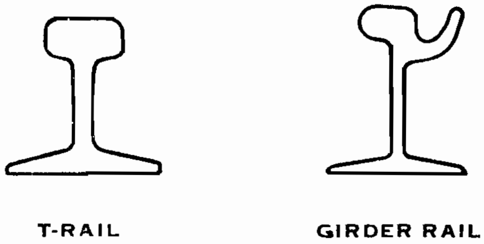
Rails for LRT are usually about 100 lb/yd (60 kg/m), compared to 115-135 lb/yd (57-67 kg/m) for freight railroads or conventional rapid rail transit. Whether to use more or less than 100 lb/yd (50 kg/m) will depend on vehicle axle loads, design stiffness, electrical requirements (one of the rails is used as a return circuit for electrical current that passes from the overhead wires through a vehicle), cost, and availability. While lighter rails are less expensive, they wear faster and must be realigned more frequently, resulting in higher maintenance costs and reduced riding comfort. The heavier more rigid (and more expensive) rails allow greater electrical return and can overcome poorer roadbeds. Welded rails are widely used today, with their advantages over the standard 40-foot (12 m) joined sections being less maintenance, better electrical conductivity, and a quieter and smoother vehicle ride.

Depending on the maximum and minimum vehicle speeds expected on a curved section of a particular radius, tracks may be banked or superelevated. Superelevation is usually defined as the height of the outside rail above the inside rail.

Two types of rail are available (shown in Figure 3-6):

1. T rail: used for non-paved track and on structures, and
2. Girder rail: used in pavement, with a steel groove in the railhead that provides a permanent flangeway for the wheel. It is heavier than T rail of corresponding stiffness.

FIGURE 3-6. TYPES OF LRT RAIL.



Source: Light Rail Transit: State of the Art Review, p. 157.

Switches

There are basically two types of switches that can be used on an LRT system:

1. Split switch: used in areas with no sharing of ROW or highway grade crossings, has two movable points, can be designed for high-speed vehicle operation, and
2. Tongue and mate switch: can be used in paved track, is simple to operate and of low cost, has only one movable point, but is normally restricted to low-speed vehicle operation.

Most track switches have electric drives (motor or solenoid) that can be activated by the driver, by a master controller, or by wayside equipment. Many are also equipped with springs that hold the switch biased in one position, allowing a vehicle to go only in the direction in which the switch is held. A vehicle approaching the switch from the end where the two rails converge to one rail will successfully cross the switch.

Construction

There are two common ways to construct a subway: cut-and-cover or tunnel boring (burrowing). The cut-and-cover method is to make an open trench excavation that is later covered at the top after the underground structure is in place. The tunnel boring method uses boring machines or "moles" to cut through hard rock or soft ground. Choice of method will depend on a number of factors:

- Amount of disruption to surface traffic: may be very significant if the cut-and-cover method is used on existing streets;
- Depth of subway: cut-and-cover will be cheaper if a shallow subway is being planned;
- Presence of underground facilities: bored tunnels might avoid this problem if they are dug deep enough (but station access might be expensive to construct);
- Composition of bedrock, soil texture; and
- Subway length: high-speed machine boring may prove very economical only if continuous tunnel lengths of over three miles (4.8 km) are needed (Ref 8).

Compared to turn-of-the-century elevated structures, modern aerial guideways are slender and elegant in appearance using modern structural design techniques in both steel and concrete. The basic guideway consists of foundations, columns, and double-deck structures. J. R. Billing and H. N. Grouni describe a particular guideway that has:

- a central spine girder that acts both as the primary structural member and an access walkway, supported by columns 100 feet (30 m) apart;
- a deck that transfers loads laterally into the spine girder; and
- barrier walls mounted on the outside of the decks for vehicle containment and noise abatement (Ref 9).

Figure 3-7 depicts this double-track elevated guideway. The total width is 26 feet (7.8 m) with a column (or pier) width of about 6 feet (1.8 m). However, due to the overhead wires, LRT on an elevated structure may be more objectionable from an aesthetic standpoint than conventional rapid rail transit that used a third rail.

There are three major types of track construction:

1. Open track: the most common method of T rail construction at grade, using rails supported on conventional ties and ballast;
2. Fixed track: used on aerial guideways or sometimes in tunnels, with T rail bolted directly to the structure; and
3. Paved track: consists of the placement of girder rail in streets, either with or without standard ties (Ref 5).

A variation of the second and third method is the use of "slab track," in which rails are laid on (and attached to) a concrete bed. If girder rail is used, concrete or asphalt can be poured up to the rail head level. Slab track has a high installation cost but minimizes realignment and other maintenance costs.

POWER SUPPLY

Distribution Characteristics

Most LRT systems use a line voltage of 550 to 650 volts direct current which was commonly used on the old streetcar lines. The major advantage of direct current (DC) is that it is easily controlled enabling vehicle motors

FIGURE 3-7. GENERAL LAYOUT OF DOUBLE-TRACK GUIDEWAY

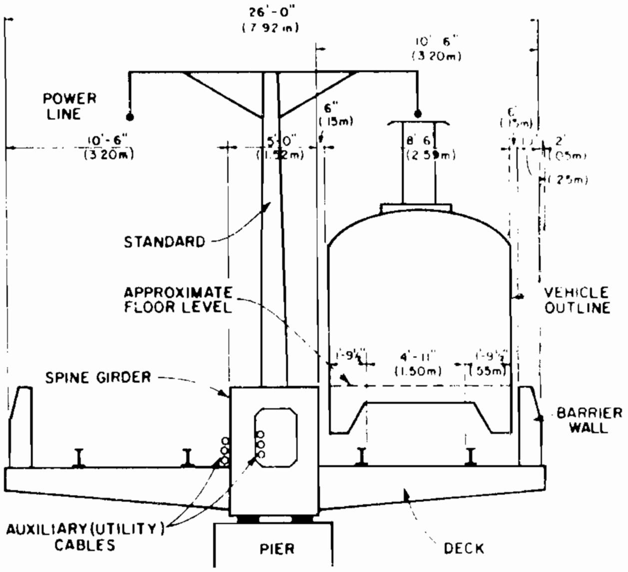
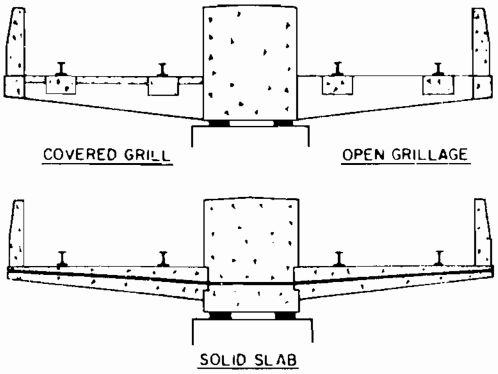


Figure 2. Deck options for a guideway structure.



Source: J. R. Billing and H. N. Grouni, Ontario Ministry of Transportation and Communications, "Design of Elevated Guideway Structures for Light Rail Transit," in Transportation Research Record # 627, <u>Rail Transit</u> (Washington, D.C.: National Academy of Sciences, 1977), pp. 17-20.

to be operated at various speeds. This differs from mainline railroads which pick up high voltage alternating current (AC) from overhead wires and convert it to usable DC by means of onboard equipment for rectification and stepping down of voltage. Even though transmission losses with DC overhead wires are much higher per mile than if AC wires were used, a substantial savings results in the costs and weights of light rail vehicles (since onboard rectification equipment is not required). Serious consideration, however, should be given to the use of 750 to 1500 volts DC to cut down on the energy losses due to resistance in the overhead wire (the new Tyne and Wear LRT system utilizes 1500 volts DC). Of course, the use of higher voltages will require new vehicle motors.

Generally, light rail systems obtain their electrical needs from convenient local sources of high-voltage alternating current. This is converted to low-voltage direct current with small solid state substations which can be placed underground if necessary. R. D. Touton describes a substation.

> Entirely adequate 600-V light rail substations with typical capacities of 2,000 to 4,000 KW are available and can be placed at 2-mile intervals on the outer portions of any light rail line. Each will operate unattended, turn itself on and off as needed, and, in the event of an overload or failure, will even bypass itself so that adjacent similar substations on either side can temporarily carry the loads. They also are virtually maintenance free, have an almost infinite service life potential, are extremely efficient, and are environmentally sound (Ref 10).

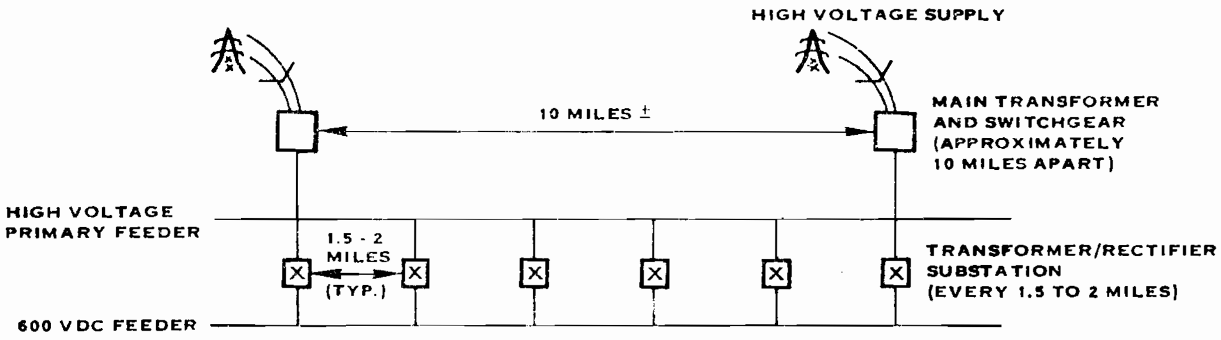
Figure 3-8 is a diagram of the power distribution and conversion system. High voltage AC is collected from the public utility system every 10 miles (16 km) and fed to transformer/rectifier substations which are placed from 1.5 to 2.0 miles (2.4 to 3.2 km) apart. These substations supply 600 volts DC to the overhead wires.

Overhead Wiring Considerations

The DOT report, Light Rail Transit: State of the Art Review, lists five concepts that should be considered in the design of LRT overhead power supply systems:

- All circuitry non-essential to power pickup should be placed in underground conduits. This generally includes the power feeder cables, signaling circuits and communication lines.

FIGURE 3-8. POWER DISTRIBUTION AND CONVERSION SYSTEM.



Source: Light Rail Transit: State of the Art Review, p 166.

- Wires are conspicuous primarily in silhouette (i.e., a dark wire against a blue sky background). Therefore, trees and structures that disrupt the wired silhouette should complement any landscaping concept.
- Poles are readily acceptable in the street scene for lighting and traffic signals. It is essential to combine multiple uses within the same poles to avoid unnecessary proliferation. The pole spacing requirements for street lighting and for light rail are similar.
- The use of existing structures to support the wires can form a cheaper and less conspicuous substitute for poles.
- Cantilever support arms of tapered tube design without stays or straps, similar to street light arms, are less intrusive (Ref 5).

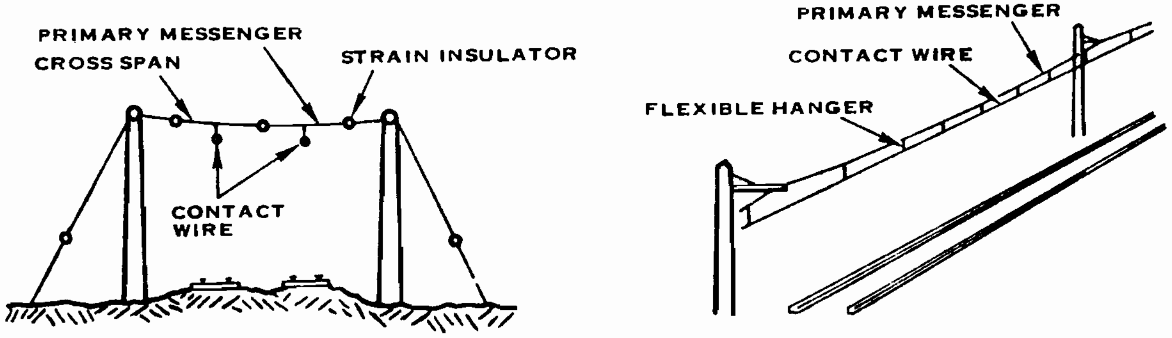
Support poles can be placed centrally between the double tracks or outside the double tracks. Spacing of poles may vary between 70 and 300 feet (21 to 92 m). The height of overhead wires generally falls in the range of 12 to 20 feet (3.7 to 6.1 m).

While both trolley pole and pantograph systems are in use today, the pantograph is heavily favored for new systems (as discussed earlier). Two basic designs are used for LRT overhead wiring:

1. Single contact wire: of limited current-carrying capacity, requires frequent supports (about every 100 feet (161 m)). Generally not used on high-speed lines because of the sag between poles.
2. Multi-wire catenary: one or more passenger wires support and maintain a contact wire in an approximately level profile, much like cables support the deck of a suspension bridge. Supports can be very widely spaced (several hundred feet), depending on the strength of the messenger wires.

Figure 3-9 depicts these two designs. The pantograph may be used with either a single contact wire or with the multi-wire catenary system. The tradeoff to be made between the two designs is the greater number of support poles required by the simple (single) contact wire and the more complex suspension of the multi-wire catenary. If expected speeds should exceed 65 mph (105 kph), an elaborate catenary system is virtually required to insure that the overhead wire is kept level.

FIGURE 3-9. SIMPLE CONTACT WIRE AND CATENARY SYSTEMS.



SIMPLE CROSS SPAN-SIMPLE CONTACT WIRE

SIMPLE CATENARY SUSPENSION

Source: Light Rail Transit: State of the Art Review, p 167.

STATIONS AND PLATFORMS

Because there is a wide range in LRT operational capabilities, there is also a wide range in possible locations and configurations of stations and platforms. A station might be nothing more than a sign on the sidewalk saying "LRT Station" or it might be an elaborate controlled-access subway structure. The major factors in determining the appropriate design will be patronage levels, method of fare collection, mode of access to stations, and demands for amenities.

Station Spacing and Configuration

For European cities the average station (or stop) spacing for an LRT system usually ranges from a quarter to a half mile (0.4 to 0.8 km). In city centers, spacing may lie between 1000 to 2000 feet (300 to 600 m) while in outlying sections the spacing may vary from 2000 to 5000 feet (600 to 1500 m). Basically there are two interrelated variables to consider: the number of stations per mile (and consequent costs) versus average vehicle operating speed. The greater the station spacing, the lower the number of passengers who have easy walking access to a station but the higher the overall operating speed. Just how far apart stations should be spaced will depend on what transportation modes will be used to reach (or leave) a station, along with an estimation of the number of passengers. Feeder systems include: walking, motorcycling, bicycling, kiss-and-ride (automobile passenger drop-off), park-and-ride, paratransit (carpool, taxi, dial-a-ride), and the conventional fixed route bus. For example, in Texas there would probably be a need for extensive parking lots (or parking garages) near some of the outlying stations in suburban neighborhoods, while walking may serve a station well in an inner city area.

When most access is on foot, stations (stops) need to be close together. For a radial line to the CBD, residential density along the line generally increases in the direction of the CBD with a corresponding increase in the number of transit riders; this (along with the fact that a greater percentage of people walk to the station) explains why stations are usually more closely spaced as the line gets closer to the CBD.

Location Considerations

A number of general factors affect station location, including such factors as:

- Ridership potential;
- Accessibility to local walking, automobile, and bus feeder modes;
- Compatibility with surrounding land use;
- Current use of site;
- Size of site;
- Potential for site expansion; and
- Cost of construction and land acquisition (Ref 11).

At-grade platforms may be located between and/or on the outside of two parallel tracks with pedestrians usually allowed to walk over the railway roadbed. Access to the platforms can be either by ramps or steps. If the station is located in the median of a street, careful consideration should be given to the safety of passengers crossing automobile traffic.

Need for Amenities

The purpose of stations is to allow for convenient and comfortable passenger movement. It is generally considered that if vehicle headways exceed ten minutes (Ref 12), some comfort features as benches or shelters are important. Shelters may simply provide protection from rain or sun, or be fully enclosed for air-conditioning or heating. Other station amenities may include such items as:

- Security: adequate lighting, police or security guard protection, emergency telephones or alarms, remote-controlled surveillance;
- Information availability: easy station identification from a distance, use of brochures, maps, displays, station attendants;
- Personal conveniences: restrooms, telephones, refreshments, newsstands;
- Attractiveness: use of modern design, well-integrated into surroundings; and
- Access by elderly and handicapped: for wheelchair access, high-level platforms (with ramps or elevators) with direct, no-step boarding on a vehicle may be required.

Dimensions

Platform widths and lengths will be determined by the following factors:

- Peak station volumes,

- Use of multiple-unit operation,
- Simultaneous loading of several vehicles, and
- Consideration of future upgrading.

Simultaneous loading involves the use of long platforms that would allow two or more vehicles to load/unload at the same time.

A typical standard is to have a platform that can accommodate two 6-axle cars——something in excess of 160 feet (50 m). Platforms can be much shorter (and perhaps not even needed) if loading through some vehicle doors can be by way of steps.

FARE COLLECTION

There is a range of fare collection methods in use. The "best" collection technique for a given system will depend on passenger volumes and costs of collection equipment. It might be possible to have different techniques on a given system; for example, fare collection in the CBD could be on limited access platforms, while in residential areas it could be by onboard driver collection. The Municipal Railway (MUNI) in San Francisco has station fare collection in its subway and collection by the vehicle operator elsewhere.

There is also the possibility of running a light rail transit operation without any fares, in which case the problem of fare collection (which may cause passenger delays) is avoided. The short Fort Worth line presently operates without fare collection.

Onboard Collection

Most present American streetcar/light rail operations use the conventional onboard fare collection technique. Exact change is usually put in a farebox as one boards a vehicle, with the operator looking on. The use of tokens or tickets bought from a vending machine may work just as well. The use of a conductor collecting fares after passengers are seated is customary on longhaul passenger trains, but has limited applicability to LRT not only because station stops are frequent but because more employees are required. One advantage is that collection of fares can be done while the vehicle is in motion.

It might be possible to allow passenger boarding from several doors of a vehicle if automated collection equipment connected with turnstiles is put directly on a vehicle. Although used with some old streetcars, problems with this technique are that passenger space inside the vehicle is taken up and extensive delays may occur if the automated equipment should malfunction during heavy loading periods.

Limited Access Platforms

Most rapid transit operations collect fares before a passenger steps onto the boarding platform. This is commonly called "in-station" fare collection and will be used on the Buffalo LRT line. Collection can be either by cashiers or automatic turnstiles. The Dallas/Fort Worth "Airtrans" system is a good example of a fully automatic operation that collects a flat-rate fare (25 cents).

If the entrances and exits of all platforms on a line are controlled, it would be possible to charge passengers based on the lengths of their trips. This is the system now in use in the Washington Metro Subway. However, the applicability of this to LRT systems that attempt to keep their operating procedures simple and their initial costs low is unclear. Controls at both entrances and exits to determine individual passenger trip lengths will require either extra personnel or more sophisticated automatic fare collection equipment.

Self-Service

The self-service ("honor") fare system is used extensively in Europe. Passengers buy tickets from streetside machines and then cancel them in a validation machine upon entering any of several doors of the vehicle. Roving inspectors check about five percent of the patrons to see if they truly have a cancelled ticket or special pass; if not, they are fined an amount that may be anywhere from two to ten times the cost of a regular fare.

With many Americans seeing great sport in "beating the system," there is uncertainty that this very efficient method could ever be used in the United States. However, the self-service procedure should not be discarded unless actual American experience shows this concept to be totally unworkable.

SIGNALING AND TRAFFIC CONTROL

Crossing Protection

LRT systems will normally have at least some at-grade crossings with streets. Crossing protection may vary from signs, flashing lights, or traffic signals to physical barriers (lowered gates). Some sort of pre-emptive signaling system might be considered in which a light rail vehicle approaching a crossing would activate a device to stop highway traffic (allowing the LRV to pass without stopping). Actuation might be by use of:

- track circuit systems,
- loop detectors between the rails,
- contacts on the overhead trolley wire, or
- radio-frequency devices on the vehicle (Ref 13).

Any pre-emption of signals in favor of LRT, however, may significantly delay platoons of automobiles operating along a street with progressively timed signals.

Vehicle Control

There are four major types of signaling/control techniques for a vehicle:

1. Visual/manual control: protection is limited by the operator's line of sight. This method was used with most streetcar systems and is used today in shared ROW operations, or where speeds are slow and visibility is good. It also permits two or more trains to load at a long station simultaneously.
2. Wayside signaling: signals are located adjacent to or over the track and give the operator information he needs about what lies on the track ahead. The signals are activated by the presence of vehicles in a certain "circuit" block. In some cases the signals can trip emergency stopping brakes or cut off the electrical power in the overhead wire if the operator does not respond.
3. Cab signaling: similar to wayside signaling, except the signals appear on the operator's console. Although it adds an expense to the system, it is possible to have the vehicle respond automatically to these changing signals.
4. Automatic (programmed) control: this requires fully-controlled ROW, and is gneerally not applicable in the initial stages of an LRT operation (if at all). Operators may not necessarily be required on each vehicle or train.

OPERATIONS

Volumes and Capacities

The passenger carrying capacity (maximum number of spaces that can be offered per hour per direction) of LRT depends on vehicle size, number of units in a train, and headway.

Light rail trains seldom consist of more than three connected vehicles. While this is partly because the extra capacity of long trains is seldom needed, it is also because multiple-unit trains in excess of three vehicles might take a long time to clear an at-grade rail/highway crossing. Severe operational problems may result if street running with mixed traffic is utilized.

The minimum allowable headway is determined by safety considerations. It is usually the conditions at stop areas (rather than line conditions) that determine this minimum. Some important parameters for determining the smallest headway are:

- Station dwell time (affected by the number of passengers boarding a vehicle, the number and arrangement of door openings, and per passenger loading time),
- Use of simultaneous loading from several vehicles at a station,
- Conflicts with other traffic, and
- Minimum safe stopping distance (plus a safety margin).

The maximum allowable headway will be based on policy considerations of service levels.

An LRT network is usually designed for peak hour volumes per line per direction of 4000 to 10,000 riders, but the mode is capable of up to 20,000 riders/hour if special operational measures are employed (Ref 5). Such measures include simultaneous stopping of several vehicles, multiple-unit operation, fast fare collection, and tight schedule control.

An example of capacity calculations is as follows:

Given:	Boeing SLRV	67 seats, total capacity of 152
	Headway	60 seconds
Solve:	Single-unit operation:	60 x 67 = 4,020 seats/hour
	(1 vehicle)	60 x 152 = 9,120 passengers/hour

Double-unit operation:	2 x 4020 = 8,040 seats/hour
(2 vehicles forming a train)	2 x 9120 = 18,240 passengers/hour

Service Levels

From a passenger's viewpoint, the level of service is the most important criterion in judging a light rail system. The most common level of service parameter is overall transit travel time. The proper measure is the time spent from the point of origin to the final destination ("door-to-door"). The door-to-door travel time consists of:

1. access time from point of trip origin to the boarding transit stop,
2. waiting time for the transit vehicle,
3. travel time on the transit vehicle,
4. transfer time (waiting and possibly walking) required if more than one transit line is used for a single trip, and
5. access time from final alighting stop to point of destination (Ref 14).

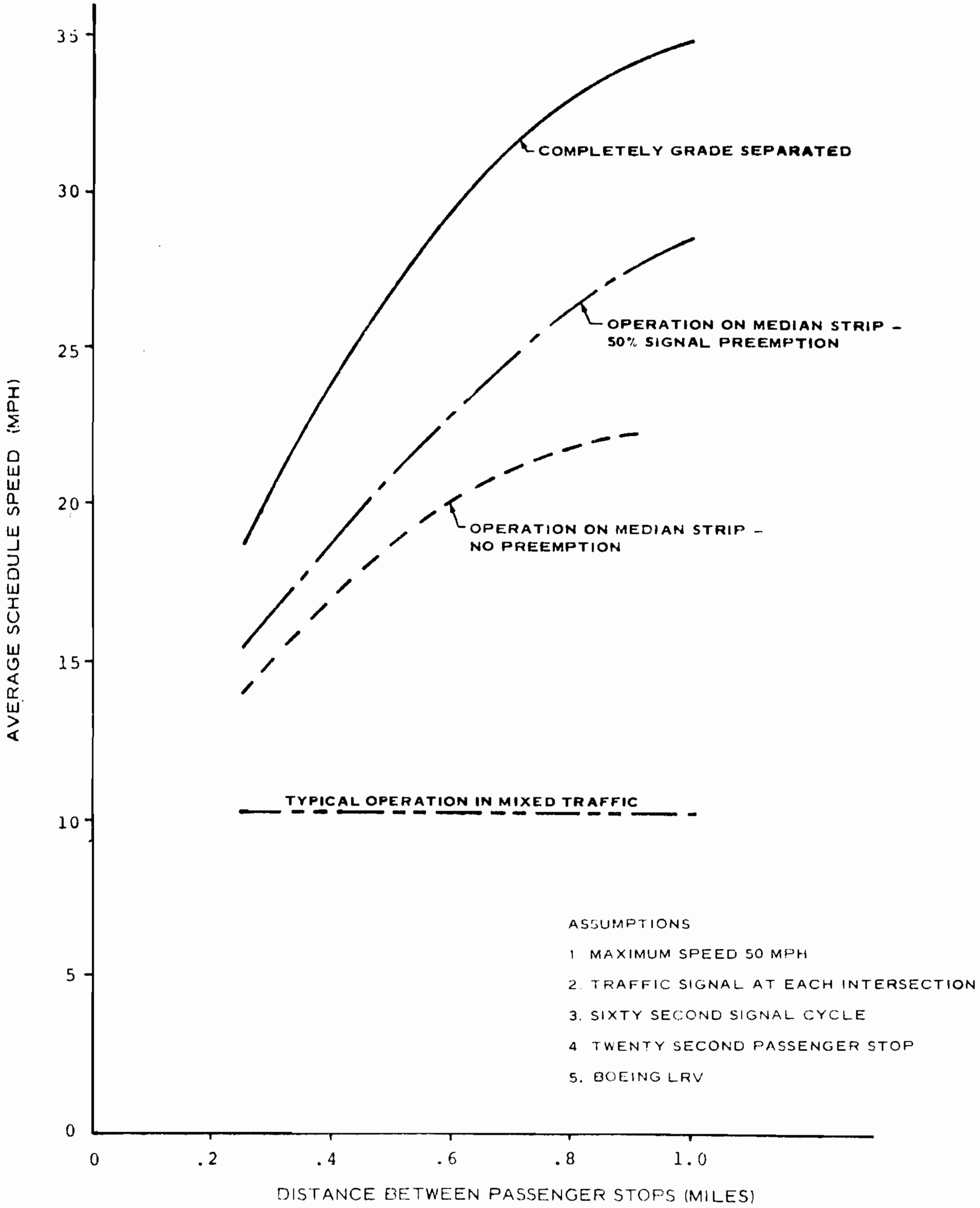
Operating speed consists of distance traveled over vehicle travel time. The operating speed will depend on station spacing, maximum speed, and acceleration/deceleration rates. Figure 3-10 shows an approximate relationship. The scheduled speed will also depend on track alignment standards, disturbances from surface traffic, station dwell times, and use of cruising (an energy-saving technique).

Fare Pricing

Policies and calculations in the following areas usually determine the appropriate fare level:

- Needs for patronage attraction,
- Competition from other modes,
- Notions of equity for the entire ridership or of relative equities for various subgroups of it,
- Needs for determined levels of operational and financial performance,
- The different costs of providing service on different kinds of routes, and

FIGURE 3-10. **RELATIONSHIP BETWEEN AVERAGE SCHEDULE SPEED AND STATION SPACING.**



Source: Light Rail Transit: State of the Art Review, p. 191.

- Constraints that may be imposed by the selected fare structure and methods of fare collection (Ref 14).

It is the transit users, or customers, who are the key participants in the determination of transit fare policy. To put it simply, patronage levels will be low if fares are perceived as being too high for the service offered. This makes the fare decision largely political with much of the consideration depending on available federal aid. The average fare for U.S. light rail systems in 1976 was 30¢.

It has generally been found that the speed, frequency, and convenience of a transit service have more of an effect on the demand than the fare. However, the subject of fare elasticity has received considerable attention in recent years. Fare elasticity is defined as the percent change in passenger demand for a percent change in fare price. Transit elasticity is usually less than 1.0, indicating that change in demand will be less than proportional to a change in fare. While this may be good if fares must be increased, it also means that large numbers of new riders cannot be encouraged to ride transit simply by decreasing the price of fares.

Maintenance

Of course, any LRT system must maintain storage and maintenance facilities. Maintenance can be divided into three areas:

- Vehicle maintenance: the importance of using common or standardized vehicles is most apparent in this area. Some of the vehicle subsystems are built in modular form, allowing for quick and easy replacement.
- Track and LRT maintenance: tracks can last for 15 to 25 years without major repairs, although replacement of some wooden ties may be required every year. Careful, frequent attention must be given to switches. ROW maintenance may include the cutting of grass and cleaning of stations.
- Overhead maintenance: wires are checked for wear and tightened or realigned where necessary. If wires should ever break, a crew should be ready for repair work in minutes.

Personnel

Light rail vehicles, even if in multiple-unit trains, can be operated by a single person. The requirements for additional staff, either on the vehicle or in stations, will depend on the method of fare collection and the need for passenger security or information. The major operational problem will be to make efficient use of these people in the peak as well as the off-peak periods. Labor union contracts usually prevent the hiring of drivers for only a few hours a day. The standard contract requires a minimum 8-hours pay each weekday with the work not to be spread over more than a 10-hour period. Any work in addition to this must be paid for at overtime rates.

Most systems also use "trainmasters" to make sure that vehicles stay on schedule, and in some cases to actually throw switches. Finally, a number of people will be needed for maintenance and administration.

Improvements/Innovative Techniques

One technique that has been in use on some rapid transit lines for many years is "skip-stop" operation to reduce passenger travel time and increase traveling comfort. In this technique, half the vehicles along a route section stop at one group of stations while the other half stop at another group. All vehicles stop in the CBD and other major transfer or terminal points. The main problem with skip-stop operation is that passenger waiting times are increased for the station groups which have access to only half of all passing vehicles.

Express routing may work well if vehicles become fully loaded at outlying park-and-ride lots with all passengers wanting to go to the CBD. Travel time for these passengers is greatly decreased since no (or very few) intermediate stops are made. This method works well with buses during peak hours, but may have limited applicability to rail transit. In order to allow express vehicles to pass those vehicles which need to stop at every station (a local service), either side tracks or off-line stations must be used (unless more than one track per direction is available).

If many American cities were to build and operate light rail systems, it would be expected that the state of the art in operation procedures would be greatly improved in order to take full advantage of the technology. However, some planners have argued that the possibilities of major new innovations will be limited since electric rail vehicles have been in operation almost 100 years.

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CHAPTER 4. WHERE IS LRT SUITABLE?

CHARACTERISTICS OF CITIES WITH LRT

The characteristics of the Light Rail Transit mode have now been described in considerable detail. Whether an LRT operation is viable or successful depends equally upon the situation or environment in which it is placed. One objective of this study was to examine this aspect: where has LRT been successful, or where is it likely to be successful? A summary is provided of some of the pertinent characteristics of U.S. cities that have retained their streetcar/LRT systems and of those that are seriously contemplating LRT proposals. Also included is a comparison of LRT with other transit modes using a mathematical optimizing model for transit system design. Finally, the study takes up the question of why the streetcar has survived in a few American cities, but disappeared in most of them.

Some city characteristics which relate to the viability of various transportation modes are population size, population density, automobile availability, current transit use, and the concentration of trip destinations (in this case, for employment purposes). These characteristics are reviewed for two groups of cities: 1) U.S. cities which retained their streetcar systems, and 2) U.S. cities which have proposed new LRT lines. The purpose of this review is to determine whether there are characteristics in common among the cities in each category, and whether city characteristics are different in "retained" cities and "proposal" cities. Later, the same characteristics are suggested to analyze the largest Texas cities to see how they compare with the "retained" and "proposal" cities.

In order to compare different cities, it is necessary to have comparable data preferably from the same source. For this reason, U.S. decennial census data were used in this examination. There are several drawbacks to these data. One is the inconsistency through the years of the Census Bureau's definition of metropolitan area. The changing definitions of metropolitan districts, metropolitan areas, Standard Metropolitan

Statistical Areas, and Urbanized Areas may show up in this report as dramatic drops and increases from one decade to another which are not explainable by population trends. In 1960, the Standard Metropolitan Statistical Areas (SMSA's) were established. The boundaries, however, coincide with political boundaries, such as townships or counties, rather than with the limits of the thickly settled areas, and they often include open rural land. The term referring to the settled portion is urbanized area. First used in 1960, it is more useful for determining the area which is functionally part of a city but which may extend beyond the political boundaries of the city.

These varying definitions of metropolitan and urbanized areas are particularly relevant to the calculation of average densities of an urban area, another drawback to census data. The average density of an SMSA is not too significant because it includes so much unsettled open space to lower the average. In addition, non-residential development, urban parks, airports, and other public land inside central cities or SMSA's contribute to lowering average densities. The urbanized area term includes non-residential development but excludes parks, airports, and similar extensive land uses. While not so useful for densities, the metropolitan area data are useful here because their availability over time, in some form, indicates growth patterns. A truer picture of any city and its metropolitan area is found when combining all the categories of information.

Finally, data on density, automobile ownership, work trips by transit, and concentration of employment in the central city are only indirect indicators of transit viability. However, these factors are known to be related to transit use, and as mentioned earlier, the census data are readily available for all these factors for all the cities.

U.S. Cities Which Retained LRT

Total Population and Population Density. All the cities which retained LRT are relatively large metropolitan areas. The 1970 population figures for the cities, their urbanized areas, and the SMSA's are shown in Table 4-1 The most functional figures are for urbanized areas which show all but New Orleans to be over a million in population. Most of the cities are close to the mean of approximately 2,400,000 for urbanized areas. The exception, with an extremely populous urbanized area, is Philadelphia at four million.

TABLE 4-1. 1970 POPULATION OF CITIES WHICH RETAINED LRT

	Central City	Urbanized Area	SMSA
Boston	641,071	2,652,575	2,753,700
Cleveland	750,903	1,959,880	2,064,194
Newark	382,417	(part of NYC)	1,856,556
New Orleans	591,502	961,728	1,045,809
Philadelphia	1,948,609	4,021,066	4,817,914
Pittsburgh	520,117	1,846,042	2,401,245
San Francisco	715,674	2,987,850	3,109,519
Mean	792,899	2,404,857	2,578,420

TABLE 4-2. 1970 POPULATION DENSITY OF CITIES WHICH RETAINED LRT

(Residents per Square Mile)

	Central City	Urbanized Area	SMSA
Boston	13,936	3,992	2,791
Cleveland	9,893	3,033	1,359
Newark	16,273	N.A.	2,648
New Orleans	6,846	5,227	532
Philadelphia	15,164	5,349	1,356
Pittsburgh	9,422	3,095	788
San Francisco	15,764	4,387	1,254
Mean	12,741	4,181	1,533

Source: U.S. Census, 1970.

It can be seen that generally the population of the central city is only a small fraction of that of the urbanized area. In about half the cases, central city populations are only about 25 percent of the urbanized areas, while the others are approximately 40, 50, and 60 percent with New Orleans having the highest percentage.

Of the central city populations, only Philadelphia has over a million. These political boundaries are not functional boundaries, except for some decision-making and taxing authorities. However, with the trend toward metropolitan transit authorities, decision-making and taxing for transit purposes encompass the larger metropolitan area. SMSA figures are also given in Table 4-1, though they reveal only slightly larger populations than the non-politically bounded urbanized areas.

The Census data for average population densities are given in Table 4-2. The central cities are, of course, much denser than the urbanized areas and SMSA's, each of which encompasses progressively more sparsely settled land. The mean density for the central cities is approximately 12,500 persons per square mile; the group includes some of the densest cities in the country. There is surprisingly little variation in the average densities of the urbanized areas; most are within 1,000 of the mean of 4,181 persons per square mile. The SMSA's have even lower average densities, and there is relatively more variation, which probably results from accidents of political boundaries.

Historical Growth Patterns. Residential densities are generally influenced by the periods during which population growth occurred and the dominant transportation modes at the time. The important modes here are the original streetcars and the automobile. When the original streetcar systems were inaugurated in the U.S. in the late 19th century, there was a very low automobile ownership (0.1 per 1000 population——see Table 4-3). Urban people lived close together where they could walk or ride public transit or horsedrawn vehicles. These available modes of transportation restricted development to a high density form.

Table 4-4 shows the populations of the central cities over time. One of the most noticeable characteristics of the cities which retained LRT is their age. Four are from the originally settled colonies, two were old port settlements, and while Cleveland is newer than the others, it had a

TABLE 4-3. AUTOS PER 1000 POPULATION IN THE U.S.

Year	Percent
1900	.10
1910	4.97
1920	76.70
1930	186.97
1940	207.82
1950	266.57
1960	343.97
1970	439.34
1975	501.90

Sources: U.S. Bureau of the Census: Historical Statistics of the U.S., Colonial Times to 1970, and U.S. Department of Commerce: "World Motor Vehicle & Trailer Production and Registration," 1974-75.

TABLE 4-4. U.S. CITIES WHICH RETAINED LRT - POPULATION WITHIN CITY BOUNDARIES

City \ Year	1790	1850	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	est. 1975
Boston	18,320	136,881	362,839	448,477	560,892	670,585	748,060	781,188	770,816	801,444	697,197	641,071	636,725
Cleveland	—	17,034	160,146	261,353	381,768	560,663	796,841	900,429	878,336	914,808	876,050	750,903	638,793
Newark	—	38,894	136,508	181,830	246,070	347,469	414,524	442,337	429,760	438,776	405,220	382,417	339,568
New Orleans	—	116,375	216,090	242,039	287,104	339,075	387,219	458,762	494,537	570,445	627,525	591,502	559,770
Philadelphia	28,521	121,376	847,170	1,046,964	1,293,697	1,549,008	1,823,779	1,950,961	1,931,334	2,071,605	2,002,512	1,948,609	1,815,808
Pittsburgh	—	46,601	156,389	238,617	321,616	533,905	588,343	669,817	617,659	676,806	604,332	520,117	458,651
San Francisco	—	34,776	233,959	298,997	342,782	416,912	506,676	634,394	634,536	775,357	740,316	715,674	664,520

Source: U.S. Census, 1790, 1850, 1880 - 1975.

substantial population by 1850. By 1890, all these cities had surpassed 100,000. The turn of the century, the time when streetcars were under way, found Philadelphia with over a million population, Boston over 500,000 and the smallest of the cities (Newark) with 246,000.

Metropolitan population growth from 1920 to 1970 is shown in Table 4-5. Even by 1920, there was a significant amount of growth outside city boundaries, particularly in the oldest and largest cities. In fact, as can be seen in Table 4-6, the land area of all these cities did not appreciably change after 1930.

Growth patterns and changes in density for the entire metropolitan areas can be ascertained by reviewing in conjunction Tables 4-4 and 4-5 on population growth in Tables 4-6 and 4-7 on population density and land area. These cities, in general show some similar patterns, with the exception of New Orleans which always remains the smallest in population and the least dense of the group. The others show a trend of early, dense growth of the core city which declined in later years as the population began to spread throughout the metropolitan area. The declining densities of the central cities coincided with the increases in automobile ownership (shown in Table 4-3). Most of the central cities began to decline in density around 1930 and have continued to decline except for a slight turnaround after World War II (indicated in 1950 figures). However, the high densities and large populations established during the time when transportation modes did not facilitate low-density development can still be seen in the 1970 data.

Automobile Ownership and Transit Usage. Transit riding and automobile ownership are two characteristics of cities which are closely related to the feasibility of a light rail system. Census data have only two items which indicate people's transportation habits. One is the number of automobiles per household; the other is the mode of travel used for the work trip.

Riding transit and having no automobile available are obviously correlated. Those who cannot afford an automobile are likely to be captive transit riders. However, in dense cities, when transit service is good, an automobile is often not necessary, and it can even be a handicap due to driving and parking congestion. Table 4-8 shows the percentage of households with no automobiles for central cities and SMSA's in 1970. The difference between the central city and the suburban ring for all LRT cities is large.

TABLE 4-5. U.S. CITIES WHICH RETAINED LRT-POPULATION OF SMSA/METROPOLITAN AREAS

City Year	1920	1930	1940	1950	1960	1970
Boston	1,772,254	2,307,897	2,350,514	2,369,986	2,589,301	2,753,700
Cleveland	925,720	1,194,989	1,214,943	1,465,511	1,796,595	2,064,194
New Orleans	397,915	494,877	540,030	685,405	868,480	1,045,809
Newark	NA	NA	NA	1,468,458	1,689,420	1,856,556
Philadelphia	2,407,234	2,847,148	2,898,644	3,671,048	4,342,897	4,817,914
Pittsburgh	1,207,504	1,953,668	1,994,060	2,213,236	2,405,435	2,401,245
San Francisco	891,477	1,290,044	1,428,525	2,240,767	2,783,359	3,109,519

Source: U.S. Census, 1920-1970.

TABLE 4-6. U.S. CITIES WHICH RETAINED LRT

Density Within City Boundaries

	1920	1930	1940	1950	1960	1970
Boston	17,178	17,795	16,721	16,767	14,586	13,936
Cleveland	14,131	12,725	12,016	12,197	10,789	9,893
Newark	NA	18,767	18,210	18,592	17,170	16,273
New Orleans	2,175	2,341	2,480	2,861	3,157	6,846
Philadelphia	14,248	15,242	15,183	16,286	15,743	15,164
Pittsburgh	14,756	13,057	12,892	12,487	11,171	9,422
San Francisco	10,853	15,105	14,227	17,385	15,553	15,764

Land Area Within City Boundaries (in Sq. Miles)

	1920	1930	1940	1950	1960	1970
Boston	43.5	43.9	46.1	47.8	47.8	46.0
Cleveland	56.4	70.8	73.1	75.0	81.2	75.9
Newark	NA	23.6	23.6	23.6	23.6	23.5
New Orleans	178.0	196.0	199.4	199.4	198.8	86.4
Philadelphia	128.0	128.0	127.2	127.2	127.2	128.5
Pittsburgh	39.9	51.3	52.1	54.2	54.1	55.2
San Francisco	46.7	42.0	44.6	44.6	44.6	45.4

Source: U.S. Census, 1920-1970

TABLE 4-7. U.S. CITIES WHICH RETAINED LRT

Density SMSA/Metropolitan Areas

	1920	1930	1940	1950	1960	1970
Boston	3107	2257	2213	3078	2672	2791
Cleveland	3980	3852	3614	2130	2611	1359
Newark	NA	NA	NA	NA	NA	2468
New Orleans	2017	1724	1618	613	777	532
Philadelphia	3187	2865	2838	1034	1224	1356
Pittsburgh	1831	1202	1228	725	788	788
San Francisco	1991	1563	1424	676	840	1254

Land Area of SMSA/Metropolitan Area (in Sq. Miles)

	1920	1930	1940	1950	1960	1970
Boston	570	1023	1062	770	969	987
Cleveland	233	310	336	688	688	1519
Newark	NA	NA	NA	NA	NA	701
New Orleans	197	287	334	1118	1118	1967
Philadelphia	755	994	1021	3550	3549	3553
Pittsburgh	659	1626	1625	3053	3051	3049
San Francisco	448	826	1003	3314	3313	2480

Source: U.S. Census, 1920-1970.

TABLE 4-8. U.S. CITIES WHICH RETAINED LRT

Percent Households with no Automobiles (1970)

	Central City	SMSA	Suburban Ring
Boston	46.7	24.0	16.2
Cleveland	31.7	17.1	8.2
Newark	51.5	21.6	13.8
New Orleans	37.3	26.4	10.1
Philadelphia	39.7	23.3	10.7
Pittsburgh	37.8	20.5	16.7
San Francisco	39.6	19.3	11.7
Mean	40.6	21.7	12.5

TABLE 4-9. U.S. CITIES WHICH RETAINED LRT

Percent Using Transit for the Trip to Work

	Central City	SMSA	Suburban Ring
Boston	38.3	19.3	13.6
Cleveland	22.0	13.2	8.5
Newark	37.6	18.2	14.0
New Orleans	30.4	19.7	5.9
Philadelphia	37.0	20.4	9.5
Pittsburgh	29.2	14.3	10.1
San Francisco	35.3	15.2	8.4
Mean	32.8	17.2	10.0

Source: U.S. Census, 1970.

The reasons for the differences are that the automobile is more suited to low density development than high density, and there is usually limited transit coverage of the areas outside cities. The LRT cities average 40.6% of the households with no automobile. The areas outside the cities average 12.5% without automobiles.

Table 4-9 shows the percentage of all workers who use transit for the journey to work in the central cities and SMSA's. In the central cities, an average of 32.8 percent of workers commute by transit; Boston has the highest percentage, 38.3. In the suburban ring, the percentage riding transit drops off to only 10 percent, on the average. The figures for transit include buses and heavy rail, the latter being found in Boston, Cleveland, and Philadelphia (San Francisco's heavy rail was not yet open in 1970).

Table 4-10 shows the total number of persons who ride transit to work in the central cities and SMSA's. This indicates the scale of total transit demand, which is important in determining the type of transit system that may be warranted. A high percentage of transit riders in a small city would not be sufficient to justify massive capital investment.

<u>Concentration of Employment</u>. Since the overwhelming majority of transit lines serve the Central Business District (CBD) and since the density of transit lines corresponds with population density (heavily concentrated in central cities), an examination of where jobs are located has some bearing on transit riding for the work trip. Tables 4-11 and 4-12 show the percentage of jobs in the central city and CBD, respectively, for those who reported their place of work in the 1970 Census. For the central city residents, employment in the central city falls in a dominant range from 75 to 89%. Newark is lower than the others because it is part of the New York Standard Consolidated Statistical Area, and many commute to New York City to work. Logically, the rates are lower for residents of the total SMSA and the suburban ring. New Orleans shows the strongest employment impact on its SMSA region of all the SMSA's for both central city and CBD employment. CBD employment is shown to be only a small portion of the central city employment in all the cities.

Table 4-13 shows the total number of persons working in each central city, while Table 4-14 shows the total number working in the CBD of each area. These numbers are intended to give an indication of scale, and they point

TABLE 4-10. U.S. CITIES WHICH RETAINED LRT

Total Transit Riders for Work Trip 1970

	Central City	SMSA	Suburban Ring
Boston	99,538	217,112	117,574
Cleveland	61,283	106,110	44,827
Newark	49,137	135,149	86,012
New Orleans	62,522	71,846	9,324
Philadelphia	274,349	380,813	106,464
Pittsburgh	54,833	122,094	67,261
San Francisco	112,632	191,863	79,231
Mean	102,042	174,998	72,956

Source: U.S. Census, 1970.

TABLE 4-11. U.S. CITIES WHICH RETAINED LRT

Concentration of Employment in the Central City:

Percent Working in Central City

	Central City	SMSA	Suburban Ring
Boston	76.0	35.9	24.3
Cleveland	74.5	52.1	41.1
Newark	56.3	19.9	12.4
New Orleans	85.7	65.6	40.3
Philadelphia	85.3	45.6	20.5
Pittsburgh	78.9	35.4	23.3
San Francisco	89.1	34.9	17.0
Mean	78.0	41.3	25.6

TABLE 4-12. % WORKING IN CENTRAL BUSINESS DISTRICT

	Central City	SMSA	Suburban Ring
Boston	13.6	7.7	6.0
Cleveland	10.8	8.9	8.1
Newark	13.7	6.4	4.9
New Orleans	24.2	19.1	12.7
Philadelphia	10.3	6.5	4.1
Pittsburgh	15.3	8.6	6.7
San Francisco	28.6	12.0	6.5
Mean	16.6	9.9	7.0

Source: U.S. Census, 1970.

TABLE 4-13. LRT CITIES

Total Number of Workers in Central City By 1970*

	Central City	SMSA	Suburban Ring
Boston	177,644	373,738	196,094
Cleveland	185,284	391,794	206,510
Newark	66,673	137,589	70,916
New Orleans	158,201	217,463	59,262
Philadelphia	559,771	772,324	212,553
Pittsburgh	138,742	286,175	147,433
San Francisco	257,351	405,729	148, 378
Mean	220,524	369,259	148,735

*Does not include workers who commute from outside the SMSA.

TABLE 4-14. LRT CITIES

Total Number of Workers in the CBD By Place of Residence

	Central City	SMSA	Suburban Ring
Boston	31,744	79,728	47,984
Cleveland	26,243	67,079	40,836
Newark	16,283	44,470	28,187
New Orleans	44,688	63,412	18,724
Philadelphia	67,916	110,385	42,469
Pittsburgh	26,858	69,099	42,241
San Francisco	82,685	139,473	56,788
Mean	42,345	81,949	39,604

Source: U.S. Census, 1970.

out that all of these cities are quite large. With the exception of Newark (not really the CBD of its region), all of the CBD's have at least 63,000 workers.

Conclusion. The cities which retained streetcar/LRT systems can be characterized as relatively large and dense in population, and they were established early in the history of the U.S. The densities of the central cities are likely contributors to the relatively high levels of transit ridership to work and the high percentage of households without automobiles. Employment is still concentrated in the central city for those who reside there, but central city employment accounts for only an average of 41.3% of jobs for all the residents of the SMSA's. The cities have experienced the usual suburbanizing trend, and in the outer areas of the metropolitan area, all of the factors which relate to transit viability are less prominent.

U.S. Cities With LRT Proposals

Total Population and Population Density. This group contains those cities which have done feasibility studies and seem to be actively pursuing the installation of LRT in their metropolitan areas. Of those considered here, only Buffalo and San Diego have proceeded with construction.

Table 4-15 shows the population figures for each census classification. The central cities are all under one million in population except for Detroit. In fact, most are under 500,000. Even for the urbanized areas, which contain over twice the population, half of the cities do not reach a million. With the exception of Detroit, these cities seem to fall into the category of medium-size cities which LRT is purported to suit. The mean population for the urbanized areas is skewed by the large population of Detroit. On the average, the proposal cities have only 73 percent of the central city population of the cities that retained LRT, and only 58 percent of the urbanized area population.

Table 4-16 shows the 1970 average population densities for central cities, urbanized areas, and SMSA's. While the average densities for the urbanized areas are fairly similar, there are large discrepancies in the central city densities. It appears that there are two types of cities considering LRT: older Eastern cities and newer Western cities. The central city densities are compared below.

TABLE 4-15. 1970 POPULATION FOR CITIES WITH LRT PROPOSALS

	Central City	Urbanized Area	SMSA
Buffalo	462,768	1,086,594	1,349,211
Dayton	244,564	685,942	850,266
Detroit	1,514,063	3,970,584	4,199,931
Portland	382,352	824,926	1,009,129
Rochester	295,011	601,361	882,667
San Diego	697,027	1,198,323	1,357,854
Orange Co.	445,826	NA	1,420,386
Mean	577,373	1,394,622	1,581,349

TABLE 4-16. 1970 POPULATION DENSITY FOR CITIES WITH LRT PROPOSALS

(Residents per Square Mile)

	Central City	Urbanized Area	SMSA
Buffalo	11,205	5085	849
Dayton	6,360	3060	498
Detroit	10,953	4553	2152
Portland	4,294	3092	276
Rochester	8,072	4127	381
San Diego	3,261	3148	319
Orange Co.	5,738	NA	1816
Mean	7,126	3844	899

Source: U.S. Census, 1970.

Older		Newer	
Buffalo	11,205	Portland	4,294
Dayton	6,360	San Diego	3,261
Detroit	10,953	Orange Co.	5,738
Rochester	8,072		
Mean	9,148	Mean	4,431

The older central cities have, on the average, twice the density of the newer ones. In general the densities of the proposal cities are lower than for the cities that retained LRT.

Historical Growth Patterns. As can be seen in the contrast between the older Eastern and newer Western cities, densities are closely related to the time when growth occurred. Data over time are shown for the proposal cities in Tables 4-17 through 4-20.

An examination of the growth trends indicates that none of these cities was established in 1790. By 1850, the cities east of the Mississippi had populations between 11,000 and 42,000. By the turn of the century, the beginning of the streetcar era, it was still only the Eastern cities which had surpassed 100,000, though Portland was not far from it. Detroit and Buffalo showed early growth not unlike the cities which retained their LRT. By the time automobiles per 1000 population in the U.S. had reached 100, or one for every 10 persons (in the 1920's), Detroit had over a million population, Buffalo was between 500,000 and 600,000, and the others (except the California cities) were in the range between 200,000 and 300,000——significantly behind the retained cities which ranged from 400,000 to 800,000 during the same era. Those cities which were the largest in the early 20th century (Buffalo, Detroit, and Rochester) are also the most dense, both in those early years and at present.

With the exception of Detroit, growth outside the central city was not too significant until fairly recently. All the central cities contained the large majority of the overall metropolitan population until about 1950. The land area for the older cities was static while the younger cities added area to the central cities. After 1950, the older central cities' populations began to decline, and the populations outside became the dominant portions. The California cities show different patterns from even Dayton and

TABLE 4-17. CITIES WITH PROPOSALS FOR LRT

Population Within City Boundaries

City/Year	1790	1850	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1975
Buffalo	—	42,261	155,134	255,664	352,387	423,715	506,775	573,076	575,901	580,132	532,759	462,768	407,160
Dayton	—	10,977	38,678	61,220	85,333	116,577	152,559	200,932	210,718	243,872	262,332	244,564	205,986
Detroit	—	21,019	116,340	205,876	285,704	465,766	993,678	1,568,662	1,623,452	1,849,568	1,670,144	1,514,063	1,335,085
Portland, O.	—		17,577	46,385	90,426	207,214	258,288	301,815	305,394	373,628	372,676	382,352	356,732
Rochester	—	36,403	89,366	133,896	162,608	218,149	295,750	328,132	324,975	332,488	318,611	295,011	267,173
Orange Co. Central Cities	—			13,589	19,696	34,436	NA	NA	42,952	60,089	288,772	445,826	489,374
San Diego	—				17,700	39,578	74,361	147,995	203,341	334,387	573,224	697,027	773,996

Source: U.S. Census, 1970.

TABLE 4-18. POPULATION OF SMSA/METROPOLITAN AREAS

	1920	1930	1940	1950	1960	1970
Buffalo	602,847	820,573	857,719	1,089,230	1,306,957	1,349,211
Dayton	210,177	251,928	271,513	457,333	694,623	850,266
Detroit	1,165,153	2,104,764	2,295,867	3,016,197	3,762,360	4,199,931
Portland	299,882	378,728	406,406	704,829	821,897	1,009,129
Rochester	320,966	398,591	411,970	487,632	586,387	882,667
Orange Co.	61,375	118,674	130,760	216,224	703,925	1,420,386
San Diego	——	181,020	289,348	556,808	1,033,011	1,357,854

Source: U.S. Census, 1970.

TABLE 4-19. U.S. CITIES WITH LRT PROPOSALS

Density Within City Boundaries

	1920	1930	1940	1950	1960	1970
Buffalo	13,029	14,732	14,617	14,724	13,552	11,205
Dayton	9,960	11,086	8,891	9,755	7,808	6,360
Detroit	12,760	11,375	11,773	13,249	11,964	10,953
Portland	4,087	4,757	4,809	5,829	5,546	4,294
Rochester	10,020	9,586	9,392	9,236	8,753	8,072
San Diego	——	1,581	2,134	3,364	2,994	3,261
Orange Co.	——	——	——	——	——	5.738

Land Area Within City Boundaries (in Sq. Miles)

	1920	1930	1940	1950	1960	1970
Buffalo	38.9	38.9	39.4	39.4	39.4	41.3
Dayton	15.8	18.1	23.7	25.0	33.6	38.3
Detroit	77.9	137.9	137.9	139.6	139.6	138.0
Portland	63.2	63.5	63.5	64.1	67.2	89.1
Rochester	29.5	34.2	34.6	36.0	36.4	36.7
San Diego	—	93.6	95.3	99.4	194.7	212.8
Orange Co.	—	——	——	——	——	77.7

Source: U.S. Census, 1970.

TABLE 4-20. U.S. CITIES WITH LRT PROPOSALS

Density of SMSA/Metropolitan Areas

	1920	1930	1940	1950	1960	1970
Buffalo	2756	1778	1812	686	824	849
Dayton	387	1399	1394	519	539	498
Detroit	4255	2819	2681	1535	1915	2152
Portland	1194	1365	1322	192	225	276
Rochester	1735	1310	1347	725	871	381
San Diego	NA	545	493	131	NA	319
Orange Co.	77	149	——	277	——	1816

Land Area of SMSA/Metropolitan Areas

	1920	1930	1940	1950	1960	1970
Buffalo	218.8	458.9	473.4	1587	1587	1590
Dayton	543.0	180.1	194.8	881.0	1228	1708
Detroit	273.8	746.5	856.3	1965	1965	1965
Portland	251.2	277.5	307.4	3663	3657	3650
Rochester	185.0	304.2	305.9	673	673	2315
San Diego	NA	332.4	520.4	4258	——	4261
Orango Co.	795	795	——	782	782	782

Source: U.S. Census, 1970.

Portland, which are relatively younger than the older cities, but also exhibit central city decline. San Diego grew late and very rapidly in recent years. It continues to add area to the city, and the central city population is growing as well as the metropolitan area. It must be remembered that while technically Orange County has three "central cities"——Anaheim, Santa Ana, and Garden Grove——the entire area is actually suburban to Los Angeles. Many of the dramatic changes in density and land area in the tables for metropolitan areas are due to changing census definitions.

Automobile Ownership and Transit Usage. The percentages of households with no automobile available are shown in Table 4-21. These numbers show the expected differences between central cities and suburban rings: the average percentage is three times higher in the central cities than in the suburbs. These figures, when compared to retained cities, show significant differences. The percentages without automobiles in the retained cities are approximately twice what is found in the cities which propose LRT. This could be because the proposal cities lack any transit other than bus, thus there is a higher need to have an automobile. Also, the lower densities of the proposal cities compared to the retained cities are more conducive to automobile travel.

Since automobile ownership is high and transit mode choices are limited in the proposal cities, it is not surprising that the percentages riding transit to work are significantly lower than the retained cities (see Table 4-22). In central cities, there is an average of 14.6%, less than half of the central city figure for retained cities. However, the figures for total SMSA's and suburban rings show much greater discrepancies between the metropolitan areas of the retained cities and proposal cities. Transit riding for the work trip is approximately three times higher in retained cities for SMSA's, and almost four times higher in the suburban rings. One explanation is that for some of the proposal cities, transit service may not extend beyond the central city.

Table 4-23 shows the total number of persons riding transit to work in the proposal cities. On the average, these numbers are much lower than for the retained cities (Detroit being the principal exception).

Concentration of Employment. The influence of the central city and the CBD on employment in the proposal cities is shown in Tables 4-24 and 4-25. The

TABLE 4-21. U.S. CITIES WITH LRT PROPOSALS

Percent Households with no Automobiles (1970)*

	Central City	SMSA	Suburban Ring
Older			
Buffalo	34.4	19.0	9.7
Dayton	23.0	11.2	5.9
Detroit	28.0	14.8	6.3
Rochester	28.2	14.3	5.7
Newer			
Portland	22.7	13.8	7.3
Orange Co.	6.3	5.5	5.1
San Diego	14.2	11.0	7.2
Mean	21.0	12.8	6.7

TABLE 4-22. U.S. CITIES WITH LRT PROPOSALS*

Percent Using Transit for the Trip to Work (1970)

	Central City	SMSA	Suburban Ring
Older			
Buffalo	21.3	10.1	4.5
Dayton	13.5	5.1	1.7
Detroit	18.1	8.0	2.5
Rochester	18.4	7.8	2.3
Newer			
Portland	10.8	5.8	2.6
Orange Co.	0.4	0.3	0.3
San Diego	5.5	4.3	3.0
Mean	12.6	5.9	2.4

*Source: U.S. Census, 1970.

TABLE 4-23. U.S. CITIES WITH LRT PROPOSALS

Total Transit Riders for Work Trip 1970

	Central City	SMSA	Suburban Ring
Buffalo	35,153	50,029	14,876
Dayton	12,718	16,776	4,058
Detroit	97,166	121,780	24,614
Portland	16,551	22,818	6,267
Rochester	21,753	27,044	5,291
San Diego	15,288	22,763	7,475
Orange County	640	1,728	1,088
Mean	28,467	37,563	9,096

Source: U.S. Census, 1970.

TABLE 4-24. U.S. CITIES WITH LRT PROPOSALS

Percent Working in Central City, 1970

	Central City	SMSA	Suburban Ring
Buffalo	74.2	43.9	29.4
Dayton	75.1	50.1	40.0
Detroit	65.6	37.6	23.1
Portland	79.0	55.3	40.4
Rochester	80.8	57.0	45.3
San Diego	83.6	58.6	33.5
Orange County	49.0	29.0	19.7
Mean	72.5	47.4	33.1

TABLE 4-25. U.S. CITIES WITH LRT PROPOSALS

Percent Working in Central Business District, 1970

	Central City	SMSA	Suburban Ring
Buffalo	13.1	8.1	5.7
Dayton	12.1	7.9	6.3
Detroit	9.4	5.6	3.7
Portland	12.2	8.1	5.5
Rochester	13.8	9.2	7.0
San Diego	5.7	4.1	2.4
Orange County	4.3	2.5	1.6
Mean	10.1	6.5	4.6

Source: U.S. Census, 1970.

figures vary quite a bit, not allowing for any generalizations——even compared to the retained cities, which also vary. It might be said that no CBD's have particularly strong concentrations of employment. San Diego has the highest central city employment rate of the proposal cities, 58.6 percent for the total SMSA. Rochester has the highest concentration in the CBD, 9.2 percent of total SMSA jobs.

Tables 4-26 and 4-27 give the total number of workers in the central cities and CBD's, respectively. With the exception of Detroit, the totals are much lower than for the retained cities. Detroit has 80,000 CBD workers; no other city has as many as 40,000.

Conclusion. In general, the cities that propose LRT systems are quite varied in population and population density. Except for Detroit, most are medium-size cities. Densities of the older central cities are relatively high, but most of their growth took place during the time of limited automobile availability. The recent influence of the automobile is particularly evident in the California cities.

MODELING ANALYSIS

The previous section gives a broad idea of some pertinent characteristics of American cities that have retained streetcar lines or are now actively considering Light Rail Transit proposals. While this information helps to give a sense of appropriate scale, it is somewhat limited. For one thing, the statistics reported are averages for entire cities or metropolitan areas, and there is obviously much variation within these areas. Further, there is no proof that LRT is the optimal transit mode in those cities that do have it. The existence or non-existence of LRT may be due to historical factors or unique local circumstances (this question is discussed later in this report).

Consequently, the project staff undertook another analysis using a mathematical optimizing model in an attempt to determine the characteristics of cities for which LRT might be the "best" transit mode. This model had been developed for an earlier study and was used to compare rail and bus transit, but it had never been specifically applied to the light rail mode. The model was utilized in this study to compare LRT with exclusive busways and conventional bus service for urban density characteristics typical of

TABLE 4-26. U.S. CITIES WITH LRT PROPOSALS

Total Number of Workers in Central City, 1970

	Central City	SMSA	Suburban Ring
Buffalo	112,935	206,278	93,343
Dayton	62,878	152,436	89,558
Detroit	320,668	537,373	216,705
Portland	112,075	203,128	91,053
Rochester	87,319	186,836	99,517
San Diego	222,518	304,028	81,510
Orange County	79,451	148,449	68,998
Mean	142,549	248,361	105,812

TABLE 4-27. TOTAL NUMBER OF WORKERS IN CENTRAL BUSINESS DISTRICT, 1970

	Central City	SMSA	Suburban Ring
Buffalo	19,948	38,065	18,117
Dayton	10,147	24,322	14,175
Detroit	45,981	80,274	34,293
Portland	17,371	29,794	12,423
Rochester	14,960	30,289	15,329
San Diego	15,251	21,083	5,832
Orange County	7,017	5,761	12,778
Mean	18,668	33,801	15,133

Source: U.S. Census, 1970.

Texas cities. While the model is abstract and the evaluation is partial, the results do provide further insights into the type of situation for which LRT is a promising alternative.

The sections that follow contain (1) a brief description of the mathematical model, (2) determination of the specific parameter values used as inputs to the model, and (3) a summary of the results.

Description of the Model

The model was developed by one of the Principal Investigators of this study for his dissertaion research at Cornell University, which was completed in 1975. A full account of the rationale and mathematical derivation, along with the relevant computer programs, is given in the dissertation (Ref 1). A shorter description was recently published by the Transportation Research Board (Ref 2). Here only a brief sketch will be given, in order to assist the reader in interpreting the results.

The motivation for the model was to develop a general methodology (rather than a case study approach) to determine (1) the optimal design of an urban transit network, with particular reference to the spacing of routes and stops, and (2) the optimal transit mode to use in the network for a city with a particular density pattern. The approach was to hypothesize an idealized city with uniform characteristics and develop a mathematical model of a simple transit system with which it would be possible to optimize the most important design variables.

Specifically, it was assumed that the idealized city is circular and has a definite center (representing the Central Business District) and that density declines uniformly from the center in all directions. The transit system was assumed to consist of radial routes emanating from the center and containing discrete stops. Each radial route is finite in length and has a definite outer terminal. The transit service consists of vehicles or trains that travel from terminal to terminal and stop at all stops. The city was assumed to be regular and radially symmetric, which means that each transit route will be identical and will serve a sector of uniform size.

To keep the model mathematically tractable, only trips to or from the center were included (CBD trips of course form the largest part of the transit market). It was assumed that travel can occur only in radial and circumferential directions. Each CBD-bound traveler first walks to the nearest transit route in a circumferential arc, then walks along the radial route to a transit stop, waits for and boards a transit vehicle, and finally completes his journey to the center on the vehicle. It was assumed that each traveler minimizes the total journey time: thus, after reaching the radial, some walk inward to the next station, and others walk outward to the next station, depending on which is quicker.

The model requires specification of the spatial distribution of the outer ends of the trips (all the inner ends are assumed to be at the center). Empirical analysis of origin-destination data for a number of American cities showed that the negative exponential function provides the best fit of any simple mathematical equation for the distribution of CBD transit trip ends. The specific equation incorporated into the model was:

$$Y = Ae^{-bx}$$

where Y = density of trip ends and x = distance from the city center. A and b are parameters for which values must be supplied as inputs to the model, while e is the base of natural logarithms.

The objective specified for the model was to minimize the total community costs of constructing and operating the transit system. The costs were defined to consist of capital investment (both for constructing guideway and purchasing vehicles), operating costs, and user time costs (including walking, waiting, and time spent riding on vehicles). The annual cost method was used to convert capital costs to annual costs.

The model is an application of the traditional benefit-cost approach long used in transportation planning. In recent years this approach has sometimes been discredited, with increasing weight in decision making given to intangible values, environmental and other impacts, and community preferences. It is generally impossible to express these criteria in a quantitative form suitable for inclusion in such a mathematical model. The position taken here is that benefit-cost analysis provides information that is very useful in decision making, but that it should not be the sole basis for decisions.

Further, the model involves the monetary valuation of travel time, also a traditional practice that has been questioned in recent years. There is no doubt that travel time has value; indeed, saving travel time is the most common justification for transportation improvements. Most of the questions forcus on the measurement of time value; there is no longer a consensus on the proper way to do this. This position taken here is that the significance of travel time is best illuminated by sensitivity analysis of time values.

It would be desirable to optimize several decision variables in designing a transit network, and ideally they should all be optimized simultaneously. The design variables in this model are: the number of radial routes (which is equivalent to route spacing), the number of stops on each route, and the spacings between stops (each inter-station spacing is an independent variable). The total length of the radial routes is also optimized in the process. In addition, because there is an important interrelationship between the spacing of routes and frequency of service, the average headway between units of service is included as a decision variable. A solution is calculated that optimizes all of these variables simultaneously.

Formulation of the model involved first deriving by integral calculus an equation representing the total community costs of the transit system. Then differential calculus was used to derive a set of nonlinear equations that must be solved simultaneously to calculate the global optimum with respect to all of the decision variables. No direct or analytical method of solution was possible. Hence a computer program was developed that iteratively approximates the simultaneous optimum to any desired degree of precision.

The model was originally applied to a range of density values (that is, the A and b parameters of the density function) relevant to medium-size cities in the Northeast and Mid-West (the highest values corresponded approximately with Detroit, and the lowest, with Syracuse, New York). Cost and performance values were inserted to represent three alternative transit modes: (1) heavy rail, or conventional subway-elevated systems, (2) exclusive bus lanes, or busways, and (3) conventional bus service running in mixed traffic on city streets. The three alternatives were compared for each of six different density configurations to determine the least cost system. The results showed that in five of the six hypothetical cities tested, conventional bus service was the least cost alternative. Only in the city with the highest trip total was the busway system optimal.

Testing the rail alternative involved a variation of the basic model, because the length of trains (number of cars) is also a decision variable.

This variable was also optimized. In all six of the tests, rail turned out to be the most expensive of the three alternatives.

The Density Function

In applying the model, the thing that distinguishes one city from another is its density profile—that is, the values of the two parameters of the negative exponential function (A and b). While this is obviously a simplistic summarizing measure, it is much superior to using the average density of the city, which would imply that the density is the same everywhere. With a density function, the density declines with increasing distance from the center of the city. Countless empirical studies have shown that this is quite realistic, and that the negative exponential function is a good representation of how density declines with distance.

Use of the model requires supplying values for the A and b parameters as inputs. Previous applications of the model showed that the extent of the optimal transit system is quite sensitive to these parameter values. Those cases all involved densities typical of medium-size cities in the Northeast and Mid-West. To apply the model to the Texas situation, it was necessary to conduct some empirical research to ascertain values of the density parameters that would correspond to Texas cities. The function in the model represents the density of CBD transit trip ends. However, some research was also done on other variables, particularly on gross population density (total population divided by total land area).

There are three ways of calculating the density parameters that have been used by previous investigators. Briefly, they are as follows:

1. Densities are calculated for geographic subdivisions of the city, such as census tracts. (Sometimes a random sample of the subdivisions is taken). Then the distance from the city center to the approximate center of each subdivision is measured on a map. Finally, the densities are related to the distances by regression analysis.[1]
2. Densities are calculated for concentric rings centered on the CBD (usually the rings are formed by grouping the subdivisions). Distances are represented by the average distance from the center to each ring. Then again, densities are related to distances by regression analysis.[2]
3. An ingenious method developed by the urban economist Edwin Mills requires only two density values, one for the central city and one for the suburbs (Ref 3). The average distances of the central city and suburbs are calculated by a geometrical formula, and then a

> mathematical approximating technique is used to estimate the density parameters.

Unfortunately, the three methods do not necessarily give identical results. Each method appears to have certain biases, and the question of the best method to use is still a matter of debate in the literature. The first two methods are considered to be more reliable than the third. The principal advantage of the Mills technique is the small amount of data needed; it is possible to estimate parameter values when there is no information for subdivisions of the city.

In this study, reliance was placed on the first two methods. The first method was used when the number of subdivisions was small; when it was large, they were grouped into rings and the second method was used. Some experimentation was conducted with the third method, but it was discarded because some of the results were considerably at variance with those of the other methods.

The first variable investigated was gross population density (total population divided by total land area, measured in persons per square mile). the population figures were taken from the 1970 Census, and the basic area subdivisions used were the census tracts as delineated for 1970.

Census reports do not contain calculations of the land area of census tracts, so it was necessary to resort to a combination of data sources and measurement techniques. Estimates of the land areas of the census tracts were obtained from published planning reports or the planning staffs for the cities of Austin, Dallas, El Paso, and Houston. Because of the large number of tracts in Dallas and Houston, it was decided to group them into concentric rings and use these as the areal subdivisions. For Fort Worth and San Antonio, approximate concentric rings were drawn on maps of the census tracts, and a planimeter was used to measure the areas of these rings. To sum up, the estimates for Austin and El Paso were based on all census tracts, while those for the other four cities were based on concentric rings formed from the census tracts. The rings were one or two miles in width.

The parameter estimates resulting from regression analysis of these data are given in Table 4-28. The A value represents the density at the center of the city, while the b value represents the rate of decline of density with increasing distance from the center. A high b value (in absolute terms)

TABLE 4-28. ESTIMATED PARAMETERS OF NEGATIVE EXPONENTIAL FUNCTION FOR GROSS POPULATION DENSITY FOR TEXAS CITIES

City	A	(-) b	Correlation Coefficient
Austin	7,358	.219	.602
Dallas	6,455	.149	.865
El Paso	6,542	.103	.346
Fort Worth	4,539	.185	.938
Houston	10,699	.193	.980
San Antonio	8,386	.246	.865

TABLE 4-29. ESTIMATED PARAMETERS OF NEGATIVE EXPONENTIAL FUNCTION FOR GROSS POPULATION DENSITY FOR SELECTED CITIES OUTSIDE OF TEXAS.

City	A	(-) b	Correlation Coefficient
Baltimore	20,190	.295	.921
Buffalo	15,281	.187	.965
Chicago	25,849	.135	.796
Cleveland	8,535	.108	.862
Denver	16,530	.353	.973
Detroit	30,261	.175	.970
New York	58,495	.137	.988
Pittsburgh	12,014	.198	.821
Rochester	15,484	.391	.983
Syracuse	10,496	.409	.942
Washington	17,522	.209	.987

indicates a compact city, while a low b value indicates a dispersed city. If we think of the density surface as a circular tent with one central pole, the A value represents the height of the pole, while the b value represents the slope of the tent's surface.

To give some basis for comparison, Table 4-29 reports the same density parameters previously estimated for 11 American cities (all east of the Mississippi River except for Denver). These estimates were not based on the 1970 Census, but on metropolitan transportation studies conducted in various years between 1953 and 1968. It can be seen that the A values for Texas cities are almost all lower than those for Eastern cities. Only Houston is an exception; its value is somewhat higher than that of Cleveland, and just slightly higher than that of Syracuse. The b values for Texas cities tend to be low, but so do many of those for the Eastern cities. A few Eastern cities have high b values (indicating they are quite compact); this is not true of any Texas city.

A graphical presentation may help to make the results meaningful. When the exponential function is plotted on semi-logarithmic graph paper, it comes out as a straight line (here density is shown on the logarithmic scale, and distance on the linear scale). Figure 4-1 shows the lines plotted for the six Texas cities, while Figure 4-2 shows the lines for the other 11 cities (both graphs use the same scales). It can be seen that on the left side of the graphs (close to the city center), the Eastern cities are generally higher, but on the right side, there is considerable overlap, and some Texas cities are higher than some Eastern cities.

The last point can be emphasized by calculating the density values estimated from the regression equations for distances of 5 and 10 miles from the center of the city. These values are shown in Table 4-30 for the Texas cities, and in Table 4-31 for the other cities. At these distances, several of the Texas cities have density estimates higher than those of several of the Eastern cities (although New York, Chicago, and Detroit remain highest of all distances).

These findings are of interest, suggesting that urban densities in Texas are not so vastly different from elsewhere as is sometimes purported. However, the transit optimizing model does not directly utilize gross population density, but rather the density of CBD transit trips. The Census does not collect data on total transit travel, but it does ask questions

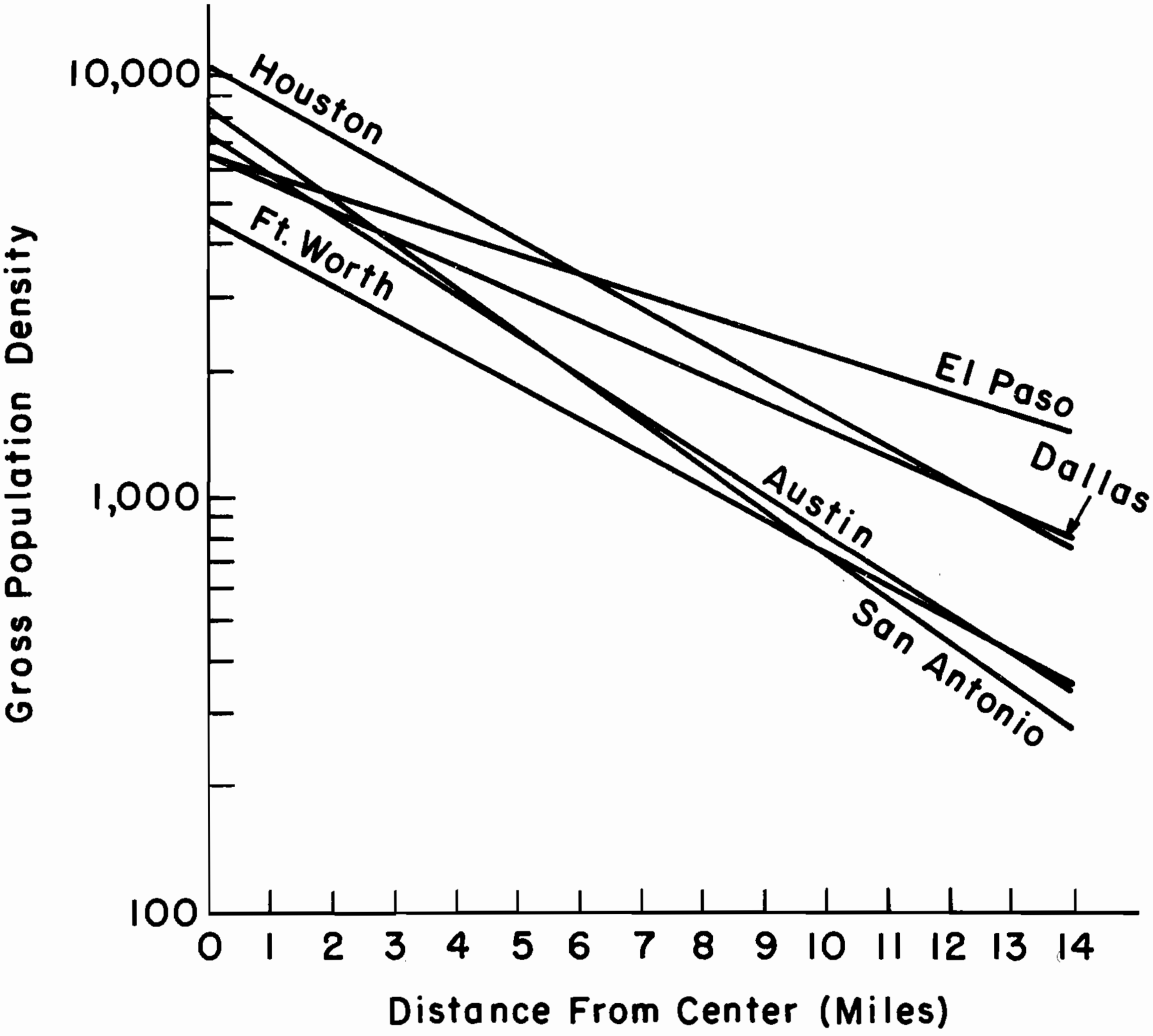

Figure 4-1. Gross Population Density of Texas Cities

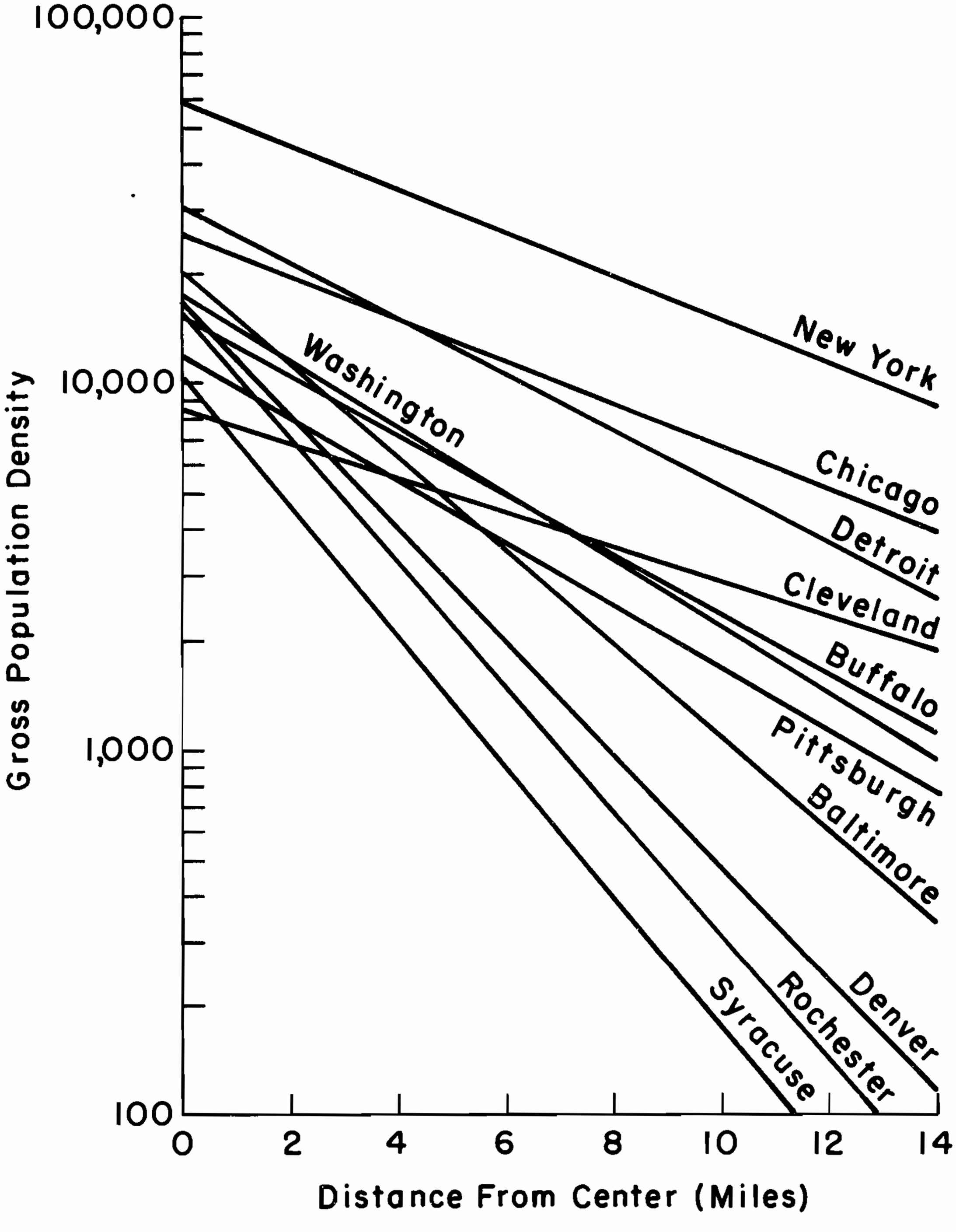

Figure 4-2. Exponential Functions for Gross Population Density

TABLE 4-30. ESTIMATED GROSS POPULATION DENSITIES OF TEXAS CITIES AT 5 AND 10 MILES FROM THE CENTER

City	5 Miles from Center	10 Miles from Center
Austin	2,462	823
Dallas	3,049	1,440
El Paso	3,968	2,407
Fort Worth	1,800	714
Houston	4,138	1,600
San Antonio	2,451	716

TABLE 4-31. ESTIMATED GROSS POPULATION DENSITIES OF SELECTED CITIES OUTSIDE OF TEXAS AT 5 AND 10 MILES FROM THE CENTER

City	5 Miles from Center	10 Miles from Center
Baltimore	4,619	1,057
Buffalo	5,999	2,355
Chicago	13,161	6,701
Cleveland	4,974	2,898
Denver	2,830	484
Detroit	12,615	5,259
New York	29,487	14,864
Pittsburgh	4,464	1,659
Rochester	2,192	310
Syracuse	1,358	176
Washington	6,162	2,167

about the journey to work. These cover the travel mode used and the location of the workplace (unfortunately the latter item is not tabulated in any detail). Published census tract reports for 1970 include, for each census tract, the number of work trips by mass transit, and the number of work trips to the CBD (but not the number of transit work trips to the CBD).

Several attempts were made to estimate indirectly the needed parameters of the exponential function for CBD transit trips from the 1970 Census data on gross population density, transit work trips, and CBD work trips. The results were disappointing——the numbers were clearly out of scale——and this approach was eventually dropped.

Another source contains exactly the data needed, but is somewhat out of data: this is the set of origin-destination studies conducted by the Texas Highway Department in all major Texas cities during the 1960's. Suitable data on the spatial distribution of transit trips to the CBD were found in the published reports for four cities: Austin, Dallas, Fort Worth, and San Antonio. No such data were ever published for Houston (which had one of the earliest O-D studies, in 1960), and El Paso was omitted because its severe topography makes concentric rings rather meaningless.

Origin-destination studies use a very large number of zones (much larger than the number of census tracts), and so the technique used for all four cities was to group the zones into concentric rings based on the CBD as the city center. The published reports for the Dallas-Fort Worth study conveniently included land area measurements for all zones. For Austin and San Antonio, the land areas were measured with a planimeter.

The results of these calculations are shown in Table 4-32. Table 4-33 shows estimates of these parameter values previously calculated for six Eastern cities (the only ones for which data were available). Comparison indicates that in general the Texas cities have lower A values (although San Antonio is an exception) and higher b values (there is some overlap here). Both of these factors——low A values and high b values——lead to smaller numbers of total transit trips. Figure 4-3 is another semi-logarithmic graph showing the regression lines for both the Texas and Eastern cities. It shows that the lines for the two largest Texas cities (Dallas and San Antonio) overlap with those for the two smallest Eastern cities (Rochester and Syracuse).

TABLE 4-32. ESTIMATED PARAMETERS OF NEGATIVE EXPONENTIAL FUNCTION FOR CBD TRANSIT TRIPS FOR TEXAS CITIES.

City	Year of Study	A	(-) b	Correlation Coefficient
Austin	1962	508	.903	.932
Dallas	1964	1,115	.485	.977
Fort Worth	1964	698	.676	.952
San Antonio	1969	2,221	.831	.996

TABLE 4-33. ESTIMATED PARAMETERS OF NEGATIVE EXPONENTIAL FUNCTION FOR CBD TRANSIT TRIPS FOR SELECTED CITIES OUTSIDE OF TEXAS.

City	Year of Study	A	(-) b	Correlation Coefficient
Buffalo	1962	2,145	.384	.974
Cleveland	1963	4,043	.275	.992
Detroit	1953	3,427	.286	.966
Pittsburgh	1958	2,345	.355	.880
Rochester	1963	2,705	.724	.993
Syracuse	1966	1,285	.632	.935

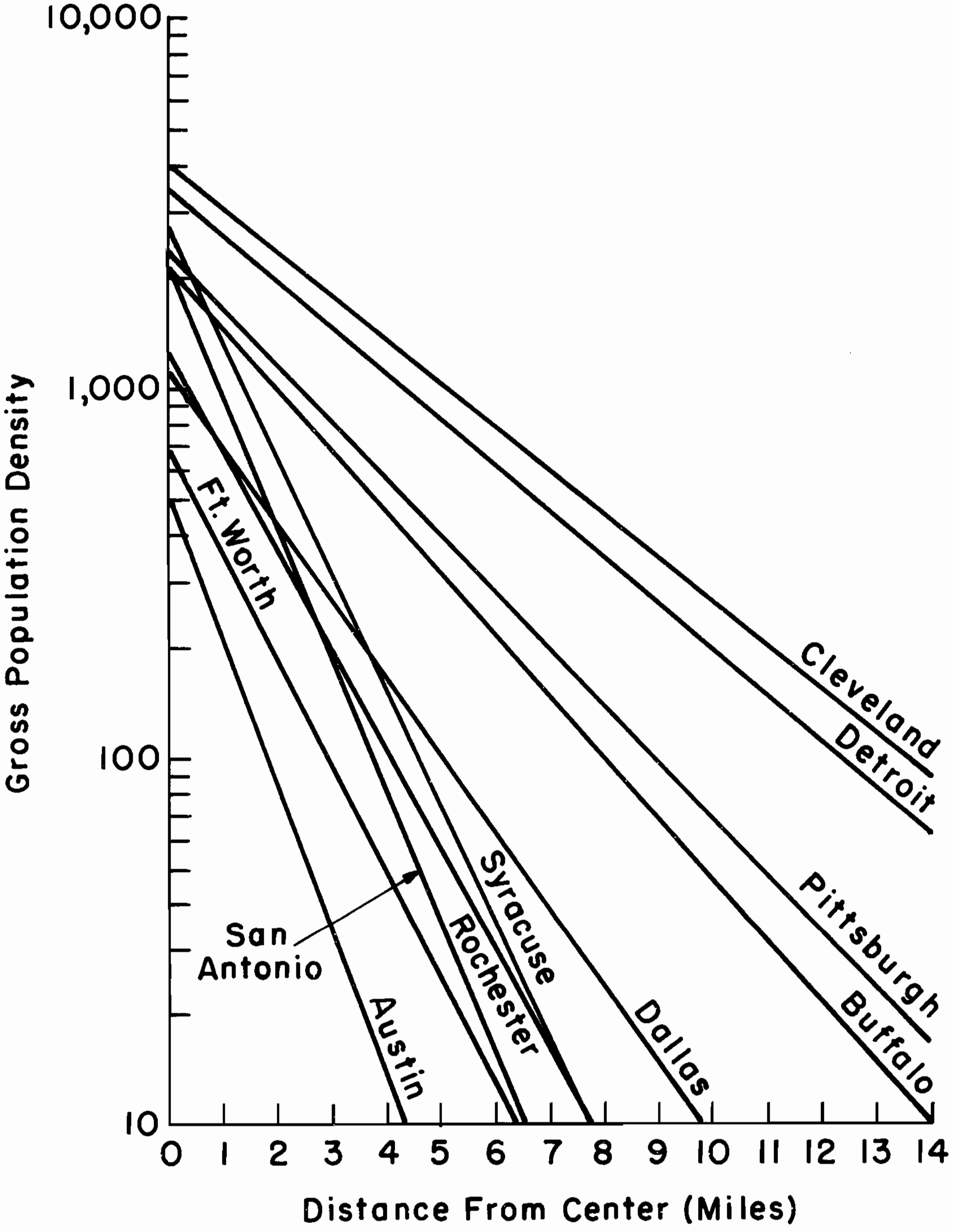

Figure 4-3. Density of CBD Transit Trips

Another interesting comparison is presented in Table 4-34 which includes both the six Eastern cities and the four Texas cities. One column shows the estimated gross population densities at a distance of five miles from the center (the cities are rank-ordered according to this variable), while another shows the estimated densities of CBD transit trips at the same distance. Among the Texas cities, only Dallas has a substantial density of transit demand at this distance: the other Texas cities have much lower values than would be expected from their population densities.

It appears from this and other evidence that Texas cities have lower levels of transit demand than would be expected from their overall population densities. To say it another way, an Eastern city and a Texas city with the same population density would not have the same level of transit usage; the Eastern city would have more transit riders. Undoubtedly this is at least partially due to higher levels of automobile ownership in Texas cities, and it indicates that neither automobile ownership nor transit riding is a simple function of population density. Of course, it is the level of transit demand (actual or potential) that must be considered in evaluating the feasibility of a transit proposal, and not merely the level of population density.

At the conclusion of this phase of the study, it was decided to apply the transit optimizing model to four sets of parameter values, representing four hypothetical cities with density profiles similar to those of actual Texas cities. The set of values selected were:

A value	b value
2,000	.25
1,500	.25
2,000	.50
1,500	.50

These sets of values actually reflect density profiles that are somewhat higher than found for any of the Texas cities. San Antonio had an A value slightly over 2,000, but this was combined with a very high b value. Dallas had a b value slightly below .50, but this was combined with an A value close to 1,000. Thus, it can be said that the four test cases are conservative in overestimating the density of transit demand in Texas cities.

TABLE 4-34. ESTIMATED DENSITIES OF POPULATION AND CBD TRANSIT TRIPS AT A DISTANCE OF 5 MILES FROM THE CITY CENTER

City	Population	CBD Transit Trips
Detroit	12,165	820
Buffalo	5,999	314
Cleveland	4,974	1,022
Pittsburgh	4,464	397
Dallas	3,049	99
Austin	2,462	6
San Antonio	2,451	35
Rochester	2,192	72
Fort Worth	1,800	24
Syracuse	1,358	55

Selection of Other Parameter Values

Application of the model also requires specification of the values of a number of other parameters, most of which concern the cost and performance characteristics of the particular transit modes tested. The values selected were intended to be typical of transit operations in the United States today, and reflect existing technology. Insofar as possible, costs were adjusted to 1978 prices.

These values are quite important in determining the outcome of the model, so they should be based on investigation of existing conditions and not simply picked out of the air. The values selected for the light rail transit mode were based on the research conducted in this study, which is summarized in other portions of this report. The other values, including those for characteristics of the two bus modes, were based on the research described in the aforementioned dissertation, except that cost figures were updated.

Certain of the parameter values are common to all transit modes tested; these are given in Table 4-35. Two of these items are particularly important: the monetary value of travel time and the interest rate (which is used to convert capital costs to annual costs). The value of time assumed was equivalent to $2.40 per hour; this is a figure that has been used by many transportation planning agencies and it is generally considered to be conservative. The interest rate chosen was 10 percent, which is the rate prescribed by the U.S. Office of Management and Budget for economic analyses of federally-aided projects.

Some of the other items may not be self-evident. The number of annual weekday equivalents is the ratio of annual passengers to average weekday passengers (it is less than 365 because passenger volumes are lower on weekends and holidays). The transit service period is the number of hours of the day during which service is offered. The peak headway factor is the ratio of peak headway to all-day average headway; it is used to incorporate the larger demand for vehicles that are out of service for routine maintenance or unscheduled repairs. Station dwell time is the period during which transit vehicles wait at a stop to load and unload passengers. The deceleration rate was assumed to be 3.0 mph/second for all modes because this is considered to be the limit beyond which standing passengers will be knocked to the floor of the vehicle.

TABLE 4-35. SUMMARY OF PARAMETER VALUES COMMON TO ALL TRANSIT MODES.

Parameter	Assumed Values
Walking speed	3.0 m.p.h.
Value of travel time	4 cents per minute
Interest rate	10 percent
Annual weekday equivalents	300 weekdays per year
Transit service period	16 hours
Peak headway factor	0.600
Spare vehicle allowance	10 percent
Layover time	10 minutes per round trip
Station dwell time	20 seconds
Deceleration rate	3.0 m.p.h./second
Economic life of fixed facilities	50 years

Table 4-36 lists parameter values that were assumed to vary among the three transit modes tested. It was assumed that the same bus vehicle would be used for the Local Bus alternative (conventional operation in mixed traffic) and the Busway alternative (operation on exclusive freeway lanes). Each of the items listed deserves a brief commentary.

The cruising speed is that speed at which the vehicles run between stops when not accelerating or decelerating. This is lower than a vehicle's limiting speed because it is very expensive to run vehicles at this speed, and it is not normal practice. The value for Local Bus represents operation in mixed traffic on city streets. The value for Light Rail reflects the Boeing-Vertol Standard Light Rail Vehicle; there are foreign-made cars with higher speeds.

The initial acceleration rate and limiting speed are used in an equation that calculates the amount of delay caused by a vehicle stop. In the model, this delay time is added to the time required for the vehicle to travel at its cruising speed to get the total vehicle travel time.

The value of operating cost for Local Bus is intended to represent a typical value for large cities in Texas at this time. It is lower than values found in Eastern cities, but higher than values for small cities in Texas. The value for Busway reflects the higher average speed in this mode. The formulation of Light Rail operating costs has two components: a charge of $1.80 per train-mile (starting with trains of one car) plus a charge of $0.60 per car-mile. Thus, for one-car train the rate is $2.40 per mile; for a two-car train it is $3.00 per mile; for a three-car train it is $3.60 per mile, and so on.

The $100,000 price for a bus was used to represent the cost of full-size city buses from the two American manufacturers. Prices for LRT vehicles have varied greatly: the $500,000 figure was used. (Recent prices for buses range to $142,000 and for LRT, $800,000).

Construction cost is the most difficult item to estimate in a systematic way since it depends greatly on local and site-specific conditions. The primary intent was to make the relationships between the modes reasonable and fair. It is clear that either a Busway or a Light Rail line is generally cheaper to build than a heavy rail line. However, no conclusive evidence was found of consistent differences between a Busway and LRT; hence it was decided to use the same values for both. It was assumed that the Local Bus alternative would use existing streets and entail no construction.

TABLE 4-36. SUMMARY OF PARAMETER VALUES WHICH VARY AMONG TRANSIT MODES.

Parameter	Local Bus	Busway	Light Rail
Cruising speed (m.p.h.)	15	45	50
Initial acceleration rate (m.p.h./second)	2.4	2.4	3.0
Limiting speed (m.p.h.)	60	60	60
Operating cost (dollars)			
Per bus-mile	1.50	1.00	—
Per train-mile	—	—	1.80
Per car-mile	—	—	.60
Vehicle cost (dollars)	100,000	100,000	500,000
Construction cost (dollars			
Per route-mile	0	5,000,000	5,000,000
Per station	0	250,000	250,000
Economic life of vehicle (years)	12	12	30
Loading standard (person trips per vehicle trip)	30	30	45

The economic lives of the vehicles reflect typical periods of use, which often involve more than one owner.

The loading standard is a facet of the model that constrains the service to be adequate to prevent passenger loads from exceeding the capacity of the vehicles. The standard is an all-day average which was set at 60 percent of the number of seats per vehicle (assumed to be 50 for bus and 75 for LRT). That is, the model prevents the average number of passengers per vehicle, over the full day, from exceeding 30 for bus and 45 for LRT.

Comparing Busway with Light Rail (probably the comparison of most interest), the latter has the advantages of higher cruising speed, higher acceleration rate, longer vehicle life, and larger passenger-carrying capacity. The bus has the advantage of a much smaller purchase price. The relative operating costs depend on the extent of train operation for the LRT mode. A single bus is cheaper to operate than a single LRT vehicle, but the rail mode can achieve similar operating costs by using long trains. It is believed that these relationships accurately reflect the actual situation.

Results of Modeling Analysis

The modeling analysis consisted of calculating the dimensions of the optimal transit system for each of four hypothetical cities with different density profiles for three alternative transit modes: local bus, busway, and light rail. The optimal system is the one that minimizes total community costs, as defined earlier. Thus, 12 optimal systems were calculated.

It will be convenient to refer to the hypothetical cities with a shorthand indicating their density parameters. For example, City 2000/25 is the city with an A value of 2,000 and a b value of .25. The total number of CBD transit trips for each city can be easily computed (assuming each city is a 360-degree circle and extends to infinity). These totals are as follows:

City 2000/25	201,062
City 1500/25	150,796
City 2000/50	50,265
City 1500/50	37,699

The bottom line in the comparison consists of the total costs for the three alternatives; these results are shown in Table 4-37. These figures are

TABLE 4-37. TOTAL COSTS

City	Local Bus	Busway	Light Rail
2000/25	$ 676,246	$ 824,537	$ 857,691
1500/25	518,172	668,070	696,303
2000/50	109,355	160,459	166,801
1500/50	85,770	131,084	136,135

TABLE 4-38. COST PER PERSON TRIP

City	Local Bus	Busway	Light Rail
2000/25	$ 3.36	$ 4.10	$4.27
1500/25	3.44	4.43	4.62
2000/50	2.18	3.19	3.32
1500/50	2.28	3.48	3.61

total costs for an average weekday and include the monetary value of travel time (which accounts for more than half the total in all cases). The Local Bus mode has the lowest total costs for all four cities. Busway is second in all cases, and Light Rail is third.

The cost figures are large because large numbers of trips are involved. Table 4-38 shows the ratios of total cost per person trip. It can be seen that the advantage of Busway over Light Rail is quite small in all cases. The two cities with b = .50 have lower figures because the average travel distance is lower (it is 4.0 miles when b = .50 and 8.0 miles when b = .25).

It is of interest to inspect the dimensions of the optimal transit systems. Table 4-39 gives the optimal number of radial routes for all cases (in reality this number would have to be an integer, but the calculations in the model do not round off to an integer). Table 4-40 shows the optimal number of stops on each radial route (the model does calculate an integer in this instance). Table 4-41 gives the optimal length of each radial route (in miles). Multiplying the number of radials by the length of each radial yields the total miles of route, which is presented in Table 4-42. In general, these results indicate that the Local Bus alternative would have a far more extensive route system than the other modes, but there would not be much difference between the optimal systems for Busway and Light Rail. The two cities that are more dispersed (with b = .25) have much larger route systems, as would be expected.

Several other characteristics of the optimal systems should be noted. Table 4-43 shows the optimal headway for each case. The Busway alternative would have the most frequent service in all cities, while Light Rail would be second, and Local Bus would be third. The interpretation of the results is as follows: Since Local Bus involves no construction cost but has a high operating cost, the outcome is a dense network of routes and stops with relatively infrequent service. The Busway alternative has a sizable construction cost but low operating cost; this results in a small route system with very frequent service. The Light Rail alternative has a similar network to the Busway, but less frequent service because the cars run in trains. Savings in operating costs are achieved in this way, but the tradeoff is increased waiting time for riders.

TABLE 4-39. NUMBER OF RADIALS.

City	Local Bus	Busway	Light Rail
2000/25	42.6	9.4	8.7
1500/25	37.0	8.3	7.8
2000/50	15.6	5.4	5.2
1500/50	13.6	4.8	4.7

TABLE 4-40. NUMBER OF STOPS ON EACH RADIAL.

City	Local Bus	Busway	Light Rail
2500/25	17	10	9
1500/25	17	9	9
2000/50	11	4	4
1500/50	11	4	4

TABLE 4-41. LENGTH OF EACH RADIAL (MILES).

City	Local Bus	Busway	Light Rail
2000/25	15.14	12.59	12.73
1500/25	15.15	11.93	12.14
2000/50	7.42	4.37	4.33
1500/50	7.43	4.03	4.02

TABLE 4-42. TOTAL MILES OF ROUTE.

City	Local Bus	Busway	Light Rail
2000/25	645.19	117.70	111.01
1500/25	560.28	99.17	94.29
2000/50	115.57	23.47	22.65
1500/50	100.86	19.41	18.75

TABLE 4-43. OPTIMAL HEADWAY (MINUTES).

City	Local Bus	Busway	Light Rail
2000/25	12.21	2.68	9.96
1500/25	14.43	3.18	10.60
2000/50	17.84	6.16	9.00
1500/50	20.74	7.36	10.70

Table 4-44 gives the average speed for each test including stops but not layover time at the end of a run. Light Rail would achieve the fastest speeds, with Busway close behind and Local Bus far in the rear.

The next three tables set aside travel time and deal only with cash costs. Table 4-45 shows the total operating, equipment and construction cost per transit rider. Light Rail has the highest figures in all cases, but only slightly above those for Busway. Table 4-46 gives only the operating cost per transit rider; Light Rail is lowest in two cases, and Busway in the other two. Table 4-47 shows the total initial investment that would be required to put each system in operation (the costs of equipment and construction). Light Rail would be most expensive in all cases, but only a little more so than Busway.

Table 4-48 reports the ratio of transit passengers per vehicle-mile operated. It has been a rule of thumb in the transit industry that a ratio of at least 3.0 is required for a service to be viable. It can be seen that this is exceeded in a majority of cases. Table 4-49 gives the total number of daily transit passengers per radial route; this is merely to give an idea of the scale of total demand which might be needed to justify a route.

To recapitulate, the basic tests with the transit optimizing model showed that for all four hypothetical cities with density characteristics similar to those of Texas cities, a conventional bus system operating on city streets in mixed traffic would be the least cost transit alternative. The large capital investment required for Busway or Light Rail system would not generate enough time savings to produce lower total costs. The optimal Busway and Light Rail systems were found to be quite similar in their dimensions, with the LRT alternative slightly more costly in all cases.

Sensitivity Tests

While a conscientious effort was made to select reasonable values for the parameters of the model, some of the values are certainly subject for debate. Often the data show a considerable dispersion, and there may exist situations where particular values would be more favorable to Light Rail Transit. To explore how this might affect the results, a number of sensitivity tests was performed in which certain parameter values were changed. To keep from greatly multiplying the number of model runs, the tests were focused on a narrow approach, namely, to see how the values would have to be perturbed to make LRT come out the least cost alternative.

TABLE 4-44. AVERAGE VEHICLE SPEED (MPH)

City	Local Bus	Busway	Light Rail
2000/25	13.38	31.99	35.48
1500/25	13.38	32.46	34.99
2000/50	12.93	30.64	32.57
1500/50	12.93	29.84	31.72

TABLE 4-45. TOTAL OPERATING, EQUIPMENT AND CONSTRUCTION COST PER TRANSIT RIDER (CENTS)

City	Local Bus	Busway	Light Rail
2000/25	102.0	157.7	158.3
1500/25	102.4	168.0	171.5
2000/50	54.6	108.0	114.7
1500/50	55.4	115.8	122.2

TABLE 4-46. OPERATING COST PER TRANSIT RIDER (CENTS)

City	Local Bus	Busway	Light Rail
2000/25	78.5	43.2	37.6
1500/25	78.7	41.0	38.0
2000/50	41.0	15.6	18.7
1500/50	41.6	14.4	17.3

TABLE 4-47. INITIAL INVESTMENT REQUIRED

City	Local Bus	Busway	Light Rail
2000/25	$ 93,301,000	$ 648,466,000	$ 687,835,000
1500/25	70,011,000	540,509,000	571,528,000
2000/50	12,623,000	127,086,000	132,320,000
1500/50	9,473,000	105,012,000	108,472,000

TABLE 4-48. PASSENGER PER VEHICLE-MILE

City	Local Bus	Busway	Light Rail
2000/25	1.91	2.32	3.40
1500/25	1.90	2.44	3.57
2000/50	3.66	6.42	9.65
1500/50	3.50	6.97	10.39

TABLE 4-49. PASSENGERS PER RADIAL

City	Local Bus	Busway	Light Rail
2000/25	4,500	20,903	22,167
1500/25	3,921	17,601	18,674
2000/50	2,923	8,735	8,901
1500/50	2,480	7,323	7,485

First, the operating cost for LRT was lowered to $1.50 per train-mile plus 50 cents per car-mile (these are 5/6 of the original values). Then the optimal LRT system was determined for City 2000/25. The result was that total costs for LRT were reduced only slightly, from $857,691 to $845,196. They were still well above the totals of $676,246 for Local Bus and $824,537 for Busway for this city.

The second test was to return the operating cost parameters to their original values and to lower the LRT construction cost per route-mile to $2,500,000 (one half of its original value). The rationale was that in some cities it might be possible to obtain a large amount of right-of-way for LRT lines at little or no cost. Construction costs for stations were left at $250,000 since they would probably not be affected by cheap right-of-way.

For City 2000/25, this reduced the total costs for LRT substantially, to $748,639. This total was still higher than that for Local Bus, but it was cheaper than that for the Busway alternative (for which the route-mile construction cost was $5,000,000).

The third test involved increasing the density of transit trip ends since it is widely believed that high density requires capital-intensive transit systems. For this, a fifth hypothetical city was "created," City 4000/25, with an A value of 4,000. This city everywhere on its surface was twice the density of trip ends as City 2000/25. To make the comparison, optimal transit systems had to be calculated for the Local Bus and Busway alternatives as well as for LRT.

This test did not change the rank order of the alternatives in respect to total costs. The figures were as follows:

Local Bus	$ 1,296,898
Busway	1,389,679
Light Rail	1,433,509

However, the differences among the three modes were reduced, so that LRT did relatively better in this comparison.

For the final test, all of the changes made in the earlier tests were combined. That is, operating costs and construction costs for LRT were both reduced (as described before) and an optimum was determined for City 4000/25.

This did succeed in making LRT the cheapest alternative with total costs of $1,247,199. Referring to the numbers above, it can be seen that this is less than the totals for either the Busway or Local Bus alternative for City 4000/25. It should be recalled, though, that the Busway mode involves a construction cost twice that for LRT. This implies a situation in which cheap right-of-way is available for LRT, but for some reason is not suitable for busways.

The sensitivity tests indicated that in cities with a very high density of transit demand and where LRT lines could be built very cheaply, Light Rail Transit could turn out to be the optimal transit mode. The conclusion can be applied to a single corridor as well as entire city.

Conclusions

A mathematical model for optimizing the dimensions of a radial transit system was adapted to the purposes of this study and used to compare Light Rail Transit with two alternative transit modes, a busway system and ordinary bus service on city streets. Empirical research disclosed the values of the negative exponential density function that would represent the density of CBD transit trips in Texas cities. The model was used to calculate the optimal transit systems for the three modes for four hypothetical cities with density patterns similar to those of Texas cities.

The tests showed that LRT would be the most expensive alternative in all four cities. Conventional bus service would be the cheapest in all four. However, sensitivity tests suggested that there could occur unusual situations, with high demand and low costs, where Light Rail would be the optimal transit mode.

The following conclusions are drawn from this phase of the research:

1. It is unlikely that a complete, citywide LRT network can be justified in any Texas city unless there is a drastic increase in demand for transit.

2. There may be individual corridors in certain Texas cities where unusually favorable conditions would make LRT a strong candidate. These conditions would probably include a high concentration of transit demand and low costs for right-of-way acquisition and construction.

3. When fixed guideway transit systems are being considered, LRT and exclusive bus lanes are fairly comparable alternatives and, according to the model used here, produce total community costs that are

quite close. It is believed that average construction costs for the two modes are similar. The principal advantage of busways is that the vehicles are much cheaper. This difference can be offset by the ability of LRT to run long trains, but this is only effective in situations of very high demand.

4. There may be other factors that make LRT more attractive than bus systems, but they fall outside the scope of the economic analysis reported here.

AN ASSESSMENT OF LRT VIABILITY

Unlike most technological changes in mass transportation currently being considered, Light Rail Transit is essentially a resurrection of an older technology that has virtually died out in the United States. It can be seen as a return to a 19th century solution to the urban transportation problem, although LRT advocates emphasize that the modern concept includes some important improvements. Of course, "old" is not necessarily equivalent to "out of date." The fact that the basic technology was invented almost 100 years ago does not rule out the possibility that it could be useful and valuable today.

This background does raise certain valid questions which will be addressed briefly in this section. To wit:

1. Why did the streetcar---once the backbone of American transit systems---disappear from virtually all cities, except for a handful (the seven "retained" cities already discussed in this report)?
2. Why was the streetcar retained in these particular cities?
3. Why has the streetcar remained a key transit mode in many foreign cities?

These are not questions of merely historical interest since the answers may provide some clues to the type of situation in which LRT would be viable today.

Why Did the Streetcar Disappear from Most American Cities?

The decline of the streetcar was an integral part of the overall decline of transit operations and transit riding in the United States. If the demand for urban public transportation had increased, or even remained stable, over the past 50 years, it is quite likely that many streetcar operations would have been preserved and even expanded. The wide-spread financial difficulties of American transit firms obviously created a climate in which retrenchment and abandonment were the norms.

Reasons for the historical drop in mass transit usage have been amply discussed elsewhere and need no elaboration here. Paramount was growing automobile ownership in this country, which was made possible by the secular increase in income, abetted by mass production of a medium-priced vehicle (Henry Ford's Model T) and introduction of the installment purchase system by General Motors. Extensive highway-building programs and the eruption of low-density suburban development after World War II (encouraged by federal mortgage programs) are also cited as major factors.

The electric streetcar was a relatively early innovation in the transit industry. It was introduced in the 1880's, spread like wildfire in the 1890's, and by 1900 had become the mainstay of urban transit. While early statistics are somewhat spotty, the available data indicate that the annual number of streetcar passengers increased until 1923 when the total peaked and then began to fall. However, the total number of passengers by all transit modes did not peak until 1926 (from whence the figure gradually fell until a revival during World War II). The source of this difference was partly that passengers on subway/elevated systems rose gradually during the 1920's, but more significantly, that the motor bus was introduced. Passengers on buses were first reported for 1922 (when the national total was 404 million); this figure rose rapidly to 2.6 billion in 1929.

This suggests that the major factor in the decline of the streetcar was replacement by buses, and indeed, this explanation is widely accepted by transit historians. There is dispute, though, over the reason for this substitution. One theory holds that it occurred because of inherent advantages in the bus, while another maintains that it resulted from a successful conspiracy on the part of large manufacturers who stood to profit from such a shift.

It has been widely claimed that the bus had a lower operating cost (per vehicle-mile) than the streetcar, and this was the major factor causing American transit companies to switch. The actual cost picture is rather cloudy, however, both because accurate cost data are hard to come by, and because overlaid on the change was another general transition from two-man to one-man operation.

In the early decades, most streetcars operated with two men, a motorman and a conductor. There were large doors for boarding in the middle of the vehicle; the conductor stood at this point and collected fares as passengers got on. One of the advantages of the PCC car introduced in the late 1930's, was that it was designed for one-man operation. Passengers all boarded at the front where the motorman collected fares and exited through a small door near the rear.

In contrast, buses in this country almost always operated with a single employee; passengers entered at the front and the driver collected fares. (This system has not been so common in Europe where buses have often operated with two men——especially double-decker buses such as used in London, where passengers board at the rear).

Thus, when American transit operators arrived at the point where they needed to decide whether to shift to bus, often they were comparing the costs of two-man operation of streetcars with one-man operation of buses——surely not a very fair comparison. By the time the PCC car came along, hundreds of transit companies had already decided to go with the bus.

Aside from this, the bus indisputably had one cost advantage over the streetcar: it operated over a right-of-way that was already available, and built and maintained at public expense. For a bus operator, the capital cost of obtaining a guideway was zero. A prospective streetcar operator would have to construct tracks, overhead wires with supporting poles, and an electric power distribution system——a reasonably substantial capital investment. Where the track was laid in an existing street, the pavement would have to be torn up, and the streetcar operator was responsible for repaving it after installing the track.

Even continuing operation of an existing streetcar line involved a slight cost disadvantage because the transit operator had to maintain the facilities needed by the streetcars——the tracks, wires, power supply, etc. In many cases, the local franchises under which streetcar firms operated made them responsible for street cleaning and snow removal on the streets that were used by their lines. Bus operators never had to bear any of these costs.

It has been alleged that this difference in financial responsibility represented an implicit government subsidy for the bus. The streetcar had to pay for its own guideway while the bus used a guideway provided free of charge by the taxpayers in general. There is certainly some validity to this argument but there is no evidence that this was a deliberate intent of local government bodies. It seems to have been an unanticipated result of the existing institutional structure, and one which apparently did not occur to anyone at the time.

The other theory advanced to explain the streetcar-bus shift alleges that a group of manufacturers (headed by General Motors) conspired during the 1930's and 1940's to persuade or force local transit firms to abandon their streetcar services and switch to bus operation. General Motors has long dominated the manufacture of urban transit buses in this country; in most years it has accounted for at least 90 percent of the buses produced (at present there is only one other transit bus manufacturer, the Grumman Flexible Corporation). These manufacturers allegedly formed a firm, National City Lines, which gradually bought up transit properties throughout the United States when they ran into financial difficulty (the transit firms sold their stock to National City Lines in exchange for cash, which they used to solve their immediate financial problems). Stock ownership gave National City Lines control over the firm's decisions, and supposedly replacement of streetcars by buses was dictated. Further, GM offered attractive financial terms to transit operators who ordered its buses.

This theory was given national publicity through the testimony of Bradford C. Snell before the Senate Subcommittee on Antitrust and Monopoly in 1974. While he presented what seems a plausible scenario, his charges have not been proven. (Since the alleged conspiracy occurred 30-40 years ago, it is now only a matter of historical interest.) It is true, though, that the Department of Justice did obtain a consent decree from General Motors which forced it to divest its stock in National City Lines.

The import of this theory is that the streetcar did not get a fair comparison with the bus, and if it had not been for the self-interested bias of the bus-oriented manufacturers, the streetcar would be much more prevalent in this country than it is today. The validity of this can only be a matter for speculation, but it is of interest that the streetcar is much more common in foreign countries where auto interests did not have such influence.

There is a final factor that, while it may seem trival, actually had a widespread effect in making the streetcar increasingly unpopular with the American public. As the automobile became more popular and automobile ownership spread, the streetcar came to be regarded by millions of motorists as a nuisance and an obstacle. The tracks in the pavement were annoying to drive across. Streetcars that were stopped to load and discharge passengers frequently blocked traffic. Since a streetcar cannot pull over to the curb (as a bus can), the passengers had to walk out in the middle of the street to reach the car. In most states, motor vehcile laws made it illegal to pass a stopped streetcar. (An alternative arrangement was to build a small passenger island in the middle of the street. This, too, interfered with automobile traffic.)

Because of these minor but frequently repeated inconveniences to motorists, any decision by a transit operator or city to abandon a streetcar line, pave over the tracks, and substitute a bus route was usually greeted with general approbation. It should be noted that the streetcar tracks were usually laid in the major arterial streets which came to have the busiest automobile traffic.

The streetcar had one other adverse impact in the form of its unsightly overhead wires. This certainly contributed to visual blight, but it is doubtful that this was as much a concern as the interference with auto traffic. For a time, many cities switched from the streetcar to the electric trolley bus which also had overhead wires. This change was generally seen as a substantial improvement.

Why Was the Streetcar Retained in Some American Cities?

We come now to the exceptions: As indicated earlier in this chapter, there are seven American cities that have retained some vestige of their early streetcar systems. Why did these lines fail to share the fate of most American streetcar services? (It should be noted that in these cities, there were also many streetcar lines that were abandoned; the retained lines are clearly exceptions.)

Each case probably involves a unique local situation, and a city-by-city history would be necessary to elicit the actual factors that operated. Take New Orleans, for example; this is the only large American city in which the electric utility company has continued to own and operate the transit system. (Other utilities were forced to divest themselves of their transit subsidiaries in the aftermath of the Public Utility Holding Company Act of 1935.) The company obviously provided its own power, and in addition, it long has followed a policy of offsetting transit losses with electricity profits. Therefore, the transit fare has been kept unusually low (it was still only 7 cents in the early 1960's), and per capita transit riding in New Orleans has been unusually high over the years.

New Orleans finally decided to give up all of its streetcar lines except one. In 1966 the median strip streetcar right-of-way in Canal street was paved over and converted to bus-only operation. The one remaining streetcar route is the St. Charles Avenue line. While it does carry a substantial number of commuters and downtown shoppers, the line was principally retained as a tourist attraction (much as the cable cars in San Francisco, which also carry some commuters). In accord with this concept, the equipment consists of 35 rather antiquated cars (of pre-PCC car vintage) which were overhauled in the 1960's so they will continue to be operable for many years into the future.

Another unique situation has apparently occurred in Philadelphia, which currently has the most extensive streetcar system of any American city and which also uses a number of pre-PCC cars. Reportedly the survival of this system is due to one man, who for many years held an influential position in local transportation policy-making and who steadfastly and successfully resisted the conversion of the streetcar routes to buses.

Thus, each city has undoubtedly had some unique factors at work in preserving streetcar service. But do the cities have anything in common, anything that might provide a useful generalization?

The answer is yes: All of the cities have at least one key section of right-of-way reserved for exclusive streetcar use——either a subway section, tunnel, totally separate right-of-way, or median strip reservation. The cases are as follows:

1. The Green Line in Boston has extensive subway sections downtown, as well as a totally separate right-of-way on the Highland Branch and median strips on other branches. The Tremont Street tunnel, used exclusively by streetcars, was the first subway constructed in the United States (it opened in 1897).
2. The Newark City Subway operates entirely on separate right-of-way, some of it underground.
3. Philadelphia's extensive system includes every possible type of alignment configuration. Besides street running, there are tunnels, median strips, and separate right of way on the suburban lines. The

Market Street Tunnel has four tracks: the two inside are used by the heavy rail line, while the two outside are used by streetcars and essentially provide local service with more frequent stops (this is the only such use of street cars in this country.

4. Pittsburgh's system includes a long streetcar tunnel under Mount Washington, plus some sections of separate right-of-way in the South Hills area.
5. The Shaker Heights lines in Cleveland operate primarily in median strips. Downtown, it shares a right-of-way with the heavy rail system.
6. The San Francisco system has a streetcar-only tunnel under Twin Peaks. The Market Street lines are to be put underground, on a level above the BART heavy rail line.
7. The St. Charles line in New Orleans operates primarily in a median strip.

Thus, the existence of some private right-of-way for streetcars seems to have been one key to their survival. However, it clearly did not guarantee survival. For example, in Los Angeles many of the streetcar lines had a separate right of way. Those cities that completely abandoned the streetcar (such as New York, Chicago, Detriot and Washington) were largely characterized by street running rather than separate alignments.

There are probably two reasons why this factor was important:

1. The streetcar lines did not particularly interfere with auto traffic, and thus were not seen as a significant nuisance or an infringement on road capacity.
2. Conversion of the streetcar right-of-way to bus use would be difficult. This is particularly true of underground segements, since buses require a larger tunnel cross-section than streetcars, and buses would require installation of ventilation equipment.

This finding has a clear implication for planning of LRT: it will be more viable where the majority of the route is on a separate right-of-way and there is no intereference with motor vehicle traffic. Where LRT shares surface streets with other traffic, conflicts will inevitably occur and it may be regarded as undesirable by motorists and transportation policy-makers.

Why Has the Streetcar Remained Popular in Foreign Countries?

The decline of the streetcar in the United States stands in marked contrast to its continued popularity in many foreign countries including most of those in Europe. Continuing reliance on streetcars has preserved a viable market for streetcar equipment abroad. Consequently, several car manufacturers have been active in supplying this market. There have been regular innovations and improvements, so that ultra-modern vehicles are common in other countries. Many foreign cities have expanded their LRT systems, and some cities that never had streetcars have recently constructed LRT lines.

There are some well-known differences between urban transportation in the United States and abroad. These have acted to preserve transit riding at a higher level abroad, which has created a climate in which streetcar service is more likely to be retained. Auto ownership levels in foreign countries have consistently lagged behind those in the United States, although some European countries are catching up rapidly. Until about 10 years ago, this was largely due to lower standards of living. Since then, higher gasoline prices have probably been the key factor.

On the average, foreign cities have much higher population densities than cities of comparable total population in the United States. This has encouraged continued high levels of transit patronage, at the same time that it has made auto usage in the central city quite costly and inconvenient. In many foreign cities, the city core has a strong historical character, and this is given more value than by most Americans. There has been strong (and popular) resistance to letting automobiles invade the historic core; proposals to widen narrow streets or straighten crooked ones are usually defeated. The density of historic structures in these cores leaves little room for expanding the parking supply.

In addition, most foreign governments have not weighted their urban transportation policies so heavily in favor of automobiles as has the United States. While some urban freeways have been built, this has not been done on so vast a scale. Decisions, on local transportation improvements are usually controlled by the central government, while in the U.S. the initiative is left to state and local governments, who have been given a set of financial incentives biased in favor of freeways.

Foreign governments have generally been more pro-transit in their policies. In most cases, urban transit systems passed into public ownership at an earlier stage than in America. Transit has long been regarded as a public service or utility, like schools, libraries, sewer, and water. There has not been the expectation that transit systems should earn a profit, or even break even. While the higher level of transit demand has tended to make foreign systems more economic, there has in fact been considerable subsidization of transit for a long time. (Note that it would probably be possible to make some of these systems profitable, but it has often been public policy to continue unprofitable routes and services.)

These things all help explain why foreign cities are more transit-oriented, but they do not specifically explain why streetcar systems have been retained. Why did these cities not abandon streetcars in favor of buses, as did American cities? (It can be argued, of course, that they did not have a dominant bus manufacturer trying to effect such a change). There have in fact been a number of major foreign cities that did abandon streetcars: Paris (1937), Manchester (1949), London (1952), Edinburg (1958), Sydney (1961), Glasgow (1962), and Bombay (1964). This is undoubtedly not a complete list.

There appear to be some national differences. Examination of the list of cities with LRT (given in Chapter 2) shows that there are very few in Great Britain or France (however, a new LRT system is being constructed in Newcastle-on-Tyne in England). West Germany, Italy, Switzerland, Austria and the Low Countries have favored LRT among the Western European countries. The vast majority of LRT systems are found in Eastern Europe or Russia; here there is clear evidence of a central government policy favoring LRT.

There are a few considerations that might make LRT seem more attractive in Europe than America. First, European countries have much higher prices for petroleum-based fuels (partially because of higher taxes), and this would reduce (and conceivably eliminate) any advantage in operating cost that buses might have.

Second, some foreign cities have very narrow streets in their historic cores. LRT can operate on a narrower right-of-way than buses, and there are some very slim LRT vehicles on the market. Amsterdam provides an excellent example of this situation: The core of the city still adheres to the 17th Century "Plan of the Three Canals" and has quite narrow streets: the city uses very narrow, long, articulated LRT vehicles of modern design.

Third, LRT has an efficiency advantage over bus in its ability to run vehciles in trains to handle high demand. Such levels of demand are more likely to occur in foreign cities.

These reasons are probably inadequate to explain why LRT has retained its popularity abroad. The basic reason is unknown; it would require more investigation than possible in this study. However, the following summary of conditions in most foreign cities provides at least a plausible view:

1. Foreign countries have over the years been more transit-oriented and less highway-oriented than the United States (both in terms of usage and public policy).
2. Consequently, retrenchment and abandonment of public transportation have been less common; there has been much less pruning of routes and services. Since streetcars lines already existed in many cities, they have continued.
3. Transportation policy abroad has been oriented more towards service than economy; subsidies have been taken for granted. Hence any small cost advantages that bus might have over LRT were not given much weight.
4. Many countries have recognized that LRT has certain inherent advantages (over bus on the one hand, and over heavy rail systems on the other). Thus, all along they have kept LRT in the forefront as one of the urban transportation options to be seriously considered. This has led in some cases to development of new and expanded LRT systems.

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3. Edwin S. Mills, "Urban Density Functions," Urban Studies, Vol. 7, No. 1 (February 1970), pp. 5-20.

FOOTNOTES

[1] This method was pioneered by Richard F. Muth in "The Spatial Structure of the Housing Market," Papers of the Regional Science Association, Vol. 7 (1961), pp. 207-220.

[2] This is the method used by Colin Clark, who first pointed out that urban population densities decline from the city center according to the negative exponential function. See Clark, "Urban Population Densities," Journal of the Royal Statistical Society, Vol. 114, Part 4 (1951), pp. 490-496.

CHAPTER 5. FACTORS RELEVANT TO EVALUATION

MONETARY COSTS

This chapter identifies the major factors that should be considered in evaluating any Light Rail Transit proposal and presents some specific information that will be useful in gauging their magnitude. Prominent among these factors, in these days of fiscal stringency in the public sector, are out-of-pocket costs which are discussed in the first part of the chapter. This is subdivided into three sections which take up, in turn, vehicle costs, construction costs, and operating costs.

Some advocates of Light Rail Transit (LRT) claim that one reason for its attractiveness as an urban transportation alternative is the existence of its proven technology. However, there are few existing systems in the U.S. which are examples of the new concept of LRT. In a search to determine monetary costs for new LRT systems, one finds the only recent cost figures are for new vehicles for old systems, refurbishing and upgrading costs for old systems, preliminary studies for construction of new systems, and some foreign experiences which are difficult to convert and compare to U.S. experience. What one does learn from the current cost reports is that the concept of LRT can be applied to such varied situations that no single costs are typical, but rather that "you get what you pay for."

The hope for LRT is that it can provide the advantages of a fixed guideway transit system at lower costs than conventional rapid transit and to cities whose densities and population do not merit conventional rapid transit. The advantages of LRT, which distinguish it from streetcars and make it comparable to conventional rapid transit, are the faster speeds obtained by running faster vehicles in separate rights-of-way and the reduced operating costs which should result from operating in trains. In an examination of current and projected costs, there are necessary tradeoffs between the performance advantages and the anticipated lower costs of an LRT alternative.

Vehicle Costs

The modern technology for a light rail vehicle (LRV) is different from that for the streetcars which run in most American systems. These streetcars were designed in 1935 by the President's Conference Committee (PCC) and were last manufactured in 1952 (Ref 1). A life of 25 years for the PCC cars means that currently existing American systems are in the market for new vehicles. San Francisco's effort in 1971 to purchase newly designed and manufactured light rail vehicles showed the need to have another "President's Conference Committee."

San Francisco's Muni solicited bids for 78 LRV's designed by the consultant firm of Louis Klauder and Associates specifically for San Francisco. The lowest bid (by Boeing) was $473,000 per car. Since Muni was looking to the Urban Mas Transportation Administration for federal matching funds on the order, UMTA played a part in Muni's rejecting the bids as too high. The problem was that the manufacturing company had to charge Muni for the engineering, development, and tooling costs because there was no assurance of future orders for the same car. This realization prompted UMTA to sponsor a committee of light rail transit operators to determine some standard design specifications that would be suitable to all (Ref 2).

The importing of a European vehicle was an alternative once proposed by UMTA instead of the standardizing of an American-made LRV. This alternative proceeded to the point of selecting the Hannover car by DuWag of Germany, but the politically sensitive issue of an adverse balance of payments situation led UMTA to move in the direction of a Standard Light Rail Vehicle (SLRV) to be manufactured in the U.S. (Ref 2). This situation has since been reversed as a result of Boeing ceasing production of the LRV.

The agreement by Muni, Boston's MBTA, and Philadelphia's SEPTA on a standard design resulted in an order for 80 Muni cars and 150 cars for MBTA. Besides the larger order, the reduced performance from the original Muni design caused the bids in 1972 from Boeing-Vertol to be $316,616 for each Muni car and $293,422 for each MBTA car. The SLRV design elimination of the powered center truck means the vehicle has a top speed of 50 mph rather than the 65 mph of the original Muni design (Ref 2).

The standardization of an LRV was intended to cause prices to be lower. This results from the efficiency of economies of scale; i.e. the increase in capital costs is minimal for additional production since the equipment already exists. Therefore, larger orders of the same vehicle simply mean that the original capital costs are spread among a larger number of units produced, thus reducing the individual unit cost.

The standardization advantages have not proved to outweigh other disadvantages. One recent disadvantage is the risk of inflation of construction costs between the time of bidding and the time the order is completed. Another disadvantage is the uncertainty of additional orders in the future, as mentioned in regard to the 1971 San Francisco experience. The anticipated replacement market is no more than 800 vehicles, and the only totally new American system beyond the preliminary study stage is Buffalo (Ref 2).

The recent Cleveland contract for LRV's in September 1977 is interesting for two reasons. It showed how little effect the development of an SLRV has had on the market pricing, and it again brought up the issue of importing foreign vehicles.

Cleveland was not a participant in the conference on guideline specifications for an SLRV. It is not known how much Cleveland specifications differed from the SLRV which Boeing had manufactured for Boston and San Francisco, but Boeing's was the highest bid at $869,492 per vehicle, a significant increase over the approximately $320,000 SLRV bid five years earlier. Boeing should have had the advantage of already having done the necessary tooling for production, but the company needed to make up for having bid too low on the original SLRV orders to be able to cover the inflated car construction costs and the problems encountered in testing and modifying the vehicles. While some say LRT's "off-the-shelf" technology required minimal development costs (Ref 3), Boeing obviously felt otherwise.

Because the Cleveland order specified number of seats rather than number of vehicles, the range in cost per vehicle was quite large. The low per-car bid was $430,000; the high was $870,000 (Boeing's) (Ref 4). The company which won the bid, Breda Construzioni Ferroviaria, an Italian firm, offered cars at $645,833 each. The unprecedented specification for number of seats has some interesting implications for the operating procedures of the vehicles. With a higher seating capacity per vehicle, the vehicles would likely run with greater headway. The number of vehicles in a train would vary depending on the seating per vehicle. It is interesting that Cleveland was not particular about the size of vehicles since operating in trains and headway affect the level of service and the operating costs.

Pullman Standard, the American runner-up for the bid, has contested the contract, first to UMTA and then in court, claiming the Italian company's bid was non-conforming. The reason given was that the 84-seat capacity of the winning LRV included seats in the articulated area, an unsafe practice (Ref 5). An unspoken reason why Pullman and other American rail car-builders are upset over the Italian order is that American companies are the underdogs in the competition. One factor which favors the European companies is that the LRT market there never really died, as it did in the U.S., and it has recently been picking up. In other words, the European companies are already experiencing economies of scale. The Italian company, for example, has filled several orders for the car it bid in Cleveland (Ref 6).

The hot issue of foreign competition is whether the U.S. government should give American companies the breaks that American car manufacturers believe the foreign governments give their industries. One example is that in Canada, the manufacturers can write-off engineering costs as research and development, which the government supports (Ref 7). Canadian officials have admitted that contract awards in their country are often based on Canadian employment opportunities and the "possible export potential" rather than being based only on the lowest bid (Ref 7). Other suspected practices by the government are the waiver of domestic taxes and subsidies to ensure full employment. There is also the complaint that foreign markets are not as open to U.S. companies as the U.S. market is to foreign companies (Ref 7).

There is no federal law requiring acceptance of the lowest bid (though the State of Ohio does have such a law) (Ref 8). A UMTA deputy administrator (Charles Bingman) has stated that the agency's policy is for a bidding procedure and the accepting of the lowest qualified bidder. He felt that UMTA's 80% funding for vehicle purchases is government involvement which encourages the private market (Ref 7). While the taxpayers are saving by purchasing the lowest bid vehicles, the taxes which an American company would pay on its car sales would not be returned to the government when the contract goes to a foreign company.

The variation in reported vehicle cost figures is partly due to the variation in vehicle size and features, but it is also due to a failure to calculate the inflation of car building costs, which is shown by the high figures in the Cleveland bids. For example, since Boeing bid the San Francisco and Boston cars at approximately $320,000 in 1972, reports in 1975 anticipated the cost of the SLRV to be in the range of $450-600,000 (Ref 9). However, by 1977, Boeing estimated the cost at $870,000. The Canadian UTDC vehicle, smaller than the SLRV by 20 feet and non-articulated, was originally estimated to cost $250,000 (Ref 9). However, in 1975 dollars, it is reported to be at $363,000, and by the time of delivery to Toronto in 1979, it will probably cost $490,000. An additional product which the UTDC company offers is an unpowered trailer vehicle for $100,000 less (Ref 3). The Tyne and Wear car, a British product for Newcastle's completely new LRT system, is larger and more powerful than the SLRV, and is estimated to cost $600,000 at delivery time (Ref 3). The German DuWag company has several versions of LRV's with a variety of features and sizes. A 1975 report claims the cost is $426,000 for a model to be used in Germany. The cars purchased for Edmonton, Canada, are a different model and are expected to cost $540,000 in 1977 (Ref 3). The DuWag car bid in Cleveland in 1977 was the second lowest seat bid at $731,000 per vehicle (Ref 7). Today (1980) these vehicles are estimated to cost approximately $800,000.

Among the most adversely affected by this alarming inflation of vehicle costs are those cities whose preliminary studies have used vehicle costs which were grossly underestimated. Two studies in 1973 dollars, for Rochester and Dayton, used vehicle cost figures of $325,000 and $253,000, respectively (Ref 10). A 1974 study for Denver used a range from $350-500,000 (Ref 3). Slightly more realistic were the studies for Pittsburgh and Austin. The Pittsburgh study, in 1975 dollars, was using vehicle costs of $543,333 per car (Ref 11). The Austin proposal had inflated the SLRV cost to $590,000 in 1976 dollars and supposed that the purchase would be part of a joint order to keep the unit cost as low as possible (Ref 12).

All studies which are done in constant dollars assume that inflation for all costs will occur before the implementation is complete. However, the recent bids have shown that the LRV market is one in which car costs are rising faster than what had been expected. An optimistic outlook for the rail car market would be that enough new systems ordering cars would drive the price down to a level which is not prohibitive. Another hope is that the technology will be perfected, and manufacturers will incur less cost in testing and modifying the new equipment.

Construction Costs

There are many variables which determine the cost of constructing a route mile for an LRT system. The combination of variables is what makes every light rail network unique. The choices that are made as to how the route should be constructed are directly related to the tradeoffs between capital costs and operating procedures. Examples of costs given here include engineering estimates for hypothetical situations and studies for proposed new lines in North America. No data were available on recently completed construction to verify the accuracy of estimates.

One variable which affects construction costs is whether land must be acquired or feasible right-of-way exists, such as railroad right-of-way, medians of freeways or boulevards, or lanes in a city street. If land must be acquired, costs are highest when commercial and industrial property is involved and when relocation awards must be made. Where railroad right-of-way exists, costs are least expensive when existing tracks can be adapted for light rail and most expensive when totally new tracks must be laid.

Another critical factor is the choice of constructing at-grade or grade-separated. Totally grade-separated means the construction of tunnels or aerial structures. Tunneling, the most expensive type of route construction, costs highest when the cut-and-cover method is used and is less when boring tunnels without street excavation (Ref 13). Aerial is the next most expensive route construction, and surface, of course, is the least. Surface construction varies in cost depending on the number of grade-separated crossings. At-grade crossings also vary in cost based on the degree of sophisticated signaling equipment involved.

Station construction costs are also quite varied. Underground stations are, of course, the most expensive, like their accompanying route construction. Size and quality of stations can be matters of aesthetic design preferences. Functional considerations include whether to have the more expensive but more efficient high-level loading platforms or low level ones. Automated fare collection equipment is an added expense, as is TV surveillance for security purposes. Parking areas provided adjacent to stations can also add considerably to their costs. The least expensive type of station is the simple shelter at surface level.

The DeLeuw, Cather and Company study of LRT, prepared for the Department of Transportation in 1976, listed engineering cost estimates from four sources (see Table 5-1). The Beetle and Dyer sources are not site-specific and thus have larger ranges than the DeLeuw figures, which were prepared for Denver. In using these or any of the following figures, it would be necessary to inflate them to the same and preferably current year to compare. Using the lowest figures for each category of cost, the costs per route mile were summed, excluding stations, maintenance facilities, engineering, and contingencies, and vehicles. The least costly per route mile estimates were $1,395,000 (Beetle), $2,400,000 (Dyer), and $3,760,000 (DeLeuw). The DeLeuw figure is high because the traction power was assumed to be third rail, a characteristic not usually associated with LRT. The highest cost estimates for a route mile, using the highest cost per category and excluding the same items, were $28,000,000 (DeLeuw), $36,220,000 (Beetle), and $36,440,000 (Dyer). The high cost systems are, of course, all underground. However, these are all fairly conservative compared to other sources which claim tunneling can be as much as $50 million per mile (Ref 9) or in the range of $70-200 million per mile (Ref 14). Tunneling costs can vary depending on the composition of bedrock and soil texture. When the cut-and-cover method is used, there are added costs for resurfacing the street over the support structure. It is also likely that these highest costs include land acquisition and relocation expenses, which the DeLeuw report does not. In reality, these most expensive subway costs will probably be avoided.

The DeLeuw, Cather study also included a diagram (see Figure 5-1) showing some hypothetical systems and their route mile costs based on the costs in the previous table. The systems which seem to be most similar to the few existing American LRT systems and to those which are currently being analyzed or planned are numbers 3, 4, 5, and 6. System 3, which includes 20% underground, 20% elevated, 20% at-grade with grade-separated crossings, and 40% at-grade with non-grade-separated crossings, has a

TABLE 5-1. COMPARATIVE UNIT CAPITAL COSTS FOR LIGHT RAIL TRANSIT AND RAIL RAPID TRANSIT (RRT), (IN THOUSANDS OF DOLLARS)

Cost Element	De Leuw 1974 LRT *	Beetle 1975 LRT **	Dyer 1975 LRT ***	Dyer 1975 RRT ****
Guideways (per mile)				
Dual aerial	6,200-8,000	10,000-15,000	2,820-17,150	2,800-17,150
Dual at grade (grade separated)	3,000	2,000-5,300	1,000-2,430	1,150-3,780
Dual at grade (grade crossing)	1,000	340	500-1,000	-
Dual underground	24,000	18,000-35,000	29,130-33,730	29,130-33,730
Trackwork (per Mile)	900	540	750-1,000	750-1,000
Stations				
Aerial	1,300-2,1000	5,000	190-4,560	700-5,160
At grade } medium to high	1,500-1,800		2,770	350-4,150
Underground } passenger-volumes	6,500-12,500	5,000-15,000	440-7,560	870-8,000
Low-level platform } low and medium	60-120	75	20-60	-
High-level platform } passenger-volumes	-	110	-	-
Traction Power (per mile)				
Third rail	1,800	-	-	700-850
Overhead wire	-	490	1,100-1,300	-
Controls				
Block (per mile)	1,300	190	210-410	690-2,650
Grade crossings (per crossing)	60	25-100	50-200	-
Maintenance Facilities (Per Vehicle)	100	60	126-454 (assuming 100 vehicles)	80-281 (assuming 100 vehicles)
Vehicles (each)	350-500	450	320	350
Engineering and Administrative	15%	15%	15%	15%
Contingencies	25%	25%	25%	25%

* Reference 77
** Reference 78
*** Reference 79
**** Reference 79

Source: DeLeuw, Cather & Assoc., Light Rail Transit: A State of the Art Review, (Washington: Department of Transportation, 1976).

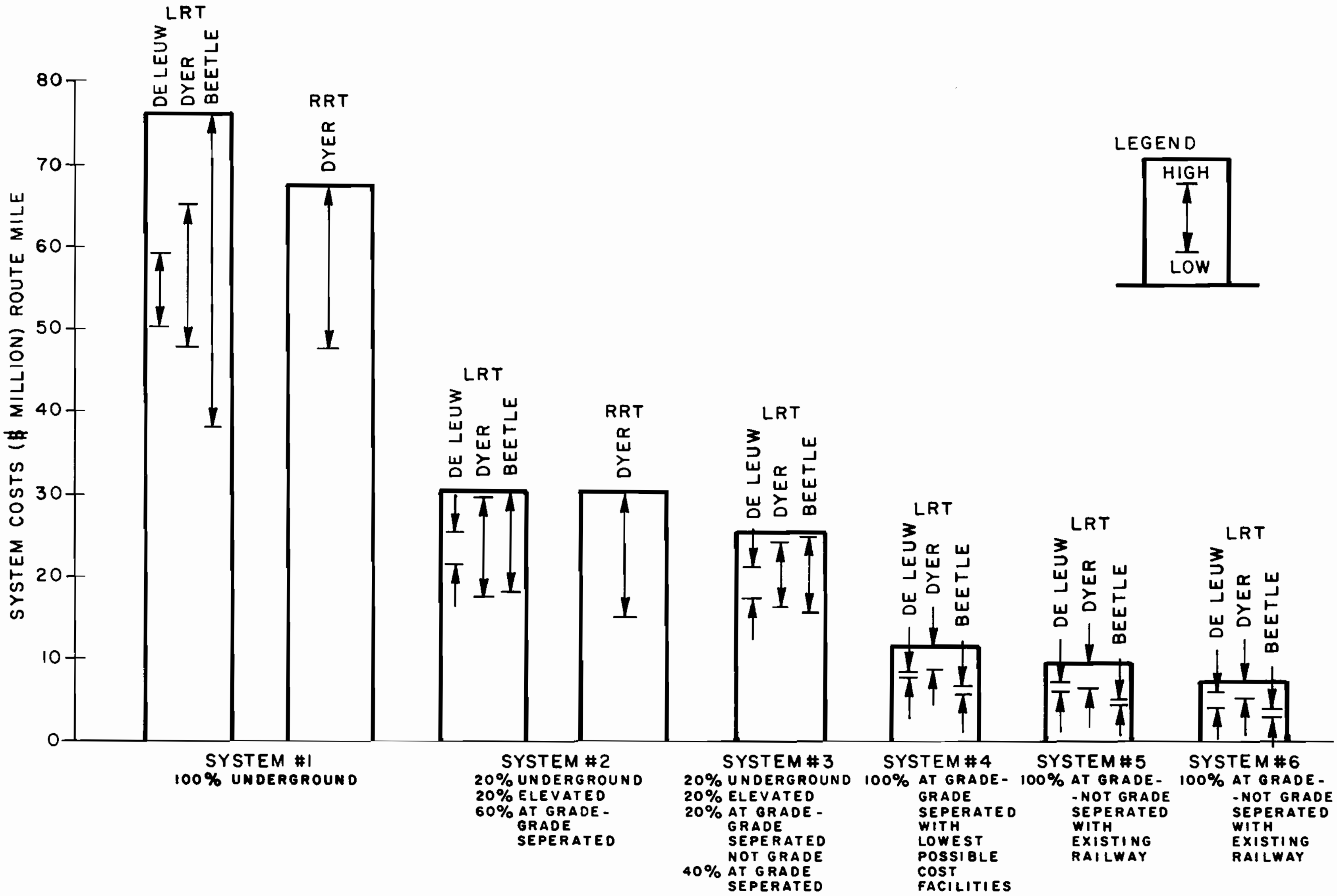


Figure 5-1. Impact of Operating and Right-of-Way Characteristics on Capital Costs (DeLeuw, Cather & Assoc., Light Rail Transit: A State of the Art Review, (Washington: Department of Transportation, 1976).

range of costs from $15 million/mile to $28 million/mile depending on which study's costs are used. Systems 4 through 6 have decreasing amounts of totally grade-separated rights-of-way and have costs as low as approximately $2 million/mile and as high as $12 million/mile. Note that these hypothetical systems include station and vehicle costs.

A look at existing systems will show that most are similar to hypothetical systems 3 through 6. Of the existing systems, only two, Newark and Philadelphia's Red Arrow line (which is partially a third rail system), have 100% fully controlled exclusive right-of-way. Philadelphia's other LRT lines are 98% in shared rights-of-way, meaning they operate in mixed traffic like streetcars. Pittsburgh's existing system is 73% in exclusive or semi-exclusive right-of-way, where semi-exclusive means it is separated from other traffic except for some crossings. San Francisco's LRT operates about one-third in each of the three types of rights-of-way. Boston's LRT has all but 22% in exclusive and semi-exclusive right-of-way (Ref 3). Shaker Heights has 45% located in a tunnel with the remainder on surface but in a boulevard median (Ref 15).

The trend in new systems is toward shorter lines in dense corridors which use exclusive right-of-way and existing semi-exclusive rights-of-way. The two newest North American systems (Edmonton, Canada, and Buffalo) are totally in separated rights-of-way and both include underground sections. The Edmonton system, which opened in 1978, is 4.5 miles with one mile in a tunnel and the remainder in an existing railroad right-of-way. The construction cost of the mile of tunnel is $37 million. The surface portion of the line figures at an average of $3.5 million/mile in 1978 dollars (Ref 3).

The Buffalo system now under construction will be of the semi-metro type (meaning it has some of the characteristics of heavy rail, but is considered to be an "end product" rather than an intermediate stage that will be upgraded later). The 6.43 mile line will have all but 1.23 miles underground. The tunnel section will include 1.7 miles of cut-and-cover and 3.5 miles of rock boring (Ref 16). The capital costs reported for Buffalo are only given as totals and therefore include vehicle and station costs. The average route mile cost, in 1974 dollars, is $38,102,644 (Ref 17). This figure is in keeping with the engineering estimates for underground route mile construction (excluding stations and vehicles).

The New Pittsburgh extension proposed for 1985 completion is a 22.3 mile system, part of which will be in a tunnel. Excluding vehicles but including stations, the route mile cost is $12,242,000 in 1975 dollars (Ref 11). This figure is very close to the Edmonton costs which are for a similar type system.

Since the development of the Boeing SLRV, many cities have prepared LRT alternative studies. The Rochester LRT system, for which a study was undertaken using 1973 dollars, is currently being considered for implementation. It is one of the semi-metro types with totally separate right-of-way, though there is no mention of underground construction. The study gives the construction costs for the 19.4 mile system at $5,829,897 per route mile. Stations, priced separately at $950,000 each, are the high-level-platform type for high-capacity patronage. The study does not mention how right-of-way will be acquired. Therefore, the relatively low cost per route mile may be omitting the land acquisition costs (Ref 10).

Several projects which have not proceeded beyond the preliminary study stage are examples of the least costly type of LRT systems. All three make extensive use of existing railroad right-of-way.

There have been two separate studies for Dayton, both dated 1973 and both planning to use upgraded existing railroad tracks. One study, for a 6.8 mile line, shows a $1,550,779 cost per route mile for land acquisition, construction, fixed facilities (which usually mean stations, power substations, and often include maintenance facilities) (Ref 18). The other study, for a 12.2 mile line, has a slightly higher per route mile cost of $1,901,639. In this study, stations are separately priced at $286,667 each (Ref 10). These figures are both on the low end of the range for route mile costs as given in the engineering studies.

A 1976 study done for a 9.74 mile line in Austin is another low cost alternative for LRT. The well documented costs can be calculated separately for the railroad right-of-way section (7.09 miles) and the on-street section (2.65 miles). The route mile cost for the former is $1,724,683 and the latter, $1,074,717, with the average route mile cost being $1,599,178. Stations are figured separately and range from approximately $48,000 to $750,000, the lower cost being a street-level shelter and the higher cost being a suburban station with parking facilities (Ref 12). These construction costs are also at the low end of the cost spectrum.

The least expensive system proposal discovered for LRT is the 1973 Portland study for a 45.5 mile system using five rail corridors. Portland is a good candidate for this low cost system because of its having at one time been a railroad crossroads. The low cost of $647,978 per route mile includes construction, electrification, and signaling, but excludes stations and the cost of obtaining right-of-way from the rail companies (Ref 18).

In some of the site-specific examples, it has not been possible to determine separate station costs and when it has, there is often no information on the design specification of the stations. Most station costs given here were average costs obtained when the only data available were station construction costs and numbers of stations. Edmonton's two underground stations were costed at $8.7 million each, but several items are not known: height or length of platforms, fare collection method, or amenities extended (Ref 3). As mentioned before, Rochester's average cost per station is $950,000 for high-level platforms, and Dayton's averaged $286,667 each.

One source claims that a shelter-type transit stop, consisting of aluminum and glass, can cost as low as a few hundred dollars. Other estimates by type are $180,000 for a simple high-level platform, unprotected station, and several million for the "Moscow-type marble edifices" (Ref 10).

Beetle's evaluation of construction costs gives separate estimates for each station component. A low-level platform, four-car train length, with shelter, would cost $75,000. An additional $36,000 would be needed for a high-level platform. Automated fare collection equipment would run $120,000 per station and would likely be accompanied by TV surveillance to detect vandalism to the machines at a cost of $50,000. In order to provide ramps and facilities for the handicapped, $10,000 more would be needed. The sum of these components would be $291,000 per station (Ref 13).

With Beetle's same cost estimates, the cost of a suburban station with parking lots can be calculated. The cost of parking is estimated at $1400 per car space. A hypothetical station might be the low-level type with no fare collection or surveillance equipment and with 100 parking spaces. This station would cost $225,000 (Ref 13). The tradeoff of deleting the fare collection equipment means an increase in operating costs when the procedure substitutes a ticket agent either at the station or on board.

The next section on operating costs will treat the issue of tradeoffs between operating procedures and the amount of capital investment in a system. The savings in capital costs usually mean a lower speed system or more manpower and thus higher operating costs.

Operating Costs

Operating costs per vehicle miles are varied and have various implications. The variation within and between systems is sometimes due to data from different sources for the same system or to different methods of record-keeping for operating costs. Some transit systems operate more than one mode, and LRT is not always reported separately. This explanation is given simply to note that some discrepancies may be due to the unreliability of data. It should also be recognized that wage rates are higher in some cities or regions of the country and thus affect operating costs. The factors influencing operating costs which will be considered here are the speed of the vehicles, the number of workers in the system, and the amount of maintenance required. These three factors are closely related to the system's design which, as discussed previously, is related to the capital investment in construction and vehicles.

Cost examples of currently operating LRT systems will be given for Newark, Shaker Heights, and San Francisco. Their operating procedures and system characteristics will be described as much as possible. Then operating procedures will be related to operating costs, as well as to the effect of capital investment.

The Newark system, which is mostly subway, operates totally on exclusive right-of-way. The station platforms are low level, and there is no multiple unit operation (Ref 19). The vehicles used are still the old PCC cars last manufactured in the 1950's. One source reports the average speed at 32 mph (Ref 3), while another reports it to be 14.2 mph (Ref 14). The discrepancies in average speed often depend on how layover time is considered. The 32 mph is probably more realistic for an exclusive right-of-way operation. A labor intensity proportion is reported to be 2.66 employees/vehicle. This represents all types of employees rather than the number of operators per car (Ref 3).

Data from Newark from 1961-70 were used to calculate a linear regression. In 1970, the operating cost per vehicle miles traveled (VMT) was $1.63. Projected to 1978, the cost per VMT would be $2.01. However, by 1972, the annual VMT dropped considerably, from 605,800 to 462,000, probably due to a cut-back in service. The 1972 cost per VMT was $2.38. There is a correlation between annual miles per peak hour vehicle and operating costs: costs per VMT decrease as miles per vehicle increase. In 1972, the $2.38 resulted from 29,000 miles per peak hour vehicle; in 1973, the cost per VMT dropped considerably, to $1.98, when miles per vehicle increased to 35,000. The 1974 cost rose to $2.04 while miles per vehicle stayed the same. For the 1972 data, trainmen's wages were 23.8% of total operating expenses (Ref 3).

The Shaker Heights system operates 55% in semi-exclusive right-of-way, separated except for crossings, and 45% in exclusive right-of-way. The cars are PCC cars but new vehicles are on order (Cleveland bid). There are two operators per traveling unit, be it a single-car or multiple-unit operation. During the peak period, there is an average of two cars per train. In off-peak, single-unit operation is the procedure. Most fares are collected off-train downtown in a pay-enter outbound, pay-leave inbound procedure. Some fares are collected by operators on the vehicles (Ref 15). Loading platforms are low-level except where the LRT vehicles share trackage with Cleveland's conventional rapid transit in the CBD area (Ref 19).

Operating costs for Shaker Heights from 1960-70 were also used to calculate a linear regression and project it to 1978. The 1970 cost per VMT was $1.54; the 1978 estimate was $1.85. As with Newark, significant reduction in VMT in the early 1970's has caused the cost to rise more than expected. Actual 1972 cost per VMT was $2.24. Operators' wages accounted for 30.9% of total operating costs for that year (Ref 3).

There is less information on the San Francisco LRT system. Prior to upgrading, the system operated about one third in each type of right-of-way: exclusive, semi-exclusive, and on streets in mixed traffic. The average speed was 16 mph. The upgrading, which includes new LRV's which will operate in multiple units, will mean more operation in exclusive and semi-exclusive rights-of-way, and the estimated average speed is 30 mph (Ref 3).

Operating costs were available for the old system for two years. In 1973, the cost per VMT was $2.20 and corresponded to approximately 49,000 annual miles per peak hour vehicle. In 1974, a slight drop in miles to 48,000 had the effect of raising cost per VMT to $2.43. Part of the rise is, of course, due to inflation. Operators' wages account for 30.7% of total operating costs in 1974 (Ref 3).

Reducing the manpower needed to operate a transit system is seen as the most effective way to reduce operating costs, since wages form the bulk of the costs and manpower is the most variable cost component. The other components are maintenance expenses, other than wages of maintenance workers, insurance costs, and fuel costs.

If LRT could operate with one operator per train, this would significantly reduce the costs. Figures 5-2 and 5-3 show the reducing effect on cost per VMT of multiple unit operation with a single driver, and also when there is only one other employee on board collecting fares. The ability to operate LRV's in multiple units with one or two employees depends on several factors. The construction of stations is one factor. Platforms must be long enough to handle the length of multiple unit trains. As reported earlier, the size of the station platform is one of the determinants of the capital costs of a new system or refurbishing an old one. The vehicles must also be adaptable for multiple unit operation, though most have this feature.

The main factor in number of employees per train is the fare collection system. The choice is whether to invest in expensive automated equipment at the time of system construction or to use personnel for fare collection. The personnel may be on the vehicles or at the station. Even with an agent at the station selling fares, there is often the need to validate tickets on board. This can be done by a conductor or by an automated validating machine, which means an increase in vehicle cost. Self-service, fully automated fare collection requires that the station have controlled access, meaning more expensive station construction. Personnel would be needed in the form of roving inspectors and electronic experts to maintain the equipment. Security personnel or TV surveillance would be needed to protect the unstaffed station, and the choice reflects another tradeoff in operating costs or capital costs.

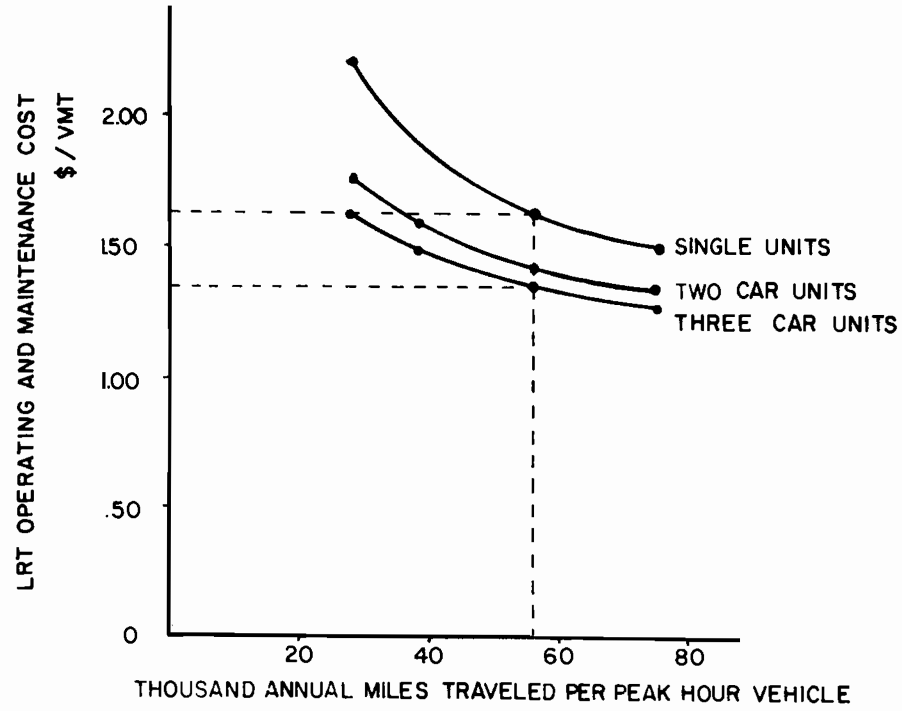


FIGURE 5-2. POTENTIAL SAVINGS FROM MULTIPLE UNIT OPERATION WITH A SINGLE DRIVER*

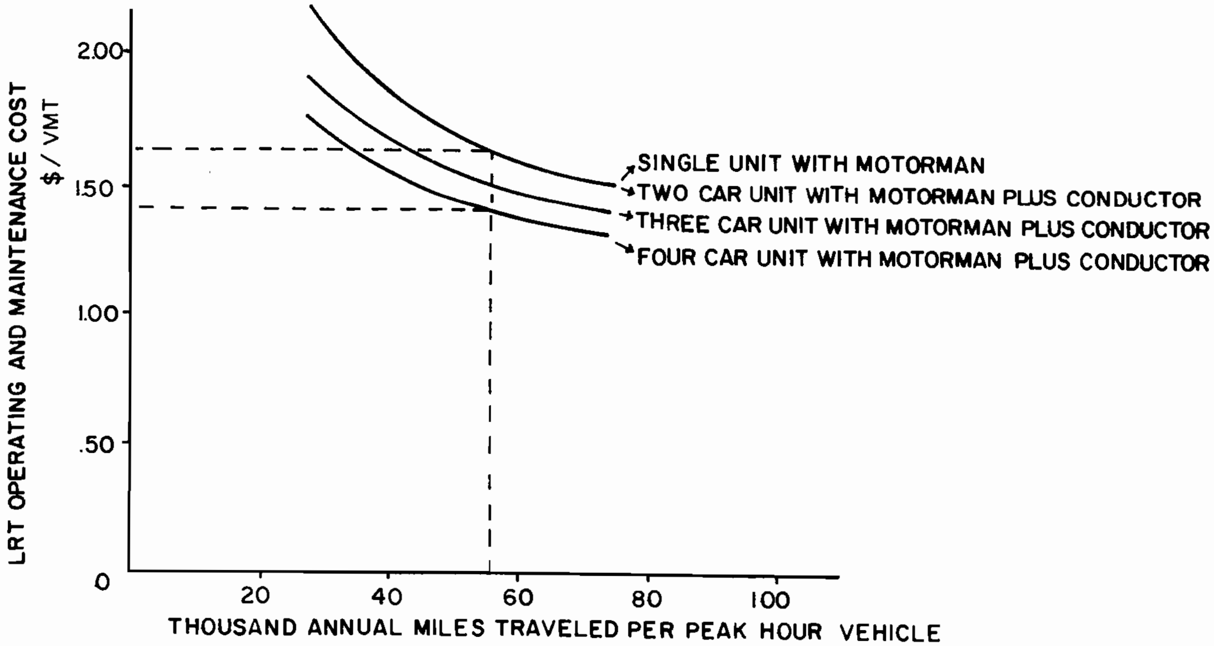


FIGURE 5-3. POTENTIAL SAVINGS FROM MULTIPLE UNIT OPERATION WITH A CONDUCTOR*

*Source: DeLeuw, Cather & Assoc. Light Rail Transit: A State of the Art Review (Washington: Department of Transportation, 1976).

There may be a problem with union operating rules if an existing system wished to convert to single-operator procedures. In a totally new system, the operating rules should be less of a factor, since there would only be new jobs (Ref 20).

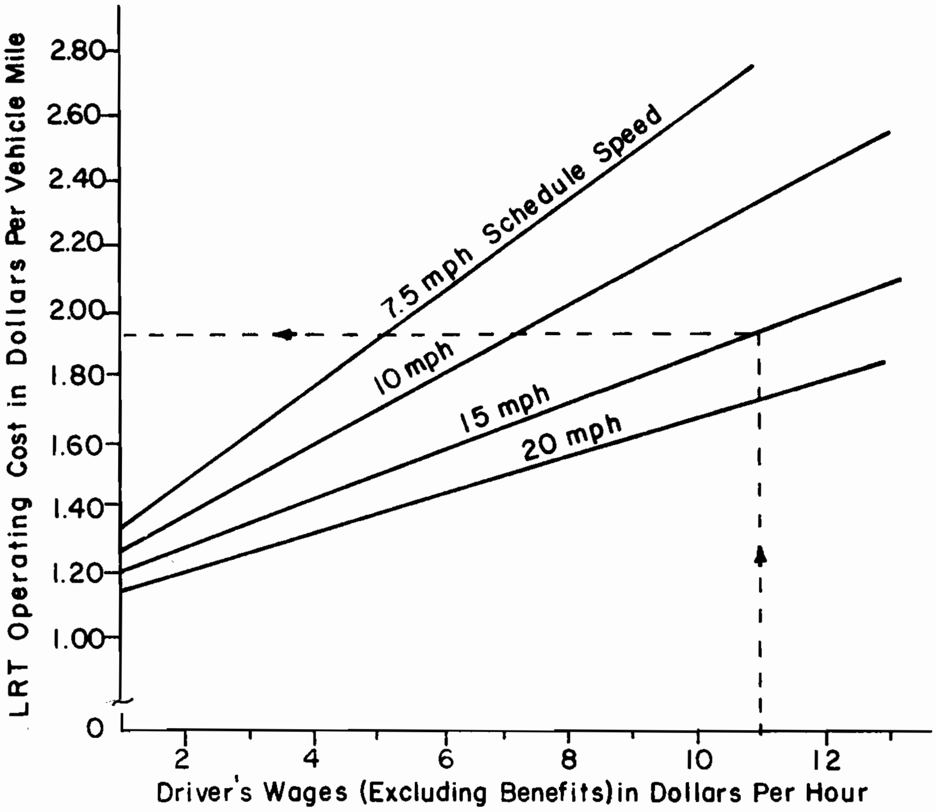
A principle closely related to the one in which costs go down as miles per vehicle go up is the one in which more vehicle miles per driver cause the cost per mile to be lower. Both of these ratios are related to the speed of the operations. Over recent years, increases in drivers' wages are cited as the reason why operating costs are rising. Figure 5-4 shows that as the speed of the vehicle increases, the driver's wage increases have less effect on costs per vehicle mile. This is because there is more service per driver at higher speeds.

As mentioned before in the discussion of construction costs, the quality of the system affects the operating costs. For the most part, the effect is due to the faster operating speed of the system due to the more expensive investment. The more the system is grade-separated, the more expensive it will be to construct, but the more efficient operating procedure it will have. When the system does have at-grade crossings, a more elaborate signaling system, involving higher investment costs, will aid in obtaining more efficient operations. The quality of the signaling system affects the overall speed. High platform stations which are more costly permit faster loading and increase the average speed of operations. Last but not least, the quality of the vehicle is a determinant of the speed of operation. As revealed in the San Francisco bidding, the cost per vehicle was reduced $150,000 when the vehicle was modified to travel at 50 mph rather than 65 mph.

The quality of the system has an effect on maintenance costs as well. New vehicles and newly constructed guideway generally require less initial maintenance, once the initial operational problems are corrected. Maintenance of guideway is necessary to allow vehicles to travel at high speeds safely. When using existing rail right-of-way, the choice to construct new tracks or upgrade the existing tracks will probably affect the cost of maintaining the tracks in the future.

Federal policy regarding capital and operating subsidy can cause some tradeoff decisions relating to the purchase of new vehicles versus maintenance of existing vehicles. However, one major Texas city (Houston) has

FIGURE 5-4. SENSITIVITY OF LRT OPERATING COST TO DRIVER'S WAGES



Source: DeLeuw, Cather & Assoc. Light Rail Transit: A State of the Art Review (Washington: Department of Transportion, 1976).

elected to refurbish existing buses rather than purchase new, less reliable buses. Another choice involving maintenance costs is whether to have elaborate electronic equipment to replace personnel in security and fare collection and incur the accompanying maintenance expenses, which may require the services of electronics experts.

While this discussion has centered only on monetary costs, it must not be forgotten that the quality of service, as determined by headway, travel time and proximity to the ridership, affects the travel costs to riders. These social costs must also be considered in choosing the quality of an LRT system.

OTHER FACTORS

Land Use and Urban Development

"Balanced" Transportation. Although some people define "balanced" transportation as simply the availability of various transportation modes, this report uses the term to signify that some sort of relationship exists between a certain transportation system (with its various modes) and the form of urban development. There are basically two ways for a city to reach such a balance:

- The present urban form shapes the appropriate transportation system, and
- implementation of a transportation system causes a restructuring or urban form.

This "balance" (or "equilibrium") is more or less achieved when the demand for transportation service meets the available supply as some corresponding quality level. In reality this seldom exists for a long time. There is actually an unending cyclic relationship that exists:

- New transportation development leads to changes in accessibility between points in the region;
- changes in accessibility lead to new activity patterns, resulting in land use changes; and
- new land development leads to new transportation development (Ref 21).

The cycle can be entered at any stage; for example, an increase in the median income of families in the region may significantly change activity patterns, and thus land development. Likewise, the overall cyclic pattern will be affected by political, legal, fiscal, environmental, and/or technical constraints.

Urban Development Supportive of LRT. While LRT is often promoted on the basis of its potential to reshape or foster development within an area, the actual justification for construction (if federal funds are involved) will largely depend on existing need (real or perceived). New transportation systems must be designed to fit cities as they now exist, and be flexible enough to evolve as the cities evolve. The level of urban development that can support LRT will depend on both the purpose of the light rail system and the manner of operation.

Light rail is usually designed as a line-haul system from suburban residential areas to the CBD. However, it could also be used for CBD circulation, connection of cities (interurban), or special applications. The term "special applications" refers to lines that are used mainly as a tourist attraction or a shuttle service. For example, the line in Fort Worth shuttles people from a parking lot to a downtown shopping mall, and a trolley line in Detroit uses old streetcars primarily as a tourist attraction. Both of these lines are considered successful, yet neither operates a "basic" transit service.

A report published in 1976 discussed the use of areawide average density figures to determine possible ridership levels:

> Calculating corridor volumes for any "typical" downtown cluster and its surrounding urban area is a highly conjectural exercise, because the volumes depend on the distribution of residential densities around the cluster. They depend both on the residential density gradient——how steeply densities decline as distance from the downtown increases——and on the geographic shape of the residential areas; for example, a city strung out along a valley or a peninsula is likely to have heavier corridor volumes than a city with the same size downtown that spreads equally in all directions on a plain (Ref 22).

A further problem with the use of residential densities concerns the method of access to a line-haul light rail line. For example, a suburban station may attract walking passengers within a quarter mile (0.4 km) radius, while those who arrive by automobile may come from five miles (8 km) away (depending on attractiveness of the line-haul route).

The 1976 report considers the size of a downtown center and existing transit ridership to be a better guide with which to evaluate a new rail system than residential densities. Based on data from Northeastern cities, light rail looks promising for downtowns in the range of 35 to 50 million square feet (3.3 to 4.7 million square meters) of floor space. This roughly corresponds to a city population of about 750,000. In special circumstances where existing ROW is available, the report concluded that individual lines may be viable in downtowns as small as 20 million square feet (1.9 million square meters) (Ref 22).

Factors Influencing Land Use Impact. The land use impact of LRT refers to changes in land development of a new rail line. It is usually hoped that the attractiveness of public transit would be so much improved that urban development would orient itself to a new rail line rather than continue the urban sprawl characteristic of dependence on automobiles. For example, the Bay Area Rapid Transit (BART) system was designed primarily to transport peak-hour commuters from suburbs to the various CBD's, resulting in reduced peak-hour highway traffic congestion and reduced commuter travel time. But it was also intended to generate the following effects:

- foster central district growth,
- generate development of subcenters throughout its region,
- raise land values,
- accommodate suburbanization of residences and centralization of employment; and
- reduce land area devoted to transportation facilities (Ref 23).

The following paragraphs present the major factors that may influence light rail's ability to attract new development.

1. General economic conditions. New growth along a radial transit line might occur only if the central business district (CBD) is strong in relation to other areas in the region, or is at least being actively revitalized.

2. Community/political support. A fundamental issue surrounds defining the type of future urban society desired.

   > Some cities may work to revitalize and encourage high density growth, some may work to shrink their central business districts and encourage the growth of suburban activity centers, and some may leave development patterns entirely to market forces (Ref 24).

   Not all communities adjacent to a station will want high-density residential development. Some authors have claimed that regional decision makers have been excessively influenced by pressure groups composed of downtown property owners (Ref 25).

3. Public land use policies. Development may be encouraged through zoning changes or taxing incentives. Other tools for managing and controlling development include: annexation policies, environmental controls, land acquisition, and subdivision controls (Ref 21).

4. Improvement in accessibility. One of the major reasons for implementation of a light rail system is to provide people with a transport mode free of highway congestion. An accessibility improvement would involve a savings in travel and/or transport costs. This may make property near a station more valuable for its current purposes or more valuable for more intensive use. How much of an incentive there may be to the locating of businesses and/or apartments next to a rail line depends on overall accessibility improvements. That is, one must determine what proportion of the trips to various destinations in the metropolitan area can best be accomplished (if at all) by light rail. A line from the suburbs to the downtown area may be of questionable value if most businesses have already relocated closer to suburban residences.

5. Land availability. Since an attempt would usually be made to put a new LRT line near already well-developed areas (in order to attract sufficient passenger demand), there might not be opportunities for substantial new development. Not only are open (undeveloped) or underutilized parcels of land near stations needed, but private and/or public developers must be able to assemble the land parcels into a site large enough for an economically viable development. Perhaps the only possibility for new growth would involve the redevelopment of existing physical structures.

6. Site attractiveness. Obviously, developable land needs convenient access to a transit station (or stop) if the line is to have any major influence. The major impact area is generally considered to be within a 1200 to 1800 foot (365 to 550 m) radius from a station (Ref 26). However, nearby land may still be unsuitable if there are serious topographical or drainage problems. The extent of development in nearby areas may also

be an influential factor. In addition, developers will usually try to avoid blighted, crime-ridden areas, unless given special incentives. An aerial structure may tend to discourage residential development immediately adjacent to a line.

7. Timing. Although there is usually real estate speculation in advance of construction, substantial development (if it occurs at all) might not take place until five years or more after the date the rail transit line is put in operation (Ref 27). The actual time span will, of course, depend on the variety of factors already noted.

Possible Effects on Existing Area Land Uses. It usually follows that the property value of land will increase if a rail transit station is placed nearby. This is due to an increase in accessibility to other areas in the region. Residences would benefit if trips to commercial or employment centers could now be accomplished at lower cost or in less time. Businesses may have an opportunity to increase their sales if more customers are able to easily get to their stores.

One should not overlook the possibility that land without access to a new, extensive transit network may actually decrease in value, since other land areas in the region have been made much more attractive (due to improvements in accessibility).

Examples of Transit-Induced Development. The introduction of trolleys in the 1890's opened up large amounts of land for development. It was successful mainly because of the dramatic improvement in speed streetcars had over the existing transportation modes (horse-drawn vehicles and walking). However, since light rail today (even with its superiority in speed over the streetcar) must compete with the popular automobile, it would normally not be expected that an LRT line would induce substantial development in an already-developed region. As summarized by Andrew Hamer:

> There is no guarantee that fixed guideway systems applied to the metropolis in this age of automobility will be able to recreate an idealized Compact City. What emerged in an age of low average incomes and primitive technology cannot be reassembled simply by resurrecting one element of the past (Ref 25).

However, through the use of government controls that would involve constraints on the use of automobiles (such as gasoline rationing or reductions in downtown parking), the implementation of light rail transit may lead to radically different urban patterns. The commitment of many European cities to a successful coordination between transit and land use planning can be seen in this quotation:

> For instance, a common feature of most European cities has been the peripheral suburban development, which unlike its counterpart in the United States, has been encouraged to develop in a planned cluster format. Such a development may consist of between 1,000 and 15,000 dwelling units clustered around a commercial and retail core. The center of the cluster contains high density residential units, largely apartments, beyond which are the less dense single family units and open space. Such a peripheral cluster is conveniently connected to the main urban center by extending a transit route into the node. Light rail is admirably suited for this task, and seldom requires feeder service in such situations because of the relatively small distances within any one cluster development. Often a light rail transit station is constructed as an integral part of the community such as beneath a shopping complex, thereby making transit access more convenient than driving (Ref 28).

A U.S. DOT report published in 1977 indicated inability to find any significant new development from light rail systems in the United States (Ref 27). Existing systems are primarily upgraded versions of former streetcar or interurban trolley operations. Most development occurred over sixty years ago, well before the automobile became a dominant mode of transportation. Even the Riverside Branch of the MBTA light rail Green Line, which was opened in 1959, is not an adequate example. This line followed a former commuter railroad route, and neighborhoods along the line were already well established as commuter bedroom communities.

The modern LRT line opened in Edmonton in 1978 and the Buffalo line now under construction have both been planned with careful consideration given to the potential for major land development (or redevelopment). While some businesses have already oriented themselves to the Edmonton line, it will be several more years before it is known if there will be major impacts on land use.

In order to learn more about the potential land use impact of light rail transit, a brief study of recent experiences with conventional rapid rail transit may prove helpful. Since rapid rail normally operates with both higher passenger volumes and higher operating speeds than LRT, one must of course be careful about making comparisons.

Toronto's first rapid rail line opened in 1954 (the Yonge Street Subway). The subway has helped to strengthen the Toronto CBD and has led to substantial development oriented to the transit stations. With the help of carefully adapted zoning changes, ten to twenty-story buildings have been clustered around a number of outlying stations, rather than randomly dispersed throughout the region. It is believed that if not for the line, most of the growth would nevertheless have occurred in the region since there was a heavy demand for city office space and apartments even before the line was finished (Ref 27).

San Francisco's BART is being closely monitored for major land use impacts. The major impact so far has been on the CBD rather than outlying stations. However, as with Toronto, the boom in office construction in the CBD would probably have occurred even if BART was never built although not to the same high degree.

In suburban areas most of the BART stations are surrounded by parking lots; this has tended to hamper high-density residential development next to a line. A report published in 1978 summarized the latest experiences with BART:

> The BART system, unlike some of the older rapid rail systems in the U.S. penetrates deeply into suburban areas. It has shown in its years of operation some evidence of potential as a contributor to additional suburbanization. Parking lots at BART stations at the extremities of the system are now filled to capacity early in the morning every work day. It is evident that many of the users of this "park-and-ride" system are taking advantage of BART's relatively rapid service to downtown San Francisco and correspondingly increasing the potential for even greater suburbanization (Ref 29).

In those cases where rail transit in American cities has had an impact on land use, the effect has generally been a refocusing of development within the region rather than a new regional increase. Property near a rail line might increase in value, but property elsewhere may subsequently decrease in value because of a lower relative accessibility.

Where there has been significant regional growth, it is unclear whether new development was actually stimulated by the rail line or was merely a spatial shift of development which would have occurred elsewhere in the region (as in Toronto and San Francisco). High-density residences may shift toward new transit facilities, causing "spot" density increases near stations.

Even though a rail line will not necessarily induce substantial new development in the region this redistribution of development may be just as important. For example, these intraregional changes may lead to increased efficiency in the use of public and private facilities. If the new urban pattern enforces a community's goals and objectives, a "net" benefit will be realized (Ref 30).

Value Capture and Joint Development. Value capture refers to a technique whereby the community captures part of the benefits from any increase in the value of land located near a recently installed transit station (or stop). Various techniques are described in the literature:

- The city can purchase land before the light rail line is built and sell or lease it after the land appreciates in value;
- private property near a station could be taxed at a higher rate and/or assessed at a higher value; or
- the city could participate in a joint venture with private developers, with a sharing of future land income (Ref 31).

Recent court cases have upheld the rights of local governments to purchase, by eminent domain, property in excess of construction funds, if the purpose is to insure financial success of the project (Ref 32).

The third technique mentioned is known as "joint development." This occurs when the public and private sectors ". . . work cooperatively in the planning, financing, and construction of development projects adjacent to and integrated with transportation facilities" (Ref 33). It is hoped that this coordination will generate a maximum stimulus to economic development and urban revitalization. Research work completed by the Rice Center for Community Design and Research has demonstrated that 20 to 40 percent of the capital costs of transit improvements may be recovered by using the value capture technique in joint development.

Social, Economic, and Political Impacts

Political/Institutional Acceptance. The ultimate decision on whether or not to construct a light rail system is largely political. This may involve federal, state, regional, and local governments as well as general citizen support.

Presently 93% of the total capital costs in Texas may be funded by the Urban Mass Transportation Administration (80%) and the State Department of Highways and Public Transportation (13%). UMTA may also fund as much as 50% of future operating deficits. This gives these levels of government a measure of control over local activities. Obviously, light rail for a particular city must be in the interests of federal and state policy if grants are to be made.

> It is in fact a waste of federal dollars, state dollars, and local dollars to grant study contracts to evaluate the feasibility of LRT projects in any city if the basic decision has not first been made that LRT projects are an alternative acceptable to the federal government in such a city (Ref 34).

Federal requirements usually state that local financial commitments must be made before a federal commitment is offered. This leads to an interesting problem because local governments do not want to commit funds unless a federal grant is certain to follow. The result is usually a case of "contingent" commitments that depend on the commitment of the other level of government (Ref 34).

The local seven percent funding for a major construction project may be a large burden on a local or regional government. The funds required for both initial construction and future operating deficits will usually come from regional property or sales taxes. In order to gain citizen support for a light rail line, an extensive network serving all sections of the jurisdiction is usually planned. The first segment will usually begin in the urban core with other segments to be built as future funds are available. Suburbs are growing wary of this process since later segments might never be built; the result is that many suburban residents may be paying taxes for transportation improvements they never receive (Ref 35).

It is sometimes argued that a major construction project for a transportation system would increase the number of jobs in a region, at least on a temporary basis (Ref 36). In fact, a major justification for construction of the Interstate Highway System was the creation of jobs and subsequent stimulation of the nation's economy. The point that must be emphasized here, however, is that virtually any major construction of public works projects, such as low-income housing, would have the same stimulating effect.

Construction Disruptions and Displacements. Any major construction activity will cause some disruption in high-density, well-developed areas due to excess noise, dust, or presence of heavy construction equipment on highways. While usually only temporary, disruption may be permanent if the end result is a physical barrier (i.e., guideway) that divides a cohesive neighborhood.

Residential and commercial relocation (displacement) will be necessary if no other comparable ROW is available in a particular developed area. Some businesses may cease all operations rather than relocate, resulting in an immediate loss of some property tax revenues to the regional government (along with a hardship for the businessman). Relocation of houses (and thus families) should be done in such a way that the well-being and lifestyle of each household and neighborhood remains basically undamaged. The following factors will affect the level of social and personal impacts:

- age and physical handicaps,
- income and education levels,
- racial/ethnic background,
- length and type of housing tenure,
- distance to new residences,
- adequacy of compensation, and
- duration of the relocation process (Ref 37).

Energy Implications

Some design and operational factors that affect direct energy consumption of light rail transit can be listed:

- hours of vehicle operation,
- vehicle miles of travel,
- frequency and duration of station stops,

- stoppages or slowdowns between stations,
- condition of track,
- operating grades, alignment characteristics,
- vehicle weights (including passengers),
- efficiency of power distribution system,
- efficiency of vehicles' motors and controls (use of chopper control, regenerative braking),
- operating (cruising) speeds, use of coasting, and
- additional requirements: station and ROW lighting, air conditioning and heating, maintenance, etc.

The rest of this section will attempt to analyze the various issues which should be considered in any energy study.

In the existing energy situation, efforts are being made to limit the dependency on foreign oil by using more energy-efficient transportation modes. Under such conditions, however, it is difficult to compare buses which use diesel fuel with light rail vehicles that use electricity generated from non-petroleum-based products (such as coal or uranium). Since the automobile is not likely ever to be completely replaced, present programs which endeavor to increase the fuel efficiency or average passenger occupancy of automobiles appear most useful in saving energy.

A determination of which transportation mode will perform best in the future may depend on what sort of future energy scenario is accepted. If the predictions of pessimists come true, there will be a severe oil shortage in the next 10 to 20 years. Such a scenario appears to show that electric rail vehicles will have a definite advantage over diesel buses or gasoline-driven cars. However, not to be overlooked is that synthetic fuels (liquified coal, hydrogen fuel) may be successfully developed in the future as a substitute for gasoline and diesel fuel.

If there were a severe shortage in the future of all usable types of energy, not just petroleum, it is still not clear if light rail would be an effective mode. Rail transit can be operated very efficiently if it encourages residential and commercial redevelopment along the line, but during a severe energy crisis the corresponding economic slowdown may not be conducive to any new construction or relocation. Perhaps technological advances will make energy-efficient all-electric vehicles attractive, or even "hybrid" vehicles which cruise with small gasoline engines (which might use synthetic fuels) and accelerate with the help of electric motors.

A Congressional Budget Office report defined four levels of energy consumption for a transportation system. These are:

1. Energy intensiveness: vehicle propulsion energy per person-mile;
2. Line-haul energy: energy consumed in station operation, vehicle and way maintenance, vehicle manufacture, and facility construction, all converted to a person-mile basis and added to vehicle propulsion energy;
3. Modal energy: line-haul energy plus access and egress energy, all corrected for trip circuity; and
4. Program energy: comparison of the modal energy used by a new transportation service with the modal energy of the service from which the new patronage is drawn (Ref 38).

The third level, modal energy, refers to the fact that energy will be used if access to a transit station is by automobile. This may be very important in Texas since a new rail line would probably have extensive parking areas near some of the suburban stations. Circuity results from the fact that a trip using a rail (or bus) route may not necessarily be as direct as making the same trip by automobile. The fourth level, program energy, takes into account whether a passenger attracted to a new rail transit system would otherwise have made the trip by automobile or by bus.

Coming up with accurate figures that would realistically compare various systems in relation to future conditions is very difficult. For example a fixed rail system installed today may have most access to outlying stations by car, but 5 to 10 years from now most access may be by walking if the line encourages nearby building construction. This affects not only the amount of energy used in access and egress, but may increase the average passenger occupancy of light rail vehicles, especially if more people use the line during off-peak periods than before (i.e., a higher daily load factor resulting in lower energy usage per passenger-mile).

Another problem is how to compare vehicles which use diesel with those that use electricity generated from, say, coal. Energy is lost as coal is converted into electricity and as electricity is distributed in overhead wires to electric rail vehicles. Likewise, energy is lost as oil is refined into gasoline or diesel fuel and during distribution from the refinery to the vehicle (in the form of transport energy). Table 5-2 shows adjustments for energy conversion rates which tend to favor electrically-operated vehicles while other reports use adjusted conversion rates that favor non-electric vehicles.

About half of all electrical power is presently generated from coal. The use of coal will probably increase in the future since America's coal reserves are about 82 times the size of its petroleum reserves (Ref 39).

Figure 5-5 shows how energy usage (not adjusted for conversion losses) for the Boeing Vertol light rail vehicle can vary with different service parameters. Modern light rail vehicles tend to use more energy per vehicle mile than the PCC car not only because of greater capacity (and thus greater weight) but because of overall higher performance, quality of service, and durability. Actual energy comparisons among transportation modes will be made in the final main section of this chapter.

Environmental Implications

Air Pollution. A definite advantage of electric rail vehicles over internal combustion vehicles is that any significant pollution occurs only at the power plant serving the rail system. Power plants are usually located in open areas that allow for dispersion of pollutants; the amount of pollutants will depend on what type of fuel the plant uses (e.g., virtually none for hydroelectricity). The major impact on air quality near a light rail line would probably be the dust induced during the construction stage.

Noise. Track and wheel conditions are the major factors affecting noise of light rail vehicles. For radii under 700 feet (210 m), special resilient wheels may be needed to limit wheel squeal caused by metal sliding on metal as a sharp turn is made (common with old streetcar lines). Use of welded rail eliminates the constant "clicking" sound as a vehicle passes over a joint.

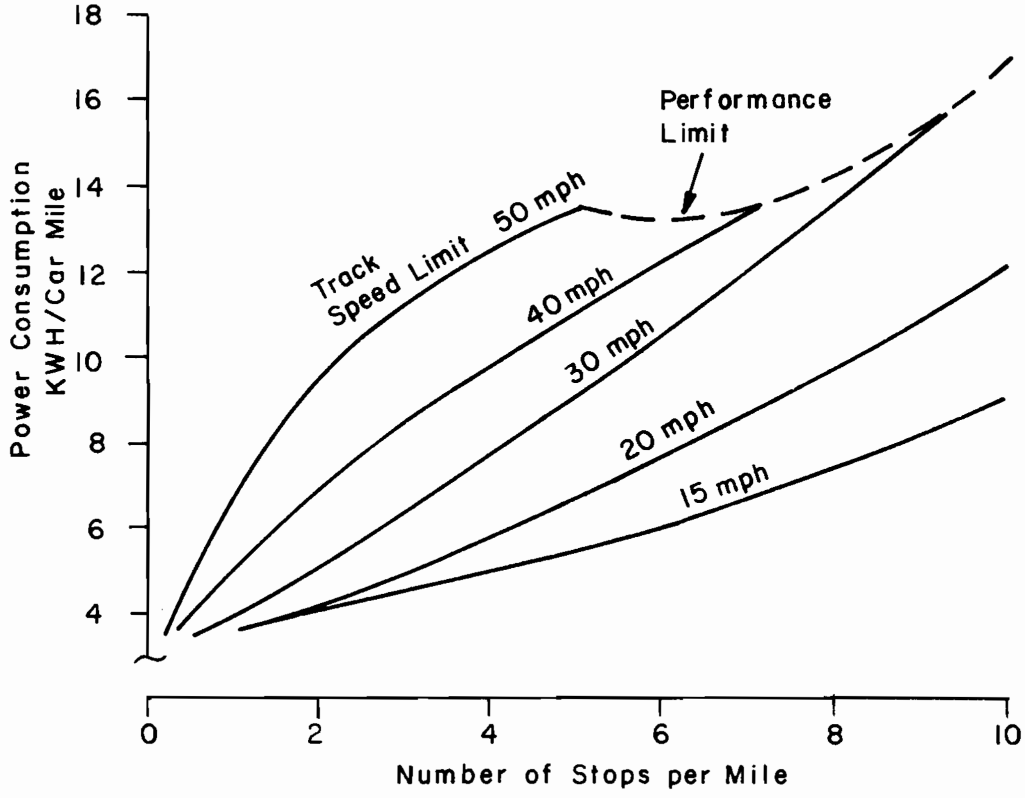
Interior noise levels should be between 65 and 75 decibels (dBA) to permit comfortable conversation. The Boeing LRV stays under 70 dBA for speeds up to 50 mph (80 kph), but existing European 8-axle articulated

TABLE 5-2. 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: Texas Transportation Institute.

FIGURE 5-5. ESTIMATED POWER CONSUMPTION FOR BOEING LRV



Notes
1. 35 KW Auxiliary Load
2. 100 Passenger Load
3. 15 Second Station Stops

Source: <u>Light Rail Transit: State of the Art Review</u>, p. 183.

LRV's vary between 67 and 84 dBA. For comparison, modern bus interiors normally vary between 70 and 78 dBA but can be as high as 95 dBA for a bus with an 8-cylinder engine under full acceleration (Ref 3).

Exterior noise levels are very important because of their impact on surrounding communities. At 50 feet (15 m) from a line, most modern LRT systems stay between 70 and 80 dBA. If this is considered too high for certain land uses, the noise level can be controlled through the use of acoustical barriers (such as a row of trees). Reduced vehicle speeds are also an effective noise mitigation technique as can be seen from tests with the Boeing LRV that have shown a 5 to 10 dBA decrease as speed is decreased from 50 mph (60 kph) to 20 mph (32 kph) (Ref 3).

Aesthetics. Light rail with its controlled guideway can limit environmental intrusion to the width needed for the tracks. At-grade tracks can be lined with rows of trees or shrubs to hide it from residences. Proper use of trees will even help shield the silhouette of overhead wiring. When the guideway cannot be hidden, the LRT line might be made attractive if care is taken in the design and location of overhead power supports. While elevated structures in the past have not been looked upon favorably, it remains to be seen if modern, sleek, aerial guideways will cause the same type of reaction.

Safety

Traffic accident rates for modern light rail vehicles depend on system characteristics such as the amount of control over the ROW, the level of protection provided at rail/highway grade crossings, and the maximum allowable operating speed.

Limited data show that streetcars operating in mixed traffic have about 40 to 60 percent more total passenger accidents per million vehicle miles than buses operating under similar conditions (Ref 3). Experience with European systems (trams) has identified three possible reasons for this:

- Trams cannot maneuver around potential accident situations as buses can;
- since most tram lines are located in the middle of the street, passengers risk having an accident as they cross traffic lanes to reach or leave a transit stop; and

- higher acceleration/deceleration rates on trams leave standing passengers with a greater risk of falling over inside the vehicle (Ref 40).

Accidents with non-rail vehicles such as cars would be drastically reduced if LRT were to use exclusive ROW, easily accessible stations, and automatic rail/highway crossing gates. To prevent pedestrians from crossing a light rail line haphazardly, center fences between the tracks could be used.

Passenger Perceptions

The following considerations will have an effect on how passengers perceive a light rail system:

- Image of rail technology: fixed-guideway transit has generally been looked upon favorably in the 1970's, probably because of its "modern" and progressive image. It is for this reason that caution must be given if modern light rail is associated with the streetcars of the past.
- Vehicle and station amenities; as discussed in Chapter 3, these amenities may not be needed from a strictly operational viewpoint but are very useful in attracting riders.
- Travel time: the total travel time (speed) of a trip from the origin to the final destination is one of the most important level of service parameters for comparing one transportation mode to another. For light rail, it is dependent on walking time, waiting and transfer time, and in-vehicle time.
- User costs: obviously the fare price in relation to other available transportation modes (if any) will have some effect on whether or not light rail is chosen for a particular trip. Changes in fares have generally caused less effect on patronage levels than changes in other service parameters such as average door-to-door travel time.
- Convenience and comfort: this includes such things as simplicity in using the system, reliability in bad weather, and ease in handling of shopping bags and other personal bulky items.
- Perceived safety: the major concern is crime at transit stops or on vehicles. Vehicle accidents do occur, though, and the publicity of a rail accident, major or minor, may discourage many potential transit riders.

LIGHT RAIL COMPARED WITH OTHER MASS TRANSPORTATION MODES

Rapid Rail and Automated Guideway Transit

Rapid Rail Transit. When peak hour volumes range from 10,000 to 20,000 passengers, rapid rail transit can be designed as an efficient operation. Vukan R. Vuchic summarized the major differences between light rail and rapid rail transit:

> The main advantages of light rail in comparison with rapid transit are its much lower investment cost, larger network and better area of coverage, and possibility of gradual development. Rapid transit, on the other hand, has lower operating cost, potential for full automation, and higher level of service. Thus, the tradeoff between the two systems is, in simplified terms, between the lower cost, sooner operation and more direct (no transfer) service of light rail, and the higher level of service and lower operating cost of the rapid transit (Ref 41).

As shown in the first section of this chapter, capital costs for light rail may range from $5 million/mile ($3.1 million/km) for an at-grade line to $70 million/mile ($43.5 million/km) for a subway line. For comparison purposes, capital costs (in 1978 dollars) for four heavy rail systems undergoing construction can be identified:

1.	Baltimore:	$720 million for 8 miles (13 km) or $90 million/mile ($56 million/km),
2.	Atlanta:	$ 1 billion for 13.7 miles (22 km) or $73 million/mile ($45 million/km),
3.	Miami:	$ 1 billion for 20.5 miles (33 km) or $50 million/mile ($31 million/km), and
4.	Washington:	$ 5 billion for 100 miles (161 km) or $50 million/mile ($31 million/km).

The numbers appear to show that light rail can be as costly as heavy rail when extensive tunnels are needed. The potential for a much lower investment cost with light rail appears when readily available surface right-of-way (ROW) can be used.

Automated Guideway Transit. Automated Guideway Transit is also known as Group (or Personal) Rapid Transit or Light Guideway Transit. It was conceptualized as a mode that could provide very frequent all day service without incurring huge labor costs. The two best prototypes of this "people-mover" concept are the systems in Morgantown, West Virginia and in the Dallas/Fort Worth Airport. The D/FW system ("Airtrans") can theoretically handle about 9800 passengers per hour per direction (two-car trains on 18-second headways), while the Morgantown system can handle 4080 passengers per hour per direction on 15-second headways (single-unit operation).

Construction costs are generally higher than that for light rail. Routes must be grade separated from all other traffic and sophisticated electronic and mechanical equipment must be installed. In 1974 dollars, excluding vehicle costs, the Morgantown system costs about $27 million per double-track mile ($16.8 million/double-track km) of elevated guideway. Updated to 1980 dollars (10% yearly inflation), this would be $48 million/mile ($30 million/km) of double-track. The single-track loop system at D/FW Airport, updated to 1980 dollars, cost about $6 million/mile ($3.7 million/km). The equivalent cost for a double-track structure would be $12 million/mile ($7.5 million/km).

The figures for Morgantown are probably more realistic. Much of the D/FW ("Airtrans") system was constructed mostly at-grade with the new airport built around it. The Morgantown system even with its major construction problems is more representative of the costs to be expected of inserting automated guideway transit into an existing urban environment.

A report published in 1977 concluded:

> We thus come to the paradox that in those line-haul applications where the unique attributes of light guideway transit would be most useful, the capital cost per passenger mile of the present generation of light guideways is so high as to be out of a reasonable range. Where passenger volume could justify its high cost, the system does not have the capacity to carry the volume at the present state of the art, unless it adopts traditional transit attributes, such as operation in trains. At these high volumes, traditional transit can provide satisfactory service frequencies at a lower capital cost, and at a generally similar or lower operating cost (Ref 14).

It appears that Automated Guideway Transit (AGT), at least in its present form, is limited to special applications rather than line-haul services.

The high capital investment may be justified only when peak hour volumes are about on the same level as the average hourly flows throughout the day.

Characteristics of Various Bus Options

Technology Options. Conventional 40-foot (12 m) city transit buses typically have about 50 seats with a total capacity of up to 85 passengers. Continuing technological developments have resulted in better operating capabilities and improved passenger comfort. Propulsion systems are commonly diesel (and sometimes gasoline or propane) engines. Other possible systems include gas turbines, steam engines, electric-powered vehicles, and hybrid combinations of two or more power sources. Electric power may come from overhead wires (the trolley bus), fuel cells, or batteries.

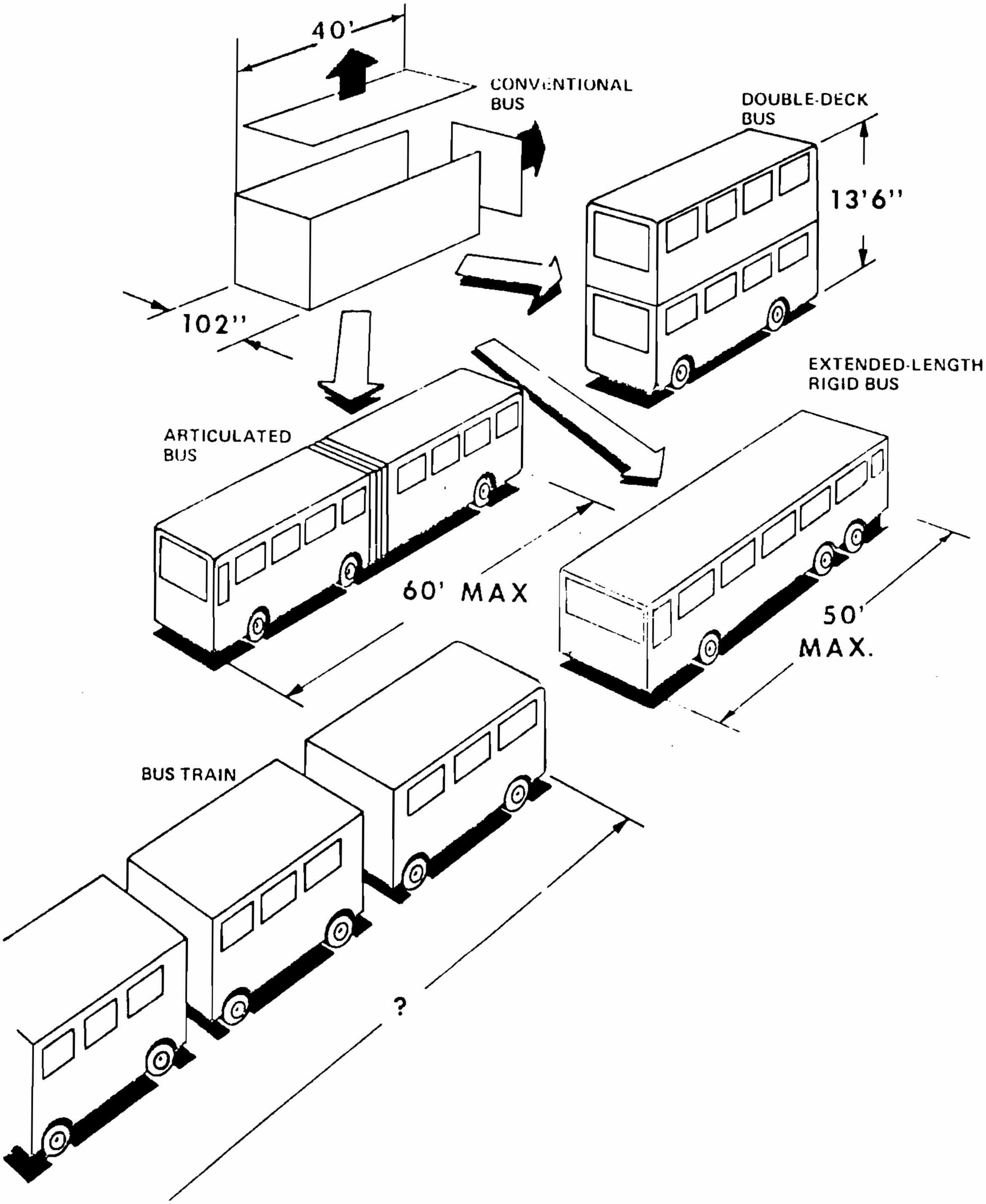
Figure 5-6 shows four bus designs of higher capacity than conventional 40-foot (12 m) buses. Extended length rigid buses and bus trains have not progressed beyond the conceptual design stage because such vehicles would suffer from operational problems on existing streets. However, either type may prove acceptable if they are restricted to specially-designed busways.

Double-deck buses are generally of equal maneuverability as single-deck buses of the same length. Capacities range from 70 seats for 33-foot (10 m) buses to 95 seats for 40-foot (12 m) buses. Total capacities are roughly 20 to 30 percent more. Two disadvantages with double-deck buses in the past have been the 15-foot (5 m) minimum vertical clearance needed and passenger complaints about having to climb a stairwell.

Figure 5-7 shows an articulated bus design. The excess length over standard buses results in little increased turning difficulty since the joint allows the bus to "bend" around a curve. Several articulated bus designs have been built with a purchase cost almost double that of conventional air-conditioned 40-foot (12 m) buses (about $170,000 each). Articulated buses 60 feet (18 m) long have about 70 seats with a total capacity of roughly 110 passengers. One European supplier has even suggested that a 55-foot (17 m) double-deck articulated bus could be built to accommodate 120 seated passengers (Ref 42).

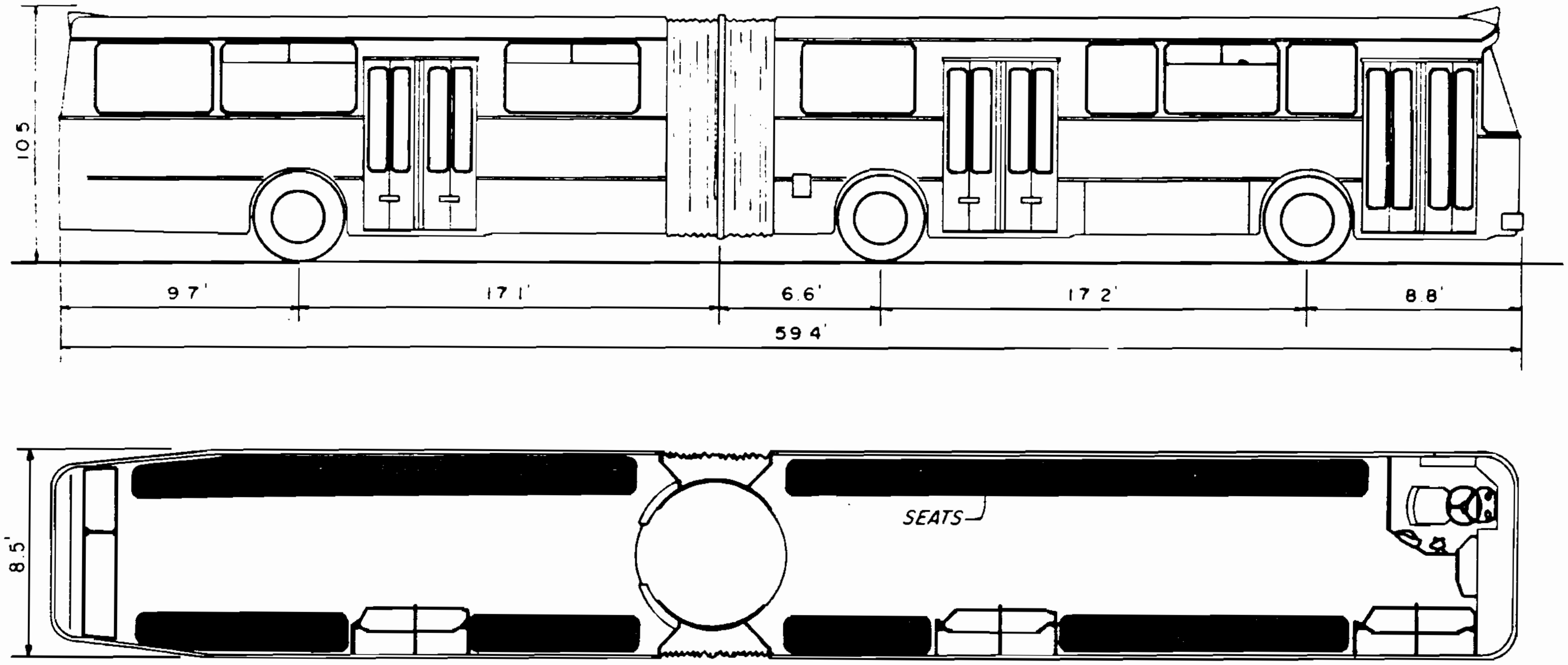
Right-of-Way (ROW) and Service Options. There are basically three levels of bus service possible:

FIGURE 5-6. HIGH CAPACITY BUS CONCEPTS



Source: U.S. DOT, Project Super Bus: High-Capacity Bus Conceptual Design Study (Washington, D.C.: GPO, 1974), p. 3.

FIGURE 5-7. PROTOTYPE ARTICULATED BUS WITH DOUBLE DOORS.



42' OUTSIDE TURNING RADIUS

Source: U.S. DOT, Bus Rapid Transit Options for Densely Developed Areas (Washington, D.C.: GPO, 1975), p. 36.

1. Rapid transit: usually refers to operation on exclusive ROW, enabling high speeds to be maintained;
2. Express: refers to the bypassing of some or all intermediate stops between outlying areas and the CBD; and
3. Local: passengers are picked up and discharged at frequent, designated stops.

Table 5-3 depicts various bus transit options for densely developed areas. What sort of bus priority measures may be desired will depend on:

- Intensity and growth prospects of development, especially in the city center;
- Present and potential reliance on public transport;
- The width, configuration, and continuity of existing streets;
- Concentrations of employment and commercial centers in relation to bus routes; and
- The extent of street congestion (Ref 43).

Bus roadways (busways) operating on exclusive ROW with complete control of access provide the highest level of bus service. Design standards can be tailored to specific operations with stations and access ramps provided where needed. Separation from regular traffic means there are no legal limits to vehicle size, operating speed, or hours of operation. Busways with on-line stations (a single lane for one-way operation with buses stopping in the lane) can safely handle 140 buses per hour per lane. The constraint on bus capacity is at the stations. If enough off-line stations are provided, a line could theoretically handle 1200 buses/hour/lane.

Average operating speeds will depend on number of station stops per mile:

1 stop per mile:	30 mph (48 kph)
2 stops per mile:	22 mph (35 kph)
3 or more stops per mile:	12 to 15 mph (19 to 24 kph) (Ref 43).

Light Rail Versus Bus Options

Capital and operating costs are usually considered the most important

TABLE 5-3. SIGNIFICANT BUS TRANSIT OPTIONS FOR DENSELY DEVELOPED AREAS

TYPE OF OPTION	PRIMARY APPLICABILITY	
	Central Business District	Radial Approaches
Bus Street	X	
Bus Lanes		
Curb -- Normal Flow	X	X
Curb -- Contra-Flow	X	X
Median	X	X
Busways -- Normal Flow		
Cut and Cover	X	X
Deep Bore		X
Open Cut		X
At-Grade		X
Elevated		X
Busways -- Contra Flow		
At-Grade		X

Source: National Cooperative Highway Research Program Report # 143, Bus Use Of Highways: State of the Art (Washington, D.C.: National Academy of Sciences, 1973), p. 12.

parameters in comparing transportation systems. However, such comparisons are misleading when they force identical types of operation on modes which operate optimally at different passenger capacities and different service levels. The following paragraphs will qualitatively compare the variety of bus options with different LRT capabilities.

Capital and Operating Efficiency and Productivity. Both buses and light rail vehicles (LRV's) can operate in a range of ROW categories. The lowest category (Category C) includes operation on regular streets with mixed traffic, while the highest category (Category A) refers to transit running on exclusive busways or rail guideways with no grade crossings of other traffic allowed.

In Category C buses have an economic advantage over LRV's since buses can use streets as they presently exist. LRV's require placement of rails in the pavement in addition to construction of an overhead power collection system. Operation of either buses or LRV's exclusively in Category A can be quite expensive since a large number of tunnels or elevated structures may be required. Bus subways, in particular, can be very expensive since the use of diesel buses would require extensive ventilation equipment.

Category B represents partially controlled ROW where some grade crossings with other traffic are allowed. Most existing and planned light rail systems fall in this category. For buses, this category can range from highway lanes reserved for transit ("bus lanes") during peak hours only to specially-built busways. The capital costs of at-grade busways are usually less than the costs of light rail guideways when built to comparable operating standards. However, this difference can be much smaller if acquisition costs for ROW per square foot (meter) are high since two light rail tracks require less width than two bus lanes. Busways have an additional advantage in that they can be used by carpools and/or emergency vehicles.

One advantage often cited for light rail over buses is the potential for higher labor productivity, resulting in lower operating costs per passenger mile. This is due to larger vehicle capacities and the capability for multiple-unit operation. Just how much of an advantage can actually be realized will depend on a variety of factors:

- Line volume: LRT operates efficiently only in the higher capacity ranges;
- Headway: one effect of using multiple-unit trains may be the reduction in train frequency, resulting in increased headways (and thus increased passenger waiting time);
- Fare collection: the capability of multiple-unit operation will not significantly lower costs if a person is still needed in each vehicle to collect fares; and
- Bus capacities: a bus operation could be made more productive (as measured by total passengers per driver) at high volumes if higher capacity articulated buses were used.

Regular 40-foot (12 m) buses operating on exclusive busways can achieve 15,000 to 18,000 passengers per hour (Ref 44). However, if the theoretical maximum of 1200 buses/hour/lane is used, assuming 50 passengers per bus, the volume would be 60,000 passengers per hour. A rate of 30,000 passengers per hour has been recorded on the Lincoln Tunnel bus lane in New York.

Operating costs may or may not be higher than for light rail carrying the same volume. If both LRT and buses can handle the peak volume expected on a line, the determination of which mode is more cost efficient will depend on total demand throughout the day. That is, one must also consider which mode can operate most efficiently at the lower off-peak volumes.

Performance and Technological Differences. The basic difference is between guided and unguided vehicle technologies. Buses are powered by internal combustion engines with the fuel tank located onboard. The power source for LRV's is an external, overhead line with several small (yet powerful) electric motors located on the trucks underneath the vehicle body.

Light rail, mainly because of the guided technology, has the following potential advantages over busways:

- narrower ROW requirements,
- greater acceleration/deceleration rates,
- greater safety and reliability, and
- easier maintenance.

The major disadvantage caused by the guided technology is that the vehicles are limited to expensive guideway networks even in low-density areas, whereas regular buses can leave a busway and continue to operate on local streets.

The service life of a bus or LRV will depend on the quality of maintenance and the intensity of use. One reason the bus has a much lower purchase cost is because the expected service life is generally much shorter (due to a less durable vehicle). The effective service life of a bus may be only 12 years while that for an LRV might be over 30 years. The major reason for cost differences, however, is due to the mass production of buses.

Flexibility in Operations and Planning. Specially-built busways are as inflexible as light rail lines for accommodation of changing urban patterns. However, a busway can be used by carpools and can even be opened to all traffic at certain hours of the day. Buses can also leave a busway and travel on regular streets, either for portions of the line-haul route or for the collection/distribution phases. Buses can also be used for off-line charter service or temporary/permanent rerouting.

Land Use Impacts. While a fixed rail system is inherently inflexible in terms of routing, some urban planners consider this an asset. A developer is pretty sure a rail line is permanent while a bus route can be changed overnight. A major rail system can help shape future growth of cities and suburbs by encouraging more concentrated land development patterns. Whereas bus systems can be designed to accommodate the changing development patterns of present American cities, an LRT system must generally be built with a more specific future scenario envisioned. Thus, one factor in the determination of LRT versus bus may be whether transit is meant to guide future development or to adjust to it.

However, if automobiles remain the dominant mode of transportation, new light rail or busway systems might be considered only for location in corridors already of sufficient density. Table 5-4 depicts a possible relation between transit modes and residential density.

Energy Usages. Table 5-5 depicts propulsion energy rates for three types of operation. The figures can be quite misleading, however, since the use of limited (and perhaps imported) petroleum is compared with electricity that can be generated from domestic (and relatively abundant) sources of coal. In the case of light rail, the term "adjusted for losses" means that the Btu values are of the coal used to make the electricity for the vehicles, along with an accounting of distribution losses and the direct vehicle consumption. The possible future use of synthetic fuel (for buses) derived

TABLE 5-4. TRANSIT MODES RELATED TO RESIDENTIAL DENSITY

Mode	Service	Minimum Necessary Residential Density (dwelling units per acre)	Remarks
Dial-a-bus	Many origins to many destinations	6	Only if labor costs are not more than twice those of taxis
Dial-a-bus	Fixed destination or subscription service	3.5 to 5	Lower figure if labor costs twice those of taxis; higher if thrice those of taxis
Local bus	"Minimum," ½ mile route spacing, 20 buses per day	4	Average, varies as a function of downtown size and distance from residential area to downtown
Local bus	"Intermediate," ½ mile route spacing, 40 buses per day	7	
Local bus	"Frequent," ½ mile route spacing, 120 buses per day	15	
Express bus —reached on foot	Five buses during two hour peak period	15 Average density over two square mile tributary area	From 10 to 15 miles away to largest downtowns only
Express bus —reached by auto	Five to ten buses during two hour peak period	3 Average density over 20 square mile tributary area	From 10 to 20 miles away to downtowns larger than 20 million square feet of nonresidential floorspace
Light rail	Five minute headways or better during peak hour.	9 Average density for a corridor of 25 to 100 square miles	To downtowns of 20 to 50 million square feet of nonresidential floorspace
Rapid transit	Five minute headways or better during peak hour.	12 Average density for a corridor of 100 to 150 square miles	To downtowns larger than 50 million square feet of nonresidential floorspace
Commuter rail	Twenty trains a day	1 to 2	Only to largest downtowns, if rail line exists

Source: Boris S. Pushkarev and Jeffrey M. Zupan, *Public Transportation and Land Use Policy* (Bloomington: Indiana University Press, 1977), p. 164.

TABLE 5-5. PROPULSION ENERGY COMPARISON[1]

Technology	# of Seats	Total Capacity	BTU's Per Veh Mile	BTU's Per Seat Mile	BTU's Per Pass Mile (Full Cap.)
40-foot diesel bus on city streets	48	72	30,000 (38,910)	625 (810)	420 (540)
40-foot diesel bus on a busway	48	72	20,000 (25,940)	420 (540)	280 (360)
Articulated, 6-axle LRV, 2 stops/mile	68	100-150	26,000 (81,500)	380 (1200)	260-170 (815-540)

[1] a) Direct conversion, b) (Adjusted for losses)

Sources: Congressional Budget Office, Urban Transportation and Energy: The Potential Savings of Different Modes (Washington, D.C.: GPO, 1977), p. 8.

Edward T. Myers, "We Disagree!" in Modern Railroads, January 1978, p. 55.

Texas Transportation Institute, "Analysis and Selection of Transitway Evolutionary Paths," Technical Memorandum #2 (submitted to North Central Texas Council of Governments, 1977.

from liquified coal would have even greater energy losses than the process of converting coal to electricity.

The potential savings for either light rail or buses have never been achieved on a regular, daily basis due to differences in peak/off-peak loading. Daily load factors (daily passenger miles/daily seat miles) may be under thirty percent even though some passengers are standing during the peak hours.

Community/Environmental Impacts. The initial success or failure of an LRT system will depend in part on how people perceive the need of a fixed guideway technology for their city. Electric rail vehicles may or may not be seen as modern technology depending on whether citizens associate modern LRV's with old streetcars.

When compared to buses, light rail can result in:

- higher riding comfort,
- lower noise levels, and
- no exhaust fumes.

Higher riding comfort is due to the larger and more stable LRV's. While LRV's can be quieter there may still be problems with wheel squeal on tight curves. The lack of any significant air pollution from the vehicle may indeed be an advantage, but it should be stressed that diesel buses cause little pollution per passenger mile when compared to automobiles.

Busway/LRT Convertibility. It has sometimes been proposed that the wisest policy may be to initially construct a busway. If passenger volumes should significantly increase in the future, it could then be converted to a light rail guideway if LRT could more economically handle the desired capacities and service levels than articulated buses or special bus platoon operations.

There are problems with such a "staged implementation" policy. LRT guideways do not need to be built to the same design standards as busways; there are different minimum turning radii requirements, variations in grade-climbing ability, and different width requirements for two tracks versus two lanes. It is obviously more expensive in the long run to go through a staging process than to go directly to construction of a light rail guideway, assuming that light rail will indeed eventually be needed. The time lag between the day buses quit running and the day the LRT line is put in operation may cause serious congestion problems if former transit passengers must in the meantime find some other way to their destinations. Some interim transit service of much lower quality is usually provided, with the result being that some passengers may permanently switch to automobiles.

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CHAPTER 6. IMPLICATIONS FOR TEXAS

This chapter of the report is intended to provide a synthesis of the findings of the previous chapters. It is intended to highlight those factors that are relevant to assessing the utility of LRT as a suitable transit mode for cities in Texas. The first section summarizes some of the overall characteristics of the largest cities in Texas and compares them with the characteristics of those American cities that have retained the streetcar/ LRT mode and those that are actively considering LRT proposals. The second section reviews a selected set of proposals for rail transit that have been advanced for Texas cities. The final section offers a set of possible guidelines to be used in selecting specific situations for exploring in more detail the feasibility of LRT.

CHARACTERISTICS OF LARGE TEXAS CITIES

This section is a companion to the first section in Chapter 4 which presented some pertinent characteristics of the seven U.S. cities that have retained some part of their original streetcar systems and the seven cities that have actively considered LRT proposals in recent years. The material presented earlier is summarized here and compared with the same characteristics for the Texas cities.

The Texas cities which are examined here are all those which in 1970 exceeded 200,000 population within the central city boundaries. This condition was felt to be reasonable as there are probably no more than three known cities with LRT (all outside the U.S.) which have population estimates below this figure. As presented throughout this report the predominant LRT experience is in cities above half a million population.

Total Population and Population Density

Population figures (1970 Census) for the Texas cities are shown in Table 6-1. The average central city population for the large Texas cities is approximately half a million though there is some variation about this

TABLE 6-1. POPULATIONS OF LARGE TEXAS CITIES, 1970

	Central City	Urbanized Area	SMSA
Austin	251,808	264,499	295,516
Corpus Christi	204,525	212,820	284,832
Dallas	844,401	1,538,684	1,555,950
El Paso	322,261	337,471	359,291
Fort Worth	393,476	676,944	762,086
Houston	1,232,802	1,677,863	1,985,031
San Antonio	654,153	772,513	864,014
Mean	557,632	754,400	872,389

Source: U.S. Census, 1970

TABLE 6-2. DENSITIES OF LARGE TEXAS CITIES IN 1970 (RESIDENTIAL POPULATION PER SQUARE MILE)

	Central City	Urbanized Area	SMSA
Austin	3492	3083	292
Corpus Christi	2033	1633	187
Dallas	3179	1986	345
El Paso	2724	2826	340
Fort Worth	1919	1708	476
Houston	3102	3115	316
San Antonio	3555	3466	441
Mean	2858	2545	342

Source: U.S. Census, 1970

mean, particularly due to the size of Houston. The predominant range is from approximately 200,000 to 850,000, with Houston at a high of 1,200,000.

The urbanized areas in Texas are not significantly larger than the city populations. This is due primarily to liberal annexation laws. There are relatively few incorporated areas surrounding the Texas cities in contrast to the situation found so consistently in the older, Eastern cities. The greatest differences in Texas between central city population and urbanized area population are for the largest areas, Dallas and Houston. In these two cases, the central city grew out to and around existing municipalities such as Highland Park, Grand Prairie, Bellaire, and Pasadena. These are also the only two urbanized areas that had surpassed a population of one million in 1970.

Population density figures are shown in Table 6-2 for central cities, urbanized areas, and SMSA's. None of the cities shows average density as high as 4000 persons per square mile. In fact, San Antonio's central city average is the highest at 3555 per square mile. One interesting phenomenon evidenced in these figures is the occurrence of higher densities for urbanized areas than for the corresponding central city. This is the case for both El Paso and Houston. There are two possible explanations. One is that Texas cities in general do not have a large dense core as do older cities, such as the retained cities and some proposal cities. The central cities in Texas are probably of a more consistent density throughout the area, or at least the older, denser core is smaller and less prominent. The urbanized areas while including the suburban ring type of development do not include large parks or airports in the calculation of average density as in the central city figures. In addition, as pointed out earlier, the trend in Texas is to annex contiguous development so that what might be included in the suburban ring in older cities is within the city limits for most Texas cities. The result is that most of the Texas cities have very close density figures for both central city and urbanized area.

Historical Growth Patterns

The predominant growth for Texas cities has taken place since 1940. This pattern can be seen in Tables 6-3 and 6-4 on city and metropolitan populations. At the turn of the century, San Antonio was the largest

TABLE 6-3. POPULATIONS OF LARGE TEXAS CITIES WITHIN CIRY BOUNDARIES

City \ Year	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1975
Austin	629	3,494	4,428	11,013	14,575	22,258	29,860	34,876	53,120	87,930	132,459	186,545	251,808	301,147
Corpus Christi		175	2,140	3,257	4,387	4,703	8,222	10,522	27,741	57,301	108,287	167,690	204,525	214,838
Dallas	430	2,000	3,000	10,358	38,067	42,638	92,104	158,976	260,475	294,734	434,462	679,684	844,401	812,797
El Paso				736	10,338	15,096	39,279	77,560	102,421	96,810	130,485	276,687	322,261	385,691
Ft. Worth			500	6,663	23,076	26,688	73,312	106,482	163,447	177,662	287,778	356,268	393,476	358,364
Houston	2,396	4,845	9,382	16,513	27,557	44,633	78,800	138,276	292,352	384,514	596,163	938,219	1,232,802	1,326,809
San Antonio	3,488	8,235	12,256	20,550	37,673	53,321	96,614	161,379	231,542	253,854	408,442	587,718	654,153	773,248

Source: U.S. Census, 1970

TABLE 6-4. POPULATIONS OF SMSA/METROPOLITAN AREAS FOR THE LARGE TEXAS CITIES

City\Year	1920	1930	1940	1950	1960	1970
Austin	57,616 (Travis Co.)	77,777 (Travis Co.)	106,193	160,980	212,136	295,516
Corpus Christi	22,807 (Nueces Co.)	51,779 (Nueces Co.)	70,677	165,471	221,573	284,832
Dallas	184,515	309,658	376,548	614,799	1,083,601	1,555,950
El Paso	101,877 (El Paso Co.)	118,461	115,801	194,968	314,070	359,291
Fort Worth	136,691	175,575	207,677	361,253	573,215	762,086
Houston	168,351	339,216	510,397	806,701	1,243,158	1,985,031
San Antonio	191,160	297,271	319,010	500,460	687,151	864,014

Source: U.S. Census, 1970

Texas city at slightly above 50,000 population. Interestingly all these Texas cities had some streetcar lines early in the 20th century. It was not until 1920 that any of these cities exceeded 100,000 in population. Since 1920 several cities began growing rapidly, particularly Houston and Dallas.

Metropolitan growth simply kept pace with central cities until about 1950 when the same two large cities began to experience more growth in the suburban fringe. Fort Worth also followed the suburbanizing trend, though a few years later. The land area within city boundaries shown in Tables 6-6 and 6-8 tend to support the concept of city expansion previously presented. These large increases in land area may explain partially the declining population densities shown in Tables 6-5 and 6-7. El Paso, Dallas and Houston central cities and Austin, Fort Worth, El Paso, and Dallas SMSA's show density increases between 1960 and 1970. Even in the earliest years of growth when automobiles were less prevalent, the highest central city densities were only in the 7000 persons per square mile range.

Automobile Ownership and Transit Usage

The overwhelming majority of population growth in Texas cities occurred after World War II and paralleled a corresponding high rate of automobile ownership. Automobile ownership patterns (shown in Table 6-9) reveal only an average of 13.6% of the central city households were without an automobile. Also there is little difference between the percentage of households with no automobile in the central cities and in the total SMSA's. The suburban rings do show an expected higher rate of automobile ownership.

The percentage of the population estimated as using transit for the work trip are shown in Table 6-10. These figures reveal relatively low levels of transit usage even for the central city. The average for the central cities is 6.5% with Dallas having the highest rate or 10.3%. El Paso shows the highest percentage of transit usage for the work trip for the SMSA's or 8.3%. El Paso and San Antonio are the only cities with more than negligible ridership outside the central cities. This could be attributable to a lack of suburban service in the other cities at the time these data were collected.

TABLE 6-5. DENSITY WITHIN CITY BOUNDARIES (PERSONS PER SQ. MILE) FOR THE LARGE TEXAS CITIES*

	1920	1930	1940	1950	1960	1970
Austin			3503.2	4126	3776	3492
Corpus Christi			6161.4	5037	4436	2033
Dallas	6966.4	6234.4	7259.5	3879	2428	3179
El Paso		7586.7	7118.4	5097	2414	2724
Ft. Worth	6457.5	3522.6	3567.5	2975	2536	1919
Houston	3792.0	4072.3	5281.8	3726	2860	3102
San Antonio	4518.0	6482.0	7110.8	5877	3662	3555

TABLE 6-6. LAND AREA WITHIN CITY BOUNDARIES (SQ. MILES) FOR THE LARGE TEXAS CITIES*

	1920	1930	1940	1950	1960	1970
Austin	NA	NA	25.1	32.1	49.4	72.1
Corpus Christi	NA	NA	9.3	21.5	37.8	100.6
Dallas	22.8	41.8	40.6	112.0	279.9	265.6
El Paso	NA	13.5	13.6	25.6	114.6	118.3
Ft. Worth	16.5	46.4	49.8	93.7	140.6	205.0
Houston	36.5	71.3	72.8	160.0	328.1	397.0
San Antonio	35.7	35.7	35.7	69.5	160.5	184.0

*Source: U.S. Census, 1970

TABLE 6-7. DENSITY OF SMSA/METROPOLITAN AREAS (PER SQUARE MILE)

	1920	1930	1940	1950	1960	1970
Austin	57.4*	77.5*	151	159	209	292
Corpus Christi	29.4*	66.8*	239	197	264	187
Dallas	995.5	613.9	685	688	297	345
El Paso	110.4	407.3	1218	185	298	340
Ft. Worth	292.3*	1023.3	723	412	358	476
Houston	216.6	424.4	498	466	727	316
San Antonio	322.5	597.6	684	401	551	441

*Data for county

TABLE 6-8. LAND AREA OF SMSA/METROPOLITAN AREAS (IN SQUARE MILES)

	1920	1930	1940	1950	1960	1970
Austin	1004*	1004*	705	1015	1015	1012
Corpus Christi	775	775	296	836	838	1526
Dallas	193.3	504.4	550	893	3653	4508
El Paso	923	290.8	95	1054	1054	1057
Ft. Worth	467.6	170.6	287	877	1600	1601
Houston	777.4	799.2	1024	1730	1711	6285
San Antonio	592.8	467.3	466	1247	1247	1960

*Data for county

TABLE 6-9. PERCENT OF HOUSEHOLDS WITH NO AUTOMOBILE IN 1970 FOR THE LARGE TEXAS CITIES

	Central City	SMSA	Suburban Ring
Austin	10.3	9.6	3.5
Corpus Christi	10.6	11.5	15.5
Dallas	14.1	11.0	5.8
El Paso	16.1	15.8	10.3
Ft. Worth	13.3	9.2	3.7
Houston	14.1	11.6	6.4
San Antonio	16.5	14.2	5.1
Mean	13.6	11.8	7.2

Source: U.S. Census, 1970

TABLE 6-10. PERCENT USING TRANSIT FOR THE TRIP TO WORK FOR THE LARGE TEXAS CITIES

	Central City	SMSA	Suburban Ring
Austin	3.8	3.3	0.5
Corpus Christi	2.9	2.2	0.1
Dallas	10.3	6.1	0.7
El Paso	9.1	8.3	2.0
Ft. Worth	4.3	2.5	0.4
Houston	7.5	5.1	0.8
San Antonio	7.5	5.7	1.2
Mean	6.5	4.7	0.8

Source: U.S. Census, 1970

Table 6-11 shows the total number of persons using transit for the journey to work in 1970. Dallas and Houston each had about 40,000 transit commuters; San Antonio had 18,000; and all the other cities had less than 10,000. It is readily apparent that few suburban residents use transit for the work trip.

Concentration of Employment

Tables 6-12 and 6-13 indicate the percentages of residents who work in the central city and the central business district, respectively. The percentages are quite high; on the average, 85.3% of central city residents work in the central city. A large part of the supposed concentration is explainable by the fact that Texas cities have such a large land area within the central city boundaries. However, the CBD's also show a fairly strong concentration of jobs, 12.8% for the central cities. Houston appears to be the most attractive CBD for central city workers while Austin is the most attractive for workers in the total SMSA.

Tables 6-14 and 6-15 show the total number of residents who work in the central city and the CBD, respectively. There is considerable variation about the mean: Dallas and Houston have extremely high values while San Antonio is slightly above the mean. These are the only three cities with substantial commuting from the suburbs to either the central city or CBD. The other four cities seem quite small in comparison.

COMPARISON OF TEXAS CITIES WITH CITIES THAT RETAINED LRT AND CITIES THAT PROPOSE LRT

The preceding discussion of each group of cities has attempted to highlight the similarities as well as the discrepancies within the groups. Even though many characteristics showed variation within the group, averages of this group will be used for numerical comparison of characteristics between groups. Diagrams accompanying the tables show the ranges from minimum to maximum values as well as the mean values. In many cases these indicate that while the mean for Texas cities appears quite different, there is actually some overlap between the numbers for the Texas cities and the "retained" or "proposal" cities.

Table 6-16 is a comparison of population, population density, and land area characteristics. In all cases the retained cities appear at one extreme,

TABLE 6-11. TOTAL TRANSIT RIDERS FOR WORK TRIP IN 1970 FOR THE LARGE TEXAS CITIES

	Central City	SMSA	Suburban Ring
Austin	3,930	4,010	80
Corpus Christi	2,197	2,231	34
Dallas	37,821	39,847	2,026
El Paso	9,883	10,164	281
Ft. Worth	6,955	7,530	575
Houston	38,113	40,279	2,166
San Antonio	17,114	18,160	1,046
Mean	16,573	17,459	887

Source: U.S. Census, 1970

TABLE 6-12. PERCENT WORKING IN CENTRAL CITY IN 1970 FOR THE LARGE TEXAS CITIES

	Central City	SMSA	Suburban Ring
Austin	90.6	86.7	64.5
Corpus Christi	81.9	67.9	23.9
Dallas	86.6	68.8	46.9
El Paso	86.7	78.5	23.9
Fort Worth	75.1	52.9	29.4
Houston	90.0	73.8	45.3
San Antonio	87.7	79.8	60.2
Mean	85.5	72.6	42.0

Source: U.S. Census, 1970

TABLE 6-13. PERCENT WORKING IN CENTRAL BUSINESS DISTRICT IN 1970 FOR THE LARGE TEXAS CITIES

	Central City	SMSA	Suburban Ring
Austin	14.0	13.4	10.2
Corpus Christi	11.3	9.3	2.9
Dallas	14.7	10.9	6.2
El Paso	11.9	10.6	2.0
Fort Worth	9.3	6.6	3.8
Houston	16.5	13.2	7.5
San Antonio	12.0	9.8	4.2
Mean	12.8	10.5	5.3

Source: U.S. Census, 1970

TABLE 6-14. TOTAL NUMBER OF WORKERS IN CENTRAL CITY IN 1970 FOR THE LARGE TEXAS CITIES

	Central City	SMSA	Suburban Ring
Austin	84,305	94,702	10,397
Corpus Christi	55,406	60,562	5,156
Dallas	289,214	416,783	127,569
El Paso	86,185	89,762	3,577
Fort Worth	113,401	155,241	41,840
Houston	417,662	536,642	118,980
San Antonio	189,804	242,015	52,211
Mean	176,568	227,958	51,390

Source: U.S. Census, 1970

TABLE 6-15. TOTAL NUMBER OF WORKERS IN CENTRAL BUSINESS DISTRICT IN 1970 FOR THE LARGE TEXAS CITIES

	Central City	SMSA	Suburban Ring
Austin	13,001	14,652	1,641
Corpus Christi	7,652	8,286	634
Dallas	49,060	65,961	16,901
El Paso	11,808	12,112	304
Fort Worth	14,104	19,489	5,385
Houston	76,575	96,278	19,703
San Antonio	26,028	29,664	3,636
Mean	28,318	35,206	6,886

Source: U.S. Census, 1970

TABLE 6-16. A COMPARISON OF AVERAGE 1970 POPULATION AND POPULATION DENSITY

	Retained LRT Cities	Proposal Cities	Texas Cities
Central City Population	792,899	577,373	557,632
Urbanized Area Population	2,404,857	1,394,622	754,400
SMSA Population	2,578,420	1,581,349	872,389
Central City Density	12,471	9,148 (East) 4,431 (West)	2,858
Urbanized Area Density	4,181	3,844	2,545
SMSA Density	1,533	899	342
City Land Area (sq. miles)	65.8	90.6	191.8

Source: U.S. Census, 1970

and the Texas cities at the opposite. There is not a large difference among the central city populations, but the urbanized and metropolitan areas of the retained and proposal cities are significantly larger than the figures for Texas. The reverse is true for density: The central city densities for the different groups are far apart, with Texas at the low end, but the figures for urbanized areas are much closer together. Inclusion of suburban development with the non-Texas central cities brings their overall density for the urbanized areas down to a point not vastly different from the densities for Texas cities.

The last row shows one significant characteristic of Texas cities that sets them apart from the others——the inclusion of large land areas within the central city. Accordingly Texas central cities command a larger proportion of their total metropolitan areas and populations than do the other types of cities.

Figure 6-1 shows the ranges and means for total population of the three groups of cities while Figure 6-2 shows the same for population density. In respect to total population, there is much overlap between the Texas cities and the others. Conversely there is very little overlap with respect to population density.

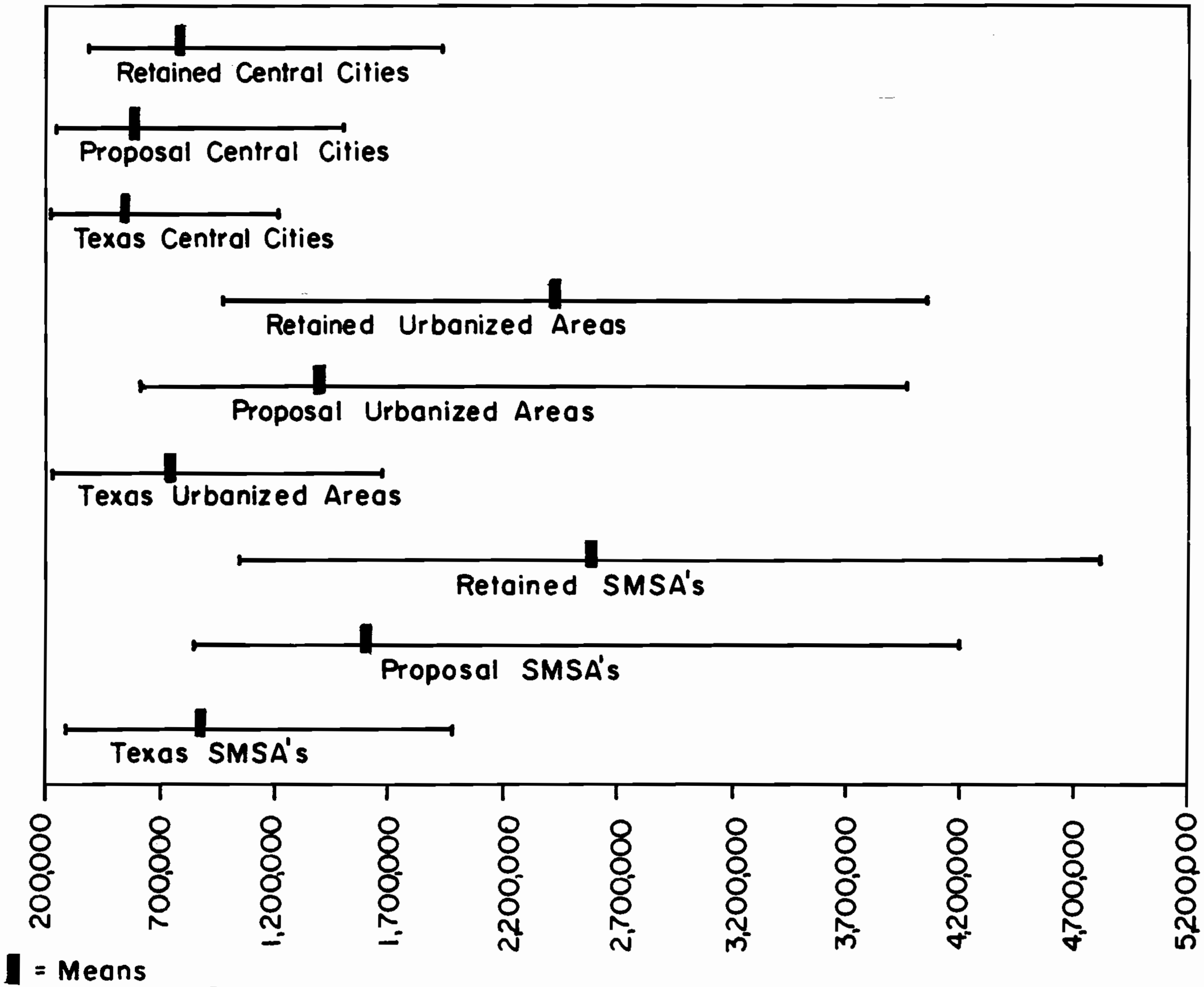
A comparison of the percentage of households without any automobile is made in Table 6-17 and Figure 6-3. Texas cities are revealed to be fairly close to the averages for proposal cities. Both groups show much more automobile influence than is found in the cities that retained LRT. The high levels of households with no automobiles found in the denser central cities do not show up for Texas cities, partly due to a less dense city core and partly because the city areas are very large and include what would be suburban development in most of the non-Texas cities.

Transit riding for the work trip is compared in Table 6-18 and Figure 6-4. The average rate for Texas central cities is less than half that for proposal cities and is approximately one-fifth of the rate in the retained cities. The percentage for Texas central cities is actually 35% lower than the rate found in the suburban fringe of the retained cities. For SMSA averages, however, the Texas cities show a rate only about 20% lower than the proposal cities.

Table 6-19 and Figure 6-5 concern the total number of residents who used transit for the journey to work in 1970. The averages for the Texas

FIGURE 6-1.

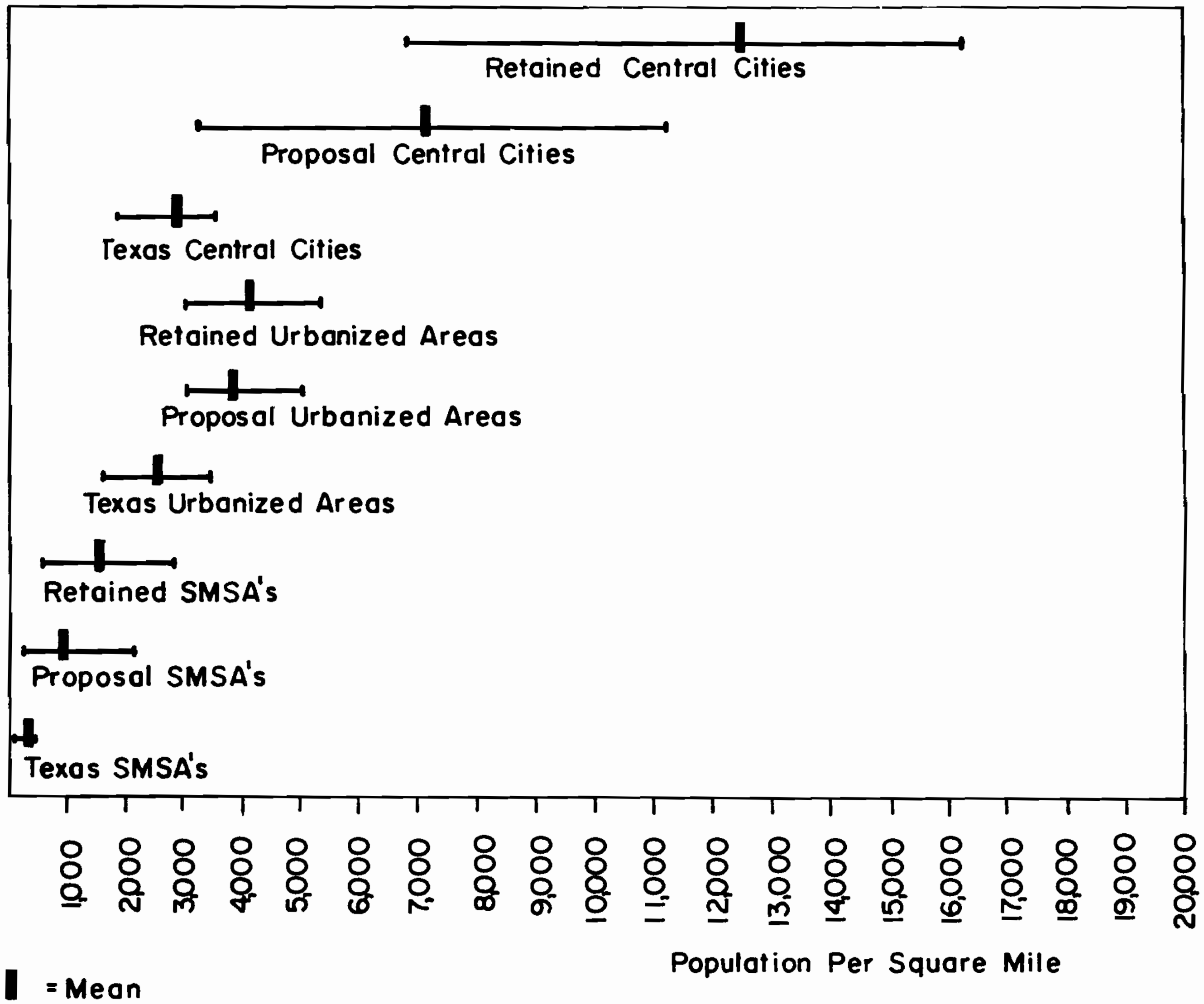
COMPARISON OF POPULATIONS -RANGES & MEANS



Source: U.S. Census, 1970

FIGURE 6-2.

COMPARISON OF POPULATION DENSITIES —RANGES & MEANS



Source: U.S. Census, 1970

TABLE 6-17. MEAN PERCENT OF HOUSEHOLDS WITH NO AUTOMOBILE, 1970

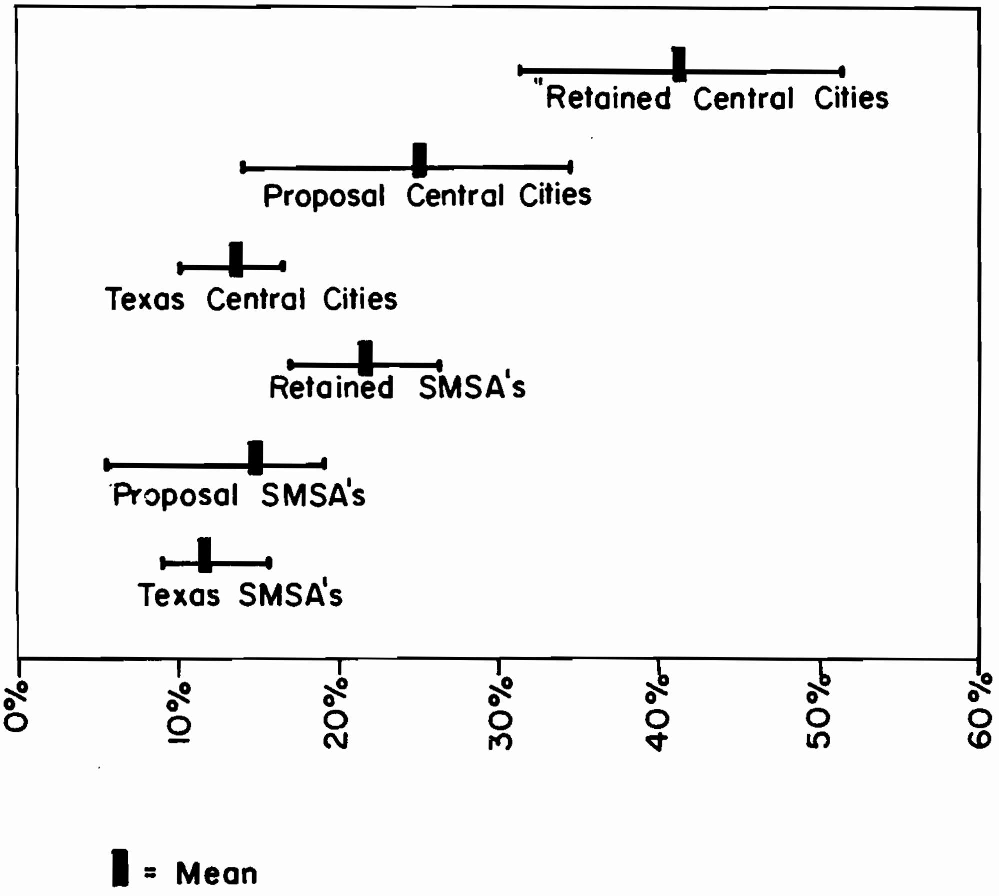
Place of Residence	Retained Cities	Proposal Cities	Texas Cities
Central City	40.6	21.0	13.6
Suburban Ring	12.5	6.7	7.2
SMSA	21.7	12.8	11.8

Source: U.S. Census, 1970

FIGURE 6-3.

PER CENT OF HOUSEHOLDS WITH NO AUTOMOBILES

1970 CENSUS



Source: U.S. Census, 1970

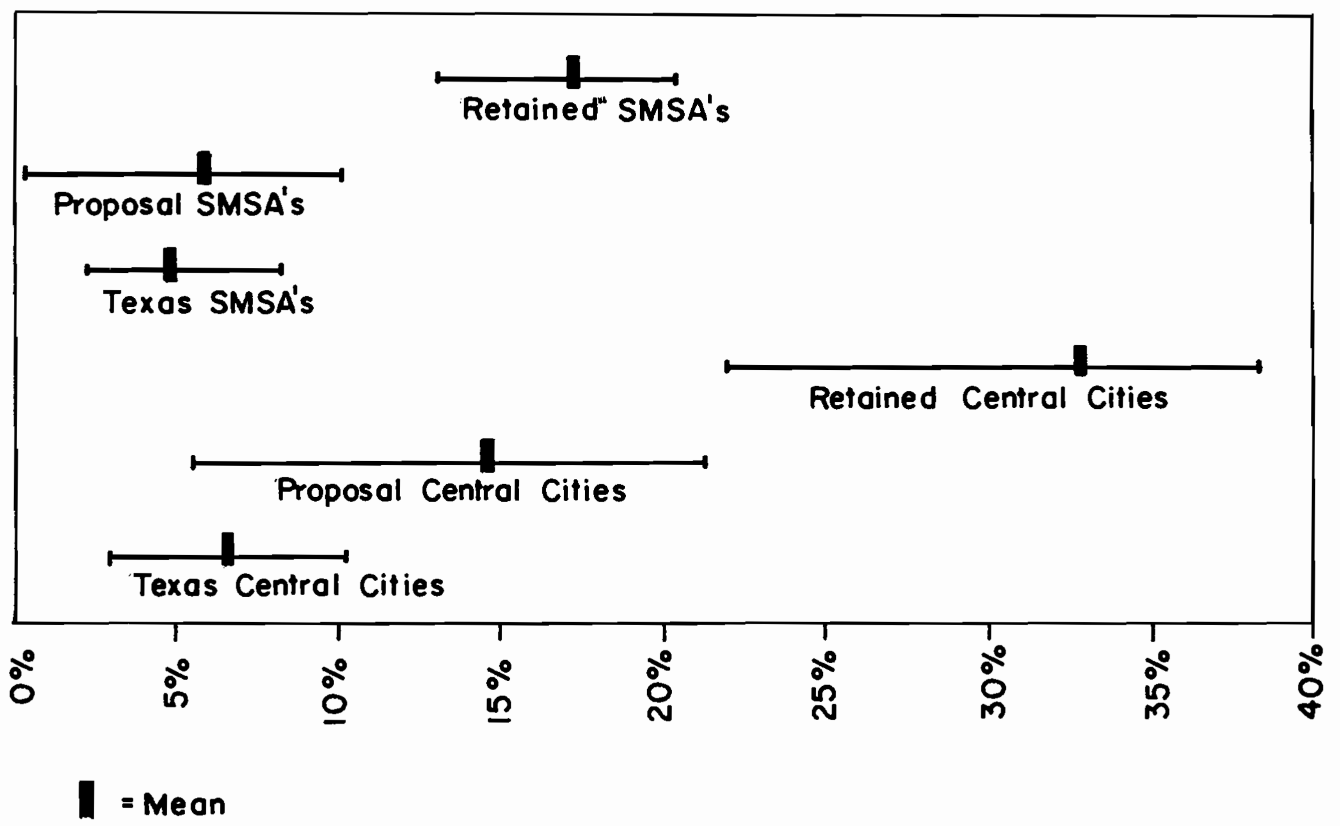
TABLE 6-18. MEAN PERCENT USING TRANSIT FOR THE JOURNEY TO WORK, 1970

Place of Residence	Retained Cities	Proposal Cities	Texas Cities
Central City	32.8	12.6	6.5
Suburban Ring	10.0	2.4	0.8
SMSA	17.2	5.9	4.7

Source: U.S. Census, 1970

FIGURE 6-4.

Per Cent of Residents Using Transit for the Trip to Work



Source: U.S. Census, 1970

TABLE 6-19. MEAN NUMBER OF RESIDENTS USING TRANSIT FOR THE JOURNEY TO WORK, 1970

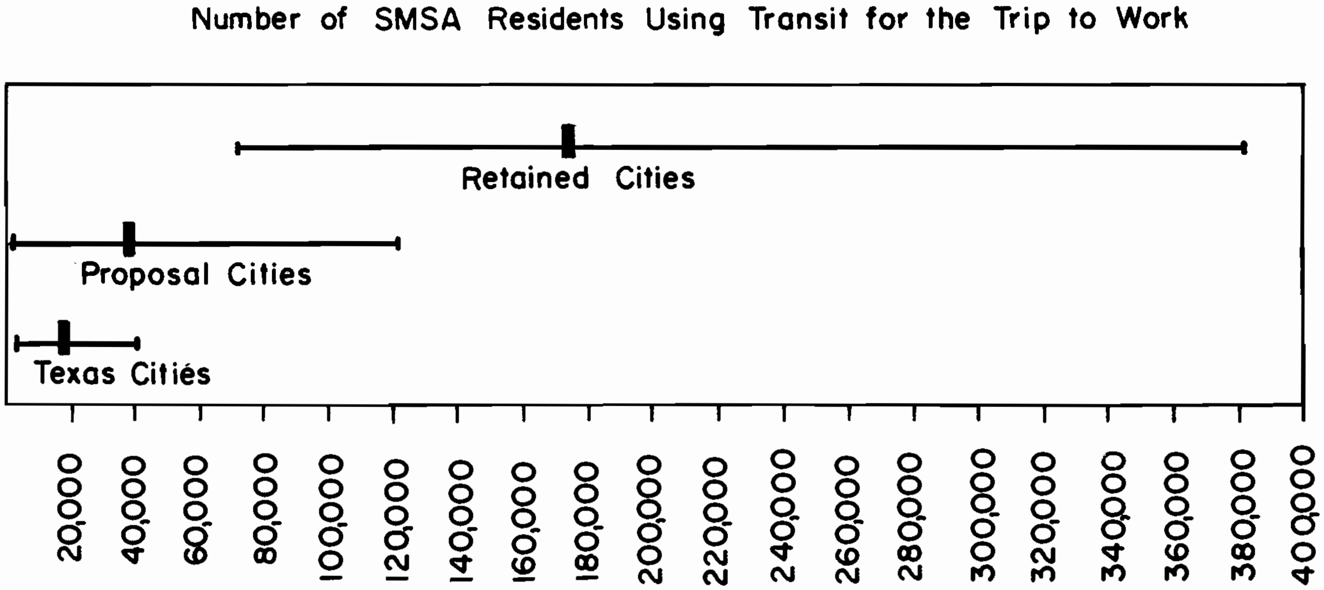
Place of Residence	Retained Cities	Proposal Cities	Texas Cities
Central City	102,042	28,467	16,573
Suburban Ring	72,956	9,096	887
SMSA	174,998	37,563	17,459

Source: U.S. Census, 1970

FIGURE 6-5.

COMPARISON OF TRANSIT USE FOR THE TRIP TO WORK

1970 CENSUS



Source: U.S. Census, 1970

cities are well below those for the proposal cities and drastically lower than those for the retained cities. Figure 6-5 indicates some overlap between the proposal cities and Texas cities.

Comparison of employment concentrations is displayed in the remaining Tables 6-20 thru 6-23 and in Figure 6-6. In this comparison Texas cities outstrip the other groups of cities in regard to central city characteristics. Larger percentages of workers are employed in the Texas central cities than both the retained and proposal cities while the average total number of central city workers in Texas cities is not much lower than the other groups. It must be repeated, though, that Texas cities generally include the dominant portion of the land area of their urbanized areas unlike the older Eastern cities which are usually surrounded by numerous satellite towns that provide competitive employment. Because Texas cities are so large in land area, employment within the central city does not necessarily imply a concentration of jobs.

On the average the CBD's of Texas cities were found to attract larger percentages of workers than the proposal cities and have corresponding larger CBD employment.

In summary, while the Texas cities are somewhat smaller on the average than the other two groups, the distinguishing characteristics in Texas cities are low population density, a high level of automobile ownership, and low transit usage. The Texas cities do possess a sizable concentration of jobs in their CBD's and, while a majority of these downtown workers presently commute by car, there is a potential market for any significant incentive for a shift toward transit.

All of the above statistics are based on the entire area of a central city, urbanized area, or SMSA. In determining the feasibility of a single major transit facility, data on the particular travel corridor involved would be more relevant. Census data on the various corridors that might be defined for Texas cities are not readily available; a considerable amount of data assembly would be required for such a detailed analysis. Were such corridor characteristics available, the Texas cities might prove to have certain corridors where the characteristics would be more favorable to transit and might resemble the characteristics of the retained and proposal cities. The comparisons presented in this report are provided to facilitate insight into the characteristics of selected cities in Texas

TABLE 6-20. MEAN PERCENT WORKING IN CENTRAL CITY, 1970

Place of Residence	Retained Cities	Proposal Cities	Texas Cities
Central City	78.0	72.5	85.5
Suburban Ring	25.6	33.1	42.0
SMSA	41.3	47.4	72.6

Source: U.S. Census, 1970

TABLE 6-21. MEAN PERCENT WORKING IN CENTRAL BUSINESS DISTRICT, 1970

Place of Residence	Retained Cities	Proposal Cities	Texas Cities
Central City	16.6	10.1	12.8
Suburban Ring	7.0	4.6	5.3
SMSA	9.9	6.5	10.5

Source: U.S. Census, 1970

TABLE 6-22. MEAN NUMBER OF RESIDENTS WORKING IN CENTRAL CITY, 1970

Place of Residence	Retained Cities	Proposal Cities	Texas Cities
Central City	220,524	142,549	176,568
Suburban Ring	148,735	105,812	51,390
SMSA	369,259	248,361	227,958

Source: U.S. Census, 1970

TABLE 6-23. MEAN NUMBER OF RESIDENTS WORKING IN CENTRAL BUSINESS DISTRICT, 1970

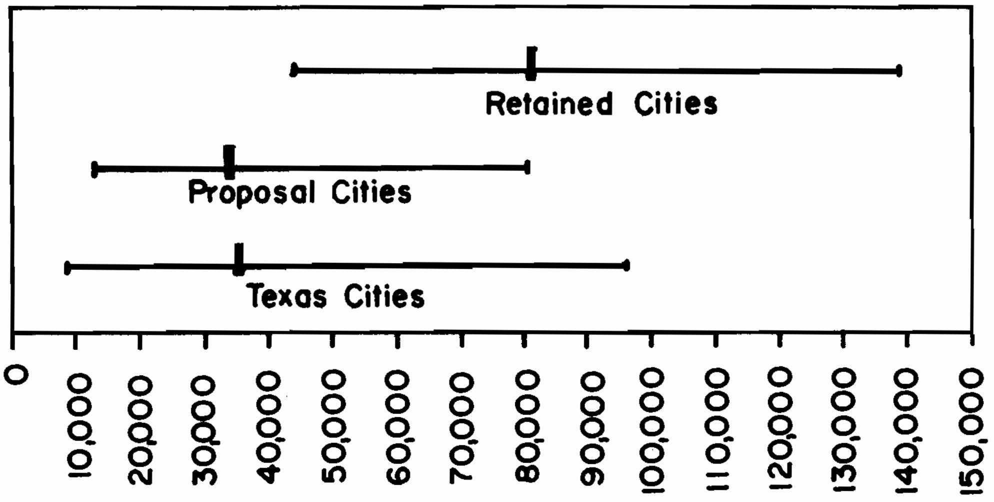
Place of Residence	Retained Cities	Proposal Cities	Texas Cities
Central City	42,345	18,668	28,318
Suburban Ring	39,604	15,133	6,886
SMSA	81,949	33,801	35,206

Source: U.S. Census, 1970

FIGURE 6-6.

NUMBER OF SMSA RESIDENTS REPORTING EMPLOYMENT IN THE CENTRAL BUSINESS DISTRICT

1970 CENSUS



▌ = Mean

Source: U.S. Census, 1970

with those in cities which have LRT service or are proposing to develop LRT in the immediate future.

PLANS AND PROPOSALS FOR TEXAS CITIES

Each of the larger cities in the state has at one time or another passively or actively considered LRT. A brief "pulse taking" was conducted over the life of this study and the findings for the largest seven cities are provided. Several other cities, primarily those along the border or those surrounding larger cities, have also discussed LRT; however, none has developed any specific studies or plans.

Houston

The City of Houston has several studies underway which involve an alternative analysis of major transit improvements. An alternative analysis study is being performed under the direct supervision of the Metropolitan Transit Authority of Harris County (Metro) and in cooperation with the Texas State Department of Highways and Public Transportation, the Houston-Galveston Area Council, the City of Houston, and other local jurisdictions. The principal study of interest is the Southwest Freeway/West Park Corridor which includes several bus-rail alternatives, with at least two LR options. This study should be completed by mid-summer of 1980 and plans are to submit this report to UMTA for the next stage.

Dallas

The City of Dallas, the North Central Texas Council of Governments, and other local jurisdictions are cooperating on an alternative analysis study of the North Central Expressway. The study which includes LRT as a major element in one alternative will result in a draft EIS.

El Paso

The City of El Paso has seventeen PCCs in various states of repair which remain from the old trolly systems. At present all electrical lines are down but most of the tracks of the old system remain. An inventory of the equipment, condition, and related factors is planned. Meantime, a trolley/LRT was a main component of a recent downtown circulation study.

Fort Worth

In cooperation with the NCTCOG and other local jurisdictions, the city staff anticipates an alternative analysis study this fall for corridors in the south to west quadrants of the city. LRT will be used as alternatives in this study. Public attitudes in a recent survey confirm a continuing posture of the general citizenry——rail is more popular than bus. In August 1979, the Fort Worth Trolley Feasibility Study was completed. This latest study represents a continuing trend of interest in LRT.

San Antonio

As recently as two years ago, LRT was considered in a sketch-planning effort conducted through the MPO. Other similar studies at varying levels of detail have been considered or conducted in the CBD area. At present no additional studies involving LRT are known.

Austin

Considerable interest in LRT has been demonstrated over the past few years. One study which resulted in a report (CARTRANS: High Speed Transit for the Texas Capital) was produced by the Texas Association of Public Transportation (TAPT). The objective of the study was to justify a feasibility study of LRT for the Austin area to be conducted by a qualified consultant.

In 1975, the Austin Transportation Study office staff incorporated busways and LRT into its study of long-range alternatives. The report published by TAPT was modified in 1976 and published as Preliminary Plan for a South Austin LRT Demonstration Line. Although the attractiveness of LRT remains, there are no known studies currently underway.

Corpus Christi

At present there are no known LRT studies either underway or planned. The City of Corpus Christi may be attractive to advocates of LRT because of its linear development and existing railroad corridors, in addition to other attributes.

GUIDELINES FOR SELECTION

This report has compiled an array of descriptive information about Light Rail Transit, including the historical development of the streetcar/LRT mode, the current status of this mode around the world, and the design and operations of LRT systems. This material should be useful to those who have heard of Light Rail Transit as a new approach to the urban transportation problem, and who wish to learn more about it. The report has also presented an analysis of city characteristics relevant to LRT, the results of applying a mathematical optimizing model to the LRT mode, and an identification of the factors important to an evaluation of LRT as an alternative to other transit modes.

By way of conclusion, guidelines are suggested which are intended to summarized the findings of the study for the benefit of state and local policy-makers. These guidelines are specifically oriented to large Texas cities, since the object of the study was to determine the applicability of Light Rail Transit to the Texas situation. The guidelines follow:

(1) It is unlikely that a <u>citywide</u> Light Rail Transit <u>system</u> will be warranted in any Texas city under present conditions or those foreseeable in the near future. That is, a comprehensive LRT network, consisting of many routes, does not seem indicated.

(2) An LRT line may be suitable in individual corridors of Texas cities under particularly favorable conditions, such as:

  (a) a high density of travel demand estimated to produce at least 8,000 LRT passengers in the peak direction in the peak hour;

  (b) location of one terminal of the line in the Central Business District (i.e., a radial line);

  (c) location of the outer terminal of the line at a major activity center and trip generator, such as a shopping center, university, airport, hospital complex, or amusement park. LRT must be fed by an excellent, integrated bus system and have park and ride support facilities.

(3) An LRT line would be most attractive in a situation where the alignment can utilize an existing right-of-way, because:

  (a) There would be little or no land acquisition cost.

  (b) There would be little or no displacement of homes or other buildings.

  (c) Most of the guideway could be constructed at ground level, which is the least expensive vertical alignment.

(4) The necessity for constructing an underground or elevated LRT guideway makes such a route very unattractive economically.

(5) Location of an LRT line within or alongside a freeway may be satisfactory, but this depends on the characteristics of the freeway. Freeway routings often avoid major activity centers where there are concentrations of transit demand. Further, pedestrian access to an

LRT stop located in the median strip of a freeway is usually poor. Hence, there should be no particular preference given to freeway alignments. Radial railroad corridors are proving to be the most desirable candidate for joint use of ROW.

(6) Street running of LRT vehicles is permissible in the Central Business District, where alternative alignments would be the most costly and where frequent stops are desirable for effective passenger collection and distribution. However, the majority of any LRT route should be on separate right-of-way in order to achieve the high average speed needed to attract passengers away from competing transportation modes.

(7) The spacing of stops on an LRT line should be more like that of a heavy rail system (conventional subway-elevated) than that on ordinary streetcar lines. This generally means a spacing of one-half to one mile between stops. The CBD is an exception since close spacing of stops (every two or three blocks, depending on block length) is desirable.

(8) The stops on an LRT route (outside of the CBD) should be designed as transfer points, with feeder bus service and extensive parking facilities to attract park-and-ride travelers. Demand responsive operations may be a suitable feeder mode in suburban areas.

(9) Federal regulations mandate that any new transit system be accesible to elderly and handicapped travelers, including those who use wheelchairs. This suggests that an LRT line should be designed for high-level loading and the stations should have platforms with ramps or elevators.

(10) One marked advantage of LRT over bus systems is the ability to run vehicles in trains, which permits flexible allocation of capacity and economies in operating costs. This advantage makes LRT an attractive option for corridors with heavy peak-period demand. However, much of this advantage is lost if it is necessary to have a fare collector on each car of a train. This suggests that there should be fare collection at stations or self-servicing operations when multi-car trains are to be used.

(11) If one objective of a transit facility is to promote intensive land development in a corridor or at certain points, then an LRT line is more likely to accomplish this than are bus options. However, experience with recent rail transit projects indicates minimal land use impact, except where there are already strong land development pressure and effective land use regulation.

(12) A phased transition from busway to LRT in the same corridor in concept requires further examination in regard to both technical aspects and federal policies.

(13) Any worsening of the petroleum supply situation in the United States will make LRT a more attractive option, because the power supply can be obtained from non-crude-oil sources.

(14) As discussed in Chapter 3, there are many technical and engineering issues that must be resolved in the design of an LRT line. It is not appropriate to make broad generalizations on these issues since

the answers will depend on local circumstances. Many of the issues involve tradeoffs between higher capital costs and lower operating costs or better service, so there are policy implications. Thorough planning and engineering studies should be conducted, and the results published, before making any final decision to proceed with an LRT line.

(15) In the evaluation of alternatives Tables 6-24 and 6-25 provide information which may be useful. A form of goal achievement matrix has often been used successfully in facilitating the identification of tradeoffs and performance measures, with respect to local objectives. It has proven to be useful at the preliminary stage of evaluation, prior to detailed engineering studies.

Given the rapid growth of Texas cities and a difficult energy situation that now appears to be a continuing feature of American life, it is clear that major transit improvements are going to be considered in several Texas cities in the next few years. Following the "alternatives analysis" procedure that has been stipulated by the Urban Mass Transportation Administration, it is probable that Light Rail Transit will be examined as one alternative. It is hoped that the information amassed in this report, and summarized in the guidelines above, will prove useful in this process.

TABLE 6-24. TYPICAL TRANSIT MODE ALTERNATIVES

Types	Examples
1. Conventional bus service on surface streets	All existing bus systems in Texas cities
2. Busway: exclusive lanes for buses (and possibly other high-occupancy vehicles), with collection-distribution on city streets at both ends of the mainline	Shirley Busway in Virginia, San Bernardino Busway in California
3. Light rail transit	
a. Street running	Most routes in downtown Philadelphia, Pittsburgh, San Francisco
b. On separate right-of-way	Boston's Green Line; Newark City Subway; Edmonton, Alberta; San Diego
4. Heavy rail transit (conventional subway/elevated system)	BART in San Francisco, Metro in Washington, Lindenwold Line in South Jersey, MARTA in Atlanta

TABLE 6-25. CRITERIA FOR COMPARISON OF TRANSIT MODE ALTERNATIVES

Criteria	Of Concern To Operator	Traveler	Community
Economic Characteristics			
Construction cost	X		X
Vehicle cost	X		X
Operating cost	X	X	X
Performance Characteristics			
Maximum vehicle speed	X		
Average vehicle speed	X	X	
Acceleration/deceleration capability	X		
Passenger-carrying capacity	X	X	
Safety from accidents	X	X	
Security from crime	X	X	X
Proven technology	X		
Reliability in adhering to schedule	X	X	
Minimal impact of vehicle breakdown	X	X	
Minimal impact of bad weather	X	X	X
In-vehicle comfort (smoothness of ride)		X	
Impacts			
Air pollution			X
Noise		X	
Visual			X
Energy efficiency	X		X
Reliance on petroleum products	X		X
Stimulus to land use development	X		X
Barrier effect of guideway			X
Land consumption	X		X
Planning Considerations			
Average door-to-door travel speed		X	X
Area coverage (density of stops)	X	X	X
Frequency of service at a stop		X	X
Necessity for transfers		X	
Necessity for feeder service	X	X	
Accessibility to the handicapped		X	X
Public appeal/image	X	X	X
Attractiveness to CBD commuters	X	X	X
Suitability for non-CBD travel	X	X	X
Effect on CBD congestion			X
Possibility for mixed alignment types	X		X
Possibility for other use of guideway			X

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APPENDIX I

APPENDIX I

TRAMWAYS OF THE WORLD

Australia

Adelaide
Melbourne

Austria

Gmunden
Graz
Innsbruck
Linz
Wien

Belgium

Antwerpen
Bruxelles
Charleroi
Gent
Oostende

Brazil

Campos de Jordao
Rio de Janeiro

Bulgaria

Sofia

Canada

Toronto
Edmonton

China

Dairen
Pinkiang
Shanghai
Shenyang
Tientsin

Czechoslovakia

Bratislava
Brno
Kosice
Liberec
Most
Olomouc
Ostrava
Plzen
Praha
Trencianska Teplice

Egypt

Alexandria
Cairo
Heliopolis

Finland

Helsinki

France

Lille
Marseille
St. Etienne

East Germany

Bad Schandau
Berlin
Brandenburg
Cottbus
Dessau
Dresden
Erfurt
Frankfurt/Oder
Gera
Gorlitz
Gotha
Halberstadt
Halle
Jena
Karl-Marx-Stadt
Leipzig
Magdeburg
Naumburg
Nordhausen
Plauen
Potsdam
Rostock
Schoneiche
Schwerin
Strausberg
Woltersdorf
Zwickau

West Germany

Augsburg
Bielefeld
Bochum
Braunschweig
Bremen
Bremerhaven
Darmstadt
Dortmund
Dulsburg
Dusseldorf
Essen
Esslingen
Frankfurt/Main
Freiburg/Breisgau
Hagen
Hamburg
Hannover
Heidelberg
Karlsruhe
Kassel
Kiel
Koln
Krefeld
Ludwigshafen
Mainz
Mannheim
Mulheim/Ruhr
Munchen
Neunkirchen
Nurnberg
Stuttgart
Ulm
Vestiche
Wuppertal
Wurzburg

Great Britain

Blackpool
Douglas

Greece

Piraeus

APPENDIX I

CONTINUED

Hong Kong

- Hong Kong

Hungary

- Budapest
- Debrecen
- Miskolc
- Szeged

India

- Calcutta

Italy

- Milano
- Napoli
- Roma
- Torino
- Trieste

Japan

- Enoshima
- Fukuoka
- Gifu
- Hakodate
- Hiroshima
- Kagoshima
- Kitakyushu
- Kochi
- Kumamoto
- Kyoto
- Nagasaki
- Okayama
- Osaka
- Matsuyama
- Sapporo
- Takaoka
- Tokyo
- Toyama
- Toyohashi

Mexico

- Mexico City
- Vera Cruz

Netherlands

- Amsterdam
- Den Haag
- Rotterdam

Norway

- Oslo
- Trondheim

Paraguay

- Asuncion

Poland

- Bydgoszcz
- Czestochowa
- Elblag
- Gdansk
- Gorzow
- Grudziadz
- Katowice
- Krakow
- Lodz
- Poznan
- Szczecin
- Torun
- Warszawa
- Wroclaw

Portugal

- Coimbra
- Lisboa
- Porto

Romania

- Arad
- Braila
- Bucuresti
- Galati
- Iasi
- Oradea
- Sibiu
- Timisoara

Spain

- Barcelona
- Soller

Sweden

- Goteborg
- Lidingo
- Norrkoping
- Stockholm

Switzerland

- Basel
- Bern
- Bex
- Geneve
- Monthey
- Neuchatel
- Zurich

United States

- Boston
- Cleveland
- Fort Worth
- Newark
- New Orleans
- Philadelphia
- Pittsburgh
- San Francisco
- Detroit

U.S.S.R.

- Alma Ata
- Angarsk
- Arkhangelsk
- Astrakhan
- Baku
- Barnaul
- Biysk
- Bogoroditsk
- Chelyabinsk
- Cherepovets
- Chernigov
- Chita
- Daugavpils
- Dneprodzerzhinsk

APPENDIX I

CONTINUED

Dnepropetrovsk
Donetsk
Dzerzhinsk
Gorki
Gorlovka
Grozniy
Irkutsk
Ivanovo
Izhevsk
Kadiyevka
Kalinin
Kaliningrad
Karaganda
Karpinsk
Kazan
Kemerovo
Khabarovsk
Kharkov
Kiev
Kirovabad
Kolomna
Komsomolsk
Konotop
Konstantinovka
Kopeisk
Kramatorsk
Krasnodar
Krasnoturinsk
Krasnoyarsk
Krivoy Rog
Kronshtad
Kursk
Kuibyshev
Leningrad
Liepaya
Lipetsk
Lvov
Magnitogorsk
Makeyevka
Minsk
Moskva
Naberezhnye Chelny
Nikolayev
Nizhniy Tagil
Noginsk
Novocherkassk
Novopolotsk
Novorossiysk
Novokuznetsk
Novosibirsk
Odessa
Ordzhonikidze
Orel
Orsk
Osinnika
Pavlodar
Perm
Pinsk
Poti
Prokopyevsk
Pyatigorsk
Riga
Rostov-na-Donu
Rzhev
Saratov
Shakhty
Smolensk
Sovyetsk
Staraya Russa
Sumgait
Sverdlovsk
Taganrog
Tallin
Tashkent
Temirtau
Tbilisi
Tomsk
Toropets
Tula
Ufa
Ulan-Ude
Ulyanovsk
Ust-Kamenogorsk
Velikiye Luki
Vinnitsa
Vitebsk
Vladivostok
Volgograd
Volzhskii
Voronezh
Voroshilovgrad
Vyazma
Yaroslavl
Yerevan
Yevpatoria
Zaporozhye
Zhdanov
Zhitomir
Zlatoust

Vietnam

Hanoi

Yugoslavia

Beograd
Osijek
Sarajevo
Zagreb

SOURCE· MODERN TRAMWAY, March 1977

APPENDIX II

APPENDIX II

PRINCIPAL LRT DEVELOPMENT ACTIVITY IN WESTERN EUROPE AND NORTH AMERICA (EXISTING OR PLANNED)

	New Cars	Expansion	LR Subway	Self-ser. Fare
Austria				
Graz	X	X		X
Innsbruck	X	X		X
Vienna	X	X	X	X
Belgium				
Antwerp	X	X	X	X
Brussels	X	X	X	X
Charleroi	Rebuilding System			
Canada				
Edmonton	New System			
Toronto	X	X		
France				
Lille	X			X
St. Etienne	X	X	X	X
West Germany				
Augsburg	X	X		X
Bonn	X	X	X	X
Bremen	X	X		X
Cologne	X	X	X	X
Dortmund	X	X	X	X
Dusseldorf	X	X	X	X
Frankfurt	X	X	X	X
Hannover	X	X	X	X
Karlsruhe	X	X		X
Mannheim	X	X	X	X
Munich	X	X		X
Nuremberg	X	X		X
Rhein-Ruhr	New System			
Stuttgart	X	X	X	X
West Germany				
Wurzburg	X	X		X
Italy				
Milan	X	X		X
Rome	X	X		X
Turin	X	X		X
Mexico				
Guadalajara	Trolleybus			
Mexico City		X		
Netherlands				
Amsterdam	X	X		X
Rotterdam	X	X	X	X
The Hague	X	X		X
Ultrecht	New System			
Sweden				
Gothenburg	X	X		X
Norrkoping		X		X
Switzerland				
Bern	X	X	X	X
Geneva	X	X		X
Zurich	X	X		X
United Kingdom				
Tyne & Wear	New System			
United States				
Boston	X	X	X	
Cleveland	X	X		
Philadelphia	X		X	
Pittsburgh	X			
San Francisco	X	X	X	

Source: E.S. Diamant, et al., Light Rail Transit: State of the Art Review, report prepared for the U.S. Department of Transportation by DeLeuw, Cather and Co., Spring, 1976, p.26.