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EVALUATION OF LIGHT RAIL TRANSIT FOR KNOXVILLE, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

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David Michael Webber

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ABSTRACT

This research attempted to forecast transit ridership through sketch planning analysis for a potential light rail transit system in Knoxville, Tennessee. The computer planning program Quick Response System II was used to estimate potential patronage on a transit system developed for study in this thesis. An economic analysis of the light rail transit system was used to predict the feasibility of LRT being implemented in the West Knoxville area.

It was concluded that the ridership levels forecasted could not economically support the light rail transit system developed for Knoxville, Tennessee in this thesis.

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CHAPTER 1

INTRODUCTION

Light rail transit (LRT) projects in North America have been on the steady increase in recent years. Cities such as Portland, San Diego and Sacramento have recently built new light rail systems. Chicago, Detroit, Houston and other major American cities are now looking into the possibility of providing light rail transit service to their citizens. Europe has long enjoyed the services of light rail, with excellent results. Whether or not light rail transit will have a large impact upon cities in the United States is yet to be determined, but through transportation planning it is possible to determine the merit of a light rail transit project. Tennessee cities such as Memphis, Nashville and Chattanooga are all conducting planning studies to determine if their cities could support a light rail transit system.

With the success of several American light rail projects and planning studies being conducted in other Tennessee cities, some residents of Knoxville thought it was an appropriate time to consider light rail transit for the Knoxville area. At the time of writing of this thesis, no formal planning analysis had been performed to study the feasibility of LRT in Knoxville, but a growing number of people in the area were

proposing that a light rail transit system was a definite possibility. It was suggested a light rail system would help to relieve the growing congestion on the Knoxville road system and would provide a definite advantage to the economic welfare of the entire area.

The objective of this thesis was to determine the economic feasibility of a light rail transit system for the Knoxville area, specifically the West Knox county area from the central business district (CBD) to the Pellessippi Technology corridor on the border with Oak Ridge. Alternative LRT service levels were defined and sketch planning techniques were used to forecast the ridership the system could expect to attract. The forecasted ridership was then compared against the cost of building and operating a light transit system in Knoxville to determine the economic feasibility of such a project. The analysis was performed on a sketch planning basis, considering a broad array of service levels.

A sketch planning model light rail transit system alignment was developed in the paper and was studied to determine its effectiveness in serving the West Knox county corridor. The model LRT system was created using many of the physical characteristics of existing systems being operated in the United States.

The computer program Quick Response System II developed by Dr. Alan J. Horowitz was used for forecasting transit ridership for the Knoxville system. QRS II uses a logit model to determine the number of trips in the study corridor, and then performs a mode split to find the number of trips that would potentially be attracted to transit. QRS II makes it possible to look at an assortment of alternative service levels when developing a demand forecast.

Forecasted demand levels do not in themselves give a total overview as to the efficiency of the transit system. An economic analysis was needed to determine if the demand levels attained could support the services needed. This paper determined what demand level was economically feasible for supporting a light rail transit system for Knoxville.

CHAPTER 2

LITERATURE REVIEW

LIGHT RAIL TRANSIT

Light rail transit is an urban railway having a largely segregated, but not necessarily grade separated right of way with speed, capacity and overall performance lower than that achieved by a fully grade separated rapid transit system. Light rail is substantially superior in capacity and performance to any form of transit operating on public streets or roadways in mixed traffic such as busses or trolleys. LRT is a medium cost mode that provides medium-speed service for a medium volume of passengers. LRT is best suited for a medium-demand corridor in medium to larger sized metropolitan areas. Light rail transit can handle 15,000 - 200,000 passengers per day or 3,000 - 20,000 passengers per peak hour direction (6). The Transportation Research Board (6) lists three attributes a transit system must have to qualify as light rail transit:

1. Run on track mostly separated from vehicular traffic.
2. Be capable of operating through grade crossings.

3. Use "straight-electric" duo-rail vehicles.

Table 2-1 compares LRT to other forms of mass transit. It can be seen that light rail offers excellent transit service at a relatively low cost. To be effective, light rail must be built and maintained at lower costs than commuter rail, automated guideways, or rapid rail systems.

LIGHT RAIL TRANSIT APPLICATIONS

Light rail can fulfill many facets of transit operations and services. Depending on the needs of the city and it's economic and geographical characteristics, LRT installations can provide several options for application in cities:

1. Line-haul routes to central business districts or other employment zones from city or suburban residential areas.
2. Provide circulation within the central business district or major activity center.
3. Feeder service to rapid transit or commuter rail.

In low density, medium sized cities LRT is used for line-haul operation in corridors that are more heavily traveled

Table 2-1
Characteristics Differentiating LRT
From Other Transit Modes

Characteristic	Light Rail	Bus	Commuter Rail	Automated Guideway	Rapid Rails*
System Costs:					
Initial	Moderate	Low/ Moderate(a)	Low- to- High	High	Very High
Operating & Maintenance, per Passenger Mile(b)	---	Higher	Higher	Similar	Lower(c)
Attributes:					
Schedule Reliability	Excellent	Fair	Good	Superior	Excellent
Grade Separation	Varies	Less	More	100%	100%
Automatic Operations	no(d)	No	No(d)	Yes	Maybe(d)
Entrained Vehicles	Yes	No	Yes	Maybe	Yes
Public Perception:					
Comfort, Ride Quality	Good	Fair	Good	Good	Good
Route Comprehensions	Easy	Hard	Easy	Easy	Easy/Hard
Social Acceptability	High	Low	High	High	(f)
Railroad Involvement:					
Operating Labor	No	No	Yes	No	No
Freight Coordination	Maybe(g)	No	Maybe(g)	No	No

* Also called "Heavy Rail" and/or "Metro"
(a) But, busway/HOV lane cost per mile can equal or exceed LRT construction cost/mile.
(b) Other modes in comparison to LRT
(c) Not always; San Diego Trolley (which is LRT) has lowest O&M $/Passenger Mile of any transit system in U.S.
(d) May have automatic train stop (ATS), without full automation
(e) Generally, a surface or aerial guideway is visible and therefore easier to comprehend than a bus route on public streets or guideway tunnel.
(f) Higher for new system, but lower for old systems operating in depressed or deteriorating urban areas
(g) Yes, if joint use or grade crossings with freight railroads

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

than those served by bus operations. When light rail is used as a CBD access mode, a radial route structure is most often used to link the central business district with outlying areas. Operation as a feeder service for heavy rail is usually confined to very large cities (6).

Several types of service can be accommodated by each level of operation listed above. Service on light rail transit routes can be one or more of the following types (6):

1. Local service.
2. Limited-stop and express service.
3. Secondary distribution services.

Local service serves all stops along a route. Limited-stop and express service is used when radial routes extend more than three miles from the CBD, and when patronage volumes are large enough to sustain this type of service. Secondary distribution routes include internal service within major activity centers. Local service is by far the most widely used form of light rail transit service.

PHYSICAL CHARACTERISTICS OF LIGHT RAIL

Light rail transit spans a wide range of technical and

application options. One of LRT's greatest assets is its flexibility to fit the needs for a diversity of cities. Several aspects of the physical characteristics of light rail will be dealt with in the following sections:

1. Right of way.
2. Guidance.
3. Power source.
4. Alignment.
5. Stations.
6. Light rail vehicles.
7. Operation.

Right of Way

A major advantage of light rail transit above other modes is its ability to operate on a variety of rights of way. LRT design can be tailored to adjust to the physical and land use limitations of its surroundings. There are three classes of right of way upon which light rail transit can operate:

1. Exclusive ROW on which operations are fully controlled and vehicular or pedestrian crossings are prohibited.
2. Semi-exclusive ROW where operations are

separated from other traffic except at grade crossings.

3. Shared ROW where LRT mixes with autos, trucks, buses, and pedestrians.

The class of ROW on which LRT operates depends upon the environment in which it operates and the availability of right of way (3).

Much of the economy of LRT comes in its ability to use existing right of way including railroad ROW, right of way for power lines, and medians of streets and highways. When there is no existing right of way for LRT to use, such as in a CBD, there are other alternatives:

1. Running on a surface mixed or partially mixed with traffic at lower speeds.
2. On an elevated guideway at three to five times the cost.
3. Underground at substantial costs.

Elevated and underground sections are obviously exclusive ROW sections and are not recommended unless there are no other alternatives. When LRT rides on the surface there is an assortment of options including shared, exclusive, and semi-exclusive rights of way:

1. LRT in shared ROW with mixed street traffic where it has low maneuverability, longer delays, and restricts traffic capacity.
2. LRT in reserved street lanes where auto traffic is prohibited. Separation is achieved by striping on pavement edges or mountable concrete curbing.
3. Dedicated street ROW with full protection of LRT track by curbs, raised medians, vegetation, fencing, or concrete barriers. Dedicated ROW allows operating speeds to increase 100 percent compared to operation in mixed lanes or reserved lanes.
4. Railroad track ROW can be used where track is abandoned or relinquished. No significant land use change is involved and no special procedures to maintain railroad operations are required. It is not desirable for LRT and railroad trains to share the same track.
5. Light rail transit in freeways on median, shoulders, or on the edge of the ROW. This alignment suffers from conflict with on and off ramps.

Table 2-2 gives some characteristics of light rail transit right of way and geometric standards.

Table 2-2
Typical Basic Geometric and ROW Characteristics
for Selected Transit Facility Types

Characteristic	Unit	Exclusive Busway	Light Rail Transit		
			In Street Center Reservation	In Exclusive Right-of-Way	Rapid Transit
Access control		Full	Paritial	Full	Full
Number of lanes or tracks		2	2	2	2
Widths:					
a. Transit vehicle	ft	8.5	9.5	9.5	10.3
b. Lane envelope clearance*	ft	12	11	12.5	13.5
c. Track gauge	ft	--	4.71	4.71	4.71
d. Emergency walkway	ft		None	2.5	2.5
e. Minimum shoulders (each)+	ft	2.5	None	None	None
f. Border barriers or fencing (each)	ft	2	None	1	1
g. Overall minimum right-of-way#					
(1) Aerial	ft	33	--	24	26
(2) At-grade	ft	33	22	30	32
(3) Subway	ft	39	--	38	40
Stations					
a. Side platform width	ft	10	6	12	12
b. Center platform width	ft	--	--	24	24
c. Platform length	ft	120	400	400	500-600

* Overall vehical clearance requirements on tangent lines.
+ Emergency walkways for busways is incorporated in busway shoulders.
# Minima based on normal structural requirements for tangent-line sections without stations, and without station acceleration and deceleration lanes and tapers for busways. Special drainage provisions. side slopes, or retaining walls on cuts and fills, and any subway lateral ventilation requirements are excluded.

Source: ITE, Transportation and Traffic Engineering Handbook, Prentice Hall, 1982.

Guidance

The railway track and it's related flange steel wheel provides the simplest, most cost effective, and most efficient guideway. The railway can be used in tunnels, elevated sections, freeway median strips, medians of streets, grass on private ROW, and on paved streets in mixed traffic.

There are three types of guidance used to operate a light rail system:

1. Manual.
2. Manual with automatic speed protection.
3. Fully automated system.

Full automation is used for fully grade separated exclusive ROW lines. Manual with speed protection is used for surface operation, mainly in mixed traffic, and manual guidance is used for all types of operation (7).

Power Source

Direct current is the prevailing method for the electrification of light rail transit systems. Common voltage for operation of light rail vehicles is 600 volts.

New Tyne and Wear systems are designed for 1500 volt direct current operation. Higher voltage will reduce electrical component sizes and will increase operating efficiency and substation spacing thus reducing cost. Most light rail vehicles collect power from an overhead contact wire by means of a pantograph or a trolley pole. Modern light rail vehicles use the pantograph exclusively. Both single wire and catenary systems may be supported on poles placed centrally between tracks or outside tracks. Direct current with a steel railway track provides safe, environmentally clean operation on all types of ROW. There is no need for ventilation and no fumes are released (7).

Alignment

Light rail transit is versatile for both horizontal and vertical curvature. Light rail vehicles (LRV) can take a horizontal curve with an inside radius as low as 42'. A vertical curve with a radius of 310' crest and 460' sag can be negotiated by most all light rail vehicles. LRV's can accommodate grades up to seven percent. Light rail's versatility concerning geometrics make it very good for use in dense urban areas (7).

Light Rail Vehicles

There are numerous light rail vehicles in use today. This paper will concentrate on those LRV's used in North America. Light rail vehicles are classified by the number of axles and the number of articulations. The following configurations are used (11):

1. Non-articulated: four axles on two trucks.
2. Single articulated: usually three trucks with six axles.
3. Double articulated: composed of three body elements with a center shorter than the end sections.
4. Trailer: operated when coupled with another vehicle.

Light rail vehicles are faster, quieter and more comfortable than streetcars. They can be equipped with air-conditioning, heating, fluorescent lighting, and insulation against street noises to increase riding comfort. LRV's can also be equipped with low or high vehicle loading to match the station platform height. The riding quality of light rail vehicles is pleasant, noise levels are low, and the visual aspects of LRV's are pleasing, thus attracting greater ridership. Characteristics of light rail vehicles as compared to other

transit vehicles are given in Table 2-3.

The Boeing light rail vehicle was the only one designed specifically for use in North American cities, however recently Buffalo, Pittsburgh, and Portland all have experimented with new light rail vehicle designs. The characteristics of the Pittsburgh and Portland LRV's are shown in Table 2-4 (6).

Stations

Light rail transit offers a wide variety of station configurations to take advantage of locational opportunities encountered along the LRT route. Light rail stations can be divided into two general categories:

1. At-grade.
2. Controlled access.

At-grade stations are used for at-grade right of way sections both within streets and in separate ROW. In most cases, at-grade stations consist of the following:

1. Paved area often raised above rail height.

Table 2-3
Characteristics of North American Urban Transit Vehicles

Characteristics	Unit	Urban Transit Bus, Nonarticulated, General Motors, RTS II, 1978	Urban Transit Bus, Articulated, AM General/MAN, SG-220-10-2A, 1978	Light Rail Vehicle Articulated, Boeing-Vertol, for Boston MTA, 1976	Rail Transit Car, Steel Wheels, Pullman-Standard, R-46,1975[a]	Regional Rail Transit Car, Rohr Corp., San Francisco BART, 1972[a]
Length of vehicle body	ft	40	59.66	71	75	71
Maximum width of body	ft	8.5	8.5	8.85	10	10.5
Height, wheels to roof	ft	9.9	10.34	11.33	12.1	10.5
Seats		458	73	52	73	72
Standees	Design/crush	23/47	37/72	167/230	142/277	60/156
Total passenger capicity	Design/crush	68/92	110/145	219/282	125/350	132/228
Maximum cars per train		—	—	3	8	10
Total train capicity	Design/crush	—	—	650/850	1690/2800	1320/2880
Width of cars	in.	17.5	17	17.58	18.08	22
Spacing between backs of transverse seats	in.	27.4	27	30.08	9	34
Area per seated passenger	in.^2	3.3	3.2	3.68	3.38	5.2
Minimum aisle width	in.	22.5	22	44.8	39	30
Clear doorway width per passenger lane	in.	30.0;22.0	24.6	27	25	27
Doorways per side x lanes per door		1x2;1x1	2x2	3x2	4x2	2x2
Passenger load factor	Design/crush	1.5/2.0	1.5/2.0	4.2/5.4	3.0/4.8	1.8/3.2
Empty weight	lb x 10^3	25.9	37.5	67	87.1	58.7
Weight per passenger (design/crush)	lb	380/280	340/260	305/240	405/250	445/255
Rated power of engines (motors)	hp	225	235	410	460	560

[a] Data are average for the normal combination of "A" and "B" cars, or motorized cars and trailers, used to make up maximum length of trains.
[b] Maximum seating could be 47, but 2 seats were removed to provide more comfort for seated passengers.
[c] Estimated, based on seat plans.
[d] Transverse seats not arranged in files, or no transverse seats.

Source: ITE, Transportation and Traffic Engineering Handbook, Prentice Hall, 1982.

Table 2-4
Characteristics of Special LRT Vehicles

Characteristic	Portland	Pittsburgh
Length	89 ft.	84 ft.
Width	8 ft. 8 in.	8 ft. 9 in.
Weight (lb.) empty	90000	86000
# Seats	76	62
# Standees	90	
Capacity	166	263
in Crush	256	
Top Speed	55 mph	55 mph
Acceleration	3 mph/sec	3 mph/sec
# Axles	6	6
Doors	4 double wide low-level doors per side	4 double wide low-level doors per side

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

2. Shelter.

3. Benches, telephone, etc.

At-grade stations are sometimes placed in pedestrian centers and shopping malls. The LRV's operate at low speeds in these areas to allow pedestrians to cross the tracks. The track is usually depressed and separated by a curb for safety and boarding.

Controlled access stations handle larger volumes of passengers and are grade separated from streets. High level platforms are used for better vehicle loading. The new LRV's are equipped with movable steps to accommodate loading from both high and low level stations. Simultaneous loadings of vehicles are essential for LRT in order to maintain speed of operation, so the station platform must be long enough to accommodate a long configuration of light rail vehicles (7).

Operation

The operational characteristics of light rail transit vary with the application. There are a wide range of headways, capacities, fare systems, and general operational characteristics available. In practice, headways range from 30 seconds to one hour, depending upon the specific

situation. The capacity of a LRT system depends upon the headway, vehicle size and train length. Light rail systems are typically designed for peak hour capacities of 4,000 to 14,000 passengers per hour (3).

Other general operational characteristics of light rail transit are listed below:

1. Energy consumption in the range of ten kwh per vehicle mile.
2. Noise levels similar to buses and rail rapid transit. Significant noise reduction can be achieved with proper vehicle design and track maintenance.
3. Environmentally clean.

EXISTING LRT SYSTEMS

There are currently nineteen light rail transit systems servicing sixteen US and Canadian cities. Table 2-5 lists the existing physically separable LRT and streetcar systems in America and Canada and the function of each system. All the systems included in the list meet the Transportation Research Board's (TRB) definition of light rail transit (6). The light rail systems are classified by the average operating

Table 2-5
Principal Functions of North American LRT Systems

Line haul/express/commuter service between employment zones (particularly central business districts) and residential areas, inluding coordination with feeder buses, auto passenger drop-offs, and/or park-&-ride: Boston (Green Line), Calgary, Cleveland, Edmonton, Newark, Philadelphia (Subway-Surface), Pittsburgh, Portland, Sacramento, San Diego, San Fransico, San Jose
Feeder service to rapid transit and/or rail: Boston (Mattapan-Ashmont), Philadelphia (Media-Sharon Hill); secondary function for Boston (Green Line), Cleveland, ewark, Philadelphia (Subway-Surface and Streetcars), San Francisco, San Jose, Toronto
Local area circulation within a portion of an urbanized area or activity center, and/or CBD distributation: Fort Worth, Philadelphia Streetcars), Toronto, and "Vintage Trolleys" in Detroit, Lowell, New Orleans, Seattle, secondary function for all other systems listed above

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

speed. The definitions for each classification are listed below (6):

1. LRT group I : Velocity avg > 15 mph.
2. LRT group II : Velocity avg >10 mph < 15 mph.
3. Streetcars : Velocity avg < 10 mph.

Group I light rail systems tend to link downtown employment with distinct residential neighborhoods ten to twenty miles away. Group II LRT systems and streetcars typically serve neighborhoods five to six miles or closer to the employment area. Table 2-6 shows a summary of statistics for LRT systems in North America for each classification (6). Table 2-7 gives the operating statistics of existing North American LRT systems.

The LRT system evaluated in this thesis for Knoxville was a Group I system.

Appendix I provides several tables showing various characteristics of light rail transit.

Table 2-6
North American LRT System Statistics

Category	LRT-Group I	LRT-Group II	Streetcars
Extent of Line			
Kilometers	204.5	160.6	176.3
Miles	127.1	99.9	109.5
Percent	38	30	32
Cars			
Number	353	626	463
Percent	24	43	32
Weekday Boardings			
Number	221400	458900	370600
Percent	21	44	35
per Kilometers			
Range	366-3018	754-5237	555-4064
Average	1083	2357	2102
per Mile			
Range	588-4854	1213-8434	894-3384
Average	1742	4594	3384
per Car			
Range	240-1000	268-1074	466-938
Average	627	733	800
Stations			
Number	234	469	1233
Average Spacing km(mi)	0.9(0.5)	0.3(0.2)	0.1(0.1)
Car Kilometers			
Car-km(Car-mi)/Year (millions)	20.8(13.0)	22.6(14.1)	19.1(11.9)
Annual km(mi)/Car (thousands)	59(37)	36(23)	41(26)
Percent of Line-km (Line-mi)			
Reserved	97	67	10
Mixed Traffic	3	33	90

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

Table 2-7
Operating Statistics of North American Light Rail Systems

City/State	km(mi) of Line	Cars	Rides/ Weekday	Cars/ km(mi)	Weekday km(mi)	Rides/ Car
LRT-Group I:						
Calgary, C-Train(a)	27.5(17.1)	83	83000	3.0(4.9)	3018(4854)	1000
Cleveland, Shaker Rapid(b)	21.1(13.1)	48	17500	2.3(3.7)	829(1336)	365
Edmonton, Northeast LRT(a)	10.5(6.5)	37	25000	3.5(5.7)	2381(3846)	676
Newark, City Subway(b)	6.9(4.3)	24	14100	3.5(5.7)	2043(3279)	588
Philadelphia:						
Media-Sharon Hill(b)	19.2(11.9)	29	9600	1.5(2.4)	500(807)	331
Portland, MAX(a)	24.3(15.1)	26	20000	1.1(1.7)	823(1325)	769
Sacramento, RT Metro(a)	29.4(18.3)	26	13200	0.9(1.4)	449(721)	508
San Diego Trolley(a)	32.8(20.4)	30	27000	0.9(1.5)	720(1157)	787
San Jose, Guadalupe(a,e)	32.8(20.4)	50	12000	1.5(2.5)	366(588)	240
Subtotals	204.5(127.1)	353	221400	1.7(2.8)	1083(1742)	627
LRT-Group II:						
Boston:						
Green Line(b)	40.1(24.9)	235	210000	5.9(9.4)	5237(8434)	894
Mattapan-Ashmont(b)	4.3(2.7)	12	7000	2.8(4.4)	1628(2593)	583
Buffalo, NetroRail(a)	10.3(6.4)	27	29000	2.6(4.2)	2816(4531)	1074
Fort Worth, Tandy	1.6(1.0)	8	5900	5.0(8.0)	3688(5900)	738
Philadelphia:						
Subway-Surface(b)	35.9(22.3)	112	49700	3.1(5.0)	1384(2229)	444
Pittsburgh, South Hills(b)	36.2(22.5)	102	27300	2.8(4.2)	754(1213)	268
San Francisco, Muni Metro(c)	32.2(20.1)	130	130000	4.0(6.5)	4037(6468)	1000
Subtotals	160.6(99.9)	626	458900	3.9(6.3)	2857(4594)	733
Streetcars:						
New Orleans, St Charles	10.5(6.5)	35	21000	3.3(5.4)	2000(3231)	600
Philadelphia, Streetcars	92.4(57.4)	110	51300	1.2(1.9)	555(894)	466
Toronto, Streetcars	73.4(45.6)	318	298300	4.3(7.0)	4064(6542)	938
Subtotals	176.3(109.5)	463	370600	2.6(4.2)	2102(3384)	800
Totals:	541.4(336.5)	1442	1050900	2.7(4.3)	1941(3123)	729

(a) New start opened since 1977
(b) Major reconstruction/rehabilitation since 1977; current peak requirement is 60 cars, 33 HV + 27 PCC
(c) Upgrade from Streetcar system since 1977
(d) East Line has no bus feeders; will update figures after 1/88 bus cut-over
(e) 10.5 km (6.5 mi) to be in service 12/87; Rides/Weekday - current projection for 1991 opening of full line

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

NEW SYSTEMS

There are several cities looking at the possibilities of constructing a light rail transit system. Some cities are in the final design stage, some in the preliminary engineering stage, and others are in the planning stage. The cities in the final design stage are Dallas and St. Louis. Cities in the preliminary engineering stage are Baltimore and Minneapolis. Some of the cities in the planning phase include Chicago, Detroit, Houston, Denver, Memphis, and Phoenix. All the cities have metropolitan populations greater than 500,000 (6).

PROBLEMS WITH LIGHT RAIL

To be competitive with other modes of transit, light rail must be cost-effective. It must be designed and operated at the lowest cost possible. The cost effectiveness usually comes in the selection of an alignment. Existing ROW must be used whenever possible. It is generally accepted that demand for a light rail system should be in the range of 15,000 to 50,000 passengers per day at the lower end to be economically justified.

Another issue with the most recent rail transit projects is

their disappointing shortfall in ridership when compared to demand forecasts. Table 2-8 compares forecast and actual passenger boardings and costs on some of the newer rail transit projects. As can be seen in the table, forecasted weekday passengers are far above the actual patronage, while the project and operating costs are far above the forecasted amounts. Therefore, light rail transit has proven not to live up to it's anticipated levels of utilization and cost (9). This makes it imperative that a thorough economic analysis be conducted, which is the topic of this thesis.

Table 2-8
Forecast and Actual Cost Per Passenger for
Recent Rail Transit Projects

	Heavy Rail Transit Projects				Light Rail Transit Projects				DPM Projects	
	Washington	Atlanta	Baltimore	Miami	Buffalo	Pittsburgh	Portland	Sacramento	Miami	Detroit
	Weekday Rail Passengers (thousands)									
Forecast	569.6	NF	103	239.9	92	90.5	42.5	50	41	67.7
Actual	411.6	184.5	42.6	35.4	29.2	30.6	19.7	14.4	10.8	11.3
% difference	-28%	--	-59%	-85%	68%	-66%	-54%	-71%	-74%	-83%
	Rail Project Capital Cost (millions of 1980 dollars)									
Forecast	4325	1723	804	1008	478	699	172	165	84	144
Actual	7986	2720	1289	1341	722	622	266	188	175	215
% difference	85%	58%	60%	33%	51%	-11%	55%	13%	106%	50%
	Annual Rail Operating Expense (millions of 1980 dollars)									
Forecast	66.3	13.2	NF	26.5	10.4	NF	3.8	7.7	2.5	7.4
Actual	199.9	40.3	21.7	37.5	11.6	8.1	5.8	6.9	4.6	10.9
% difference	202%	205%	--	42%	12%	--	45%	-10%	84%	47%
	Total Cost per Rail Passenger (1980 dollars)									
Forecast	3.04	NF	NF	1.73	2.15	NF	1.68	1.53	0.9	1.14
Actual	8.75	5.93	12.92	16.77	10.57	7.94	5.19	6.53	7.11	10.21
% difference	188%	--	--	872%	392%	--	209%	328%	693%	795%

a Annual total cost of rail service divided by annual equivalent of "Weekday Rail Passengers," computed using numbers of average weekday equivalents per year derived from annual total and average weekday rail ridership reported by project operators. Annual total cost of rail service is the sum of (1) the annualized value of "Rail Project Capital Cost," computed assuming a 40-year project lifetime and a discount rate of 10% per year, and (2) "Annual Rail Operating Expense."

NF indicates no forecast of a data item was obtainable from published sources.

Source: U.S. Department of Transportation, "Urban Rail Transit Projects: Forecast Versus Actual Ridership and Cost", 1990.

CHAPTER 3

DESCRIPTION OF KNOXVILLE LRT CORRIDOR

It has been proposed that a light rail transit system be deployed in Knoxville to provide service from the Central Business District to Oak Ridge. The corridor defined for analysis in this thesis was formed to predict demand for a light rail transit line-haul from the CBD extending through West Knoxville to the Oak Ridge Highway. A line-haul route was chosen to run along Kingston Pike, the reasoning for this will be discussed in chapter 4, and the corridor would encompass all areas along the route that would contribute passengers to the light rail system.

The location of the corridor as it relates to Knox county is shown in figure 3-1. The corridor contains approximately 60,000 acres of land. Some of the major areas contained in the study corridor are: the Central Business District, the University of Tennessee, West Town Mall, the town of Farragut, and the residential districts Sequoyah Hills, Lyons View, and West Hills. The corridor is bounded on the North by Middlebrook Pike, the South by the Tennessee River, the West by the Pellissippi Parkway, and the East by the Central Business District.

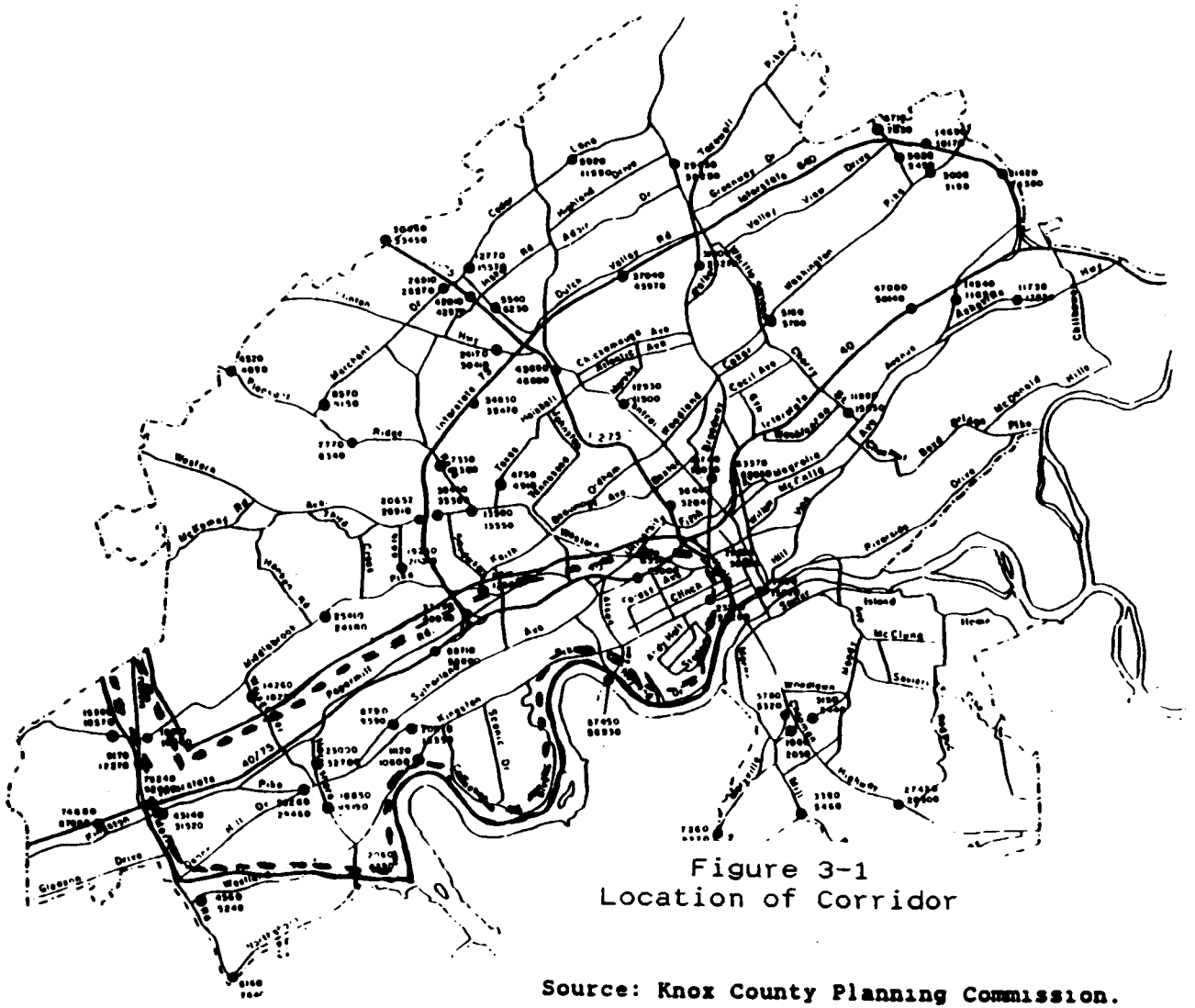


Figure 3-1
Location of Corridor

Source: Knox County Planning Commission.

For analysis purposes, the study area was divided into 69 traffic zones as defined by the Knoxville Planning Commission. A map showing the traffic zones used for the corridor is shown in figure 3-2.

SOCIO-ECONOMIC DATA

Socio-economic data is an important factor to forecasting travel demand. In trip generation, trip productions are based upon factors such as income level and autos per household. Trip attraction is based upon employment and number of dwelling units. Also, the mode split to estimate the number of trips potentially using transit is dependent upon the characteristics of the transit and highway systems as well as socio-economic data. In order to estimate the trip attractions and productions, the West Knox county corridor would have to be evaluated as a closed system. By using a closed system, only the trip attractions and productions that occur within the corridor would be considered when determining trip ends. This would provide for a situation in which only the people beginning and ending a trip within the West Knox Corridor would be considered as candidates for using the transit system. The 1980 Census Journey to Work Data for Knoxville (1) was used in estimating the percentage of trips from each traffic zone that both originated and ended within

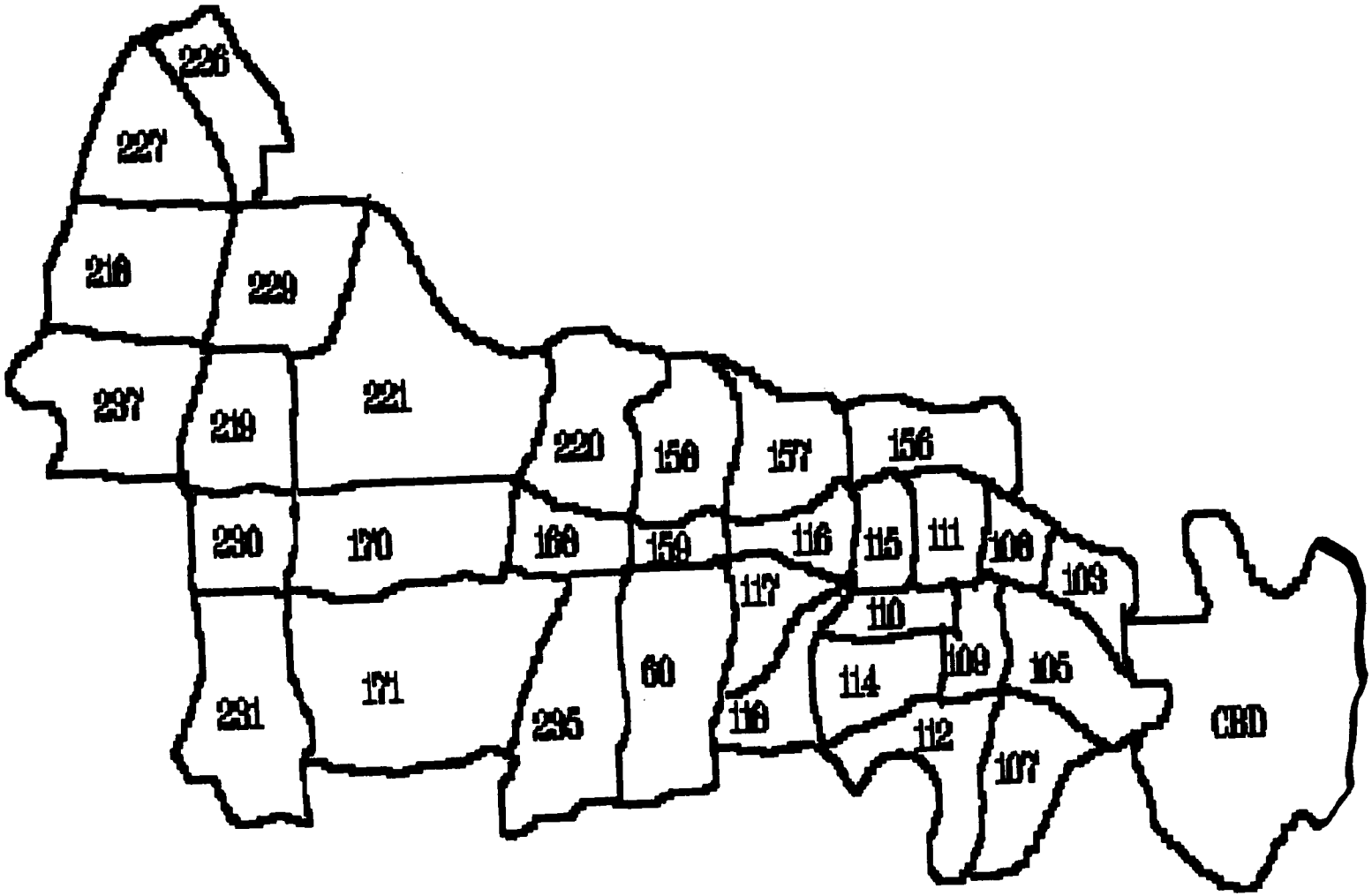


Figure 3-2
Traffic Zones Used in Study

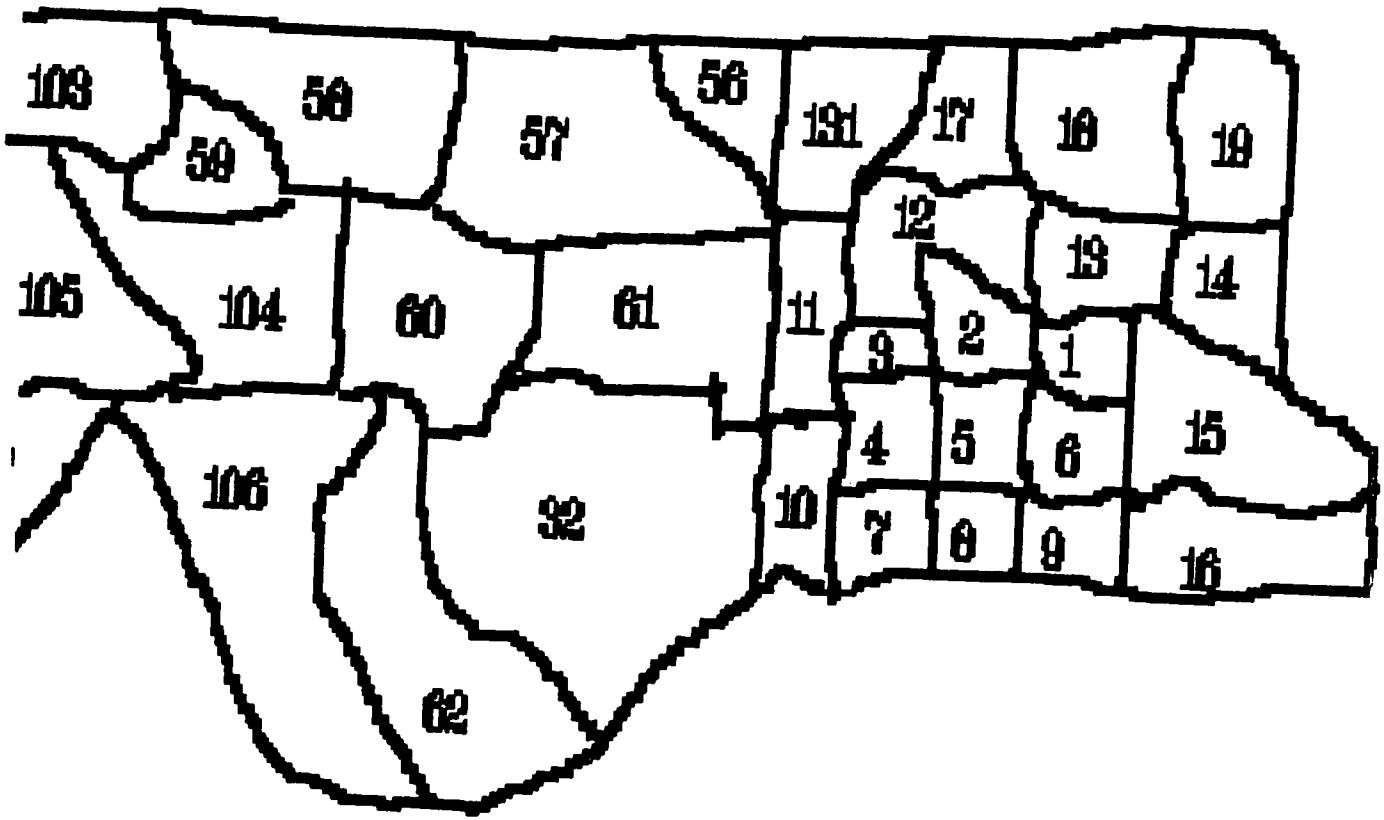


Figure 3-2 (cont.)
CBD Zones

the corridor. The journey to work data gave the number of trips originating from each zone and the zones in which these trips ended. The percentage of trips that stayed within the West Knox County corridor was calculated as the number of trips ending in zones within the corridor divided by the total number of trips originating from the traffic zone. This percentage was then used to reduce the number of trips generated by the socio-economic data to estimate the number of trips staying within the corridor. It was assumed that utilization of a LRT system would be essential to work trips, making this approximation realistic.

The socio-economic data used in this study was obtained from the Knoxville Metropolitan Planning Commission. Table 3-1 provides a summary of the projected 2005 socio-economic data estimated by the planning commission for each zone of the study corridor. The percentage used column was the percentage of the total trips going to a destination of origin within the corridor. The total 2005 projected population for the 69 zones in the study corridor was 86,022. There will be 36,382 dwelling units in the study area in 2005. The labor force was expected to be 47,833 and the total employment will be 102,351. Labor force represents the number of people that are eligible to be employed, and employment was the number of people who work in a particular zone. The corridor auto ownership was estimated to be 67,840.

Table 3-1
2005 Socio-Economic Projections for
Study Corridor

TRAF ZONE	POP	DUs	LABOR FORCE	EMPLOY-MENT	AUTO OWNERSHIP	% USED
1	25	11	17	1729	3	100
2	71	20	28	4065	6	100
3	80	22	32	1086	7	70
4	83	59	67	3915	67	100
5	72	33	37	3934	36	67
6	15	4	13	6176	2	100
7	150	106	100	326	38	100
8	0	0	0	1816	0	100
9	0	0	0	236	0	100
10	150	106	121	211	119	85
11	700	396	473	444	398	10
12	52	55	8	1169	23	100
13	100	75	75	1437	25	100
14	11	4	7	528	2	100
15	1230	908	674	848	1059	53
16	0	0	0	458	0	100
17	51	53	18	385	22	100
18	0	0	0	1682	0	15
19	19	9	7	2255	3	10
32	8284	707	2560	15909	1362	79
48	462	230	217	1327	163	68
49	33	22	6	745	19	100
50	100	52	43	979	42	100
51	646	303	228	522	286	38
54	155	64	78	635	79	48
55	108	52	25	495	54	59
56	19	10	7	139	10	100
57	148	103	74	399	85	100
58	180	89	89	189	78	20
59	128	61	45	1822	93	100
60	1252	664	749	6480	676	66
61	3578	2441	2406	1186	2978	83
62	0	0	0	2249	0	100
102	88	38	47	132	49	78
104	430	204	274	412	236	100
105	1037	480	477	1365	801	74
106	0	0	0	344	0	100
107	2131	1119	1056	875	2161	75
108	624	263	272	127	428	56
109	907	485	468	307	716	77
110	1248	722	617	3311	940	100
111	1586	1024	863	215	1210	100
112	1487	727	788	231	1454	78
114	211	140	117	394	212	85
115	859	360	489	2125	694	130
116	460	344	394	3420	488	55

Source: Knox County Planning Commission.

Table 3-1 (cont.)

TRAF ZONE	POP	DUs	LABOR FORCE	EMPLOY-MENT	AUTO OWNERSHIP	% USED
117	1286	741	930	2643	1373	100
118	1535	603	897	2747	1182	89
131	100	105	15	351	43	78
156	4646	2288	3196	2332	4569	100
157	3769	1786	2295	186	3579	100
160	5770	2905	3479	3590	5152	94
168	105	39	53	1000	82	67
170	0	0	0	2175	0	56
171	4807	1872	2758	455	4438	94
219	1610	598	846	883	1365	58
220	8274	3512	5038	1905	7177	64
221	8184	3030	4915	483	6775	75
226	901	318	479	150	877	47
227	1004	354	525	886	992	62
228	919	341	483	96	799	100
229	689	256	362	61	614	77
230	1246	460	713	776	1206	67
231	2363	844	1306	179	2099	72
235	3827	1541	2390	154	3435	65
236	1004	355	525	120	932	78
237	1838	681	967	96	1558	92
SUBTOTALS:	82847	35194	46238	100302	65371	

In general, the west corridor was expected to have (4,

1. A median family income higher than Knox county as a whole.
2. A population younger than the average with a high proportion of individuals in the age group 25-44 and under 14.
3. Residential densities low compared to other urban centers.
4. Housing types ranging from large apartment complexes to large single family homes.

CURRENT ROAD SYSTEM

The road network and the existing traffic on the road system in the corridor were very important factors in determining the demand for the proposed light rail system. The major roadway facilities include a major arterial and a freeway running east-west. The major roads, Kingston Pike and Interstate 40, are highlighted in figure 3-3. Kingston Pike is a four lane with a two way left turn lane through much of it's length. However, in the Sequoyah Hills area the road narrows to a two lane and creates a bottleneck for traffic between the west suburbs and the UT/CBD area. Interstate 40 is a six lane with a concrete barrier separating east and west traffic. The

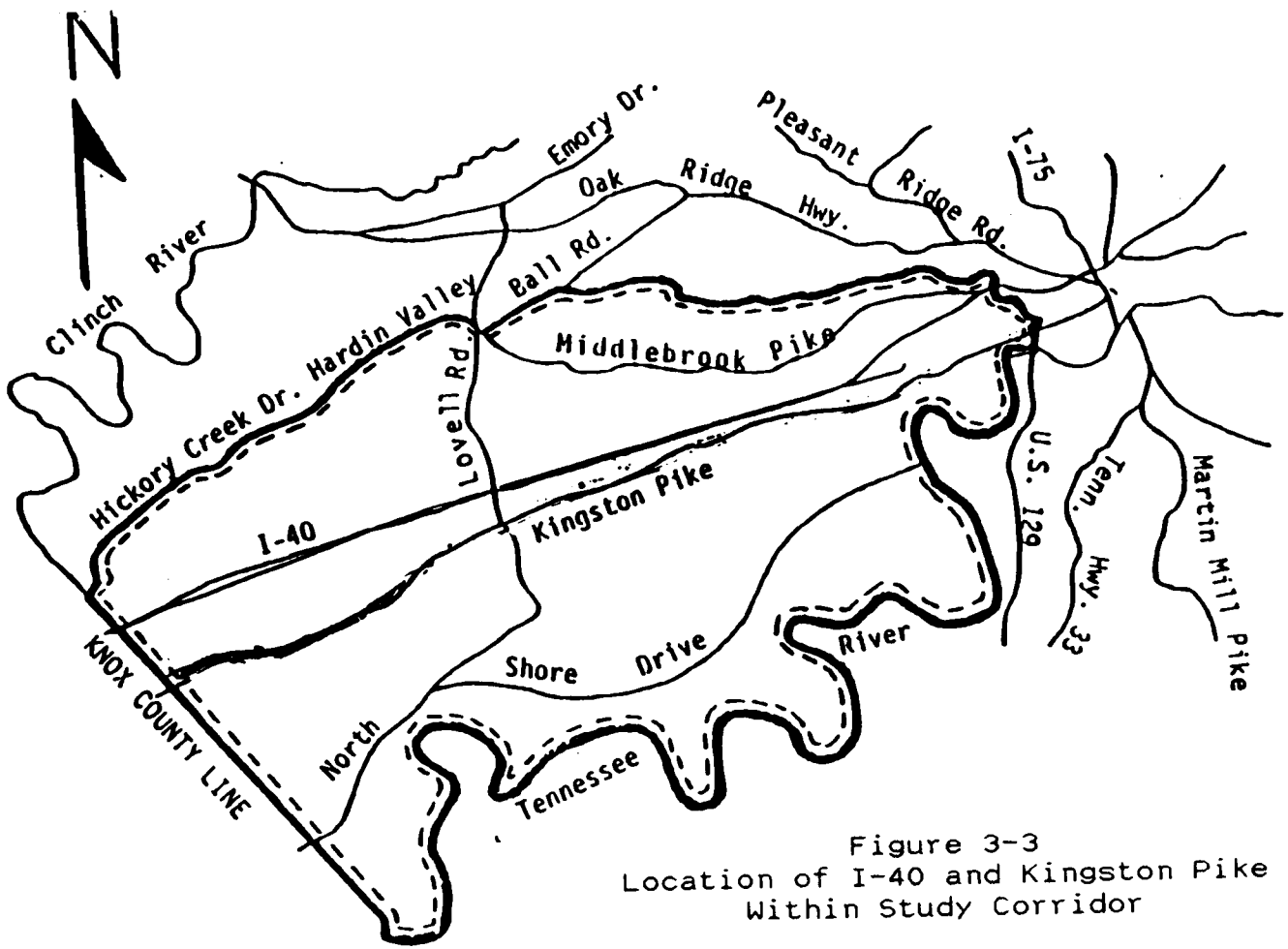


Figure 3-3
Location of I-40 and Kingston Pike
Within Study Corridor

Source: Leung, Yin Chao, "Utilization of Railroad ROW for Commuter Travel in West Knox County", 1975.

largest 1987 traffic volumes within a section for the two roads are given below:

	ADT	DHV
Kingston Pike	43,140	5,177
Interstate 40	98,800	11,856

1987 data, TDOT

The volume shown for Kingston Pike is for the area adjacent to West Towne Mall. The volume for I-40 is for the section intersecting Interstate 75.

These two roads carry most of the trips in the study corridor that would potentially be diverted to a light rail route if it were located along Kingston Pike.

CHAPTER 4

LRT SYSTEM EVALUATED FOR STUDY

This chapter will describe the light rail transit system used to test the feasibility of deploying light rail transit in Knoxville. The purpose of this study was to determine on a sketch planning basis whether light rail transit would be feasible in Knoxville. Defining an appropriate transit system was important in estimating the demand levels and expected costs and revenues. Several of the factors that QRS II uses to forecast demand and the economic study depend on the transit system described in this chapter. The LRT system to be evaluated in this study was designed to attract the greatest amount of ridership at the least cost. The expertise of Li Yang Feng who was a transit planner for the city of Shanghai, China was used extensively in developing the transit network. This chapter will identify the following characteristics of the light rail transit system evaluated for Knoxville:

1. The line-haul transit route selected.
2. The location of all major stops.
3. The physical characteristics of the transit system.

SELECTION OF THE TRANSIT ROUTE

There were two main objectives when determining a route for a line-haul transit route:

1. Select a route location in order to attract the greatest ridership possible.
2. Select a location to reduce the costs of construction and maintenance.

The ITE manual (3) states twelve other factors to be considered when locating a light rail transit route:

1. The overall area to be served, its geography, topography, and land use.
2. Policies and master plans regarding land use and transportation.
3. Service area coverage standards.
4. Location of major traffic generators.
5. Patronage volumes and patterns in time and space.
6. Accessibility standards, and resulting stop, and station locations.
7. Service headway standards.
8. Capacities of available systems and vehicles.
9. Streets and other ROW available for transit

use.

10. Land available for yards and maintenance facilities.
11. Role of other urban transit systems.
12. Interfaces with intercity transportation systems.

Dr. Horowitz states in his QRS II manual (2) that a typical transit network will attract ridership from one-fourth mile on either side of the route. The only area that has potential ridership along a one-fourth mile strip with a distribution of residential locations, employment locations, malls, shopping centers, and UT is Kingston Pike. As presented in chapter 3, Kingston Pike runs along the center of the study corridor. Access to Oak Ridge would be provided by the Pellissippi Parkway which leads to Oak Ridge and the technology corridor established in the area. A light rail line-haul located along Kingston Pike offers the best route for attracting transit ridership for sketch planning analysis.

As presented in figure 4-1, the light rail transit line-haul begins in the CBD near the old L & N station and runs down Gay street until reaching the intersection with Cumberland. The route then runs down Cumberland, joining Kingston Pike as it travels west until reaching the intersection with the Pellessippi Parkway. The track then follows the Pellissippi

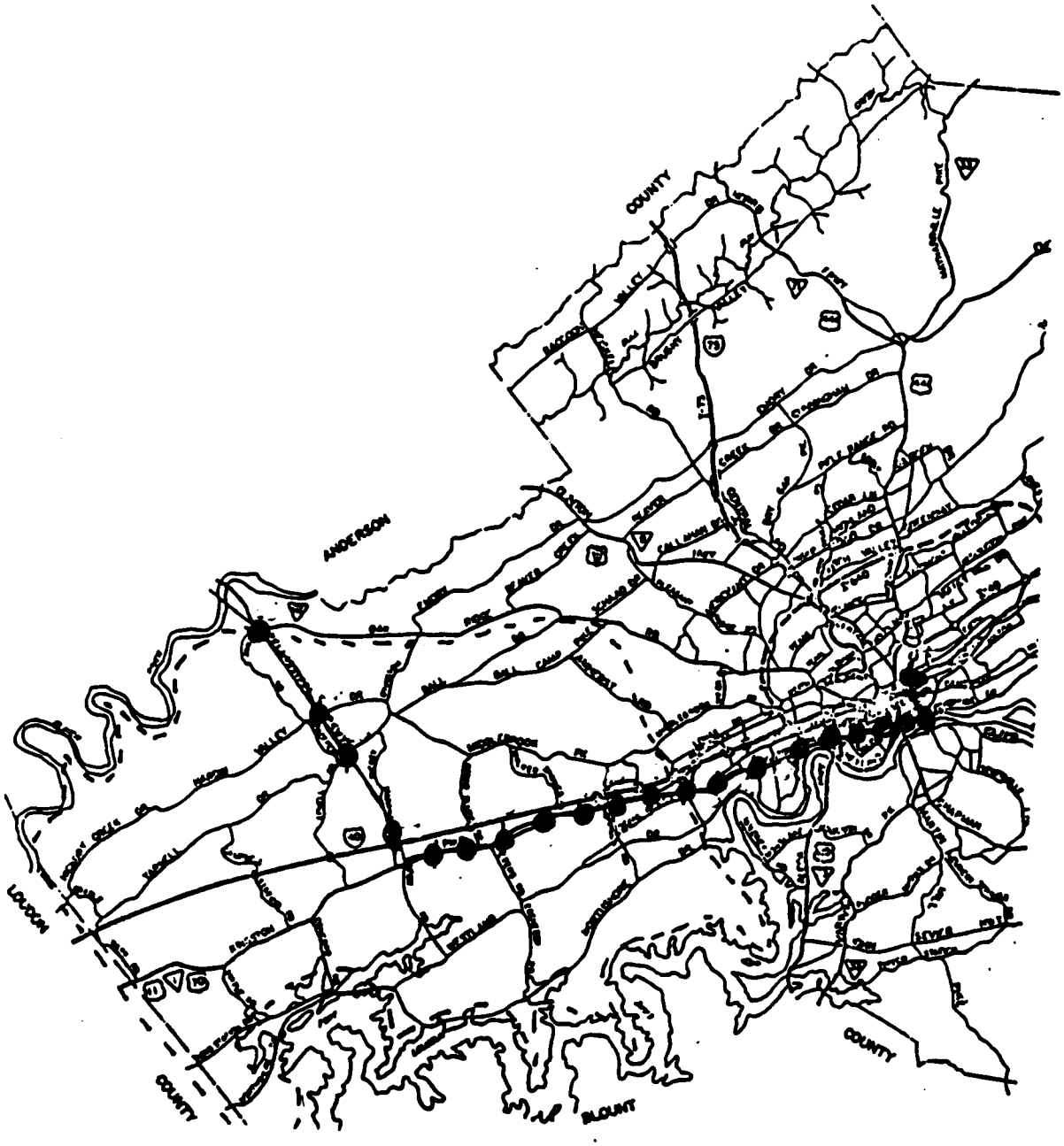


Figure 4-1
Stop Locations

Parkway until the final stop on the Oak Ridge Highway is reached.

The potential problems with a light rail transit route along Kingston Pike included the availability of right of way. Since this was a sketch planning analysis, it was assumed that a surface track ROW can be built along the entire route.

LOCATION OF TRANSIT STATIONS

Station locations were determined by two criteria:

1. The maximum walking distance a transit patron will walk to reach a light rail transit station.
2. The land use along Kingston Pike, in the CBD, and along the Pellissippi Parkway. Can the location support a light rail transit stop.

The ITE manual (3) states that most transit patrons will walk 0.4 to 0.6 miles to a station, while some patrons will walk as long as 0.6 to 1.0 miles. These figures were used when determining potential locations for the LRT stops.

All the stations will be at-grade low level platform

stations in order to reduce costs and provide easy access to existing facilities along the route. Table 4-1 identifies all of the station locations chosen, while Figure 4-1 shows the route and stations used to evaluate the possibility of light rail transit in west Knoxville. It was assumed that park and ride lots would not be considered in the sketch planning analysis.

PHYSICAL CHARACTERISTICS OF THE TRANSIT SYSTEM

There are five important physical characteristics of the proposed light rail transit system for Knoxville:

1. The guidance system.
2. The light rail vehicle used.
3. Power source.
4. Right of way.
5. Operation.

Guidance

The guidance system selected was important to determine the average speed of the light rail vehicle. The speed would determine how many vehicles would be needed to maintain a

Table 4-1
Stop Locations

Station #	Station Name	Station Location
1	CBD	Old L&N Station
2	Downtown	Gay and Cumberland
3	Dougherty	Dougherty on Cumberland
4	Fifteenth	Fifteenth and Cumberland
5	Walgreens	Walgreens Betweem 20th and 21st on Cumberland
6	Laurel Apartments	Laurel Apartments
7	Calvary Church	Calvary Church
8	Laurel Church	Laurel Church
9	Scenic Drive	Scenic Drive and Kingston
10	Western Plaza	Mueller Drive and Kingston
11	Krogers	Krogers at Knox Plaza
12	Food Lion	Forrest Hills Food Lion
13	Bearden Center	Agnes and Kingston
14	The Village	The Village Shopping Center
15	Arby's	Papermill and Kingston
16	Office Town	Wellington and Kingston
17	K-Mart	Morrell and Kingston
18	West Towne Mall	Montvue and Kingston
19	Olde Kingston Towne	Old Kingston Towne Shopping Center
20	Western Springs Plaza	Shopping Center
21	Ted Russel Ford	Walker Springs and Kingston
22	Ten Mile Center	Ebeneezer and Kingston
23	Town & Country	Shopping Center
24	Market Place East	Suffolk and Kingston
25	Windsor Square	Hayfield and Kingston
26	Franklin Square	Hampton and Kingston
27	Mayo	Mabry Hood and Kingston
28	Hardees	Hardees on Mabry Hood
29	Technology Drive	Technology Drive and Pellissippi
30	Dutch Town Road	Dutch Town and Pellissippi
31	Lovell Road	Lovell and Pellissippi
32	Charmichel Drive	Charmichel and Pellissippi
33	Hardin Valley Drive	Hardin Valley and Pellissippi
34	Coward Mill Road	Coward Mill and Pellissippi
35	Oak Ridge Highway	Oak Ridge Highway and Pellissippi

specific headway. The maximum cruising speed for the LRV in the system was calculated at 50 mph with manual guidance. The manual guidance would allow the light rail vehicle to be able to operate in mixed traffic. The acceleration rate will be designed for 3.5 feet per second squared when the vehicle leaves from a stop (8).

Light Rail Vehicle

The importance of the light rail vehicle in the sketch planning analysis was in determining the speed of the vehicle. The speed of the vehicle determined the roundtrip travel time which was used to calculate disutility along the line haul for use in the mode split logit model. The light rail vehicle assumed for this analysis was similar to the one being used in Pittsburgh and Portland, as described in table 2-4. The light rail vehicle used had seating capacity of 76 seats.

Power Source

A direct current operating on 600 volts was the power source assumed for the Knoxville light rail transit system. An overhead catenary wire would supply the electrical power to the light rail vehicle. Using electricity as the power source would make the light rail system more acceptable

environmentally and would reduce the noise.

Right of Way

As mentioned previously, it was assumed that a surface track would be feasible for the entire route. It was also assumed that exclusive ROW would be utilized along Kingston Pike, and semi-exclusive ROW with mixed traffic use would be used in the central business district. This was a sketch planning analysis and the cost of ROW along the route was not considered.

Operation

Various headways were utilized in order to determine the number of vehicles required. Since demand is sensitive to headways it became a variable in the sensitivity analysis and values between five and twenty minutes during the peak, and thirty minutes for offpeak service were selected. The impact of headways on service and cost will be discussed in chapter 7. The next chapter discusses the demand analysis.

CHAPTER 5

DEMAND ANALYSIS

Quick Response System II developed by Dr. Alan J. Horowitz was used to evaluate the demand of a potential light rail transit system in Knoxville. The system evaluated was described in chapter 4. A hypothetical transit alignment was needed to determine the factors that QRS II used to forecast demand. The following areas will be covered in this chapter.

1. Inputting the highway network.
2. Inputting the transit network.
3. How QRS II forecasts transit demand.

INPUTTING THE HIGHWAY NETWORK

To forecast transit ridership, QRS II must have defined the number of trips within a study area, the origins and destinations of these trips, and the path between each O-D pair a trip will take to minimize travel time. These three steps, trip generation, trip distribution, and trip assignment will provide QRS II the necessary information, so that a mode split model can estimate the number of trips attracted to transit.

The first step in forecasting transit ridership in the Knoxville study corridor was to find out how many daily trips are made within the corridor. The Knox County Metropolitan Planning Commission (MPC) was very helpful in supplying the essential information for inputting the highway network in QRS II. The MPC supplied from a model of the Knoxville transportation system in the form of a transit zone map, the socio-economic data for each zone, the coordinates of all zonal centroids, and the lengths of all roads to be converted to links.

Trip generation determines trips produced and attracted per zone based upon zonal socio-economic data. The cross-classification and trip attraction relationship outlined in NCHRP 187 were utilized to estimate zonal person trip productions and attractions. Trip productions were then distributed based on the gravity model, considering the minimum travel time between zones. A post distribution mode split model was used to determine the percentages of trips taking transit.

Initially the highway network was tested to verify that the traffic volumes assigned to the major freeways and arterials were in fact realistic. The percentages and default values used in running the highway network analysis are noted in Appendix 2.

INPUTTING THE TRANSIT NETWORK

This step of the demand analysis consisted of taking the transit system alignment discussed in chapter 4 and integrating it with the highway network. QRS II defines the location of a transit route through the use of transit centroids (2). Transit centroids depict the location of transit zones on the highway network. QRS II matches the first five characters of the label for the transit centroid to the corresponding highway centroid's label. This tells QRS II which highway zone the corresponding transit zone falls in. A centroid connector is used to distinguish what percentage of the highway zone's person trips are associated with a stop or transfer point along the transit route. A highway zone can be split into several centroid connectors, each carrying a percentage of the highway zone's person trips to a transit stop or transfer point which is located within the zone.

A transit zone centroid was created for all highway zones that would contribute trips to the transit system. One-half mile on either side of the line-haul was determined as the maximum distance that would attract ridership to the transit system, so the line was drawn one-half mile on either side of the transit route splitting the highway zones. The next step was to determine what percentage of the divided highway zones would contribute person trips to the transit network. A

centroid connector was then used to estimate what percentage of person trips from the highway zone would be boarding one of the stops within the zone. The percentage of trips from the highway zone was input on the centroid connector attribute page. For example, let us consider highway zone 158 as shown in figure 5-1. A corresponding transit zone was created and labeled as zone 158. There are three stops along the route in zone 158. It was determined that zone 158 would attract passengers from one-half mile on either side of the line-haul route, so the zone was split into sections. It was then determined what percentage of person trips in this zone were located in each section and assigned them to the corresponding stop. This would tell QRS II how many people are potentially boarding the transit system at each stop.

There are several other factors that must be input into QRS II while developing the transit network such as the access time, disutility, and captivity. The factors used for this study were those recommended in the QRS II manual (2) and are outlined in Appendix 2.

HOW QRS II FORECASTS TRANSIT DEMAND

QRS II forecasts transit ridership by applying a logit mode split model to the number of trips on the highway network.

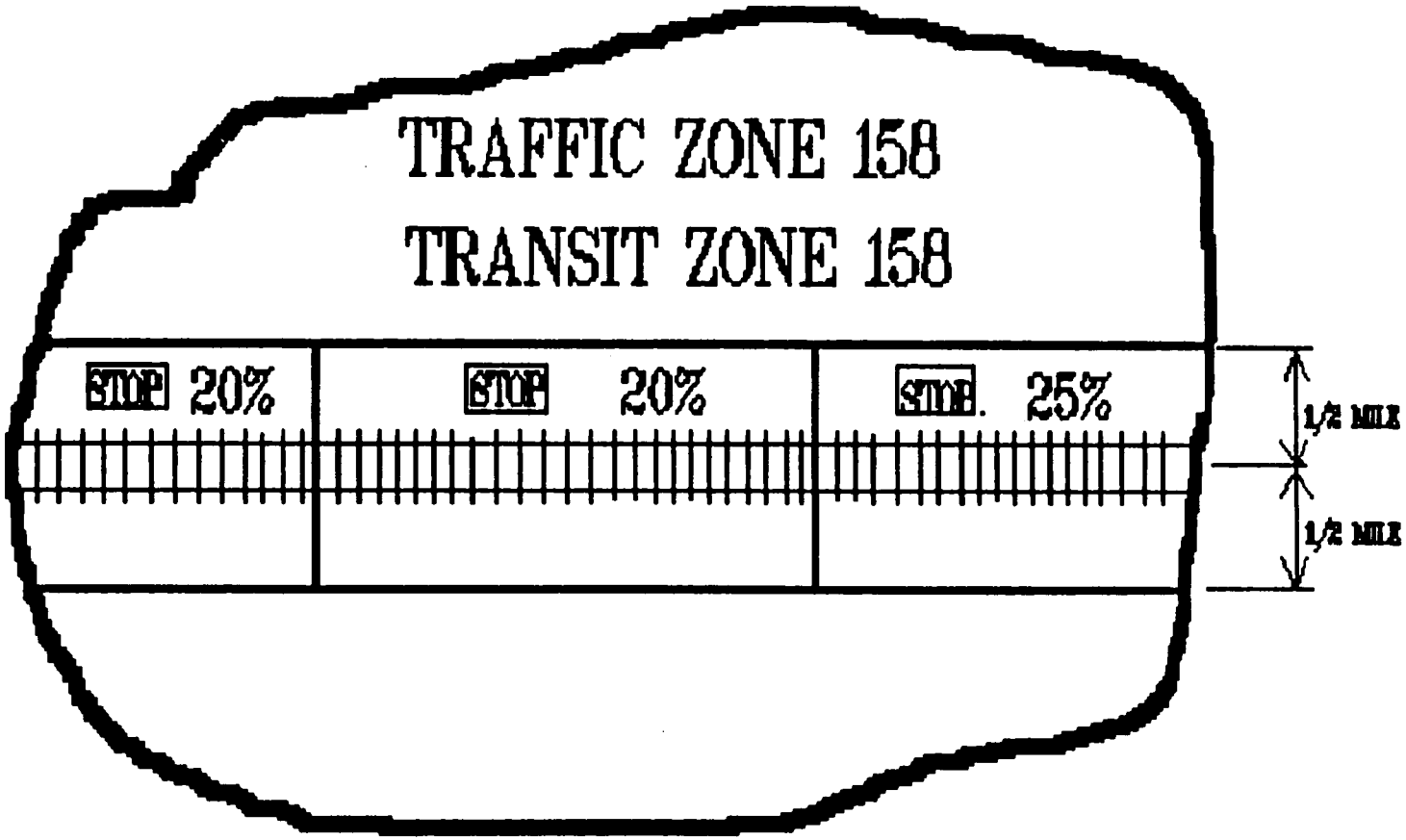


Figure 5-1
Example Transit Zone

QRS II bases the mode split on the number of captive transit riders and the difference in disutility between automobile and transit trips. Disutility is defined as the measure of the combined effect of time, cost and inconvenience of a trip by transit.

Transit disutility is calculated by adding riding time and weighted wait time plus the average fare times the value of time. Wait times for a transit trip are weighted so that one minute of wait time equals two minutes of riding time. The wait time is made up of the wait time for waiting on the transit vehicle to arrive; the transfer time; and the egress time, which is the time to exit the transit vehicle and walk to the desired destination. The calculation of disutility between two highway zones is taken as the weighted average of the disutilities between all transit zones in each highway zone. The weighting is based on the area split. The area split is the percentage of the highway zone that is within the area that attracts transit ridership. The difference in disutility is computed from the time differences between the two modes in each direction of travel. The disutility between transit and highway trips is calculated as (2):

$$Dijk = (Tij+Tji-Dij-Dji)/2 - Dk-Di-Dj$$

where:

Dijk = the disutility difference between transit and highway trips for zones i and j;

Dij = weighted average disutility from zone i to zone j by transit;

Dji = weighted average disutility from zone j to zone i by transit;

Dk = transit specific constant for purpose k;

Di = production extra disutility for zone i; and

Dj = attraction extra disutility for zone j;

Tij and Tji = the travel time between zones for highway trips.

The headway on the transit route is the single most important factor in computing disutility differences. As mentioned before, disutility for waiting is twice as much as that for riding, so how often a transit vehicle is able to pick up potential riders at a potential station has a very pronounced affect on the wait time. Another important factor is travel time, which is directly related to the speed of the transit vehicle and number of stops.

The captivity rate is an adjustable factor that is set by the operator within QRS II. Suggested captivity rates are given by Dr. Alan J. Horowitz in the QRS II manual and are based

upon the household income. It assumed that household income is directly related to automobile ownership. A captivity rate of one percent was used for this study. This factor is suggested by Horowitz in Appendix C of the QRS II manual (2).

The formula that QRS uses to assign trips to transit is shown below (6):

$$Pijk = Si*Sj\ [(1-Yik)/(1+\exp\{-M*Dijk\})+Yik]$$

where:

Pijk = probability that a person trip from i to j takes transit;
Si = sum of the area splits for zone i;
Sj = sum of the area splits for zone j;
Yik = captivity for zone i and for purpose k; and
M = mode split multiplier, which equals the disutility.

From this equation QRS II determines what percentage of trips assigned to the highway network will take transit, and this is used to determine total boardings (2).

CHAPTER 6

RESULTS OF DEMAND ANALYSIS

QRS II was used to estimate the forecasted transit ridership for the alignment studied. There are several factors that have a pronounced influence on the final results generated by QRS. A sensitivity analysis was used to determine the influences of the input variables on the demand forecast. Factors such as captivity percentage, mode split multiplier, and disutility multipliers were considered constants. The default values suggested in the QRS II manual and shown in Appendix 2 were used for every run. The factors that change from different transit alternatives were considered as variables. The following factors were determined to be variables and were modified to determine their influences on the demand forecast:

1. Headway
2. Fare
3. Default Access Time
4. Default Speed
5. Capacity

Changing these factors in various combinations was tried to project all reasonable possibilities in testing the transit system.

After making several runs of QRS II and changing the above factors, it was determined that headway and fare were the two variables that affected the demand forecast the greatest. Changing the access time and speed did not make a difference in the forecasted daily ridership. Changing the access time from ten minutes to twenty minutes had no affect on the ridership. This is due to the fact that an extra ten minutes disutility along a nineteen mile route would not have a pronounced affect, and access time is not counted as wait time, but as ride time. Also, changing the speed from forty to fifty miles per hour did not make a difference in the transit demand. This result came from the fact that along this transit route the stops are spaced at one-half mile intervals. The transit vehicle rarely has enough distance between stops to accelerate to cruising speed, and a ten mile per hour difference would not be significant in attracting more transit riders. Changing the capacity of the transit vehicle also did not affect the demand. The highest load factor was 0.27, so the capacity of the system never was even close to being reached.

Figures 6-1 and 6-2 show the forecasted transit ridership for Knoxville, Tennessee in the year 2005 for various headways and fares. The ridership shown is in passengers per day, with each day covering the time period between 6 am and 6 pm. The highest ridership was attained by reducing headway and fare.

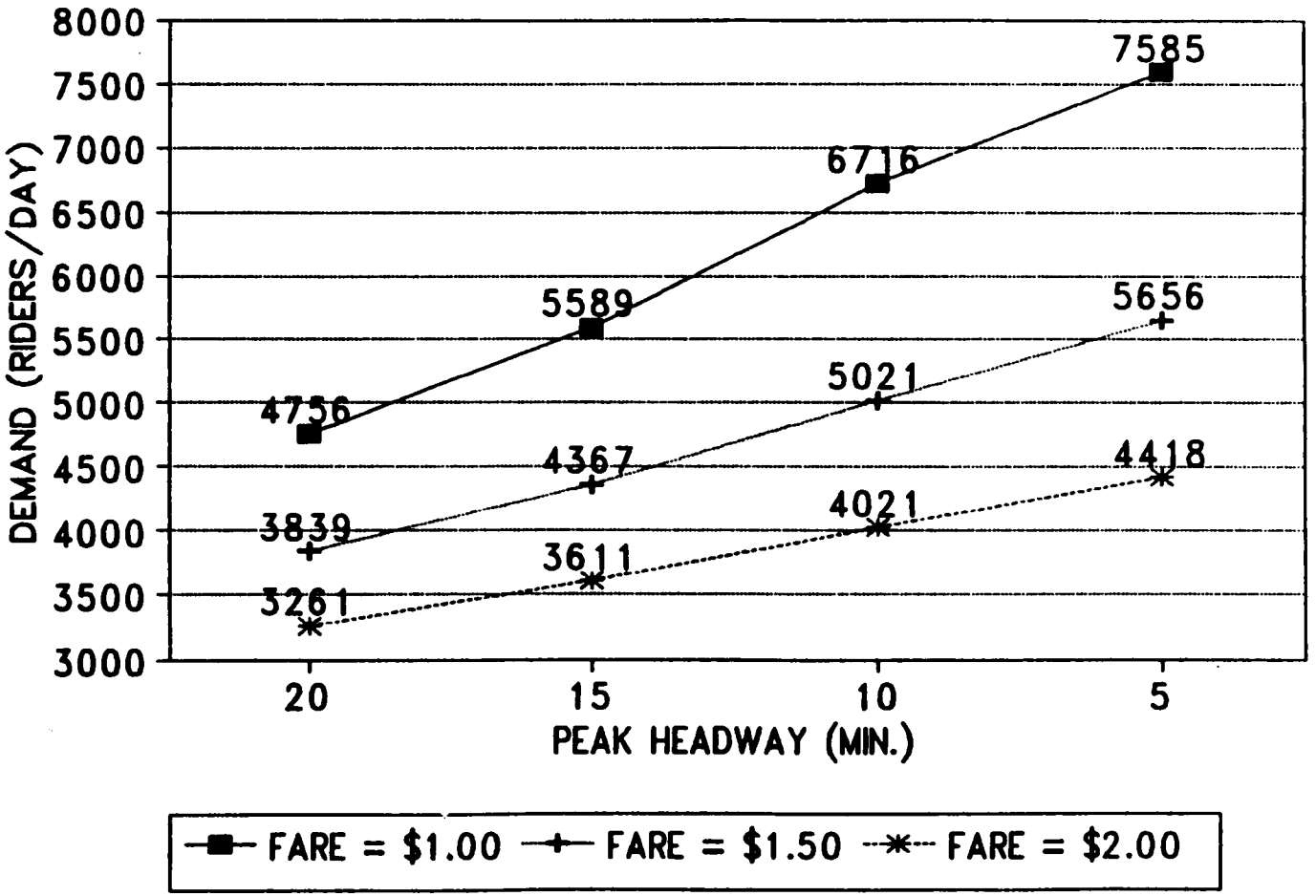


Figure 6-1
Demand Vs. Headway
Offpeak = 30 Minutes

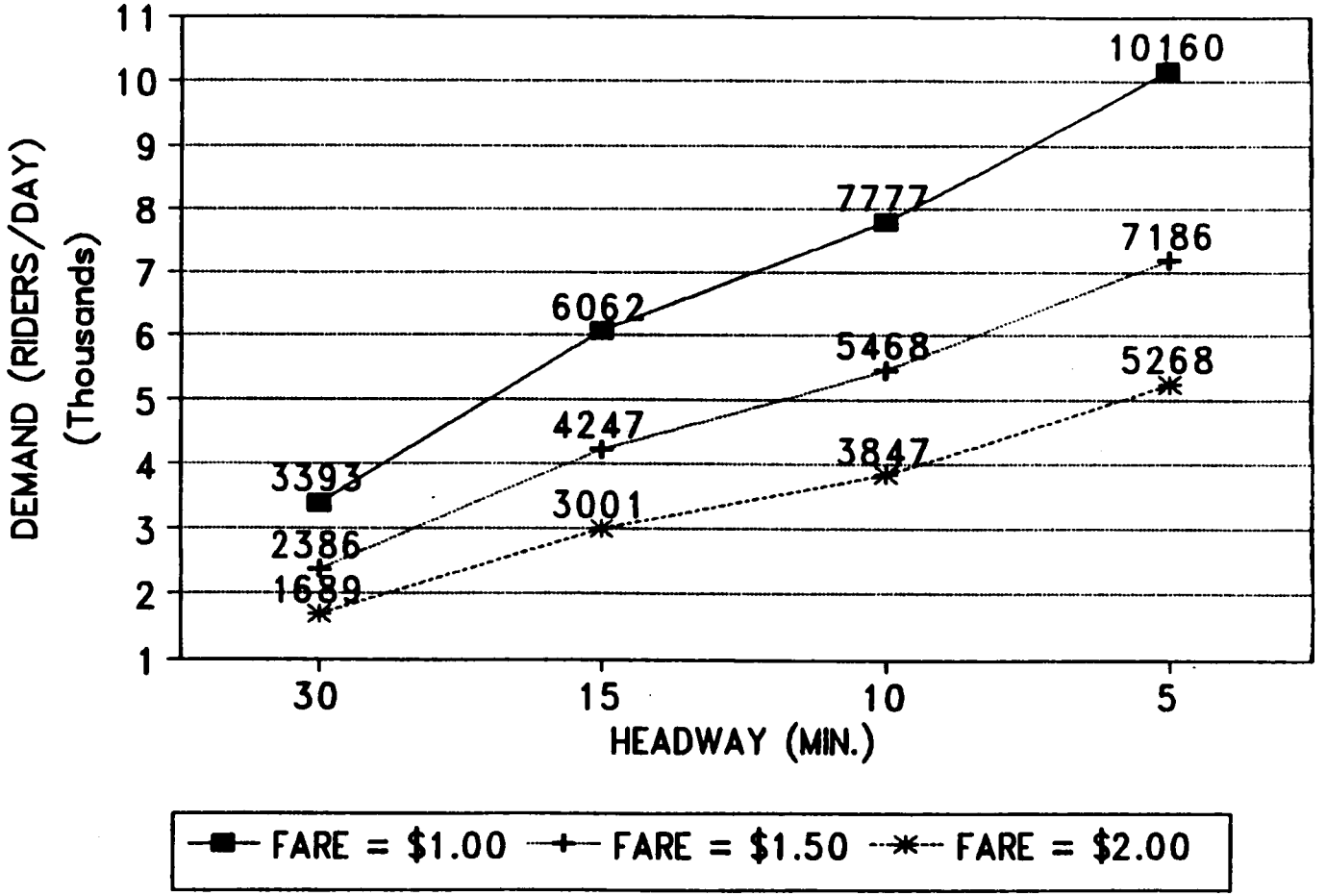


Figure 6-2
Demand Vs. Headway
Same Headway All Day

The smaller the headway, the less the wait time, the less the disutility, and the more attractive the transit system. This relationship is evident in figures 6-1 and 6-2. A wide variety of headways were considered for the analysis. Headways ranging from five minutes to thirty minutes running continuously throughout the day from 6 am to 6 pm were considered. Also, a thirty minute offpeak headway ranging from 10 am to 4 pm and peak headways of twenty, fifteen, ten and five minutes were considered. By comparison, the Knoxville bus system runs from 6 am to 6 pm with a thirty minute headway from 10 am to 4 pm with a 20 minute peak headway. The fare charged for a transit trip played a significant role in determining the demand. Logically, it would be assumed that the average rider would be concerned with the cost of transportation expenses. If traveling by transit was much cheaper than traveling by automobile, it is understandable that a larger portion of commuters would choose the most inexpensive mode. Fare is also a factor when determining disutility. A value of time in units of dollars per hour is used to relate fare and disutility. For example, a value of time of $2/hr would create a situation where a fare of $2 would be equivalent to one hour of disutility. Fares ranging from $1.00 to $2.00 were used to evaluate the transit system alignment. The Knoxville bus system has a $1.00 fare. It was assumed that a higher fare would be charged for light rail transit due to its greater comfort and service levels

than bus transit. The length of the line-haul for the LRT system evaluated would increase the fare.

The largest demand projected for the Knoxville transit system by this study was 10,160 passengers per day with a headway of five minutes running continuously throughout the day and a fare of $1.00. The lowest ridership forecasted was for a headway of 30 minutes running continuously throughout the day and a fare of $2.00. This patronage came out to be 1,689 riders per day.

DEMAND COMPARISON WITH OTHER OPERATING SYSTEMS

The highest ridership attained in this analysis was 10,160 passengers per day at 5 minute headways running continuously throughout the day and fare of $1.00. Whether this was a viable system from the standpoint of economics will be dealt with later, but this level of ridership was compared to the nations other light rail projects. Reference is made to Table 2-7 which defines ridership for several light rail systems in North America. It can be seen that the current systems operating with a line length and service comparable to the Knoxville system are the Sacramento, San Diego, and Portland light rail projects. Of these three, the Sacramento system has the lowest ridership of 13,200 passengers per day

operating on a minimum headway of fifteen minutes (8). The Knoxville system was forecasted to attract 10,160 passengers per day at five minute continuous headways and a $1.00 fare. This transit ridership forecast was below the Sacramento system operating with a lower level of service. The Knoxville system operating on a thirty minute offpeak and fifteen minute peak headway with a $1.00 fare was forecasted to attract 5,589 passengers per day, not even one-half of the Sacramento LRT ridership. On a riders per capita basis, the Knoxville LRT system evaluated was forecasted to attract one trip per day per 30 residents for a thirty minute offpeak headway and a fifteen minute peak headway. The Sacramento system attracts one trip per day per 25 residents, so the ridership per resident for both cities is similar. As noted in table 2-8, the Sacramento system was projected to attract 50,000 riders per day. The Portland and San Diego LRT systems shown in figure 2-7 show riderships of 20,000 and 27,000 riders per day respectively, twice as much as any demand computed during this analysis for the Knoxville light rail transit system.

SENSITIVITY OF STUDY

How accurate was this study's forecasted transit demand for a transit system in Knoxville, Tennessee? The common adage is that the output is only as good as the input. First of

all, the transit system was hypothetical. Place the system in another corridor, with another transit vehicle, different stop locations, a different track, etc.. the result could be different.

While sketch planning uses many assumptions and user default values, it should be noted:

1. This study used the most accurate information available in forecasting transit demand.
2. The socio-economic data and the QRS II network were taken directly from data provided by the MPC. The transit zones used match directly with the MPC, the centroids and links inputted into QRS II were given to the author by the Knoxville Metropolitan Planning Commission.
3. The Quick Response System II computer program is considered one of the best transportation planning tools available. It is used by many cities worldwide.
4. The factors used for the analysis given in the QRS II manual are established standards developed from research on other transit systems.
5. The most convincing argument to the sensitivity of this study is the fact that several runs

were made to encompass many possibilities in forecasting the transit system's patronage. QRS II made it possible to change certain attributes and look at the transit system under various circumstances. Enough runs were able to be made through QRS so that any questions as to how demand might change were satisfied.

An attempt was made to be complete in the calculation of the demand because it was assumed that the transit system would attract passengers from one-half mile on either side of the track. The accepted standard is one-fourth mile. Also when determining the area split for the transit zone centroid connectors, the estimated percentage of trips contributing from the highway trip table was always rounded upward. However, one area not considered was the attractiveness of park and ride lots at outlying stations to attract commuters residing in suburban areas of West Knox County who have travel destinations within the corridor such as UT and the CBD. Because West Knox County currently does not have a local bus system the reverse flows could not be well served.

CHAPTER 7

ECONOMIC ANALYSIS

Once the ridership levels had been forecasted in terms of ridership per day, the next step was to determine if the system was feasible or not. This chapter concentrates on determining the economic viability of building a light rail transit system in Knoxville, given the ridership for various headways and fares.

METHODOLOGY

Two analysis methods were performed for the economic evaluation of the light rail project. A break even analysis was conducted as was comparing the subsidy levels required to construct and operate the light rail system versus the existing Knoxville bus system subsidies. In the break even analysis the cost of operating and building the transit system was compared to the revenue brought in by rider fares and assumed subsidies. The methodology defined a cost per year for operating the transit system and then divides by the fare plus the subsidy for each rider. This gave the total passengers per year that would have to ride the transit system for revenue to equal costs. The subsidy used to compare to the Knoxville bus system was calculated by dividing the cost

of operating the system annually by the forecasted ridership developed in the demand analysis. This gave the total revenue that would be required to break even. Subtracting the fare collected from the total revenue determined the subsidy that must be funded per passenger trip. Reference is made to Chapter 4, which describes the transit system to be evaluated in detail. Costs included capital costs such as vehicle type, track type, stations, and ROW usage as well as operating costs. All cost data used for evaluating the Knoxville transit system were taken from Stone (8).

ECONOMIC SPREADSHEET EXPLANATION

A spreadsheet was developed to figure the daily passengers required to make revenues equal costs, for different headways, fares and subsidy levels, and to define the subsidy levels needed for a forecasted ridership. An example spreadsheet along with results can be seen in Figure 7-1. The results of all the spreadsheet runs is provided in Appendices 3 and 4. This section will describe how the spreadsheet calculates the results. Each item in the spreadsheet will be discussed.

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	5 MINUTES
NUMBER OF TRANSIT VEH	20
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 62400 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 1474200 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	11,400,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	2,346,240.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	11,867,310.00
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	9,180,000.00
REVENUES ($/RIDER)	1.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 16,349,524.00 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 4,808,684

PASSENGERS PER DAY TO BREAK EVEN = 18,566

Figure 7-1
Economic Spreadsheet

Route length : The overall route length from beginning station to the end.

Roundtrip travel time (or cycle time) : The time it takes for one LRV to start at the beginning of the line-haul, go to the end, and return to the beginning station. This is calculated from a spreadsheet developed by Stone (8). Output for this spreadsheet is shown in Figure 7-2. The spreadsheet uses the vehicle speed, acceleration, and the distance between stops to calculate a travel time.

Number of stations : The number of LRT stations along the route.

Headway : The peak headway along the route. As with the demand analysis, this is an input variable.

Number of transit vehicles : This is calculated as the roundtrip travel time divided by the headway plus one vehicle for storage and one for maintenance.

Interest rate : This is used for determining the annual costs for certain items such as the track and LRVs. The value of 4% is used because this is approximately the annual rate of inflation.

Operating days per year : The number of days per year the transit system is operating. Five days a

01-Jan-00

TRAVEL TIME MODEL
SUBJECT - Spreadsheet Template

ACCELERATION: 3.50 FT/SEC**2 F9 FOR UPDATE ALT+H FOR HELP INITIAL TIME: 0.00 MIN
DECELERATION: -3.50 FT/SEC**2 ALT+P FOR PRINTOUT INITIAL DISTANCE: 0.00 MILES

SEGMENT HEAD			SEGMENT TAIL			CRUISE	TIME (MIN)			
REFERENCE	MILEPOST	MPH	REFERENCE	MILEPOST	MPH	(MPH)	DWELL	TRAVEL	SEGMENT	TOTAL
CBD	0.00	0.00	DOWNTOWN	0.50	0.00	50.00	0.33	0.95	1.28	1.28
DOWNTOWN	0.50	0.00	DOUGHERTY	1.00	0.00	50.00	0.33	0.95	1.28	2.56
DOUGHERTY	1.00	0.00	15TH	1.60	0.00	50.00	0.33	1.07	1.40	3.96
15TH	1.60	0.00	WALGREENS	2.20	0.00	50.00	0.33	1.07	1.40	5.36
WALGREENS	2.20	0.00	LAUREL APTS	2.80	0.00	50.00	0.33	1.07	1.40	6.76
LAUREL APTS	2.80	0.00	CALVERY CHURCH	3.50	0.00	50.00	0.33	1.19	1.52	8.28
CALVERY CHURCH	3.50	0.00	LAUREL CHURCH	4.10	0.00	50.00	0.33	1.07	1.40	9.68
LAUREL CHURCH	4.10	0.00	SCENIC DR.	4.60	0.00	50.00	0.33	0.95	1.28	10.96
SCENIC DR.	4.60	0.00	WESTERN PLAZA	5.20	0.00	50.00	0.33	1.07	1.40	12.36
WESTERN PLAZA	5.20	0.00	KROGERS KNOX PLA	5.70	0.00	50.00	0.33	0.95	1.28	13.64
KROGERS KNOX PLA	5.70	0.00	FN FOOD LION	6.10	0.00	50.00	0.33	0.83	1.16	14.80
FN FOOD LION	6.10	0.00	BEARDEN CENTER	6.70	0.00	50.00	0.33	1.07	1.40	16.20
BEARDEN CENTER	6.70	0.00	THE VILLAGE	7.40	0.00	50.00	0.33	1.19	1.52	17.72
THE VILLAGE	7.40	0.00	ARBYS	7.90	0.00	50.00	0.33	0.95	1.28	19.00
ARBYS	7.90	0.00	OFFICE TOWN	8.40	0.00	50.00	0.33	0.95	1.28	20.28
OFFICE TOWN	8.40	0.00	K-MART	8.80	0.00	50.00	0.33	0.83	1.16	21.44
K-MART	8.80	0.00	WEST TOWN MALL	9.20	0.00	50.00	0.33	0.83	1.16	22.60
WEST TOWN MALL	9.20	0.00	OLDE KING. TOWNE	9.70	0.00	50.00	0.33	0.95	1.28	23.88
OLDE KING. TOWNE	9.70	0.00	WEST. SPRINGS PL	10.40	0.00	50.00	0.33	1.19	1.52	25.40
WEST. SPRINGS PL	10.40	0.00	TED RUSSEL FORD	11.00	0.00	50.00	0.33	1.07	1.40	26.80
TED RUSSEL FORD	11.00	0.00	TEN MILE CENTER	11.40	0.00	50.00	0.33	0.83	1.16	27.96
TEN MILE CENTER	11.40	0.00	TOWN & COUNTRY	12.00	0.00	50.00	0.33	1.07	1.40	29.36
TOWN & COUNTRY	12.00	0.00	MARKET PLACE EAS	12.50	0.00	50.00	0.33	0.95	1.28	30.64
MARKET PLACE EAS	12.50	0.00	WINDSOR SQUARE	12.90	0.00	50.00	0.33	0.83	1.16	31.80
WINDSOR SQUARE	12.90	0.00	FRANKLIN SQUARE	13.60	0.00	50.00	0.33	1.19	1.52	33.32
FRANKLIN SQUARE	13.60	0.00	MAYO	14.10	0.00	50.00	0.33	0.95	1.28	34.60
MAYO	14.10	0.00	HARDIES	14.50	0.00	50.00	0.33	0.83	1.16	35.76
HARDIES	14.50	0.00	TECHNOLOGY DRIVE	15.10	0.00	50.00	0.33	1.07	1.40	37.16
TECHNOLOGY DRIVE	15.10	0.00	DUTCH TOWN RD	15.70	0.00	50.00	0.33	1.07	1.40	38.56
DUTCH TOWN RD	15.70	0.00	LOVELL RD.	16.50	0.00	50.00	0.33	1.31	1.64	40.20
LOVELL RD.	16.50	0.00	CHANNICHAL DR	17.00	0.00	50.00	0.33	0.95	1.28	41.48
CHANNICHAL DR	17.00	0.00	HARDIN VALLEY DR	17.50	0.00	50.00	0.33	0.95	1.28	42.76
HARDIN VALLEY DR	17.50	0.00	COWARD MILL RD	17.90	0.00	50.00	0.33	0.83	1.16	43.92
COWARD MILL RD	17.90	0.00	OAK RIDGE HWAY	18.90	0.00	50.00	0.33	1.55	1.88	45.80
OAK RIDGE HWAY	18.90	0.00	END	18.90	0.00	50.00	0.33	0.00	0.33	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
		0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	46.13
			TOTAL DISTANCE	18.90	MILES	TOTAL	11.55	34.58	46.13	
			AVG SPEED	24.56	MPH	(MIN)				

Figure 7-2
Time Spreadsheet

Source: Stone, John R., Brian J. Gardner and Armin M. Meerz, "Guided Bus: Technology for the Research Triangle", 1990.

week for the year was used, which was 259 days per year.

Hours of operation per year : The number of hours in a year that each transit vehicle operates.

Route vehicle miles per year : The number of miles per year that all of the transit vehicles in the fleet travel.

Track : The route length times the unit cost.

Train cars : The number of transit vehicles times the unit cost.

Administration expense : An annual cost given by Stone to cover the cost of organizing and operating a LRT system.

Regular route hour expense : Route hours times the unit cost.

Regular route mile expense : Route miles times the unit cost.

LRT stations : Number of LRT stations times the unit cost.

Maintenance facilities : The number of transit vehicles times the unit cost.

Revenue : The fare charged to the transit rider.

Subsidy : The government subsidy given for each rider. For the break even analysis the subsidy is given as $2.40 per rider. This is approximately the 1991 subsidy of the Knoxville bus system per

passenger (5). For the comparing subsidies analysis, this is calculated as the total cost divided by forecasted ridership from the demand analysis for the given headway and fare, minus the fare.

Annual recovery factor : The annual worth given the present value over N years and i interest rate.

The annual costs were developed by applying an annual worth factor to the capital costs such as the track and train cars, and adding the other yearly costs such as administrative expenses. For the break even analysis, the passengers per year to break even economically was defined as the annual cost divided by the fare plus the subsidy. The passengers per day to break even was the passengers per year to break even divided by the operating days per year. For the comparison of subsidies analysis, the passengers per day to break even was the demand forecasted by this thesis.

RESULTS OF BREAK EVEN ECONOMIC ANALYSIS

As with forecasting the transit demand, the economic analysis was based upon a chosen headway and fare. From

chapter 6 it can be seen that headway influences several of the other factors in the spreadsheet such as number of vehicles, vehicle hours, and vehicle miles per year. The fare and subsidy chosen was very important also due to the fact that the ridership to break even was defined as the annual cost of operating the light rail system divided by these two figures added together. The spreadsheet made it possible to evaluate the effects of changing the headway, fare, and subsidy with accuracy and speed. Table 7-1 gives a quick synopsis of the results from all the spreadsheet runs provided in Appendix 3.

It can see from table 7-1 that a headway of five minutes with a fare of $1.00 would require the largest demand calculated in this study. This was obvious because the low headway would create the need for more transit vehicles and the low fare would create less revenue, and vice versa for the thirty minute headway and $2.00 fare.

An economic bottom line dominates almost all transportation project development, and it would surely hold true in this case. Figures 7-3 through 7-5 indicate the projected performance of a light rail transit system operating in the West Knox Corridor in Knoxville, Tennessee. As can be seen, the number of riders needed to break even financially was well above the forecasted number of passengers in every case.

Table 7-1
Passengers Per Day to Break Even

FARE	PEAK HEADWAY 5	10	15	20	30
$1.00	18566	10695	8071	7197	5448
$1.50	16186	9324	7037	6274	4749
$2.00	14347	8264	6237	5561	4210

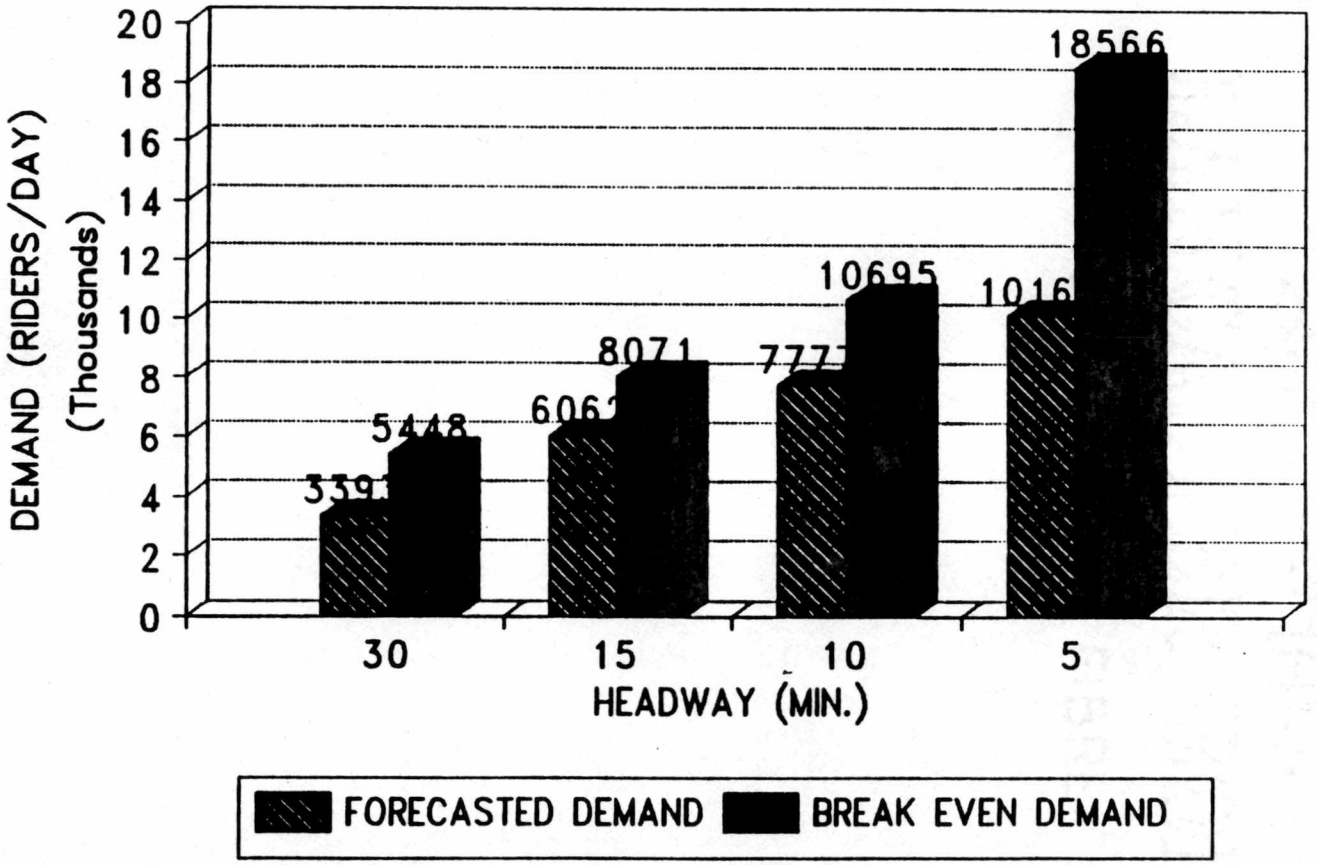


Figure 7-3
Estimated Demand Vs. Economic Demand
Continuous Headway : Fare=$1.00

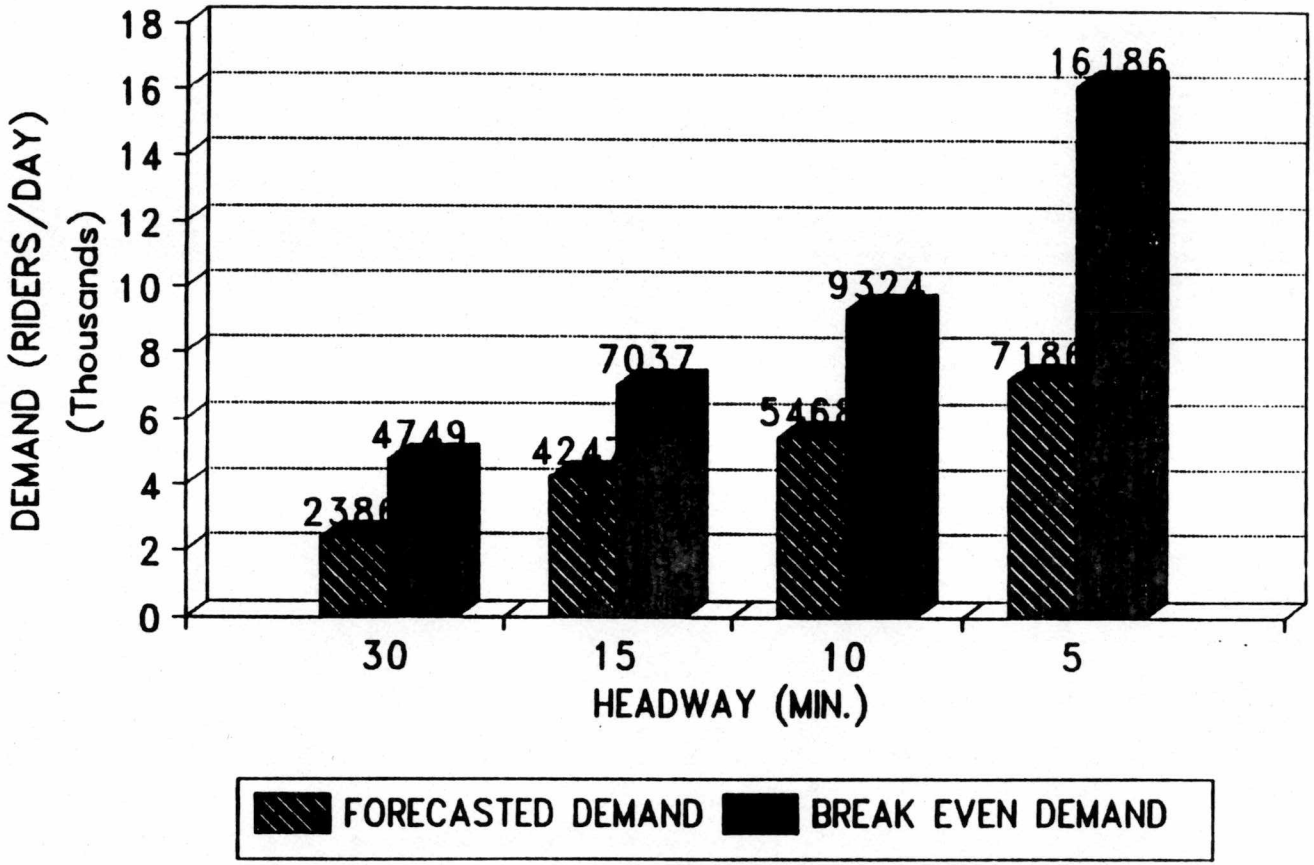


Figure 7-4
Estimated Demand Vs. Economic Demand
Continuous Headway : Fare=$1.50

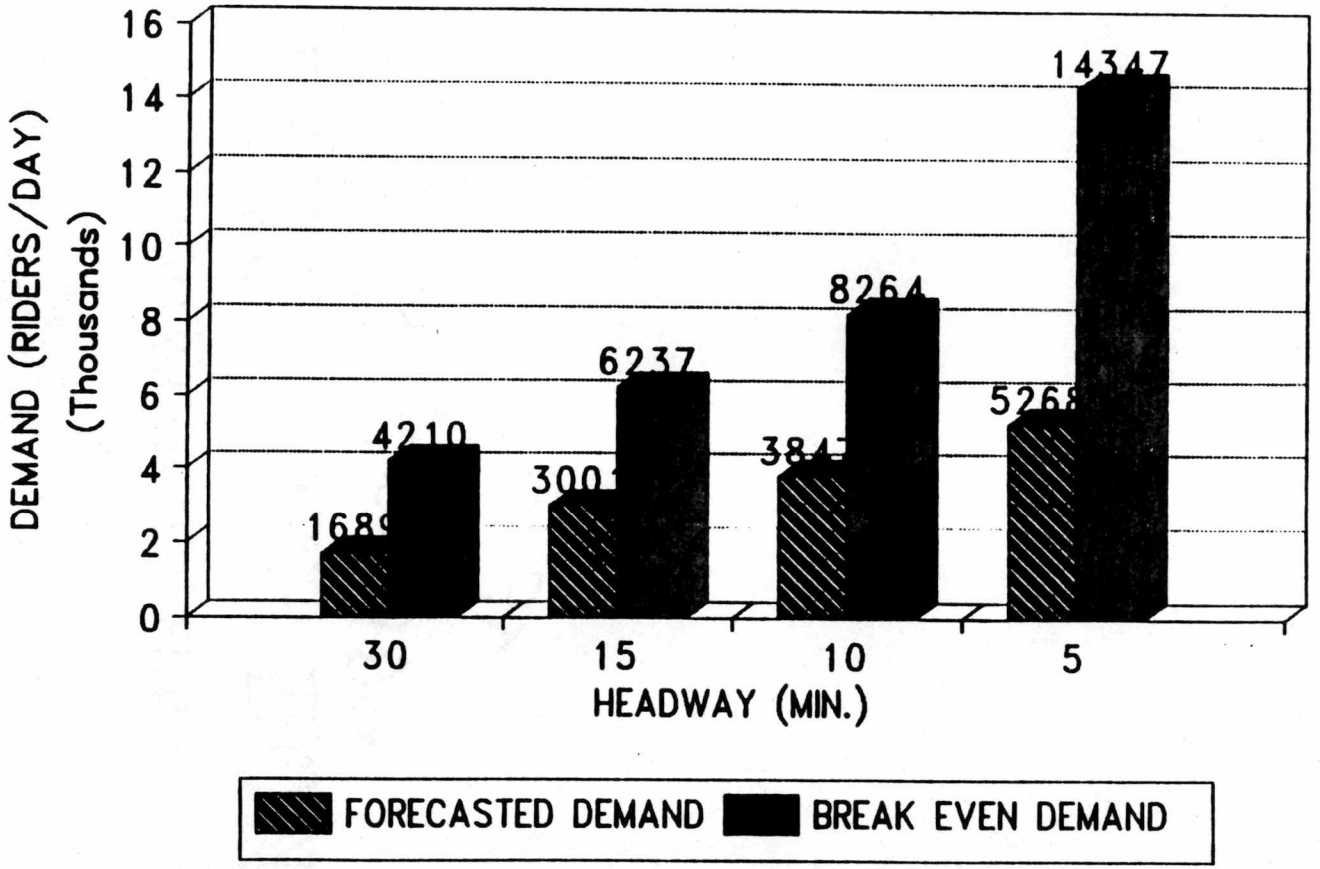


Figure 7-5
Estimated Demand Vs. Economic Demand
Continuous Headway : Fare=$2.00

RESULTS OF COMPARISON OF SUBSIDIES ANALYSIS

The forecasted ridership developed for this thesis was used for this analysis. As mentioned earlier, the ridership varied depending upon the headway and fare. Figure 6-1 gives the forecasted ridership levels calculated for an offpeak headway of 30 minutes and a peak headway of 20 minutes, which corresponds to the existing Knoxville bus system level of service operating in the West Knox Corridor. Table 7-2 lists the subsidy levels required to break even given the demand forecast. Appendix 4 provides the spreadsheet runs.

Table 7-2

Subsidy Given Ridership

Fare	Ridership Forecast	Required Subsidy/Trip
$1.00	4,756	$4.14
$1.50	3,839	$4.87
$2.00	3,261	$5.50

As is noted in Table 7-2, the lowest subsidy is $4.14 per passenger. The Knoxville bus system's average subsidy was $2.40 per passenger, and the Kingston Pike bus route has a subsidy of $2.32 per passenger (5). Therefore; it is

estimated that the subsidy to operate the light rail transit system evaluated for this thesis would be approximately twice the current subsidy given the Knoxville bus system.

CHAPTER 8

CONCLUSION

Light rail transit is becoming popular in the United States due to its ability to provide urban transportation at costs less than heavy rail and service levels greater than buses. Whether or not light rail will be feasible in a specific city depends largely on the characteristics of the city itself. The cities with light rail systems in the United States have at least twice the population of Knoxville. The reasons given for building a light rail system in Knoxville is the ability to potentially reduce traffic congestion. The idea that the Knoxville road system is overburdened and congested is a matter of perception to most people.

The analysis performed during this thesis determined that:

1. The forecasted ridership was dependent upon headway and fare. Both these parameters affect the disutility of the transit system.
2. The forecasted ridership was below any operating light rail transit system in North America.
3. The ridership needed to break even economically would have to be larger than the forecasted patronage.

4. The subsidy required to break even was projected to be much higher than that of the Knoxville bus system given the demand forecast statistics.

The development of a light rail system in the West Knox Corridor would require a subsidy level between $4.14 to $5.15 per passenger versus the existing $2.32 per rider by bus. The merit of this additional expense has to be weighted against the mobility and environmental objectives achieved by a LRT system. Without a complete public transit system, it would be difficult to serve many destinations including reverse flows and provide access from outlying transit stations to destinations not accessible on foot. Some increased demand may be expected for the potential to develop outlying park and ride lots, but with drive times of 20-25 minutes from the outlying stations to the CBD, the desire to change mode may not be popular. Critical bottlenecks such as Kingston Pike through Sequoyah Hills, the UT strip or Interstate 40 may be well served if LRT can utilize other alignments, especially the railroad corridor. However, the corridor would not serve the major destinations and activity centers and could serve to limit demand. The decision to develop LRT service in West Knox County will need to be considered on a scope beyond economic analysis provided in this thesis.

REFERENCES

(1) Bureau of the Census, "Census Journey to Work Data for Knoxville, Tennessee", 1980.

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APPENDICES

Appendix 1

CHARACTERISTICS OF LRT

KEY DESCRIPTIVE STATISTICS

City/State	% R/W Reserved	Avg Station Spacing km(mi)	% Dbl Track	# Thru Routes	# Cars 4-Axl (a)	# Cars 6-Axl (b)	System Avg Speed km(mi)/h
LRT-Group I:							
Calgary, C-Train	100%	0.9(0.6)	100%	3	0	83	29(18)
Cleveland, Shaker Rapid	100%	0.8(0.5)	100%	2	0	48	30(18)
Edmonton, Northeast LRT	100%	1.3(0.8)	100%	1	0	37	30(19)
Newark, City Subway	100%	0.6(0.4)	100%	1	24	0	34(21)
Philadelphia:							
Media-Sharon Hill	87%	0.4(0.2)	71%	2	29	0	26(16)
Portland, MAX	99%	1.0(0.6)	89%	1	0	26	30(19)
Sacramento, RT Metro	90%	1.0(0.7)	40%	1	0	26	34(21)
San Diego Trolley	100%	1.5(0.9)	99%	2	0	30	29(18)
San Jose, Guadalupe	100%	1.0(0.6)	95%	2	6(c)	50	32(20)
Subtotals/Averages	97%	0.9(0.5)	86%	15	53	300	
LRT-Group II:							
Boston:							
Green Line	89%	0.5(0.3)	100%	4	0	235	16(10)
Mattapan-Ashmont	100%	0.5(0.3)	100%	1	12	0	20(12)
Buffalo, NetroRail	100%	0.7(0.5)	100%	1	27	0	20(12)
Fort Worth, Tandy	100%	0.4(0.3)	100%	1	8	0	17(11)
Philadelphia:							
Subway-Surface	16%	0.2(0.1)	100%	5	112	0	18(11)
Pittsburgh, South Hills	97%	0.4(0.3)	90%	4	47	55	22(14)
San Fransico, Muni Metro	44%	0.3(0.2)	100%	5	0	130	18(11)
Subtotals/Averages	67%	0.3(0.2)	(100%	21	206	420	
Streetcars:							
New Orleans, St Charles	88%	0.2(0.1)	100%	1	35	0	15(9)
Philadelphia, Streetcars	5%	0.2(0.1)	100%	7	110	0	14(9)
Toronto, Streetcars	4%	0.1(0.1)	100%	9	318	0	15(9)
Subtotals/Averages	10%	0.1(0.1)	100%	17	463	0	
Totals:	60%	0.3(0.2)		53	722	720	

(a) Non-articulated, rigid body
(b) Articulated
(c) Vintage trolley cars for downtown loop, not included in totals

Source: NTRB, Special Report No. 221 "Light Rail Transit. New Systems at Affordable Prices", 1989

STATION AND GRADE CROSSING FREQUENCIES

City/State	Passenger Stops (a)	Grade Crossings Intersections (b)	Spacing km(mi)	No. With Priority (c)	Grade Separations
LRT-Group I:					
Calgary, C-Train	30	43	0.6(0.4)	40	15
Cleveland, Shaker Rapid	28	24	1.1(0.7)	0	26
Edmonton, Northeast LRT	8	9	1.2(0.7)	9	3
Newark, City Subway	11	1	3.4(2.2)	1	8
Philadelphia:					
Media-Sharon Hill	50	4	0.4(0.2)	25	2
Portland, MAX	25	52	0.5(0.3)	52	20
Sacramento, RT Metro	27	72	0.4(0.2)	70	15
San Diego Trolley	22	77	0.4(0.3)	57	5
San Jose, Guadalupe	33	51	0.6(0.4)	51	21
Subtotals	234	333		332	115
LRT-Group II:					
Boston:					
Green Line	84	52	0.8(0.5)	0	28
Mattapan-Ashmont	8	2	2.2(1.4)	0	5
Buffalo, Metrorail	14	7	1.5(0.9)	7	N/A
Fort Worth, Tandy	4	3(d)	0.5(0.3)	0	2
Philadelphia:					
Subway-Surface	167	4	1.4(0.9)	1	0
Pittsburgh, South Hills	82	43	0.8(0.5)	30	10
San Francisco, Muni Metro	110	39	0.1(0.1)	0	2
Subtotals	469	150		38	55
Streetcars:					
New Orleans, St Charles	50	90	0.1(0.1)	0	1
Philadelphia, Streetcars	573	14	0.3(0.2)	0	0
Toronto, Streetcars	610	3	0.9(0.5)	0	1
Subtotals	1233	115		0	2
Total	1936	598		370	172

(a) Stations and Car Stops
(b) Line segments except Street-Mixed Traffic
(c) Railroad-type gates &/or flashers, plus traffic lights w/LRT pre-empts, priority, green wave, etc.
(d) 1-vehicular & 2-pedestrian crossings

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

TRACK TRAFFIC PATTERNS, ELECTRIFICATION, AND SIGNALING

City/State	Double Track km(mi) (a)	Double Track %	Trcta Power (VDC)	Substations No.	Substations Rating (mW)	Type of Overhead (b)	Signals Blk (c)	Signals Tfc (c)
LRT-Group I:								
Calgary, C-Train	27.5(17.1)	100%	600	17	(e)2	Both	91%	9%
Cleveland, Shaker Rapid	21.1(13.1)	100%	600	6	(d)	Catenary	85%	47%
Edmonton, Northeast LRT	10.5(6.5)	100%	600	6	(d)	Catenary	100%	—
Newark, City Subway	6.9(4.3)	100%	600	4	0.75	Trolley	100%	(1%
Philadelphia:								
Media-Sharon Hill	13.7(8.5)	71%	635	4	(h)	Trolley	50%	25%
Portland, MAX	21.6(13.4)	89%	750	14	0.75	Both	52%	49%
Sacramento, RT Metro	11.7(7.3)	40%	750	14	1	Both	70%	32%
San Diego Trolley	32.7(20.4)	99%	600	20	1	Both	91%	9%
San Jose, Guadalupe	30.9(19.2)	95%	750	15	1.5	Both	58%	42%
Subtotals	176.6(109.8)							
LRT-Group II:								
Boston:								
Green Line	40.1(24.9)	100%	600	11	3-6	Trolley	61%	39%
Mattapan-Ashmont	4.3(2.7)	100%	600	1	6	Trolley	100%	—
Buffalo, MetroRail	10.3(6.4)	100%	650	5	2	Catenary	81%	19%
Fort Worth, Tandy	1.6(1.0)	100%	600	1	(h)	Trolley	—	—
Philadelphia:								
Subway-Surface	35.9(22.3)	100%	600	(e)	—	Trolley	11%	89%
Pittsburgh, South Hills	32.6(20.3)	90%	650	6	6	Both	90%	10%
San Francisco, Muni Metro	32.2(20.1)	100%	600	12	2-8	Trolley	19%	81%
Subtotals	157.0(97.7)							
Streetcars:								
New Orleans, St Charles	10.5(6.5)	100%	600	(h)	(h)	Trolley	—	100%
Philadelphia, Streetcars	92.3(57.4)	100%	600	(e)	—	Trolley	—	100%
Toronto, Streetcars	73.4(45.6)	100%	600	(h)	(h)	Trolley	—	100%
Subtotals	176.2(109.5)							
Total	509.8(317.0)							

(a) Includes paired 1-way street single tracks functioning as double track
(b) Type of Construction Catenary, Trolley, or Both
(c) % of Line km(mi) Equipped: Blk-Block Signals; Tfc-Traffic Lights; May not add to 100% as some segments have no signals others both Blk & Tfc
(d) 1.5 and 3.0 mW
(e) 28 major substations serve all electric transit in City of Philadelphia
(f) 4 of 11 substations also serve other lines
(g) Substations also provides power to Red Line rapid transit
(h) Data not available at time of publication

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

REVENUE SERVICE VEHICLES

City/System	Car Types (a)	Builder	Fleet	Characteristics of Car Equipment: Acceleration (b)	Max Speed (c)	Length (d)	Weight (e)
LRT-Group I:							
Calgary, C-Train	LRV-6-A	Siemens	83	1.1(2.2)	80(50)	24(80)	32(35)
Cleveland, Shaker Rapid	LRV-6-A	Breda	48	1.3(3.0)	88(55)	24(80)	40(45)
Edmonton, Northeast LRT	LRV-6-A	Siemens	37	1.0(2.2)	80(50)	24(80)	31(34)
Newark, City Subway	PCC-4-R	St Louis	24	1.8(4.0)	72(45)	14(46)	17(19)
Philadelphia:							
Media-Sharon Hill	LRV-4-R	Kawasaki	29	1.3(3.0)	100(62)	16(53)	27(30)
Portland, MAX	LRV-6-A	Bombardier	26	1.3(3.0)	88(55)	27(89)	42(46)
Sacramento, RT Metro	LRV-6-A	Siemens	26	1.1(2.5)	80(50)	24(80)	36(40)
San Diego Trolley	LRV-6-A	Siemens	30	1.0(2.2)	80(50)	2480)	33(36)
San Jose, Guadalupe	LRV-6-A	UTDC	50	1.3(3.0)	88(55)	27(89)	45(49)
Subtotals			353				
LRT-Group II:							
Boston:							
Green Line	LRV-6-A	Kinki	100	1.3(2.8)	80(50)	22(72)	38(42)
(Also In Service)	LRV-6-A	Boeing	135	1.3(3.0)	88(55)	22(72)	30(33)
Mattapan-Ashmont	PCC-4-R	Various	12	1.8(4.0)	72(45)	14(46)	17(19)
Buffalo, MetroRail	LRV-4-R	Tokyu	27	1.3(3.0)	80(50)	20(67)	30(33)
Fort Worth, Tandy	PCC-4-R	St Louis	8	1.8(4.0)	72(45)	14(46)	17(19)
Philadelphia:							
Subway-Surface	LRV-4-R	Kawasaki	112	1.3(3.0)	80(50)	15(50)	26(29)
Pittsburgh, South Hills	LRV-6-A	Siemens	55	1.3(3.0)	80(50)	26(84)	36(40)
(Also In Service)	PCC-4-R	St Louis	47	1.8(4.0)	72(45)	14(46)	17(19)
San Francisco,							
Muni Metro	LRV-6-A	Boeing	130	1.3(3.0)	88(55)	22(72)	30(33)
Subtotals			626				
New Orleans, St Charles	VTL-4-R	Perley-Thos	35	0.8(1.7)	43(27)	14(48)	19(21)
Philadelphia, Streetcars	PCC-4-R	St Louis	110	1.8(4.0)	72(45)	14(46)	17(19)
Toronto, Streetcars	LRV-4-R	UTDC	196	1.5(3.2)	85(53)	16(53)	23(26)
(Also In Service)	PCC-4-R	Various	122	1.8(4.0)	72(45)	14(46)	17(19)
Subtotals			463				
Total			1442				

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

RIGHT-OF-WAY LOCATIONS

City/State	km(mi) of Line							% of Line		
	Subway/Tal	Exclusive (a)	Pvt R/W (b)	Median (c)	Lanes/Wall (d)	Mixed Tfc (e)	Total	Grade Sep	Surf-Reserved	Mixed Tfc
LRT-Group I:										
Calgary, C-Train	1.9(1.2)	1.3(0.8)	13.2(8.2)	8.7(5.4)	2.4(1.5)	—	27.5(17.1)	12%	88%	—
Cleveland, Shaker Rapid	—	11.3(7.0)	—	9.8(6.1)	—	—	21.1(13.1)	53%	47%	—
Edmonton, Northeast LRT	2.3(1.4)	—	8.2(5.1)	—	—	—	10.5(6.5)	22%	78%	—
Newark, City Subway	2.1(1.3)	4.8(3.0)	—	—	—	—	6.9(4.3)	>99%	<1%	—
Philadelphia:										
Media-Sharon Hill	—	—	16.2(10.1)	—	0.3(0.2)	2.6(1.6)	19.2(11.9)	—	87%	13%
Portland, ROW	—	8.7(5.4)	3.7(2.3)	8.6(5.2)	3.4(2.1)	0.1(0.1)	24.3(15.1)	36%	>63%	<1%
Sacramento, RT Metro	—	9.5(5.9)	12.4(7.7)	1.0(0.6)	3.7(2.3)	2.8(1.8)	29.4(18.3)	32%	59%	10%
San Diego Trolley	—	—	30.1(18.7)	1.6(1.0)	1.1(0.7)	—	32.8(20.4)	—	100%	—
San Jose, Guadalupe	—	15.8(9.8)	1.8(1.1)	14.1(8.8)	1.1(0.7)	—	32.8(20.4)	48%	52%	—
Subtotals	6.3(3.9)	51.4(31.9)	85.7(53.2)	43.4(27.1)	12.8(7.5)	5.5(3.5)	204.5(127.1	28%	69%	3%
LRT-Group II:										
Boston:										
Green Line	7.2(4.5)	17.1(10.6)	—	11.4(7.1)	—	4.4(2.7)	40.1(24.9)	61%	28%	11%
Mattapan-Ashmont	—	4.3(2.7)	—	—	—	—	4.3(2.7)	>99%	<1%	—
Buffalo, Metrorail	8.4(5.2)	—	—	—	1.9(1.2)	—	10.3(6.4)	81%	19%	—
Fort Worth, Tandy	0.6(0.4)	—	1.6(0.6)	—	—	—	1.6(1.0)	40%	60%	—
Philadelphia:										
Subway-Surface	4.0(2.5)	—	—	1.6(1.0)	—	30.3(18.8)	35.9(22.3)	11%	5%	84%
Pittsburgh, South Hills	3.8(2.5)	9.7(6.0)	20.9(13.0)	0.8(0.5)	—	1.0(0.6	36.2(22.5)	37%	60%	3%
San Francisco, Muni Metro	10.2 6.4)	—	1.2(0.8)	2.6(1.6)	—	18.2(11.3)	32.2(20.1)	32%	12%	56%
Subtotals	34.2(21.4)	31.1(19.3)	23.1(14.4)	16.4(10.2)	1.9(1.2)	53.9(33.4)	160.6(99.9)	41%	26%	33%
Streetcars:										
New Orleans, St Charles	—	—	—	9.6(5.6)	0.2(0.1)	1.3(0.8)	10.9(6.5)	—	88%	12%
Philadelphia, Streetcars	—	—	—	—	4.2(2.6)	88.2(54.8)	92.4(57.4)	—	9%	91%
Toronto, Streetcars	0.2(0.2)	—	—	2.6(1.6)	—	70.5(43.8)	73.4(45.6)	<1%	>3%	96%
Subtotals	0.2(0.2)	—	—	11.6(7.2)	4.4(2.7)	160.0(99.4)	176.3(109.5	<1%	9%	>99%
Totals: km(mi)	40.8(25.5)	82.5(51.2)	109.8(67.6)	71.6(44.5)	18.3(11.4)	219.4(136.3)	541.4(336.5	23%	36%	41%

(a) Aerial or surface with no grade crossings
(b) Surface, LRT private R/W with grade crossings
(c) Surface, reserved medians of highways and streets with grade crossings
(d) Surface, reserved lanes (other than medians) and LRT/pedestrian malls
(e) Street lanes shared and other traffic; "streetcar" operation

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1988

REVENUE SERVICE VECHILES (cont.)

Characteristics of Latest Car Equipment

City/State	Car Types (a)	Endedness	Train (b)	Seats	Capacity (c)	AC? (d)	ATS/ATO
LRT-Group I:							
Calgary, C-Train	LRV-6-A	Double	3	64	144	No	ATS
Cleveland, Shaker Rapid	LRV-6-A	Double	2	84	144	Yes	ATS
Edmonton, Northeast LRT	LRV-6-A	Double	3	64	144	No	ATS
Newark, City Subway	PCC-4-R	Single	1	54	83	No	No
Philadelphia:							
Media-Sharon Hill	LRV-4-R	Double	2	50	95	Yes	No
Portland, MAX	LRV-6-A	Double	2	76	160	No	ATS
Sacramento, RT Metro	LRV-6-A	Double	4	64	144	Yes	No
San Diego Trolley	LRV-6-A	Double	4	64	144	(e)	No
San Jose, Guadalupe	LRV-6-A	Double	2	75	160	Yes	No
LRT-Group II:							
Boston:							
Green Line	LRV-6-A	Double	3	50	130	Yes	No
Mattapan-Ashmont	PCC-4-R	Single	1	52	83	No	No
Buffalo, MetroRail	LRV-4-R	Double	3(f)	51	121	Yes	ATS
Fort Worth, Tandy	PCC-4-R	Double	1	60	83	Yes	No
Philadelphia:							
Subway-Surface	LRV-4-R	Single	1	51	90	Yes	No
Pittsburgh, South Hills	LRV-6-A	Double	2	62	151	Yes	ATS
San Fransico,							
Muni Metro	LRV-6-A	Double	3	68	130	No	No
Streetcars:							
New Orleans, St Charles	VTL-4-R	Double	1	52	68	No	No
Philadelphia, Streetcars	PCC-4-R	Single	1	50	83	No	No
Toronto, Streetcars	LRV-4-R	Single	1	46	95	No	No

(a) LRV-Light Rail Vehicle, PCC-Presidents' Conference Committee, VTL-Pre-PCC Vintage Trolley; # Axles, 4 or 6, R-Rigid, Non-Articulated, A-Articulated

(b) Maximum Cars/Train in Regular Operation

(c) Car Length (Feet) x 1.8- comfortable load of seats + standees at +_4/m^2

(e) 6-Yes, 24-No

(f) 4-car Trains for Special Events

Source: NTRB, Special Report No. 221 "Light Rail Transit, New Systems at Affordable Prices", 1989

Appendix 2

QRS DEFAULT VALUES USED

SYSTEM ATTRIBUTES

S.N.	STRING	Values
1	Fare (cents)	150
2	Default Access Time (minutes)	10
3	Default Headway (minutes)	5
4	Start Hour (0..23)	6
5	End Hour (0..23)	18
6	Scale (pixels per mile)	100
7	Default Speed (miles per hour)	40
8	Default HBW Captivity (%)	1
9	Default HBNW Captivity (%)	1
A	Default NHB Captivity (%)	1

TRIP PRODUCTION PARAMETERS

E. Exit to Main Menu
1. Average Trip Production ==> 14.1
2. Average Home-Based Work Percent ==> 16.
3. Average Home-Based NonWork Percent ==> 61.
4. Average NonHome-Based Percent ==> 23.
5. Use Average Productions ==> No
6. Balancing Type (P,A,N) ==> Productions held constant
7. Inflation Index ==> 1.
8. Make NHB Productions Equal Attractions ==> Yes
9. Flip Directions of Direct and Reverse ==> No

TRIP ATTRACTION RATES

E. Exit to Main Menu
Home-Based Work
1. Retail Employees ==> 1.7
2. NonRetail Employees ==> 1.7
3. Dwelling Units ==> 0.
Home-Based NonWork
4. Retail Employees ==> 10.
5. NonRetail Employees ==> 0.5
6. Dwelling Units ==> 1.
NonHome-Based
7. Retail Employees ==> 2.
8. NonRetail Employees ==> 2.5
9. Dwelling Units ==> 0.5

TRIP DISTRIBUTION PARAMETERS

E. Exit to Main Menu
1. Home-Based Work Parameter ==> 0.1
2. Home-Based NonWork Parameter ==> 0.1
3. NonHome-Based Parameter ==> 0.1
4. Distribution Model Type (E,P,F) ==> Exponential
5. Number of Iterations ==> 3
6. Do Home-Based Work ==> Yes
7. Do Home-Based NonWork ==> Yes
8. Do NonHome-Based ==> Yes
9. Add User-Defined Trip Table ==> No
A. Person Trip Tables ==> Yes

VEHICLE ASSIGNMENT PARAMETERS

E. Exit to Main Menu
1. Travel Time Step Size ==> 0.25
2. Volume/Capacity Multiplier ==> 0.15
3. Volume/Capacity Exponent ==> 4.
4. Base Traffic Multiplier ==> 1.
5. Actual Speed Multiplier ==> 1.
6. Free Speed Multiplier ==> 1.15
7. Equilibrium Iterations ==> 0
8. Equilibrium/Incremental Assignment ==> Yes
9. Left-Hand (UK Style) Drive ==> No

VEHICLE OCCUPANCY PARAMETERS

E. Exit to Main Menu
1. Home-Based Work Occupancy ==> 1.38
2. Home-Based NonWork Occupancy ==> 1.82
3. NonHome-Based Occupancy ==> 1.43
4. Trip Type (P,V) ==> Vehicle
5. Hour Adjustment ==> Yes
6. Full 24 Hours, Use Default HAF ==> No
7. Default Hour Averaging Factor (HAF) ==> 1.

PATH FINDING PARAMETERS

E. Exit to Main Menu
1. Exponential Function Parameter ==> 0.1
2. Exponential Limit, Regular ==> 22.9
3. Exponential Limit, Coordinated ==> 11.9
4. Exponential Limit, Stop ==> 23.
5. Waiting Threshold ==> 23.
6. Number of Seats ==> 76.
7. Do mode split ==> Yes
F. Transit File Name ==> tran.dta

TRANSIT DISUTILITY PARAMETERS

E. Exit to Main Menu
1. Wait Weight ==> 0.95
2. Access Time Weight ==> 1.3
3. Transfer Weight ==> 0.8
4. Wait Penalty ==> 8.4
5. Transfer Penalty ==> 23.
6. Coordinated Transfer Penalty ==> 12.
7. Value of Time ==> 8.
8. Mode Split Multiplier (hbw) ==> 0.075
9. Mode Split Multiplier (hbnw) ==> 0.075
A. Mode Split Multiplier (nhb) ==> 0.075
B. Transit Specific Constant (hbw) ==> -4.
C. Transit Specific Constant (hbnw) ==> -4.
D. Transit Specific Constant (nhb) ==> -4.

Appendix 3

BREAK EVEN ECONOMIC ANALYSIS RESULTS

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	5 MINUTES
NUMBER OF TRANSIT VEH	20
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 62400 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 1474200 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	11,400,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	2,346,240.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	11,867,310.00
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	9,180,000.00
REVENUES ($/RIDER)	1.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 16,349,524.00 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 4,808,684

PASSENGERS PER DAY TO BREAK EVEN = 18,566

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	5 MINUTES
NUMBER OF TRANSIT VEH	20
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS x 5 DAYS/WK x 12 HRS/DAY = 62400 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR x 3120 HRS/YEAR x 18.9 MILES/TRIP x X vehicles = 1474200 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	11,400,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	2,346,240.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	11,867,310.00
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	9,180,000.00
REVENUES ($/RIDER)	1.50	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 16,349,524.00 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 4,192,186

PASSENGERS PER DAY TO BREAK EVEN = 16,186

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	5 MINUTES
NUMBER OF TRANSIT VEH	20
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 62400 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 1474200 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	11,400,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	2,346,240.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	11,867,310.00
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	9,180,000.00
REVENUES ($/RIDER)	2.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 16,349,524.00 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 3,715,801

PASSENGERS PER DAY TO BREAK EVEN = 14,347

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	10 MINUTES
NUMBER OF TRANSIT VEH	11
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 34320 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 810810 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	6,270,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	1,290,432.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	6,527,020.50
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	5,049,000.00
REVENUES ($/RIDER)	1.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 9,418,140.70 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 2,770,041

PASSENGERS PER DAY TO BREAK EVEN = 10,695

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	10 MINUTES
NUMBER OF TRANSIT VEH	11
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 34320 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 810810 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	6,270,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	1,290,432.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	6,527,020.50
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	5,049,000.00
REVENUES ($/RIDER)	1.50	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 9,418,140.70 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 2,414,908

PASSENGERS PER DAY TO BREAK EVEN = 9,324

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	10 MINUTES
NUMBER OF TRANSIT VEH	11
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 34320 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 810810 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	6,270,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	1,290,432.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	6,527,020.50
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	5,049,000.00
REVENUES ($/RIDER)	2.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 9,418,140.70 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 2,140,487

PASSENGERS PER DAY TO BREAK EVEN = 8,264

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	15 MINUTES
NUMBER OF TRANSIT VEH	8
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 24960 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 589680 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	4,560,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	938,496.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,746,924.00
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,672,000.00
REVENUES ($/RIDER)	1.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 7,107,679.60 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 2,090,494

PASSENGERS PER DAY TO BREAK EVEN = 8,071

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	15 MINUTES
NUMBER OF TRANSIT VEH	8
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 24960 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 589680 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	4,560,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	938,496.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,746,924.00
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,672,000.00
REVENUES ($/RIDER)	1.50	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 7,107,679.60 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 1,822,482

PASSENGERS PER DAY TO BREAK EVEN = 7,037

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	15 MINUTES
NUMBER OF TRANSIT VEH	8
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 24960 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 589680 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.0(
TRAIN CARS ($/VEH)	570,000.00	4,560,000.0(
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.0(
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	938,496.0(
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,746,924.0(
LRT STATIONS ($/STATION)	30,000.00	1,050,000.0(
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,672,000.0(
REVENUES ($/RIDER)	2.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 7,107,679.60 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 1,615,382

PASSENGERS PER DAY TO BREAK EVEN = 6,237

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	20 MINUTES
NUMBER OF TRANSIT VEH	7
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 21840 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 515970 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	3,990,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	821,184.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,153,558.50
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,213,000.00
REVENUES ($/RIDER)	1.00	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 6,337,525.90 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 1,863,978

PASSENGERS PER DAY TO BREAK EVEN = 7,197

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
PEAK HEADWAY	20 MINUTES
NUMBER OF TRANSIT VEH	7
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 21840 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 515970 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	3,990,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	821,184.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,153,558.50
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,213,000.00
REVENUES ($/RIDER)	1.50	
SUBSIDY ($/RIDER)	2.40	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 6,337,525.90 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 1,625,007

PASSENGERS PER DAY TO BREAK EVEN = 6,274

Appendix 4

SUBSIDY ECONOMIC ANALYSIS RESULTS

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
HEADWAY	20 MINUTES
NUMBER OF TRANSIT VEH	7
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 21840 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 515970 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	3,990,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	821,184.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,153,558.50
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,213,000.00
REVENUES ($/RIDER)	1.00	
SUBSIDY ($/RIDER)	4.14	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 6,337,525.90 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 1,231,804

PASSENGERS PER DAY TO BREAK EVEN = 4,756

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
HEADWAY	20 MINUTES
NUMBER OF TRANSIT VEH	7
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 21840 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 515970 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.00
TRAIN CARS ($/VEH)	570,000.00	3,990,000.00
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.00
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	821,184.00
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,153,558.50
LRT STATIONS ($/STATION)	30,000.00	1,050,000.00
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,213,000.00
REVENUES ($/RIDER)	1.50	
SUBSIDY ($/RIDER)	4.87	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 6,337,525.90 $/YR

PASSENGERS PER YEAR TO BREAK EVEN = 994,301

PASSENGERS PER DAY TO BREAK EVEN = 3,839

LIGHT RAIL ECONOMIC ANALYSIS

ROUTE LENGTH	18.9 MILES
ROUNDTRIP TRAVEL TIME	90 MINUTES
NUMBER OF STATIONS	35
HEADWAY	20 MINUTES
NUMBER OF TRANSIT VEH	7
INTEREST RATE	4.0%
OPERATING DAYS/YR	259

HOURS OF OPERATION PER YEAR
52 WEEKS * 5 DAYS/WK * 12 HRS/DAY = 21840 HRS/YR

ROUTE VEHICL-MILES PER YEAR
1.25 TRIPS/HR * 3120 HRS/YEAR * 18.9 MILES/TRIP * X vehicles = 515970 VEH-MI/YR

ITEM	UNIT COSTS	TOTAL COSTS
TRACK ($/MILE)	600,000.00	11,340,000.0(
TRAIN CARS ($/VEH)	570,000.00	3,990,000.0(
ADMINISTRATION EXPENSE ($/YR)	160,000.00	160,000.0(
REGULAR ROUTE HOUR EXPENSE ($/YR)	37.60	821,184.0(
REGULAR ROUTE MILE EXPENSE ($/VEH-MI)	8.05	4,153,558.5(
LRT STATIONS ($/STATION)	30,000.00	1,050,000.0
MAINTENANCE FACILITIES ($/VEH)	459,000.00	3,213,000.0
REVENUES ($/RIDER)	2.00	
SUBSIDY ($/RIDER)	5.50	
USEFUL LIFE OF TRACK (YRS)	25	
USEFUL LIFE OF RAIL CAR (YRS)	30	
ANNUAL RECOVERY FACTOR FOR 4% OVER 25 YRS =	0.064	
ANNUAL RECOVERY FACTOR FOR 4% OVER 30 YRS =	0.0578	

ANNUAL COSTS = 6,337,525.90 $/YR

PASSENGERS PER YEAR TO BREAK EVEN =	844,599
PASSENGERS PER DAY TO BREAK EVEN =	3,261

Appendix 5

Sample QRS II Runs

SYSTEM ATTRIBUTES

S.N.	STRING	Values	Date
1	Fare (cents)	200	7-10-91
2	Default Access Time (minutes)	10	3-12-91
3	Default Headway (minutes)	5	7-10-91
4	Start Hour (0..23)	6	3-12-91
5	End Hour (0..23)	18	3-12-91
6	Scale (pixels per mile)	100	3-12-91
7	Default Speed (miles per hour)	40	3-12-91
8	Default HBW Captivity (%)	1	3-12-91
9	Default HBNW Captivity (%)	1	3-12-91
A	Default NHB Captivity (%)	1	3-12-91

C) Change system attribute value.
D) Display work-sheet.
R) Return to previous display.

ENTER YOUR CHOICE

SYSTEM STATISTICS

5267.5 Total revenue riders
5267.5 Total boardings
4675.6 Assigned revenue riders
4675.6 Assigned boardings

SYSTEM ATTRIBUTES

S.N.	STRING	Values	Date
1	Fare (cents)	150	7-10-91
2	Default Access Time (minutes)	10	3-12-91
3	Default Headway (minutes)	5	7-10-91
4	Start Hour (0..23)	6	3-12-91
5	End Hour (0..23)	18	3-12-91
6	Scale (pixels per mile)	100	3-12-91
7	Default Speed (miles per hour)	40	3-12-91
8	Default HBW Captivity (%)	1	3-12-91
9	Default HBNW Captivity (%)	1	3-12-91
A	Default NHB Captivity (%)	1	3-12-91

C) Change system attribute value.
D) Display work-sheet.
R) Return to previous display.

ENTER YOUR CHOICE

SYSTEM STATISTICS

7186.1 Total revenue riders
7186.1 Total boardings
6409.0 Assigned revenue riders
6409.0 Assigned boardings

VITA

David Michael Webber was born on Beale AFB, California on September 30, 1966. He attended elementary school at Summit Elementary in Austin, Texas and graduated from Science Hill High School in Johnson City, Tennessee in June, 1985. The following September he entered The University of Tennessee, Knoxville and in May, 1990 received the degree of Bachelor of Science in Civil Engineering. He reentered The University of Tennessee, Knoxville in June, 1990 and in December, 1991 received a Master of Science degree in Civil Engineering.

He is presently employed as a Civil Engineer at Farnsworth and Wylie, PC in Bloomington, Illinois.