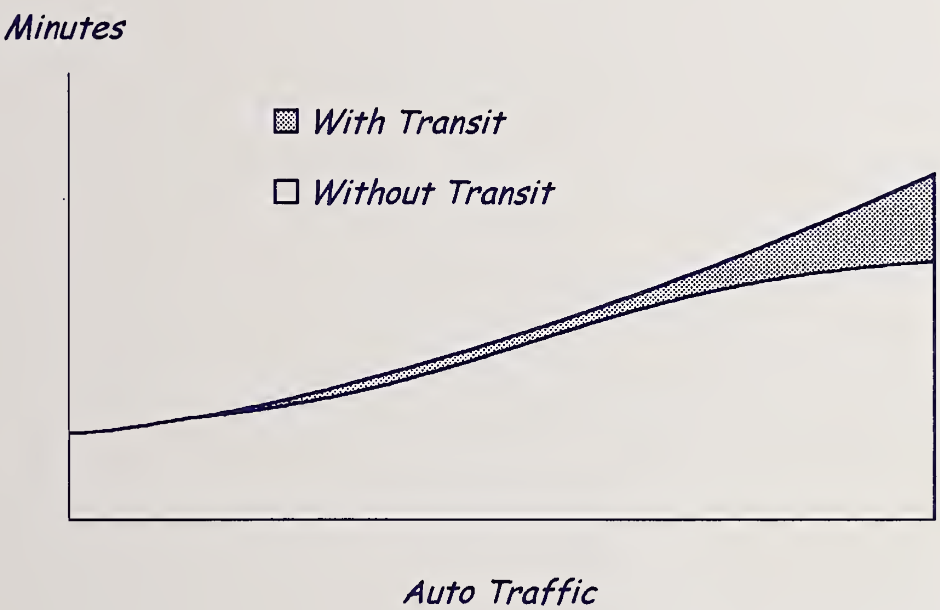
U.S. Department
of Transportation
**Federal Transit
Administration**

Transit Benefits 2000 Working Papers

Appendices: Six Strategic Transit Corridor Case Studies

Office of Policy Development



2000

An FTA Policy Paper

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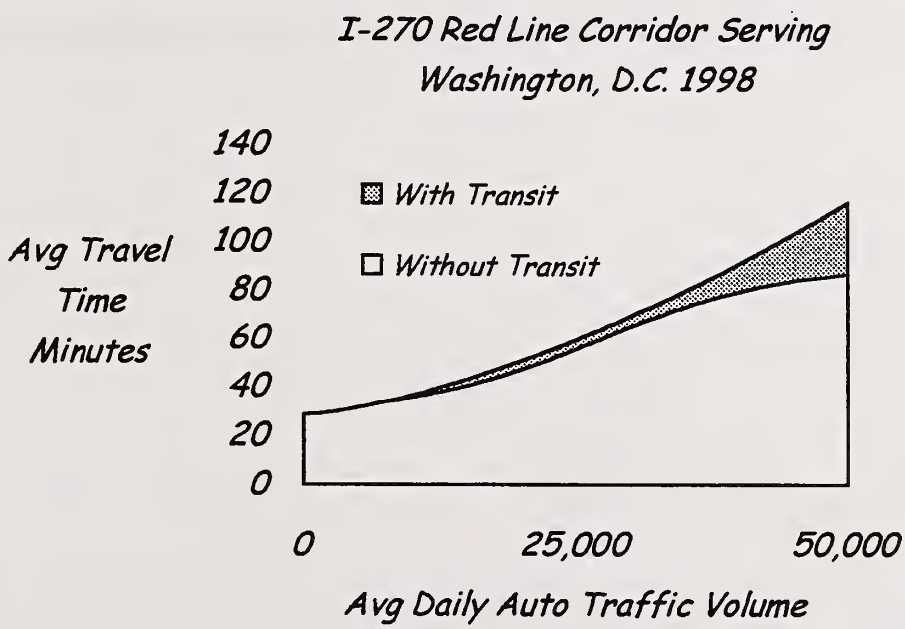

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An FTA Policy Paper

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Appendix 1. The Interstate 270 Metro Red Line Corridor Serving Washington, D.C.

Executive summary

The pilot study's purpose was to test the methodology to develop a performance metric which, efficiently, measures transit effectiveness in congestion management. This report provides an application of the methodology using the door to door trip times collected by Hickling Lewis Brod Decision Economics (HLB) in 1994 and the ones newly collected. First, the report estimated the model's structural parameters to calculate the hours of delay saved due to transit for 1994 and applied the same equations to estimate the savings for the years 1995, 1996, and 1997. Second, the report re-estimated the structural parameters of the model to calculate the 1998 delay savings due to transit.

The benefits are calculated for three user groups:

Benefits to highway users (Club), these are the hours saved by the common segment user of the I-270 corridor.

Benefits to Transit users (Market), these are the hours saved by the users of transit between Shady Grove and Farragut North station.

Benefits to the highway network users within the corridor (spillover), these are the hours saved by users of parallel and adjacent highways to the common segment within the corridor. .

Findings for 1994 and 1999

<u>Hours of Delay Saved Using the 1994 Data</u> Using convergence level from the 1994 corridor study, HLB found that peak period delay saving due to transit is around seven minutes. Using a travel time value of $15 per hour and an average of 250 working days per year, Table A 1.1 shows the peak delay saving due to the metro rail on I-270 corridor can be valued at $87.4 million for 1994 alone. HLB does not discern any anomalous results, indicating that the methodological framework is operating as expected.

Table A 1.1 Delay Savings Due to Transit based on the 1994 convergence data

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	9,848	$ 147,720	$ 36,929,998
Club	7,725	$ 115,879	$ 28,969,725
Spillover	5,727	$ 85,904	$ 21,475,877
Total	23,300	$ 349,502	$ 87,375,600

Table A 1.1 shows that the 1994 delay saving attributed to transit on the I-270 corridor is estimated at about $87.4 million. This can be translated to $3.05 million per rail mile.

Similarly, feeding the volume levels for 1995, 1996, and 1997, for the Washington-Gaithersburg I-270 corridor into equations (1) and (2), HLB estimated the hours of delay saved due to transit for each of the three years. Figure A 1.1 shows the "with-" and "without transit" curves using *the 1994 convergence data* for the I-270 corridor.

Because the model parameters were estimated based on historical HPMS data, a decrease in door to door travel time due to recent infrastructure improvements—opening of HOV lanes—is not reflected in the results shown in Table A 1.2. Therefore, the above results may overestimate the results for the years after the opening of the HOV lanes.

Regarding the methodology accuracy, HLB does not discern any anomalous results, indicating that the methodological framework is operating as expected. In fact, the methodology report states that in *the absence of major infrastructure improvement,* the structural parameters of the estimated equations are stable. Therefore, the trip volume in the corridor along with the ridership level can be inserted into these equations to estimate the delay savings due to transit. It is only in the presence of major changes in the level of highway supply or transit service that the behavioral equations underlying mode choice will change and need to be re-estimated.

Hours of Delay Saved Using the 1998 Data

Similarly, using the convergence level from the newly collected data, Table A 1.3 through Table A 1.5 show the 1998 delay savings due to transit per user category.

Table A 1.2 Summary Table of Delay Savings based on the 1994 convergence data

	Transit Effect on Corridor Travel Time (in minutes)		Hours of delay saved due to transit		
	With Transit	Without Transit	Min.per PeakTrip	Thous. Daily Hrs. (1,000)	Annual Dollar Savings
1994	71.1	77.8	6.7	23.3	$87,375,600
1995	72.3	79.1	6.8	24.0	$89,812,666
1996	73.6	80.6	7.0	24.7	$92,489,113
1997	74.9	82.0	7.1	25.4	$95,307,355

Table A 1.3 Daily Club Benefits for Red Line I-270 Corridor

Station	In-bound Trips	Out-bound Trips	Savings (hours)
Shady Grove	9,377	9,368	1,438.99
Rockville	3,696	3,644	535.29
Twinbrook	3,547	3,513	487.78
White Flint	3,905	3,935	511.57
Grosvenor	3,522	3,404	425.35
Medical Center	4,131	4,133	475.80
Bethesda	8,056	8,385	883.48
Friendship Heights	8,617	8,784	868.28
Tenleytown-AU	5,985	6,183	560.46
Van Ness-UDC	6,692	6,280	547.70
Cleveland Park	4,548	4,480	346.52
Woodley Park-Zoo	5,892	5,648	398.65
Dupont Circle	20,109	20,939	1,260.45
Farragut North	25,302	25,107	1,354.41
Total			10,095

Table A 1.4 Daily Market Benefits for I-270 Corridor

	Distance (miles)	Traffic Volume	Savings (hours)
Common Segment			
K Street	0.1	16,850	5.43
Whitehurst Freeway	1	16,850	48.86
Canal Street	0.1	16,850	4.89
Clara Barton Parkway	3.3	16,850	161.25
Cabin John Parkway	1.5	16,850	73.29
I-495	4.17	219,650	1,475.63
I-270	14.12	194,475	6,193.50
Access Segment			
(on average)	4.3	16,850	233.46
Total	28.59		8,196.31

Table A 1.5 Daily Spillover Benefits for I-270 Corridor

Highways in the corridor	Distance (miles)	Traffic Volume	Savings (hours)
MD 355	12.62	63,550	1,938.10
MD 191	9.84	19,050	302.00
MD 187	5.32	128,950	1,878.85
MD 185	8.59	68,625	949.70
MD 190	5.86	47,575	673.72
MD 396	2.21	11,075	59.15
MD 188	3.25	11,150	58.38
Total			5,860

Table A 1.6 Network Benefit Summary

Benefit Category	Daily Savings In Hours	Daily Savings In Dollars	Yearly Savings In Dollars
Market	10,095	$ 151,421	$ 37,855,246
Club	8,196	$ 122,945	$ 30,736,165
Spillover	5,860	$ 87,898	$ 21,974,568
Total	24,151	$ 362,264	$ 90,565,978

Table A 1.6 shows that the 1998 delay saving attributed to transit on the I-270 corridor is estimated at about $90.6 million. This can be translated to $3.2 million per rail mile.

Figure A 1.1 shows that the vertical difference between the "with-" and "without transit" curves did not vary between 1994 and 1998. This is due to the slight change in the convergence level between 1994 and 1998.

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door to door travel time data should be collected to estimate an accurate performance metric.

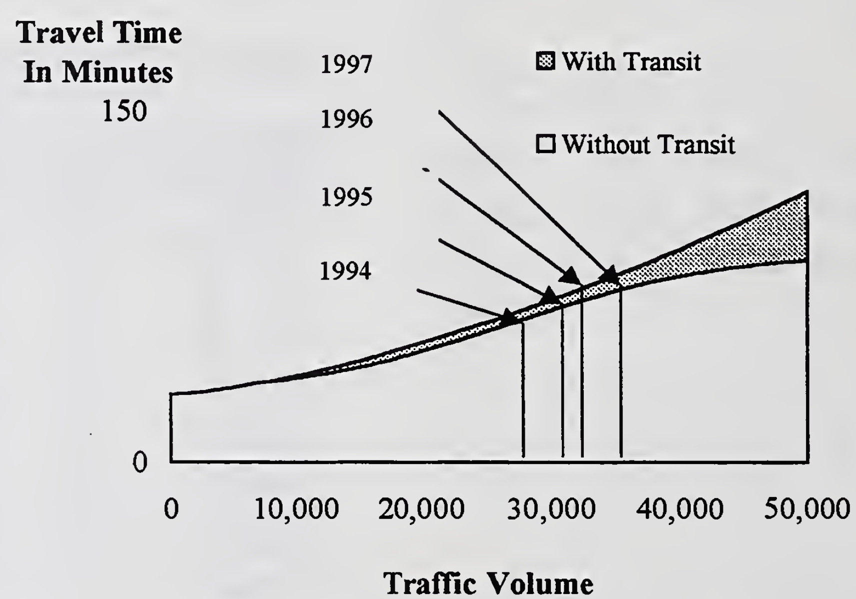


Figure A 1.1 Highway Travel Times With and Without Transit, Washington, D.C. I-270

Introduction

This is the Pilot Study report, which completes Subtask 2a of Streamlined Strategic Corridor Travel Time Management study. The purpose of the study is to use the convergence measurement technique to derive a repeatable performance measurement for rail transit in congested corridors. The pilot study purpose is to test the methodology to develop a performance metric which, efficiently, measures transit effectiveness in congestion management.

Study Methodology

The pilot study was conducted on the Washington-Gaithersburg I-270 corridor during the first 2 weeks of December 1998. The study consisted of testing the methodology in two phases. In the first phase, HPMS data was used to estimate the model parameters, then HLB's data from 1994 study was used to populate the model and calculate the hours of delay saved due to transit. In the second phase, data was collected on site—I-270 corridor—by a survey team, and the hours of delay saved were estimated using the new data.

Each survey crew was required to follow specific routes that consisted of an access segment—which depends on the catchment zone considered for the trip—and a common segment (which is the same segment for all the trips). The data collected included start times and arrival times by mode, congestion level, seating availability, weather, road conditions, and travel costs for each segment.

Data was collected over a period of three consecutive days (Tuesday to Thursday) during a two weeks period. The same days of the week were sampled to eliminate fluctuations in traffic patterns and volumes due to the day of week effects. More than one day of sampling was required to ensure a statistically adequate sample size and to minimize the effects of unusual or circumstantial conditions.

This pilot study employed the exact same maps and routes used in the 1994 study. Consequently, the results from this study allowed for not only a comparison of the metric-hours of delay saved due to transit—between 1994 and 1998 but for an interpretation of how the convergence level affects the metric over time as well.

Methodology Testing

The testing of the methodology consists of analyzing the travel times in the "with-" and "without transit" cases, and the hours of delay metric based on 1994 data and data newly collected. The analysis is critical in determining the consistency and the reliability of the methodology.

To estimate the model parameters HLB relied on traffic data from Washington Council of Governments (WASHCOG) and Montgomery County Department of Park and Planning, and on metro rail ridership data from Washington Metropolitan Area Transit Authority (WMATA).

HLB also used HPMS/STEAM delay models developed by Cambridge Systematics to obtain historical travel time in the corridor. The model estimation process was performed in several three steps:

Step 1: HLB used the 1994 door-to-door travel time data, historical HPMS data, and the convergence level to estimate the "without transit" and the "with transit" curves and calculate the travel time saved due to transit per person, per day.

Step 2: Traffic volume for the years 1995, 1996, and 1997 were used to calculate the hours of delay saved due to transit per person, per day.

Step 3: The door-to-door travel times were collected and used to re-estimate the "without transit" and the "with transit" curves.

Then, the delay metric is estimated and compared to the previous years-estimated metrics. The comparison analysis determines the effectiveness of the "hours of delay saved due to transit" metric as a rail transit performance indicator.

Plan of the Report

The objective of this report is to present the results from the I-270 Washington-Gaithersburg corridor pilot study. After this introduction, Chapter 2 presents an overview of the model and methodology to estimate the delay saving. Chapter 3 shows the model estimation results using 1994 convergence level on historical traffic data. The chapter gives an estimation of the hours of delay saved due to transit per person per day, and provides a monetary value of the delay saved for the years 1995 through 1997. Chapter 4 presents the results from the 1998 door-to-door travel survey and shows the model estimation of the delay saving using the new data. The chapter concludes with an interpretation of the effect of the convergence level on the estimated metric. The appendices at the end of this report provide supporting data and supplementary results on the survey findings by route.

Methodology and Model Overview

The methodology consists of four steps:

1. Estimating the Corridor Performance Baseline
2. Estimating the Corridor Performance in the Absence of transit
3. Extrapolating Delay Savings Due to Transit
4. Estimation of Corridor Performance without Re-calibration
5. Estimating the Corridor Performance Baseline

The Model This model establishes a functional relationship between the person trip volume – all modes—and the average door to door travel time by auto in the corridor.

The door to door travel time by auto can be determined using a logistic function which calculates the door to door travel time in terms of travel time at free flow speed, trip time by high capacity rail mode, and the volume of trips in the corridor for all modes. The door to door travel time can be estimated as follows:

$$\mathbf{T = (T_c - T_{ff}) / (1 + e^{-(\delta + \varepsilon V1)}) + T_{ff}} \qquad \mathbf{(1)}$$

Where T_{a1} is auto trip time,

Tc is trip time by high-capacity rail mode

T_{ff} is auto trip time at free-flow speed,

V is person trip volume in the corridor by auto, and

δ, ε are model parameters

Equation 1 implies that the door to door auto trip time is equal to the trip time at free-flow speed plus a delay which depends on transit travel time and the person trip volume in the corridor.

In other words, when the highway volume is close to zero, travel time is equal to travel time at free flow speed.($T = T_{ff}$). As the volume increases, the travel time is equal to T_{ff} plus a delay due to the high volume, but adjusted to the travel time by high capacity transit. That is the high capacity transit alleviates some of the highway trip delay as some trips shift to transit.

Equation 1 is transformed into a linear functional form before the parameters δ and ε can be estimated, the transformed equation will be:

$$U = \delta + \varepsilon V_1 \tag{2}$$

Where $U = \ln [(T_c - T_{ff}) / (T - T_{ff}) - 1]$

Equation 2 is estimated using Ordinary Least Squares regression.

Data The data required for the estimation of the above equations are:

person trip volume on the highway which can be calculated by dividing the traffic volume by the average vehicle occupancy (auto and buses). This data are available through HPMS data base and MPO's traffic data.

free flow trip time is a constant.

high capacity trip time is a constant.

The parameters δ and ε do not have to be re-estimated each year, they are both specific to the corridor and are relatively stable over the years. So periodically, the person trips volume can be inserted into Equation 1 to estimate the door to door travel time by auto.

Estimating the Corridor Performance in the Absence of transit

The Model This model represents the concept to quantify the role of transit in congestion management. In the absence of transit, the travel time Ta is estimated as:

$$T_a = T_{ff} * (1 + A (V^*)^\beta) \tag{3}$$

Where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V^* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door to door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

The existing auto and bus person trips on the highway.

The percentage of person transit trips shifting to auto

The percentage of person transit trips shifting to bus

The number of additional cars in the highway

The number of additional buses in the highway

The occupancy per vehicle in the absence of transit

The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$\mathbf{V^{*} = V_1 + \alpha_1 V_c + \alpha_2 V_b} \qquad \textbf{(4)}$$

Where V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor, and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

Type 1: "Explorers" who are casual switchers and who will divert to Single Occupancy Vehicles in the absence of transit.

Type 2: Commuters with low elasticity of demand with respect to generalized cost and who will divert to use the bus or carpool.

Type 3: Commuters with high elasticity of demand with respect to generalized cost and who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher the shift of transit riders to cars and buses. Therefore, higher degree of convergence will lead to higher delay, which translates into higher savings due to transit.

In words, Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high which translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve (as the volume increases, travel time increases at an increasing rate). Figure A 1.2 illustrates the relationship between the volume and travel time both in the presence and in the absence of transit.

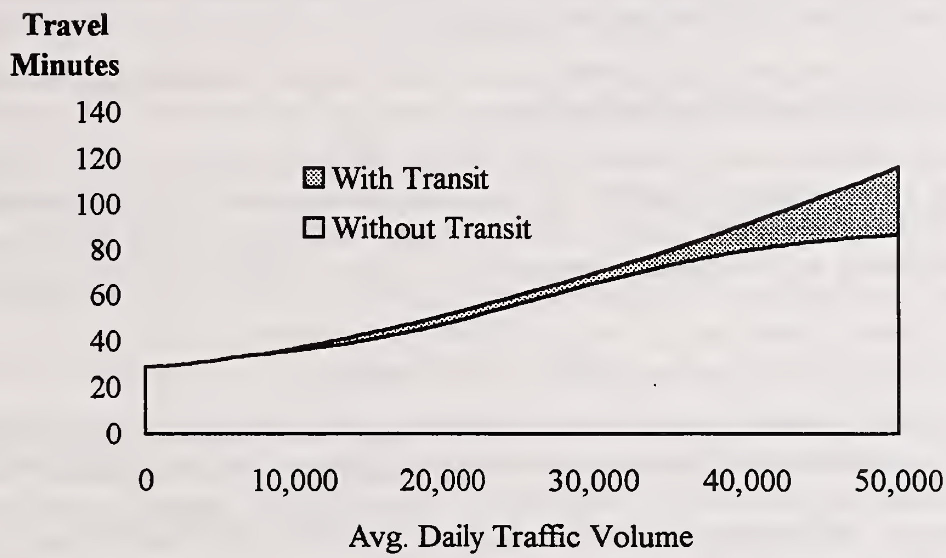


Figure A 1.2 Highway Travel Times With and Without Transit: I-270 Red Line Corridor, 1998

<u>Data</u> The data required to populate this model consist of:

Highway person trip volume (used in the previous model)

Transit ridership data

Fleet composition (cars and buses percentages out of the total traffic)

Cars and buses vehicle occupancy

Passenger car equivalent factor

Degree of convergence to determine the percentage person trips shifting to cars and buses

Free-flow travel time which is a constant

Equation 3 is specific to the corridor and does not need to be estimated each year. It will only be necessary to re-estimate them with an updated degree of convergence if a major change is made to the transit level of service or the highway structure.

Extrapolating Delay Savings Due to Transit

While the MLC hypothesis proves to be valid during the peak period only, the delay savings due to transit can be estimated during off-peak as well. This metric can be estimated as the vertical difference between the “without transit” curve and the “with transit” curve. That is at a specific person trip volume, the difference in travel times between the two cases can be defined as “the hours of delay saved due to transit”.

The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by Metro riders (market benefits), savings by highway users (club benefits), and savings by users of parallel highways (spillover benefits).

The *market* benefits are estimated based on delay saved (which depends on the distance traveled) for each rider within the common segment.

The *club* benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution.

The *spillover* benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment. The spillover benefits are calculated by multiplying the traffic volume with a percentage of the delay savings. This percentage decreases as the distance between the common segment and the parallel highway increases.

Estimation of Corridor Performance without Re-Calibration

The framework, presented above, provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay without the need for repeated MLC surveys. The approach rests on the theoretical proposition, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Principal Findings Using the 1994 Data

The first phase of the pilot study consists of using the 1994 I-270 corridor convergence data and historical HPMS data to test the study methodology and to estimate the hours of delay saved due to transit in the corridor. This chapter presents an analysis of the 1994 convergence data which is critical to determine the convergence level and then use this level to estimate the metric for the years 1994, 1995, 1996, and 1997.

The Convergence Level

The starting point to estimate the "without transit" curve is to determine the convergence level based on the key findings from the 1994 travel data. Table A 1.7 shows a summary of the performance and service characteristics for the Washington-Gaithersburg I-270 corridor in 1994.

Table A 1.7 Performance and Service Characteristics in 1994

	Automobile	Metro Rail
Number of stops	N/A	13
Number of Streets and Highways	6	N/A
Tolls/Fares for a one way (in dollars)	$0.00	$3.15

The level of convergence for the 1994 Washington-Gaithersburg I-270 Corridor is based on the following key findings from the study:

- Average door-to-door travel times for auto and metro rail, are similar, 67.4 minutes by rail versus 71.9 minutes by auto (Table A 1.8).

- Travel time reliability, as represented by the standard deviation of average travel time, is greater for heavy rail mode compared to the auto mode (Table A 1.8).
- Commuters experienced longer travel times in the morning than the evening reflecting the different traffic dynamics of the inbound peak flow versus the outbound peak flow (Table A 1.9).
- Statistical analysis shows that the mean trip time by auto was at most 10 minutes longer with 95% confidence (Table A 1.10).
- The common segment travel time was greater for the auto mode than for the transit mode, 50.7 minutes versus 37.8 minutes. The difference of 12.9 minutes between the two modes is due to congestion on the highways (Table A 1.8).
- Access segment travel times indicate that auto commuters spent 8.4 minutes on average less outside the common segment than transit commuters (Table A 1.8).

Table A 1.8 Results for the Washington-Gaithersburg I-270 Corridor

	Automobile	Metro Rail
Total Travel Time		
Mean	71.9	67.4
Standard Deviation	14.7	8.0
Access Segment Travel Time		
Mean	21.2	29.6
Standard Deviation	8.8	6.1
Common Segment Travel Time		
Mean	50.7	37.8
Standard Deviation	13.2	5.0
Sample Size	38	34

Table A 1.9 Comparison of AM and PM Trip Times by Modes

	Auto	Metro Rail
Inbound AM Average Trip Time	78.7	66.8
Outbound PM Average Trip Time	65.1	68.0

Table A 1.10 Statistical Testing of Convergence Hypothesis

Difference in Mean Travel Times by Mode: (Auto- Metro Rail minutes)		4.5
Standard Error of the Difference of the Means (minutes):		2.8
Hypothesis	Significant at the	Significant at the
"The difference between the mean travel times by modes is at most..."	0.10 Level (90% Confidence)	0.05 Level (95% Confidence)
7 Minutes	NO	NO
8 Minutes	NO	NO
9 Minutes	YES	NO
10 Minutes	YES	YES
11 Minutes	YES	YES

Methodology Application on I-270 Corridor using 1994 Data

Data HLB obtained traffic volume data (HPMS data) from the regional MPO, Metropolitan Washington Council of Government (WASHCOG) and Maryland Department of Transportation. The ridership data were obtained from the Washington Metropolitan Area Transit Authority (WASHCOG). In addition, the 1994 door to door travel time survey results were used to derive the degree of convergence in the corridor.

Model The traffic volume and travel time data were used to populate the model, Equation 1 is estimated as follows:

$$\mathbf{T_{a1} = 51 / (1 + e^{-(-3.28 + -0.000121\,(V))}) + 29,} \tag{1}$$

Similarly, Equation 2 is estimated based on auto travel volume, transit ridership data, and convergence level estimate from the survey.

$$\mathbf{T_{a2} = 29 \;\; * \;\; (1 + 2.68E\text{-}07\,(V^*)^{1.5})} \tag{2}$$

The auto traffic volume in the absence of transit is determined by adding the auto volume in the presence of transit to the generated auto trips by transit riders. The generated is based on:

About 7% of person transit trips will be forgone (determined by the corridor convergence level).

The average vehicle occupancy (HOV and non-HOV) is 1.2 for cars and 40 for buses.

Car trips will make about 80% of trips.

Benefit Estimation To estimate the travel time saving (TTS) attributed to transit, the current traffic volume is inserted into Equation 1 and 2. An auto volume of 37,500 results into:

$$\mathbf{T_{a1} = 71.1,\;\; T_{a2} = 77.8,\; and\; .\; TTS = T_{a2}\; -\; T_{a1} = \;6.7}$$

That is on average, in I-270 corridor, transit saves about 6.7 minutes per auto trip (14.1 seconds per mile) during the peak period

Once the average travel time saving per vehicle is estimated, the savings are weighted to reflect the congestion level at each time of the day. App. Annex A shows the daily Average Traffic Volume distribution.

The benefits are calculated for three user groups:

1. Benefits to highway users (Club), these are the hours saved by the common segment user of the I-270 corridor (see Table A 1.11).
2. Benefits to Transit users (Market), these are the hours saved by the users of transit between Shady Grove and Farragut North station (see Table A 1.12).
3. Benefits to the highway network users within the corridor (spillover), these are the hours saved by users of parallel and adjacent highways to the common segment within the corridor (see Table A 1.13).

Table A 1.11 Club Benefits for I-270 Corridor using 1994 Data

	Distance (miles)	Avg Traffic Volume	Daily Savings (hours)
Common Segment			
K Street	0.1	13,975	4.59
Whitehurst Freeway	1	13,975	41.27
Canal Street	0.1	13,975	4.13
Clara Barton Parkway	3.3	13,975	136.17
Cabin John Parkway	1.5	13,975	61.90
I-495	4.17	202,650	1,386.25
I-270	14.12	181,750	5,893.81
Access Segment (on average)	4.3	13,975	197.16
Total	28.59		7,725.26

Table A 1.12 Market Benefits of I-270 Corridor using 1994 Data

Station	In-bound Trips	Out-bound Trips	Daily Savings (hours)
Shady Grove	8,321	8,315	1,300.38
Rockville	3,550	3,502	523.67
Twinbrook	3,855	3,822	540.08
White Flint	3,661	3,692	488.55
Grosvenor	3,650	3,492	446.61
Medical Center	3,927	3,924	460.26
Bethesda	7,625	7,817	844.93
Friendship Heights	8,520	8,582	868.92
Tenleytown-AU	5,210	5,406	497.89
Van Ness-UDC	6,422	6,052	536.28
Cleveland Park	4,204	4,125	325.53
Woodley Park-Zoo	7,309	7,215	510.88
Dupont Circle	20,411	20,725	1,286.19
Farragut North	23,364	21,150	1,217.83
Total			9,848

Table A 1.13 Spillover Benefits of I-270 Corridor using 1994 Data

Highways in the corridor	Distance (miles)	Avg Traffic Volume	Daily Savings (hours)
MD 355	12.62	61,250	1,902.02
MD 191	9.84	18,000	290.55
MD 187	5.32	125,600	1,863.41
MD 185	8.59	65,250	919.46
MD 190	5.86	44,000	634.45
MD 396	2.21	11,025	59.95
MD 188	3.25	10,700	57.05
Total			5,727

Table A 1.14 shows that the 1994 delay saving attributed to transit on the I-270 corridor is estimated at about $87.4 million. This can be translated to $3.05 million per rail mile.

Feeding the volume levels for 1994, 1995, 1996, and 1997, for the Washington-Gaithersburg I-270 corridor into equations (1) and (2), HLB estimated the hours of delay saved due to transit for each of the four years. Figure A 1.3 shows the "with-" and "without transit" curves using *the 1994 convergence data* for the I-270 corridor.

Table A 1.14 Benefit Summary using 1994 Data

Benefit Category	Daily Savings In Hours	Daily Savings In Dollars	Yearly Savings In Dollars
Market Benefits	9,848	$ 147,720	$ 36,929,998
Club Benefits	7,725	$ 115,879	$ 28,969,725
Spillover Benefits	5,727	$ 85,904	$ 21,475,877
Total	23,300	$ 349,502	$ 87,375,600

Table A 1.15 Summary Table of Delay Savings based on the 1994 convergence data

	Travel time in the corridor (in minutes)		Hours of delay saved due to transit		
	In presence of Transit	In absence of Transit	per trip during peak period (min)	All user-categories per day (hours)	Yearly Savings in Dollars
1994	71.1	77.8	6.7	23,300	$ 87,375,600
1995	72.3	79.1	6.8	23,950	$ 89,812,666
1996	73.6	80.6	7.0	24,664	$ 92,489,113
1997	74.9	82.0	7.1	25,415	$ 95,307,355

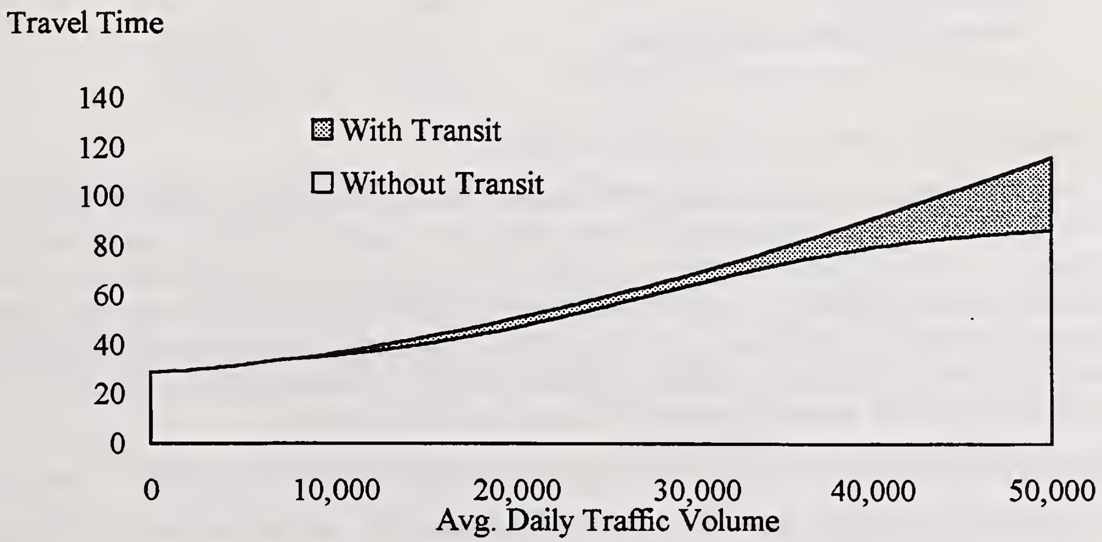


Figure A 1.3 Illustration of the "With-" and "Without Transit" Curves Using 1994 Convergence Data

The above results indicate a peak-period delay saving due to transit of about seven minutes. Using a travel time value of $15 per hour and an average of 250 working days per year, Table A 1.15 shows the peak delay saving due to the metro rail on I-270 corridor can be valued at $89.8 million in 1995 and about $95 in 1997. The door to door travel times for 1995, 1996, and 1997 were not collected on site but estimated using Equation 1. Because the model parameters were estimated based on historical HPMS data, a decrease in door to door travel time due to recent infrastructure improvements—opening of HOV lanes—is not reflected in the results shown in Table A 1.15. Therefore, the above results may overestimate the results for the years after the opening of the HOV lanes.

Regarding the methodology accuracy, HLB does not discern any anomalous results, indicating that the methodological framework is operating as expected. In fact, the methodology report states that in *the absence of major infrastructure improvement,* the structural parameters of the estimated equations are stable. Therefore, the trip volume in the corridor along with the ridership level can be inserted into these equations to estimate the delay savings due to transit. It is only in the presence of major changes in the level of highway supply or transit service that the behavioral equations underlying mode choice will change and need to be re-estimated.

An Update of the I-270 Corridor Equilibrium Study

This section presents the results from the 1998 door-to-door travel survey. The chapter also shows the model estimation results using the new data and concludes with an interpretation of the effect of the convergence level on the estimated metric. Table A 1.16 presents the performance and service characteristics during the 1998 door to door travel survey.

Table A 1.16 Performance and Service Characteristics in 1998

	Automobile	Metro Rail
Number of stops	N/A	13
Number of Streets and Highways	6	N/A
Tolls/Fares for a one way (in dollars)	$0.00	$3.25

Pilot Update of the I-270 Corridor Equilibrium Study

The 1994 Washington-Gaithersburg I-270 corridor results presented in Table A 1.11, Table A 1.12, and Table A 1.13 can be compared with pilot I-270 results for 1998 in matching Table A 1.21, Table A 1.22, and Table A 1.23. A comparison of Table A 1.10 and Table A 1.15 indicate that the convergence hypothesis remains statistically valid for a door to door trip time difference (auto versus metro rail as main mode) of *at most* 10-11 minutes. The average trip time difference measured in 1998 of 5.7 minutes remains very close to the 4.5 minute difference in 1994. Annex A 1.2 provides the 1998 survey findings by route in the I-270 corridor.

The key findings from the 1998 travel time for Washington-Gaithersburg I-270 Corridor are:

- Average door-to-door travel times for auto and metro rail, are still similar, 59.9 minutes by rail versus 65.6 minutes by auto (Table A 1.17).
- Travel time reliability, as represented by the standard deviation of average travel time, is again greater for rail mode compared to the auto mode (Table A 1.17).

- Auto commuters experienced longer travel time in the morning than in the evening reflecting the different traffic dynamics of the inbound peak flow versus the outbound peak flow, rail commuters did not experience any significant difference in travel time between morning and evening trips (Table A 1.14).
- Statistical analysis shows that the mean trip time by auto was at most 10 minutes longer with 95% confidence, similar results were obtained from 1994 trip data (Table A 1.15).
- The common segment travel time was greater for the auto mode than for the transit mode, 43.4 minutes versus 36.1 minutes. The difference of 7.3 minutes between the two modes is due to congestion on the highways (Table A 1.13).
- Access segment travel times indicate that auto commuters spent about 2 minutes on average less outside the common segment than transit commuters (Table A 1.13).

Table A 1.17 Travel Time Results

	Automobile	Metro Rail
Total Travel Time		
Mean	65.6	59.9
Standard Deviation	7.1	6.0
Access Segment Travel Time		
Mean	22.2	23.8
Standard Deviation	5.6	6.5
Common Segment Travel Time		
Mean	43.4	36.1
Standard Deviation	8.6	6.5
Sample Size	30	30

Table A 1.18 Comparison of AM and PM Trip Times by Modes

	Auto	Metro Rail
Inbound AM Average Trip Time	66.7	59.7
Outbound PM Average Trip Time	64.6	60.1

Table A 1.19 Statistical Testing of Convergence Hypothesis

Difference in Mean Travel Times by Mode (Auto - Metro Rail minutes):		5.7
Standard Error of the Difference of the Means (minutes):		2.2
Hypothesis: "The difference between the mean travel times by mode is less than…"	Significant at the Level (90% Confidence)	Significant at the 0.05 Level (95% Confidence)
7 Minutes	NO	NO
8 Minutes	NO	NO
9 Minutes	NO	NO
10 Minutes	YES	YES
11 Minutes	YES	YES

Methodology Application on I-270 Corridor

Data HLB obtained traffic volume data (HPMS data) from the regional MPO, Metropolitan Washington Council of Government (WASHCOG) and Maryland Department of Transportation. The ridership data were obtained from the Washington Metropolitan Area Transit Authority (WASHCOG). In addition, door to door travel time survey was conducted to derive the degree of convergence in the corridor.

Model The traffic volume and travel time data were used to populate the model, Equation 1 is estimated as follows:

$$T_{a1} = (90 - 50) / (1 + e^{-(-7.41 + 0.000144 (V))}) + 50 \quad (1)$$

When V is equal to 0, the travel time is equal the travel time at free flow speed (50 minutes). For an auto traffic volume of 49,500 between Gaithersburg and Downtown DC (based on WASHCOG 1998 O-D tables), the travel time is equal to 66.95 minutes.

Similarly, Equation 2 is estimated based on auto travel volume, transit ridership data, and convergence level estimate from the survey.

$$T_{a2} = 50 * (1 + 7.94E\text{-}08 (V^*)^{1.44}) \quad (2)$$

Table A 1.20 shows an example of the data used to estimate Equation 1 and 2. Volume 1 and Travel Time 1 on the table shows the auto volume and travel time in the presence of transit while Volume 2 and Travel time 2 shows the estimated volume and travel time in the absence of transit.

Table A 1.20 Example of Data used to estimate the equations

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	10,095	$ 151,421	$ 37,855,246
Club	8,196	$ 122,945	$ 30,736,165
Spillover	5,860	$ 87,898	$ 21,974,568
Total	24,151	$ 362,264	$ 90,565,978

The auto traffic volume in the absence of transit is determined by adding the auto volume in the presence of transit to the generated auto trips by transit riders. The generated results are based on:

- About 10% of person transit trips will be forgone (determined by the corridor convergence level).
- The average vehicle occupancy (HOV and non-HOV) is 1.2 for cars and 40 for buses.
- Car trips will make about 80% of trips.
- Benefit Estimation

To estimate the travel time saving (TTS) attributed to transit, the current traffic volume is inserted into Equation 1 and 2. An auto volume of 37,500 results into:

$$\mathbf{T_{a1} = 66.95,\ T_{a2} = 73.53,\ and\ .\ TTS = T_{a2} - T_{a1} = 6.58}$$

That is on average, in I-270 corridor, transit saves about 6.58 minutes per auto trip (15 seconds per mile) during the peak period

Once the average travel time saving per vehicle is estimated, the savings are weighted to reflect the congestion level at each time of the day. The benefits are calculated for three user groups:

- Benefits to highway users (Club), these are the hours saved by the common segment user of the I-270 corridor (seeTable A 1.21).
- Benefits to Transit users (Market), these are the hours saved by the users of transit between Shady Grove and Farragut North station (see Table A 1.22).
- Benefits to the highway network users within the corridor (spillover), these are the hours saved by users of parallel and adjacent highways to the common segment within the corridor (see Table A 1.23).

Table A 1.21 Club Benefits for I-270 Corridor

	Distance (miles)	Avg Traffic Volume	Daily Savings (hours)
Common Segment			
K Street	0.1	16,850	5.43
Whitehurst Freeway	1	16,850	48.86
Canal Street	0.1	16,850	4.89
Clara Barton Parkway	3.3	16,850	161.25
Cabin John Parkway	1.5	16,850	73.29
I-495	4.17	219,650	1,475.63
I-270	14.12	194,475	6,193.50
Access Segment (on average)	4.3	16,850	233.46
Total	28.59		8,196.31

Table A 1.22 Market Benefits for I-270 Corridor

Station	In-bound Trips	Out-bound Trips	Daily Savings (hours)
Shady Grove	9,377	9,368	1,438.99
Rockville	3,696	3,644	535.29
Twinbrook	3,547	3,513	487.78
White Flint	3,905	3,935	511.57
Grosvenor	3,522	3,404	425.35
Medical Center	4,131	4,133	475.80
Bethesda	8,056	8,385	883.48
Friendship Heights	8,617	8,784	868.28
Tenleytown-AU	5,985	6,183	560.46
Van Ness-UDC	6,692	6,280	547.70
Cleveland Park	4,548	4,480	346.52
Woodley Park-Zoo	5,892	5,648	398.65
Dupont Circle	20,109	20,939	1,260.45
Farragut North	25,302	25,107	1,354.41
Total			10,095

Table A 1.23 Spillover Benefits for I-270 Corridor

Highways in the Corridor	Distance (miles)	Avg Traffic Volume	Daily Savings (hours)
MD 355	12.62	63,550	1,938.10
MD 191	9.84	19,050	302.00
MD 187	5.32	128,950	1,878.85
MD 185	8.59	68,625	949.70
MD 190	5.86	47,575	673.72
MD 396	2.21	11,075	59.15
MD 188	3.25	11,150	58.38
Total			5,860

Table A 1.24 Benefit Summary

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	10,095	$ 151,421	$ 37,855,246
Club	8,196	$ 122,945	$ 30,736,165
Spillover	5,860	$ 87,898	$ 21,974,568
Total	24,151	$ 362,264	$ 90,565,978

Table A 1.24 shows that the 1998 delay saving attributed to transit on the I-270 corridor is estimated at about $90.6 million. This can be translated to $3.2 million per rail mile.

The convergence level is calculated as the percentage change between auto and metro rail travel times.

For 1994 : $D = (71.9 - 67.4) / 71.9 = 6.26\%$, and

For 1998: $D = (65.6 - 59.9) / 65.6 = 8.68\%$.

Based on the study methodology, the convergence level directly impacts the hours of delay saved. This impact is illustrated by a shift in the "with-" and "without transit" curves when the equations are re-estimated.

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door to door travel time data should be collected to estimate an accurate performance metric.

Annex A 1.1 Time of Day Trip Distribution for the I-270 Corridor

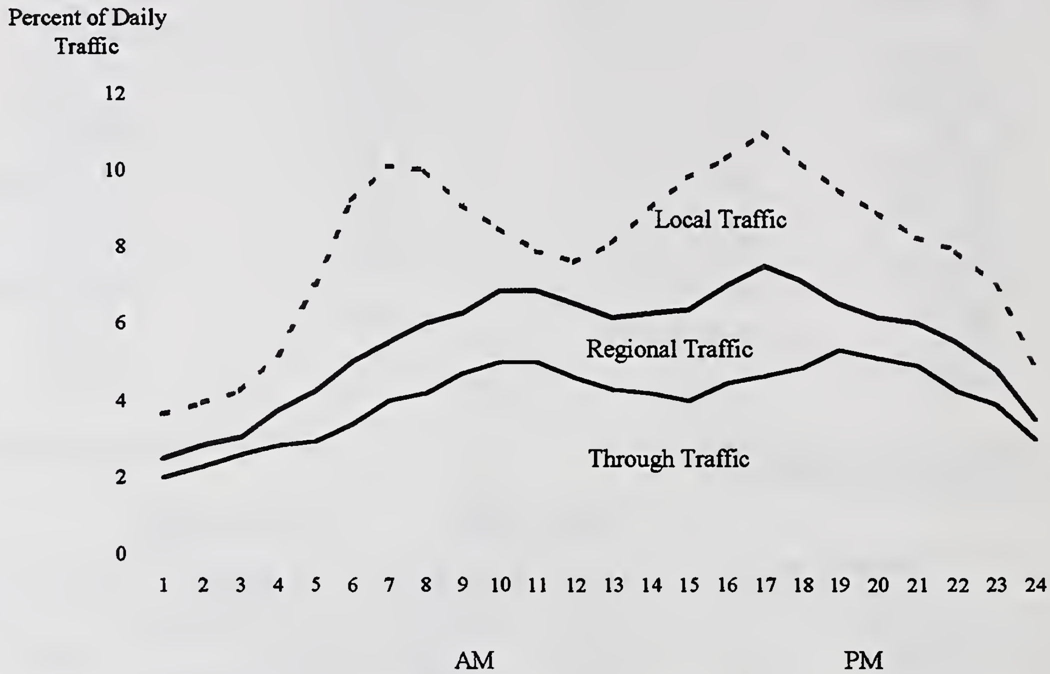
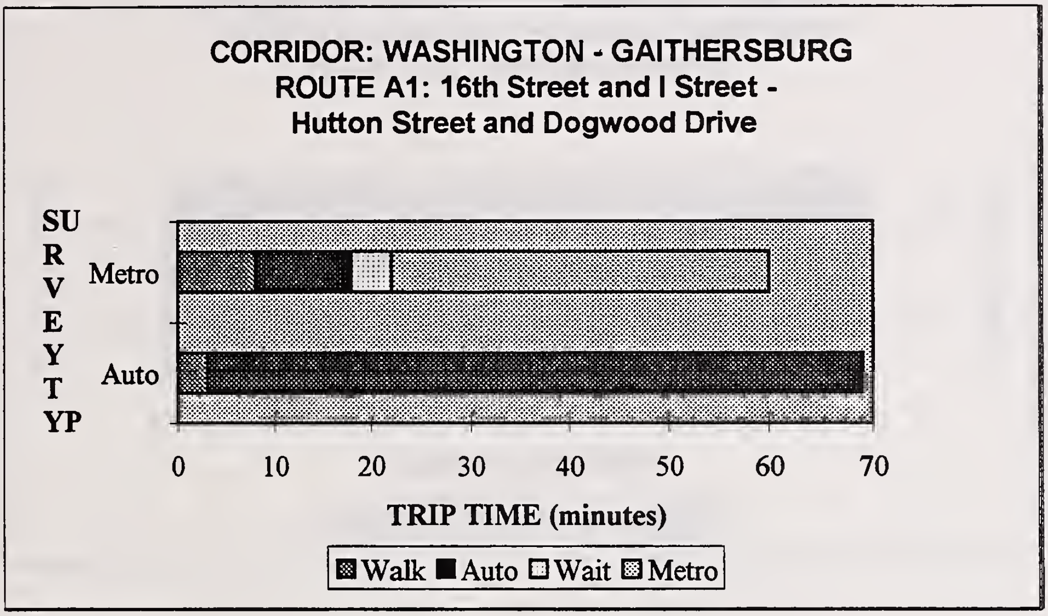


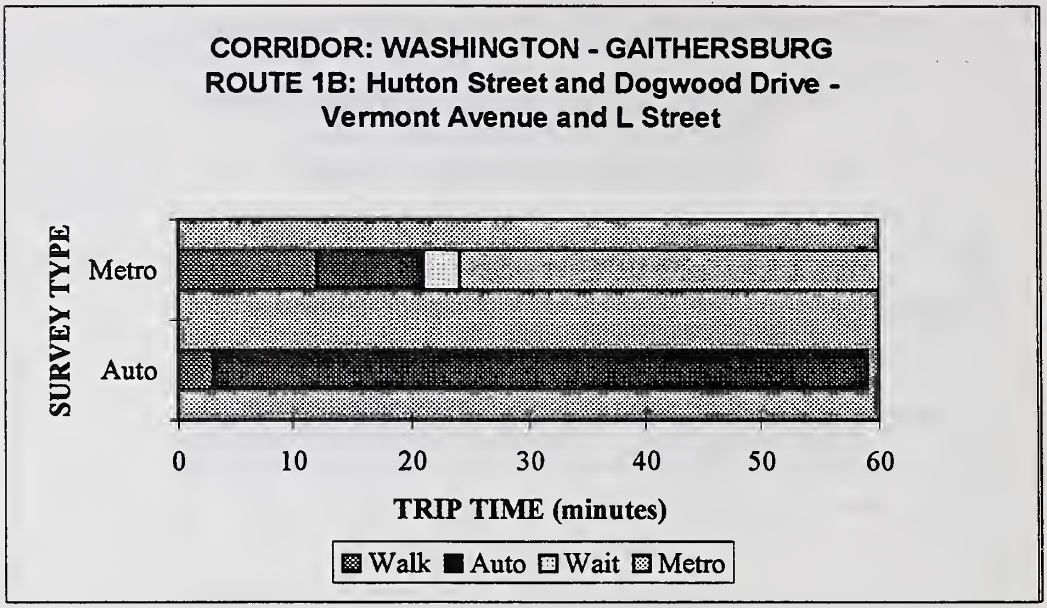
Figure A 1.4 Typical Traffic by Time of Day on a Major Roadway in the I-270 Region

Annex A 1.2 The 1998 survey findings by route in the I-270 corridor.

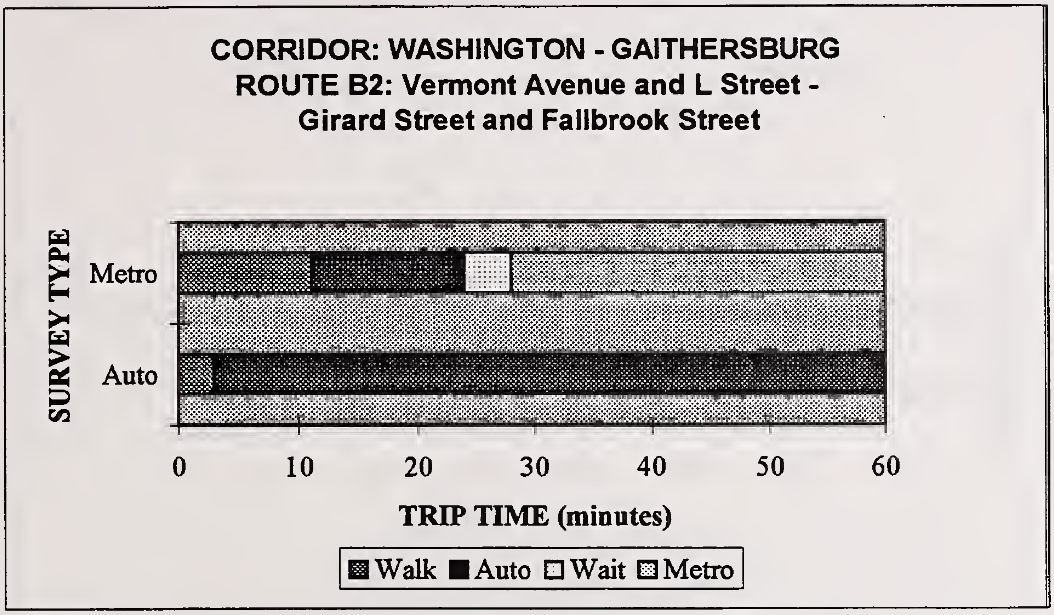


CORRIDOR: WASHINGTON - GAITHERSBURG
SUMMARY TABLE FOR
ROUTE A1:
16th Street and I Street - Hutton Street and Dogwood Drive

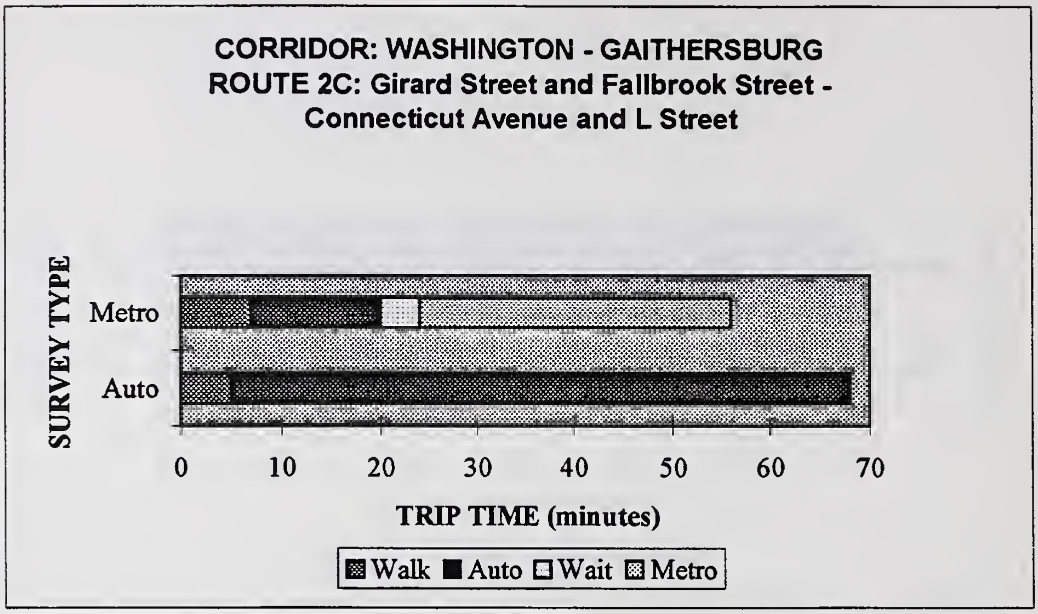
	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	69	60
In Common Segment	41	38
Outside Common Segment	28	22
Wait Time	0	4
Walk Time	3	8
DISTANCE (miles)		
Direct Distance	19.2	19.2
Route Distance	28.6	23.6
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	24.9	23.6
In Common Segment	35.6	32.2
Outside Common Segment	9.2	8.7



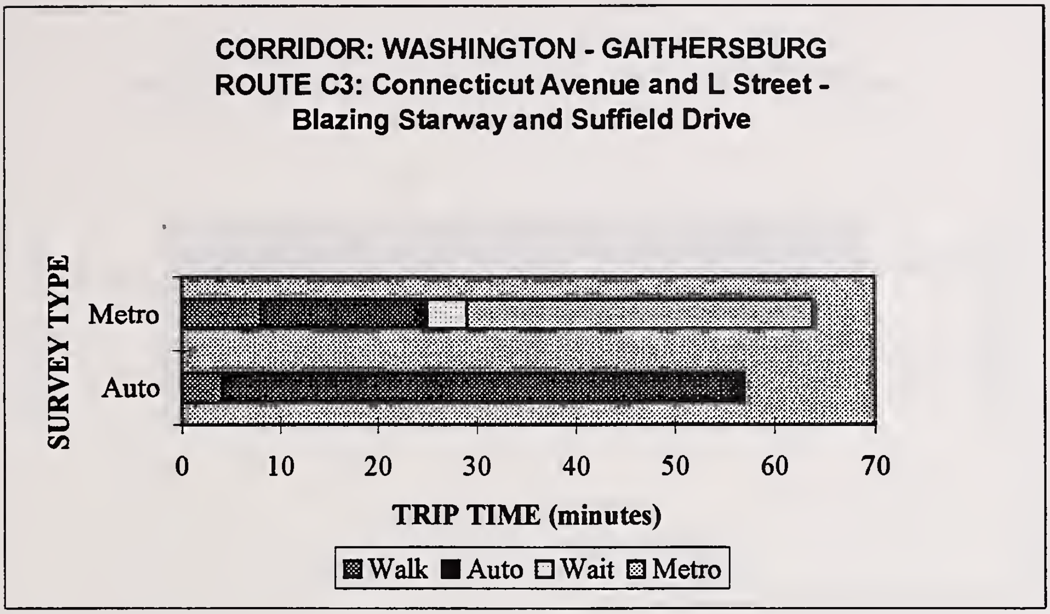
CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE 1B: Hutton Street and Dogwood Drive - Vermont Avenue and L Street	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	59	60
In Common Segment	30	36
Outside Common Segment	29	24
Wait Time	0	3
Walk Time	3	12
DISTANCE (miles)		
Direct Distance	18.8	18.8
Route Distance	28.6	23.8
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	29.1	23.8
In Common Segment	48.6	34.0
Outside Common Segment	8.9	8.5



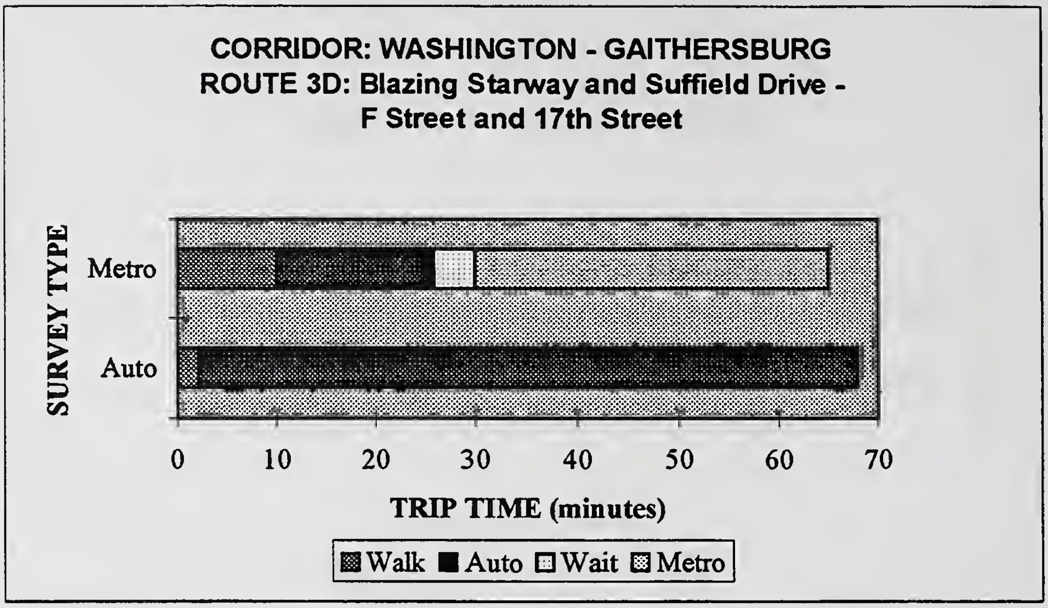
CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE B2: Vermont Avenue and L Street - Girard Street and Fallbrook Street	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	60	60
In Common Segment	35	32
Outside Common Segment	25	28
Wait Time	0	4
Walk Time	3	11
DISTANCE (miles)		
Direct Distance	19.0	19.0
Route Distance	28.6	24.4
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	28.6	24.4
In Common Segment	41.7	38.3
Outside Common Segment	10.3	8.6



CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE 2C: Girard Street and Fallbrook Street - Connecticut Avenue and L Street	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	68	56
In Common Segment	49	45
Outside Common Segment	19	11
Wait Time	0	4
Walk Time	5	7
DISTANCE (miles)		
Direct Distance	17.9	17.9
Route Distance	28.2	24.2
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	24.9	25.9
In Common Segment	29.8	27.2
Outside Common Segment	12.3	20.7



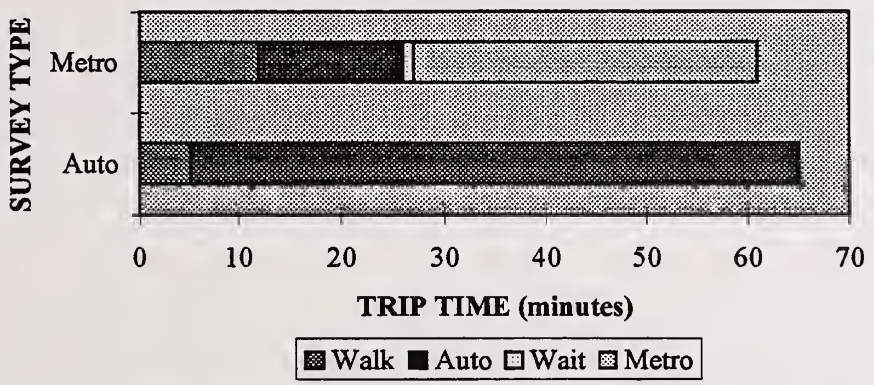
CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE C3: Connecticut Avenue and L Street - Blazing Starway and Suffield Drive	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	57	64
In Common Segment	35	35
Outside Common Segment	22	29
Wait Time	0	4
Walk Time	4	8
DISTANCE (miles)		
Direct Distance	18.5	18.5
Route Distance	27.6	25.0
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	29.1	23.4
In Common Segment	41.7	35.0
Outside Common Segment	9.0	9.5



CORRIDOR: WASHINGTON - GAITHERSBURG
SUMMARY TABLE FOR
ROUTE 3D:
Blazing Starway and Suffield Drive - F Street and 17th Street

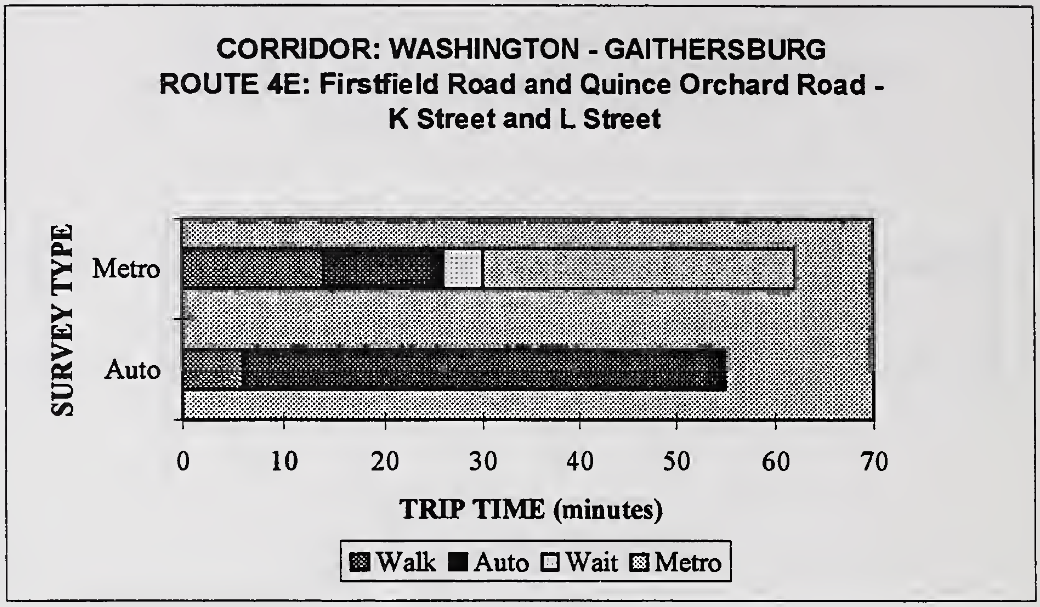
	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	68	65
In Common Segment	48	35
Outside Common Segment	20	30
Wait Time	0	4
Walk Time	2	10
DISTANCE (miles)		
Direct Distance	18.0	18.0
Route Distance	27.7	25.2
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	24.4	23.3
In Common Segment	30.4	35.0
Outside Common Segment	10.2	9.6

CORRIDOR: WASHINGTON - GAITHERSBURG
ROUTE D4: F Street and 17th Street - Firstfield Road and Quince Orchard Road

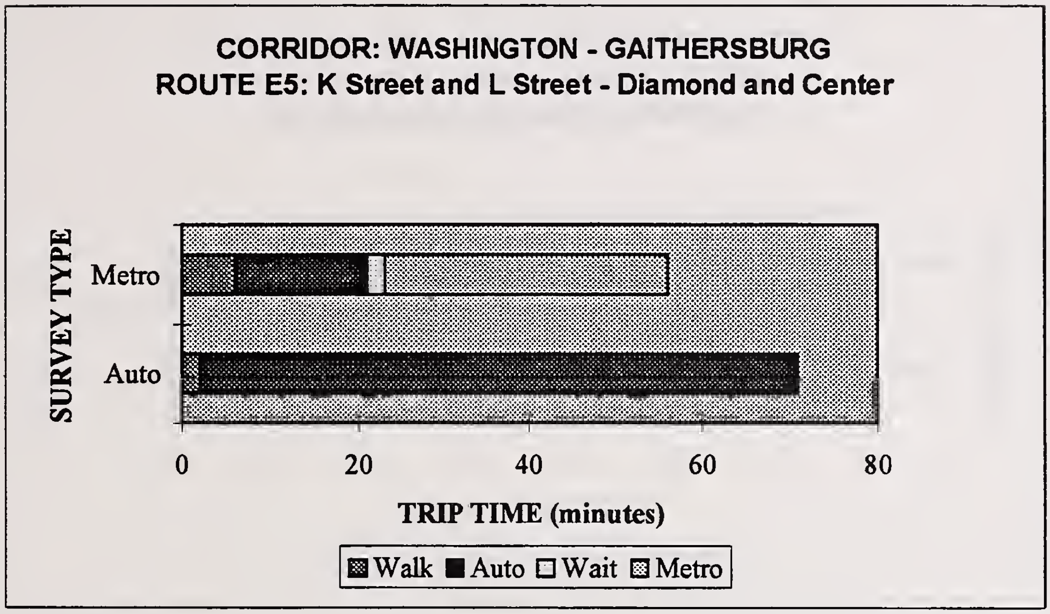


CORRIDOR: WASHINGTON - GAITHERSBURG
SUMMARY TABLE FOR
ROUTE D4:
F Street and 17th Street - Firstfield Road and Quince Orchard Road

	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	65	61
In Common Segment	34	34
Outside Common Segment	31	27
Wait Time	0	1
Walk Time	5	12
DISTANCE (miles)		
Direct Distance	17.8	17.8
Route Distance	28.9	26.2
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	26.7	25.8
In Common Segment	42.9	36.0
Outside Common Segment	8.9	12.9

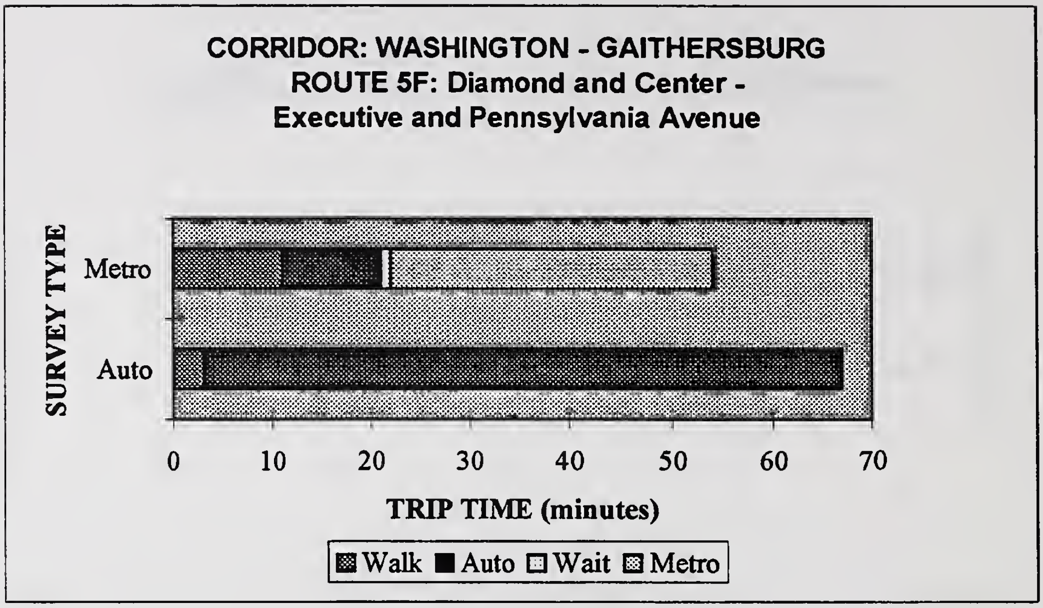


CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE 4E: Firstfield Road and Quince Orchard Road - K Street and L Street	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	55	62
In Common Segment	39	32
Outside Common Segment	16	30
Wait Time	0	4
Walk Time	6	14
DISTANCE (miles)		
Direct Distance	18.1	18.1
Route Distance	29.5	26.1
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	32.2	25.3
In Common Segment	37.4	38.3
Outside Common Segment	19.5	11.4

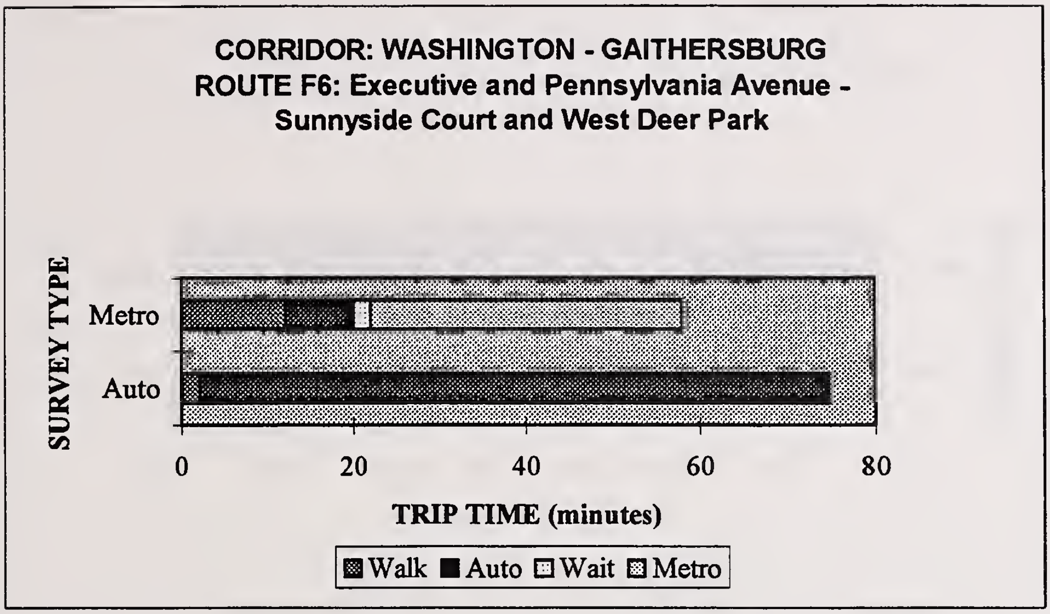


CORRIDOR: WASHINGTON - GAITHERSBURG
SUMMARY TABLE FOR
ROUTE E5:
K Street and L Street - Diamond and Center

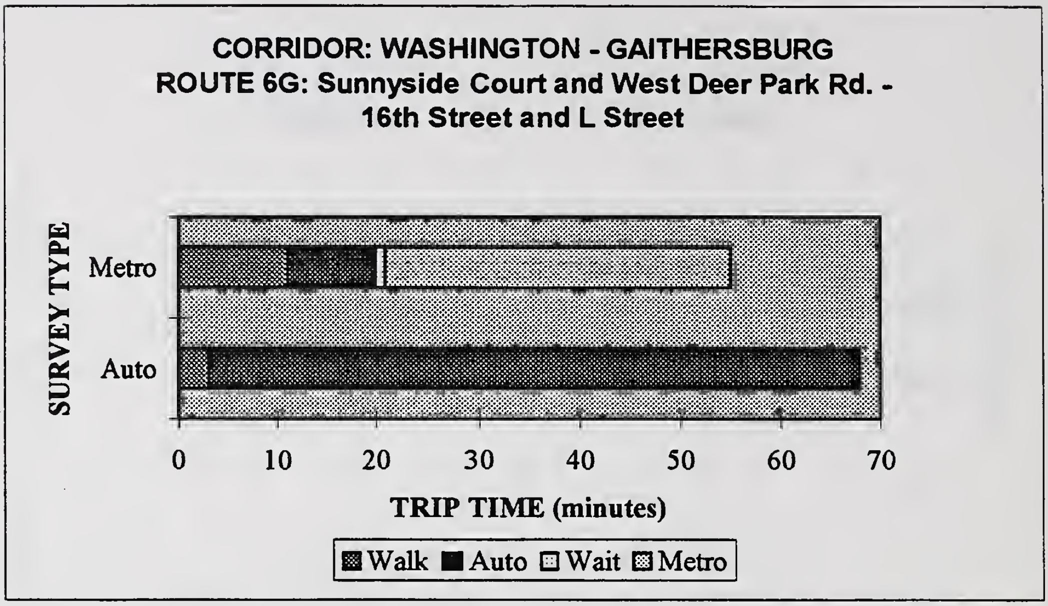
	SURVEY TYPE	
	Auto	Metro
TIME (minutes)		
Trip	71	56
In Common Segment	53	33
Outside Common Segment	18	23
Wait Time	0	2
Walk Time	2	6
DISTANCE (miles)		
Direct Distance	18.3	18.3
Route Distance	28.8	23.6
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	24.3	25.3
In Common Segment	27.5	37.1
Outside Common Segment	15.0	8.3



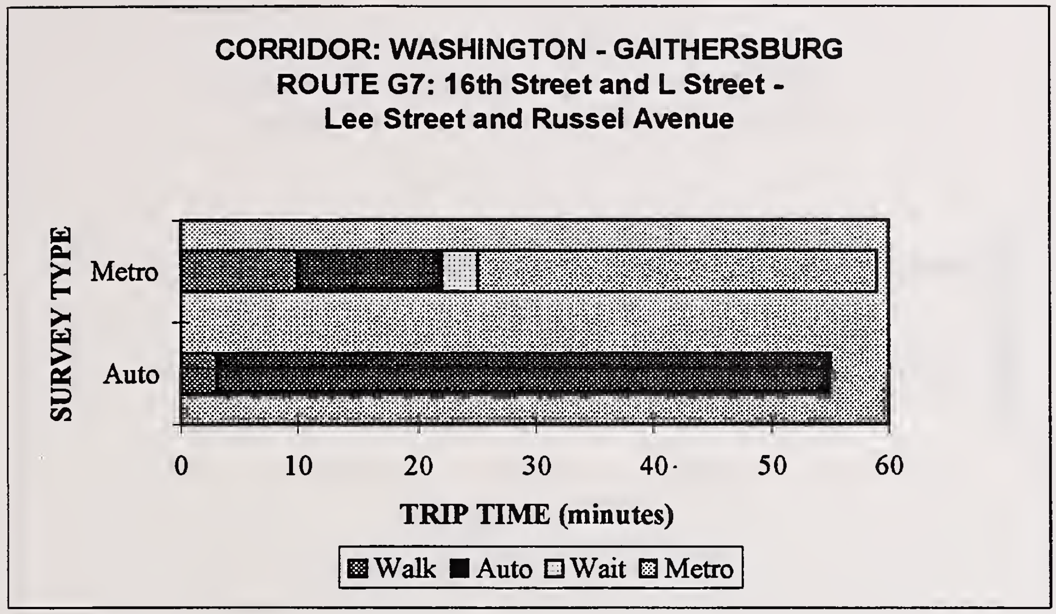
CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE 5F: Diamond and Center - Executive and Pennsylvania Avenue	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	67	54
In Common Segment	50	32
Outside Common Segment	17	22
Wait Time	0	1
Walk Time	3	11
DISTANCE (miles)		
Direct Distance	18.9	18.9
Route Distance	28.6	24.0
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	25.6	26.7
In Common Segment	29.2	38.3
Outside Common Segment	15.2	9.8



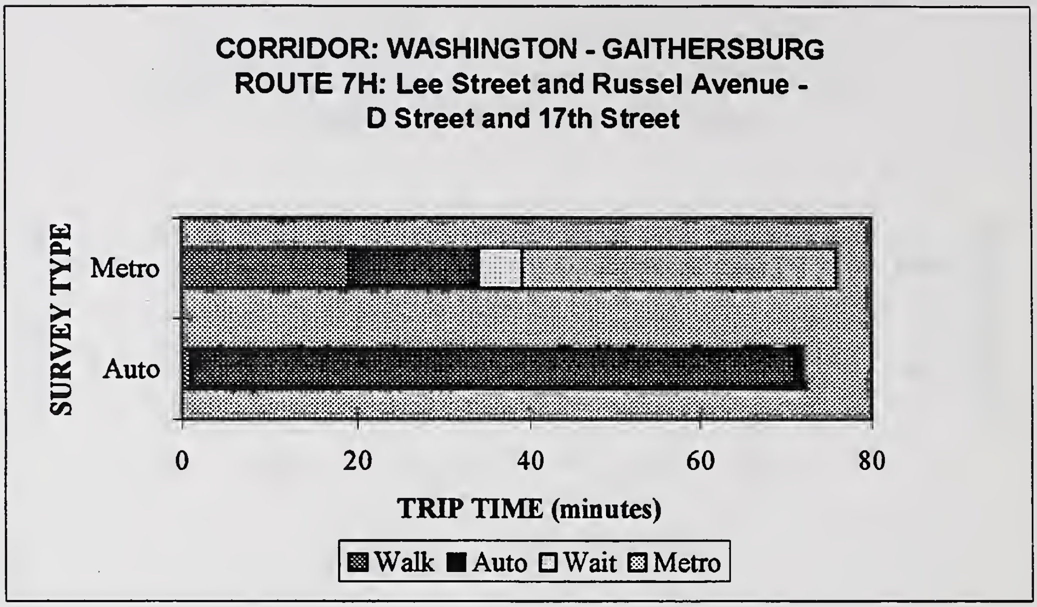
CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE F6: Executive and Pennsylvania Avenue - Sunnyside Court and West Deer Park Rd.		
	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	75	58
In Common Segment	60	36
Outside Common Segment	15	22
Wait Time	0	2
Walk Time	2	12
DISTANCE (miles)		
Direct Distance	18.5	18.5
Route Distance	28.6	22.9
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	22.9	23.7
In Common Segment	24.3	34.0
Outside Common Segment	17.2	6.8



CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE 6G: Sunnyside Court and West Deer Park Rd. - 16th Street and L Street	SURVEY TYPE	
	Auto	Metro
TIME (minutes)		
Trip	68	55
In Common Segment	51	34
Outside Common Segment	17	21
Wait Time	0	1
Walk Time	3	11
DISTANCE (miles)		
Direct Distance	19.0	19.0
Route Distance	28.1	23.0
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	24.8	25.1
In Common Segment	28.6	36.0
Outside Common Segment	13.4	7.4

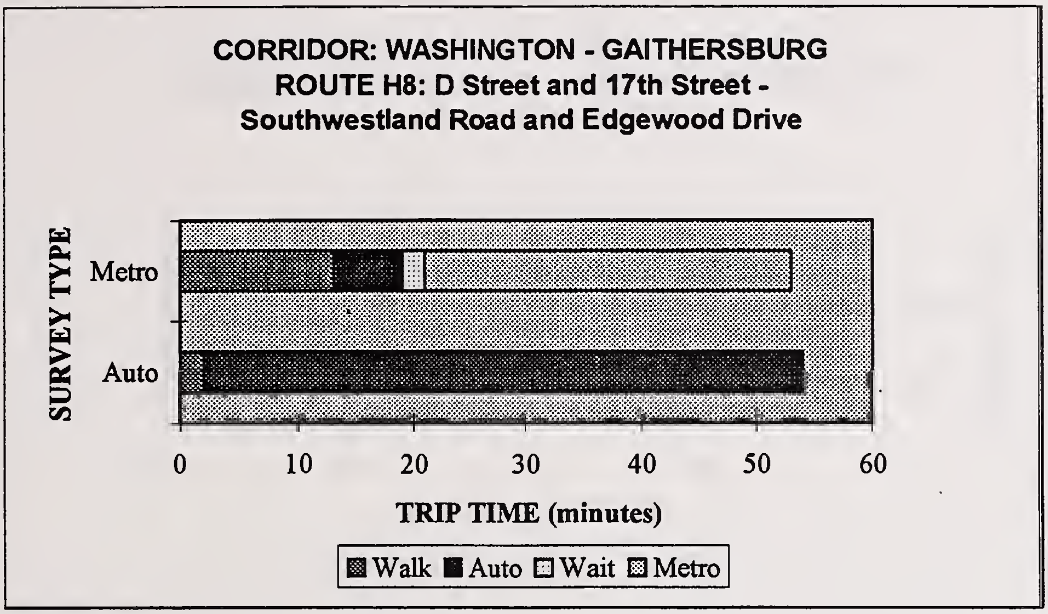


CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE G7: 16th Street and L Street - Lee Street and Russel Avenue	SURVEY TYPE	
	Auto	Metro
TIME (minutes)		
Trip	55	59
In Common Segment	36	34
Outside Common Segment	19	25
Wait Time	0	3
Walk Time	3	10
DISTANCE (miles)		
Direct Distance	19.1	19.1
Route Distance	28.7	24.2
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	31.3	24.6
In Common Segment	40.5	36.0
Outside Common Segment	13.9	9.1

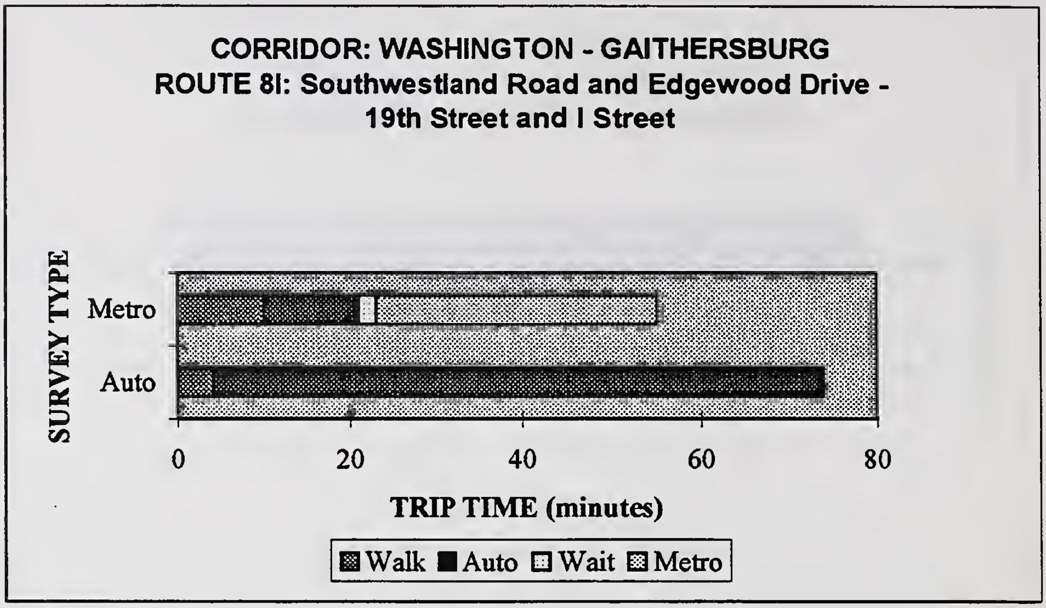


CORRIDOR: WASHINGTON - GAITHERSBURG
SUMMARY TABLE FOR
ROUTE 7H:
Lee Street and Russel Avenue - D Street and 17th Street

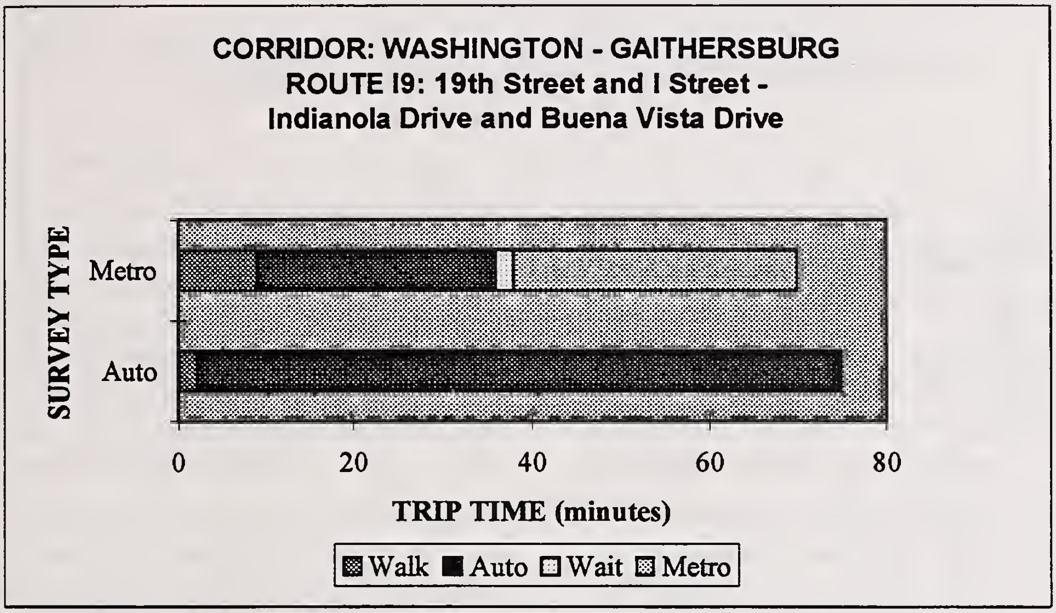
	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	72	76
In Common Segment	52	37
Outside Common Segment	20	39
Wait Time	0	5
Walk Time	1	19
DISTANCE (miles)		
Direct Distance	18.6	18.6
Route Distance	28.4	24.4
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	23.7	19.3
In Common Segment	28.0	33.1
Outside Common Segment	12.3	6.2



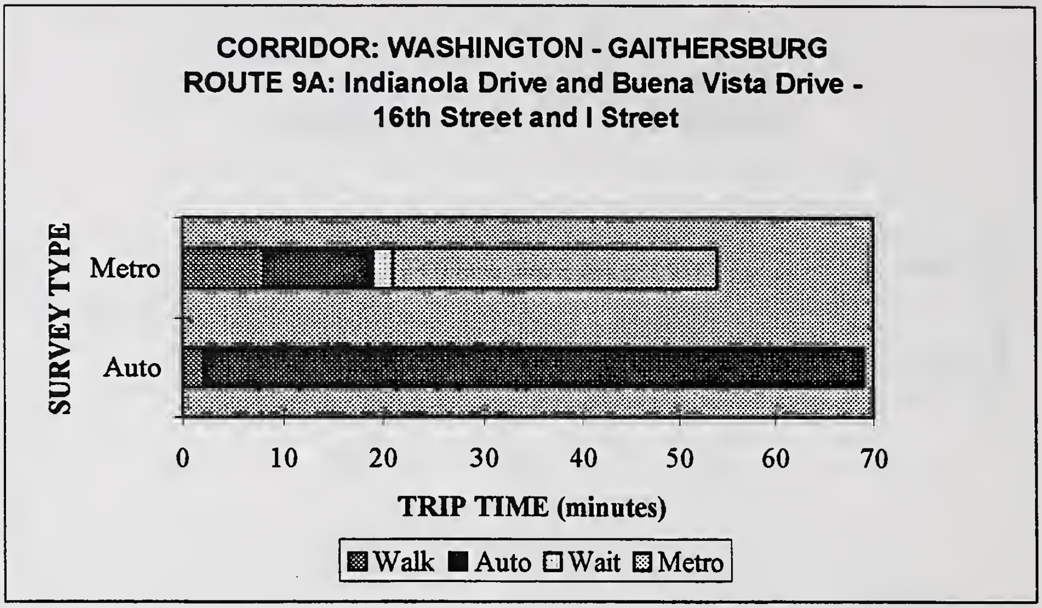
CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE H8: D Street and 17th Street - Southwestland Road and Edgewood Drive	SURVEY TYPE	
	Auto	Metro
TIME (minutes)		
Trip	54	53
In Common Segment	33	32
Outside Common Segment	21	21
Wait Time	0	2
Walk Time	2	13
DISTANCE (miles)		
Direct Distance	19.1	19.1
Route Distance	26.9	22.7
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	29.9	25.7
In Common Segment	44.2	38.3
Outside Common Segment	7.4	6.6



CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE 8I: Southwestland Road and Edgewood Drive - 19th Street and I Street	SURVEY TYPE	
	Auto	Metro
TIME (minutes)		
Trip	74	55
In Common Segment	50	32
Outside Common Segment	24	23
Wait Time	0	2
Walk Time	4	10
DISTANCE (miles)		
Direct Distance	18.3	18.3
Route Distance	26.5	22.6
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	21.5	24.7
In Common Segment	29.2	38.3
Outside Common Segment	5.5	5.7



CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE I9: 19th Street and I Street - Indianola Drive and Buena Vista Drive		
	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	75	70
In Common Segment	40	59
Outside Common Segment	35	11
Wait Time	0	2
Walk Time	2	9
DISTANCE (miles)		
Direct Distance	18.0	18.0
Route Distance	27.1	21.5
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	21.7	18.4
In Common Segment	36.5	20.7
Outside Common Segment	4.8	6.0



CORRIDOR: WASHINGTON - GAITHERSBURG SUMMARY TABLE FOR ROUTE 9A: Indianola Drive and Buena Vista Drive - 16th Street and I Street	SURVEY TYPE	
TIME (minutes)	Auto	Metro
Trip	69	54
In Common Segment	45	33
Outside Common Segment	24	21
Wait Time	0	2
Walk Time	2	8
DISTANCE (miles)		
Direct Distance	18.5	18.5
Route Distance	27.7	21.4
Common Segment Distance	24.3	20.4
SPEED (mph)		
Trip	24.1	23.8
In Common Segment	32.4	37.1
Outside Common Segment	8.5	2.9

Appendix 2. The Midway Orange Line Corridor Serving Chicago

Executive Summary

Working Paper 1 (Subtask 1d, November 25, 1998) develops a theoretical and measurement framework within which the Mogridge-Lewis Convergence Hypothesis (MLC) can be employed in measuring the savings in highway delay attributable to transit and its equilibrating effect on the level of service in the corridor.

The framework also provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay without the need for repeated MLC surveys. The approach rests on the theoretical proposition, proven in Working Paper 1, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Purpose and Method

This Working Paper presents a case study of the methodology developed in Subtask 1c in application to the Midway Airport-Chicago corridor. The methodology consists of calibrating the MLC-traffic model with survey data. The model is then used to quantify delay savings attributable to train at present, and at alternative roadway traffic volumes (each for different user categories).

The study consists of four main steps:

Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and train ridership data along the corridor;

Conducting door-to-door travel time surveys and deriving the inter-modal convergence;

Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and

Quantifying delay savings by user category, namely, (i) train riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

The Midway Airport-Chicago corridor was selected to measure the performance of the train system connecting several residential areas with the Central Business District of Chicago, Illinois. MLC theory predicts that the improved transit system will attract modal explorers, reduce congestion, and improve roadway travel times. As a result, we would expect to see improvements in both highway and transit door-to-door travel times

Principal Findings

The case study finds that based on the MLC model calibrated with 1999 survey data, the magnitude of peak-period delay savings per trip due to transit is about 4 minutes and 43 seconds per door-to-door trip (about 24 seconds per mile). These savings amount to about 8 percent of total door-to-

door journey times and align with reasoned expectations.

HLB estimated the hours of delay savings for three different user groups: Train riders (market benefits), users of the I-55 common segment (club benefits), and users of parallel highways (spillover benefits). Table A 2.1 presents the estimated delay savings by category of user. Based on an assumed value of peak travel time of $15 per hour and an average of 250 working days per year, Table A 2.1 indicates aggregate peak delay savings due to transit of $47.3 million for 1999. The savings can be translated to $3.9 million per rail mile.

Table A 2.1 Benefits Summary for the Midway Airport-Chicago Corridor

Benefit Category	Daily Savings In Hours	Daily Savings In Dollars	Yearly Savings In Dollars
Market	1,116	$ 16,735	$ 4,183,761
Club	6,953	$ 104,294	$ 26,073,520
Spillover	4,547	$ 68,211	$ 17,052,831
Total	12,616	$ 189,240	$ 47,310,111

The summary table shows that 55% of the savings are savings by the highway common segment users while only 8% of the savings are savings by the CTA Orange Line users. These results illustrate the significant contribution of transit in reducing congestion on highways near transit lines.

Figure A 2.1 displays the "with-" and "without transit" curves using 1999 convergence data. The vertical difference between the "with-" and "without transit" curves represents the delay savings due to transit at different volumes of I-55 traffic. The curves indicate that in the absence of major infrastructure improvements or radical traffic growth, the performance metric will remain stable.

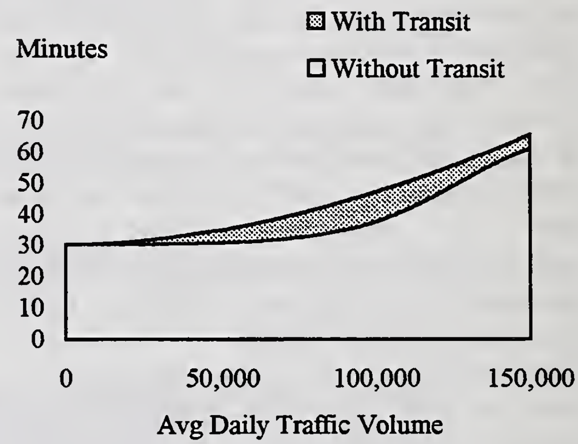


Figure A 2.1 Illustration of the "With" and "Without Transit" Curves for the Midway Airport-Chicago Corridor

Introduction

This report presents the results for the Midway Airport-Chicago corridor case study as part of Streamlined Strategic Corridor Travel Time Management study. The purpose of the study is to use the convergence measurement technique to derive a repeatable performance measurement for rail transit in congested corridors. This case study measures the performance of Dallas's CTA Orange Line using the methodology developed in Subtask 1c. The methodology consists of calibrating the Mogridge-Lewis Convergence Hypothesis (MLC) model with survey data and using the model to quantify delay savings attributable to transit at different roadway traffic volumes. The savings are estimated for three different user categories using highway traffic data and train ridership in the corridor.

Study Methodology

The study methodology consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and train ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence; (this report also presents a comparison between 1995 travel time survey and the new survey)
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) train riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

During the first step, HLB collected HPMS data, local arterials traffic data, and train ridership data from the Illinois Department of Transportation and Chicago Transit Authority (the local transit authority). The data were used to estimate the model parameters.

For the second step, data was collected on site by a survey team. A corridor, as defined in this study, is a principal transportation artery into the central business district. Multiple transportation services are available to commuters who use this artery. Additionally, during the peak period a large number of commuters utilize this route in their door-to-door commute.

A statistical sample of trips was generated in the corridor by identifying random trip end point in the zones at either end of the corridor and joining them so that trips alternated between zones. These zones are catchment zones where travelers converge or diverge from either the transit station or the principal highway route. In this study these zones are defined as the access segment and the component of the corridor common to all trips for a given mode, regardless of trip end location, is defined as the common segment.

Survey crews were instructed to follow specific routes that consisted of an access segment—dependent on the catchment zone considered for the trip—and a common segment. The data collected include start times and arrival times for each segment, by mode, congestion level, seating availability, weather, road conditions, and travel costs for each segment.

Data were collected over a period of three consecutive days (Tuesday to Thursday) during the last week of October 1999. The days of the week were sampled to eliminate fluctuations in traffic patterns and volumes due to the day of week effects. Trips were validated to minimize the effects of unusual or circumstantial conditions. Sixty valid trips were selected to ensure a statistically adequate sample size. The study employed the maps and routes connecting several zones within a residential area to several points within Chicago's central business district.

Step three consisted of estimating the "with transit" curve based on the traffic volume and the door-to-door travel time. Using the model developed in Subtask 1c, HLB derived the "without transit" curve and estimated the hours of delay saved due to transit. This performance metric is defined as the vertical difference between the two curves.

In step four, the hours of delay saved due to transit are aggregated into three user categories. Savings by common highway-segment users are estimated using the traffic volume on the segment. Savings by train riders are estimated using the ridership data for each station along the corridor. Savings by parallel highway users are estimated using traffic volume on parallel highways and arterials within the corridor. The magnitude of the savings decreases as the distance between the common segment and the arterial increases.

Plan of the Report

This report presents the results from the Midway Airport-Chicago corridor case study. Following this introduction, Chapter 2 presents an overview of the model and methodology to estimate the delay saving. Chapter 3 displays the corridor characteristics and a description of the principal modes of transportation within the corridor. Chapter 4 presents the results from the 1999 door-to-door travel survey and its comparison to 1995 travel survey. The chapter also shows the model estimation results and estimates the hours of delay saved due to transit per person per day, and provides a monetary value of the delay saved for three user categories. Appendices provide maps of the residential area and the central business district as well as supporting data and supplementary results on the survey findings by route.

Methodolgy and Model Overview

The methodology consists of four steps:

1. Estimating the Corridor Performance Baseline
2. Estimating the Corridor Performance in the Absence of transit
3. Extrapolating Delay Savings Due to Transit
4. Estimation of Corridor Performance without Re-calibration

Estimating the Corridor Performance Baseline

<u>The Model</u> This model establishes a functional relationship between the person trip volume –all modes—and the average door-to-door travel time by auto in the corridor.

The door to door travel time by auto can be determined using a logistic function which calculates the door to door travel time in terms of travel time at free flow speed, trip time by high capacity rail mode, and the volume of trips in the corridor for all modes. The door-to-door travel time can be estimated as follows:

$$\mathbf{T = (T_c - T_{ff}) / (1 + e^{-(\delta + \varepsilon V1)}) \quad + T_{ff}} \qquad (1)$$

Where T_{a1} is auto trip time,

Tc is trip time by high-capacity rail mode

T_{ff} is auto trip time at free-flow speed,

V is person trip volume in the corridor by auto, and

δ, ε are model parameters

Equation 1 implies that the door-to-door auto trip time is equal to the trip time at free-flow speed plus a delay that depends on transit travel time and the person trip volume in the corridor.

In other words, when the highway volume is close to zero, travel time is equal to travel time at free flow speed.($T = T_{ff}$). As the volume increases, the travel time is equal to T_{ff} plus a delay due to the high volume, but adjusted to the travel time by high capacity transit. That is the high capacity transit alleviates some of the highway trip delay as some trips shift to transit.

Equation 1 is transformed into a linear functional form before the parameters δ and ε can be estimated, the transformed equation will be:

$$\mathbf{U = \delta + \varepsilon V_1} \qquad (2)$$

Where $U = \ln [(T_c - T_{ff}) / (T - T_{ff}) - 1]$

Equation 2 is estimated using Ordinary Least Squares regression.

Data The data required for the estimation of the above equations are:

Person trip volume on the highway that can be calculated by dividing the traffic volume by the average vehicle occupancy (auto and buses). These data are available through HPMS database and MPO's traffic data.

Free flow trip time is a constant.

High capacity trip time is a constant.

The parameters δ and ε do not have to be re-estimated each year, they are both specific to the corridor and are relatively stable over the years. So periodically, the person trips volume can be inserted into Equation 1 to estimate the door to door travel time by auto.

Estimating the Corridor Performance in the Absence of transit

The Model This model represents the concept to quantify the role of transit in congestion management. In the absence of transit, the travel time Ta is estimated as:

$$\mathbf{T_a = T_{ff} \; * \; (1 + A\,(V^*)^{\beta})} \qquad (3)$$

Where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door-to-door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

The existing auto and bus person trips on the highway.

The percentage of person transit trips shifting to auto

The percentage of person transit trips shifting to bus

The number of additional cars in the highway

The number of additional buses in the highway

The occupancy per vehicle in the absence of transit

The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$\mathbf{V^* = V_1 + \alpha_1 V_c + \alpha_2 V_b} \qquad \mathbf{(4)}$$

Where V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor, and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

Type 1: "Explorers" who are casual switchers and who will divert to Single Occupancy Vehicles in the absence of transit.

Type 2: Commuters with low elasticity of demand with respect to generalized cost and who will divert to use the bus or carpool.

Type 3: Commuters with high elasticity of demand with respect to generalized cost and who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher the shift of transit riders to cars and buses. Therefore, higher degree of convergence will lead to higher delay, which translates into higher savings due to transit.

In words, Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high which translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve (as the volume increases, travel time increases at an increasing rate). Figure A 2.2 illustrates the relationship between the volume and travel time both in the presence and in the absence of transit.

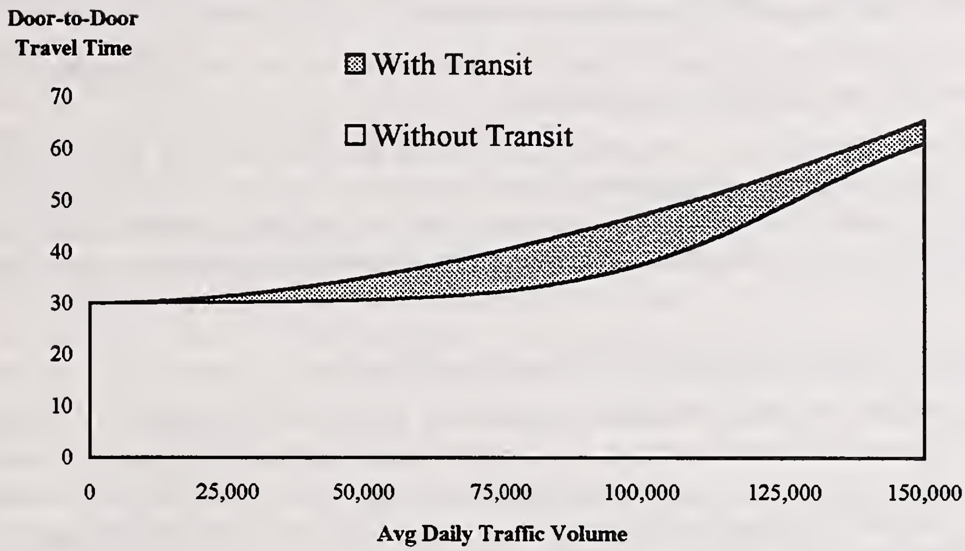


Figure A 2.2 Illustration of the "With" and "Without Transit" Curves for the Midway Airport-Chicago Corridor

Data The data required to populate this model consist of:

Highway person trip volume (used in the previous model)

Transit ridership data

Fleet composition (cars and buses percentages out of the total traffic)

Cars and buses vehicle occupancy

Passenger car equivalent factor

Degree of convergence to determine the percentage person trips shifting to cars and buses

Free-flow travel time which is a constant

Equation 3 is specific to the corridor and do not need to be estimated each year. It will only be necessary to re-estimate them with an updated degree of convergence if a major change is made to the transit level of service or the highway structure.

Extrapolating Delay Savings Due to Transit

While the MLC hypothesis proves to be valid during the peak period only, the delay savings due to transit can be estimated during off-peak as well. This metric can be estimated as the vertical difference between the "without transit" curve and the "with transit" curve. That is at a specific person trip volume, the difference in travel times between the two cases can be defined as "the hours of delay saved due to transit".

The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by train riders (market benefits), savings by highway users (club benefits), and savings by users of parallel highways (spillover benefits).

The *market* benefits are estimated based on delay saved (which depends on the distance traveled) for each rider within the common segment.

The *club* benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution.

The *spillover* benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment. The spillover benefits are calculated by multiplying the traffic volume with a percentage of the delay savings. This percentage decreases as the distance between the common segment and the parallel highway increases.

Estimation of Corridor Performance without Re-calibration

The framework, presented above, provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay *without* the need for repeated MLC surveys. The approach rests on the theoretical proposition, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Corridor Overview

The Midway Airport-Chicago corridor is about 12 miles in length and connects the residential areas surrounding Midway Airport with Central Business District in Chicago, Illinois. The Midway catchment zone is centered at Midway Airport. Trip end points within the residential zone are no more than a 15-minute drive to the Midway CTA Station. The downtown Chicago zone, centered on the Downtown Loop, extends no more than one block outside the Downtown Loop. Travelers disembark at the station which is closest to the trip end point. The Midway CTA Orange transit line opened for service on October 31, 1993. App. Annex A1 provides maps of the residential and business district zones considered in this study.

Principal Travel Modes

The "principal travel mode" is defined as the mode used during the common segment of each individual trip. The Chicago-Midway Corridor is primarily served by two key transportation modes, automobile and heavy rail (CTA Orange Line). The study of the corridor focused on both inbound and outbound commuter trips between the central business district in Chicago, (the loop), and the residential area surrounding the Midway Airport. Automobile routes can be broken into three distinct sections:

1. The route between the residential point and the junction of Cicero Avenue and I-55, the Stevenson Expressway (Access1);

2. The route between the junction of Cicero Avenue and I-55 and the junction of the John F. Kennedy Expressway (I-90/94) and Madison Street in Chicago (Common Segment); and
3. The route between the junction of the John F. Kennedy Expressway (I-90/94) and Madison Street and the CBD point (Access2).

For a morning rush hour trip, survey drivers followed Access1 to the common segment. The route taken for the common segment began at the junction of Cicero Avenue and I-55, the Stevenson Expressway and proceeded East on I-55 to the JFK Expressway North and exited at the Madison Street exit. From the end of the common segment, the driver followed Access2 to the downtown points, at which time they parked at the closest parking lot and proceeded on foot to the end point. The evening rush hour trip covered the same progression in the opposite direction, except that the common segment began at the junction of Monroe Street and the JFK Expressway.

The routes for the CTA Orange Line mode can be broken into three distinct sections

1. The route between the residential point and the Midway CTA Station (Access1);
2. The route between the Midway CTA Station and the Lasalle/Van Buren CTA Station (Common Segment); and
3. The route between the Lasalle/Van Buren CTA Station and the CBD point (Access2).

For a morning rush hour trip, survey crews drove Access1 to the Midway CTA Station parking lot and walked from the lot to the train station. The route taken for the common segment consisted of a train ride that begins at the Midway CTA Station and continues to the Lasalle/Van Buren CTA Station. From the end of the common segment, the surveyor walked Access2 to the downtown points. The evening rush hour trip covered the same progression in the opposite direction. On average, trains run every 10 minutes during peak hours. Table A 2.2 displays some of the principal performance and service characteristics of the corridor. Figure A 2.3 shows the Midway Airport-Chicago corridor and the main highways and arterials in the area.

Table A 2.2 Performance and Service Characteristics

	Automobile	Train
Number of stops	N/A	8
Number of Streets and Highways	2	N/A
Tolls/Fares for a one way (in dollars)	$0.00	$1.50

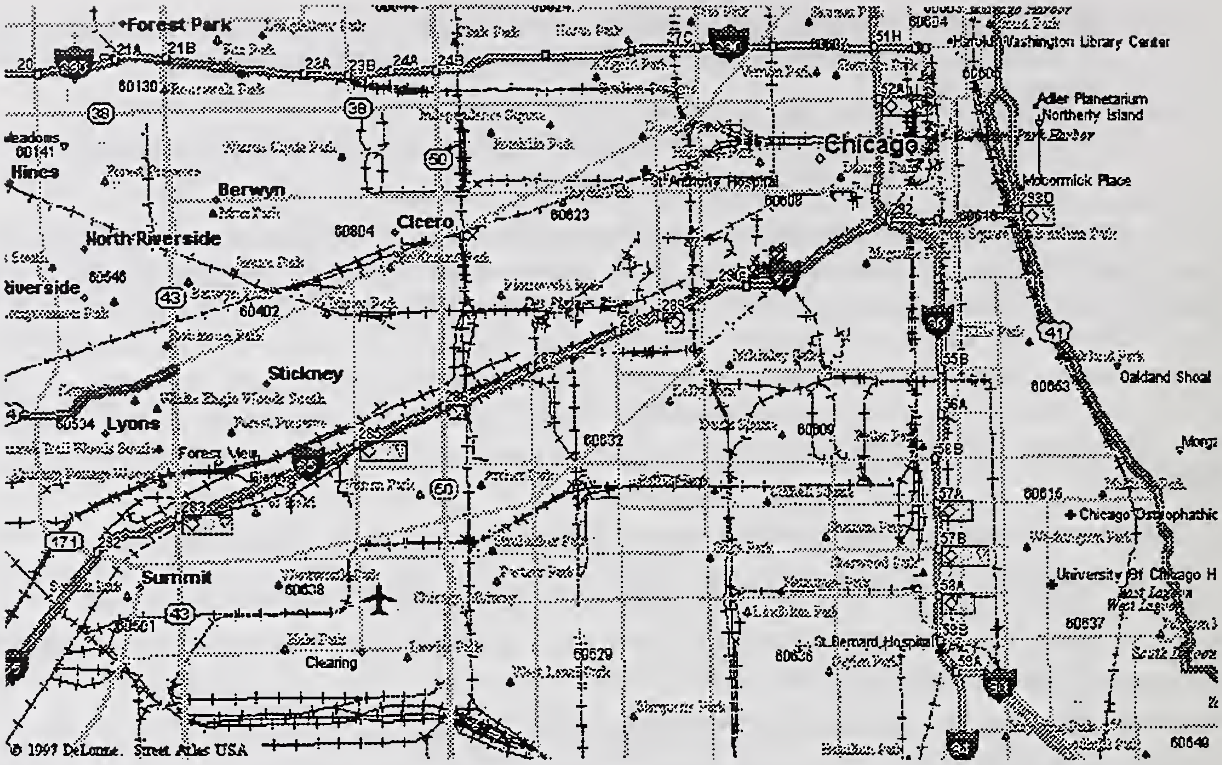


Figure A 2.3 Map of the Midway Airport - Chicago Corridor

Principal Findings

This chapter starts by presenting the results from the door-to-door travel survey conducted during the last week of October 1999. The travel survey data are used to derive the inter-modal convergence level in the Midway Airport-Chicago corridor. The chapter then presents the estimation of the hours of delay saved due to transit for different user categories.

The Convergence Level

The starting point to estimate the "without transit" curve is to determine the convergence level based on the key findings from the 1999 door to door travel data.

The door-to-door travel survey for the Midway Airport-Chicago corridor found that:

- Average door-to-door travel times for auto and rail, are similar, 61.1 minutes by rail versus 57.8 minutes by auto (Table A 2.3). The 1995 findings show a similar travel time by rail (60.6 minutes) but a lower travel time by auto (54.2 minutes). The findings imply that the roadways are experiencing higher congestion in 1999 compared to 1995, leading to an increase of 6.6 percent in travel time.
- Travel time reliability, as represented by the standard deviation of average travel time is 7.6 for train mode and 9.8 for the auto mode (Table A 2.3).
- Commuters experienced similar travel times in the morning and in the evening reflecting the similar traffic dynamics of the inbound peak flow versus the outbound peak flow in the corridor (Table A 2.4).

- Statistical analysis shows that the mean trip time by train was at most 7 minutes longer with 90% confidence (Table A 2.4), compared to 9 minutes in 1995. This finding validates the MLC hypothesis stating that higher congestion leads to higher intermodal travel time convergence.
- The common segment travel time was slightly lower for the train mode than for the transit mode, 29.8 minutes versus 31.4 minutes. The difference of 2 minutes between the two modes is due to the congestion on I-55 (Table A 2.3).
- Similarly, access segment travel time was higher for train commuters than for auto commuters (31.3 minutes) and transit commuters (26.3 minutes) (Table A 2.3).

Table A 2.3 Results for the Midway Airport-Chicago Corridor based on 1999 and 1995 findings

	1999 Findings		1995 Findings	
	Automobile	CTA Rail	Automobile	CTA Rail
	Total Travel Time			
Mean	57.77	61.06	54.2	60.6
Standard Deviation	9.76	7.60	13.3	8.2
	Access Segment Travel Time			
Mean	26.33	31.28	28.2	32.1
Standard Deviation	4.58	8.12	9.5	6.5
	Common Segment Travel Time			
Mean	31.44	29.78	26.1	28.5
Standard Deviation	9.31	2.80	7.5	3.8
Sample Size	30	30	30	30

Table A 2.4 Comparison of AM and PM Trip Times by Modes

	Auto	CTA Rail
Inbound AM Average Trip Time	58.22	60.0
Outbound PM Average Trip Time	57.33	62.1

The results in Table A 2.4 indicate that transit in the defined corridor has drawn door-to-door travel times by highway and train to within 7 minutes of one another during congested roadway conditions (with 95 percent statistical confidence).

Although an inter-modal travel time convergence of 7 minutes is sufficient to yield delay savings to highway users (as compared to the "without rail" case – see below), full convergence would of course yield even greater savings

The Mogridge-Lewis framework predicts that non-time related roadway travel costs (i.e, the non-time elements of "generalized cost" such as parking costs, fuel costs and so on) account for the "7 minute wedge." Train users are expected to re-explore the roadway option to the point at which the value of non-time generalized cost factors just equals the value of the travel time advantage offered by road. If non-time costs are moderate to high, travel time convergence will occur at a non-zero time differential between road and rail.

Table A 2.5 Statistical Testing of Convergence Hypothesis

	1999 Findings		1995 Findings	
Difference in Mean Travel Times by Mode: (Auto- CTA Orange Line)	3.3		6.4	
Standard Error of the Difference of the Means (minutes):	2.3		2.7	
Hypothesis:	Significant at	Significant at	Significant at	Significant at
"The difference between the mean travel times by modes is at most..."	0.10 Level (90% Confidence)	0.05 Level (95% Confidence)	0.10 Level (90% Confidence)	0.05 Level (95% Confidence)
7 Minutes	YES	NO	NO	NO
8 Minutes	YES	YES	YES	NO
9 Minutes	YES	YES	YES	NO
10 Minutes	YES	YES	YES	NO
11 Minutes	YES	YES	YES	YES

Methodology Application on Midway Airport - Chicago Corridor

Data HLB obtained traffic volume data (HPMS data) from the Illinois Department of Transportation and Chicago Transit Authority (the local transit authority. In addition, door-to-door travel time survey was conducted to derive the degree of convergence in the corridor.

Model The traffic volume and travel time data were used to populate the model. Equation 1 is estimated as follows:

$$T_{a1} = (70 - 30) / (1 + e^{-(-6.871 + 5.422\text{E-05}(V))}) + 30 \quad (1)$$

When V is equal to 0, the travel time is equal the travel time at free flow speed (30 minutes). For an auto traffic volume of 136,000 between Midway Airport and Downtown Chicago (based on 1998 O-D tables), the travel time is equal to 54 minutes.

Similarly, Equation 2 is estimated based on auto travel volume, transit ridership data, and convergence level estimate from the survey.

$$T_{a2} = 30 * (1 + 6.62779\text{E-10}\,(V^*)^{1.79}) \quad (2)$$

The auto traffic volume in the absence of transit is determined by adding the auto volume in the presence of transit to the generated auto trips by transit riders. The generated trips are based on the following assumptions:

- About 40% of person transit trips will be forgone (determined by the corridor convergence level).
- The average vehicle occupancy is 1.2 for cars and 40 for buses.
- Car trips will make about 90% of trips.

Benefit Estimation

To estimate the travel time saving (TTS) attributed to transit, the current traffic volume is inserted into Equation 1 and 2. An auto volume of 138,100 results into:

$$T_{a1} = 55.93,\ T_{a2} = 60.63, \text{ and. } TTS = T_{a2} - T_{a1} = 4.71$$

That is on average, on Midway Airport-Chicago corridor, transit saves about 5 minutes per auto trip (24 seconds per mile) during the peak period. Once the average travel time saving per vehicle is estimated, the savings are weighted to reflect the congestion level at each time of the day.

Feeding the volume levels for 1999, for the Park Lane-Dallas corridor into equation (1) and (2), HLB estimated the hours of delay saved due to transit for 1999. The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by train riders (market benefits), savings by I-55 common segment users (club benefits), and savings by users of parallel highways (spillover benefits).

The market benefits are estimated based on delay saved (which depends on the distance traveled) by each rail rider within the common segment (Table A 2.6). The club benefits are estimated based on the volume on the common segment using origin-destination table and the

Table A 2.6 Market Benefits for the Midway Airport-Chicago Corridor

Station	Trips	Daily Savings (hours)
Midway	7542	355.23
Pulaski	5481	258.16
Kedzie	2726	121.97
Western	3315	148.33
35th and Archer	2078	88.09
Ashland	1262	53.50
Halsted	2258	90.40
Roosevelt	2021	80.91
Adams/Wabash	6665	251.14
Lasalle/Van Buren	3268	123.14
Total	36,616	1,116

daily trip distribution (Table A 2.7). The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment

(Table A 2.8). The magnitude of savings by the commuters on these highways decreases with the distance to the common segment.

Table A 2.9 shows the summary of benefits by category. The results indicate that the delay saving due to transit is about 5 minutes per trip one way (about 24 seconds per mile). Using a travel time value of $15 per hour and an average of 250 working days per year, the yearly delay saving can be valued at $47.3 million in 1999. This can be translated into a $3.9 million per rail mile in the Midway Airport-Chicago Corridor. The summary table shows that 55% of the savings are for the highway common segment users while only 8% of the savings are for the CTA Orange Line users. These results illustrate the significant contribution of transit in reducing congestion on highways near transit lines.

Table A 2.7 Club Benefits for the Midway Airport-Chicago Corridor

	Distance (miles)	Avg Daily Traffic Volume	Daily Savings (hours)
Common Segment			
I-55	8	167,100	2,274
I-90/94	4	300,400	3,270
Access Segment (on average)	3	138,100	1,409

Table A 2.8 Spillover Benefits for the Midway Airport-Chicago Corridor

Highways in the corridor	Distance (miles)	Average Daily Traffic Volume	Daily Savings (hours)
Ogden	3	18,700	183.20
Cermak	4	13,800	135.20
Archer	8	20,000	522.50
Pershing	2	17,900	132.98
47th Street	5	20,900	170.63
55th St. (Garfield)	6	12,600	246.88
51st St.	6	12,600	154.30
I-90/94	3	313,300	2,302.00
Ashland	2	30,100	147.44
Michigan	3	18,000	132.26
Halsted	3	20,000	195.94
Canal	1	20,000	48.98
Cicero	1	57,200	175.12
Total			4,547.42

Table A 2.9 Benefits Summary

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	1,116	$ 16,735	$ 4,183,761
Club	6,953	$ 104,294	$ 26,073,520
Spillover	4,547	$ 68,211	$ 17,052,831
Total	12,616	$ 189,240	$ 47,310,111

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door-to-door travel time data should be collected to estimate an accurate performance metric.

Annex A 2.1 Views of Chicago Midway Orange Line Corridor

Figure A 2.4 Map of the Residential Area, Midway Airport Vicinity

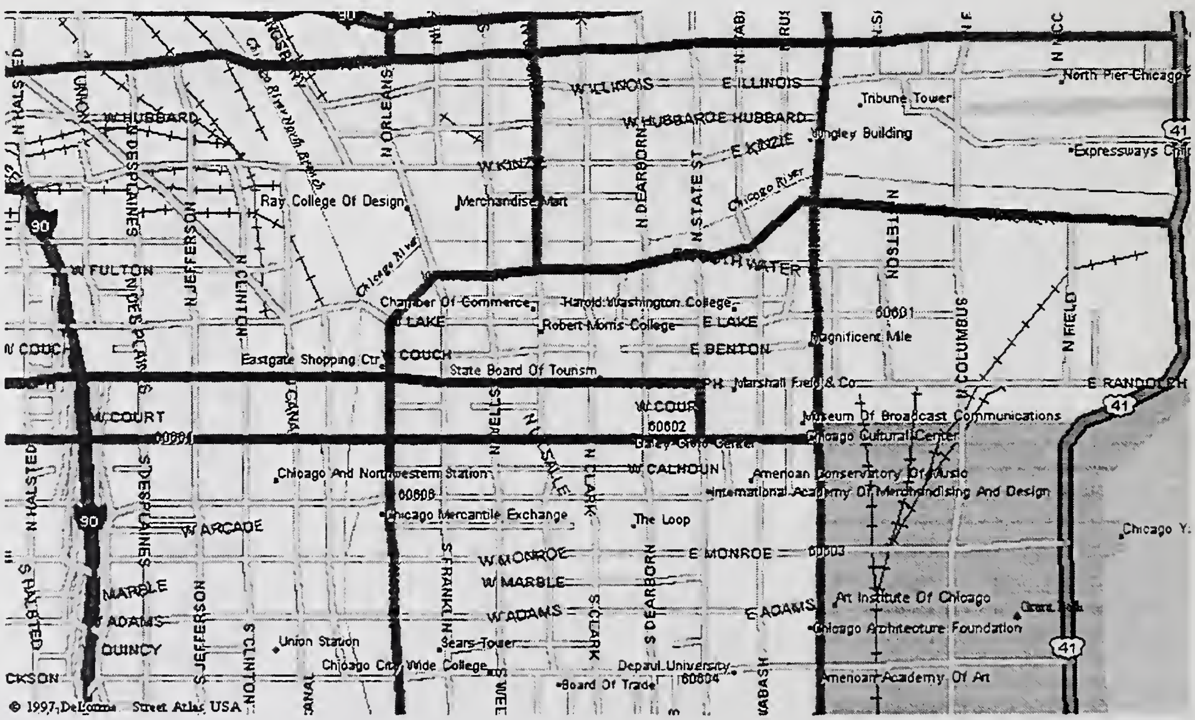
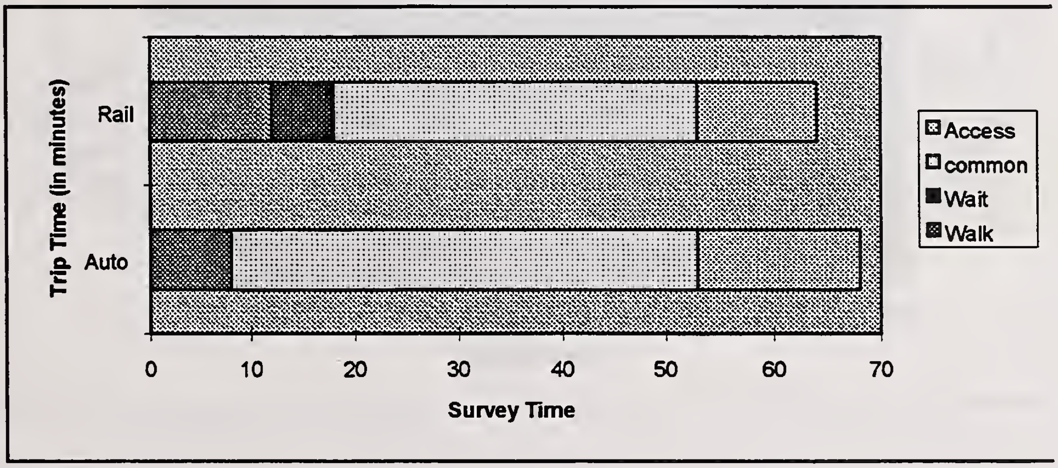


Figure A 2.5 Map of Loop Business District, Downtown Chicago

Annex A 2.2 The survey findings by route

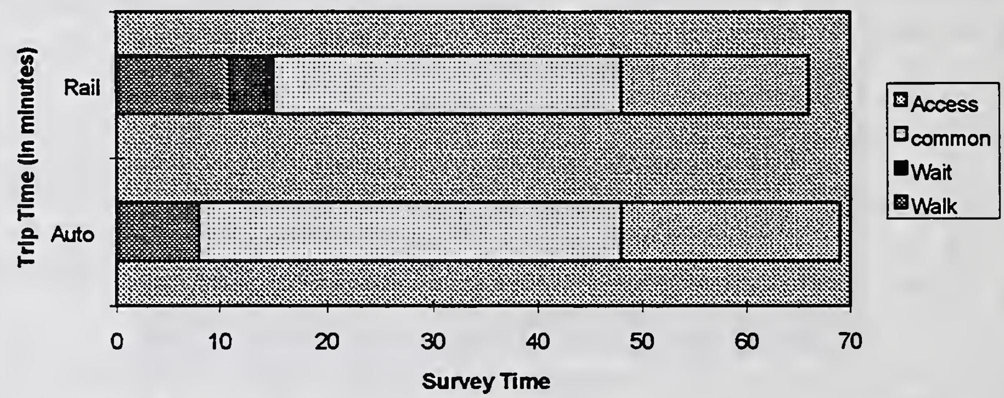
CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE A-1:
W. Madison & N. Clark St. - 62nd & Karlov

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	68	64
In Common Segment	45	35
Outside Common Segment	15	11
Wait Time	0	6
Walk Time	8	12
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	11.5	11.7
In Common Segment	11.1	17.1
Outside Common Segment	18.8	13.6

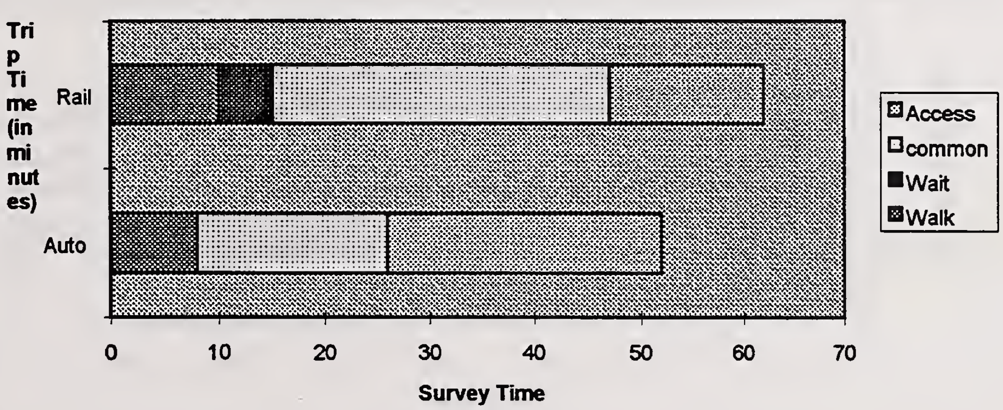


CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE B-2:
W. Quincy & LaSalle - Marquette & Kilpatrick

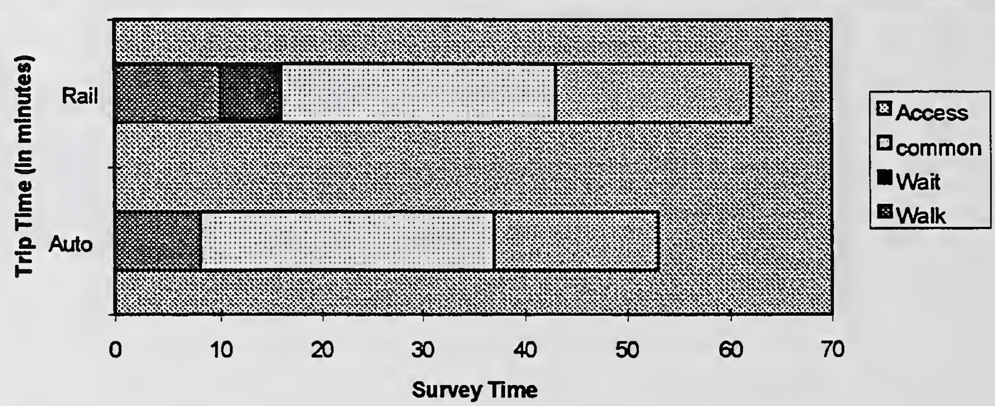
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	69	66
In Common Segment	40	33
Outside Common Segment	21	18
Wait Time	0	4
Walk Time	8	11
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	11.3	11.4
In Common Segment	12.5	18.2
Outside Common Segment	13.4	8.3



CORRIDOR: Midway Station - Chicago SUMMARY TABLE FOR ROUTE C-3: W. Monroe St. & Dearborn St. - 53rd & Mulligan	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	52	62
In Common Segment	18	32
Outside Common Segment	26	15
Wait Time	0	5
Walk Time	8	10
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	15.0	12.1
In Common Segment	27.7	18.8
Outside Common Segment	10.8	10.0

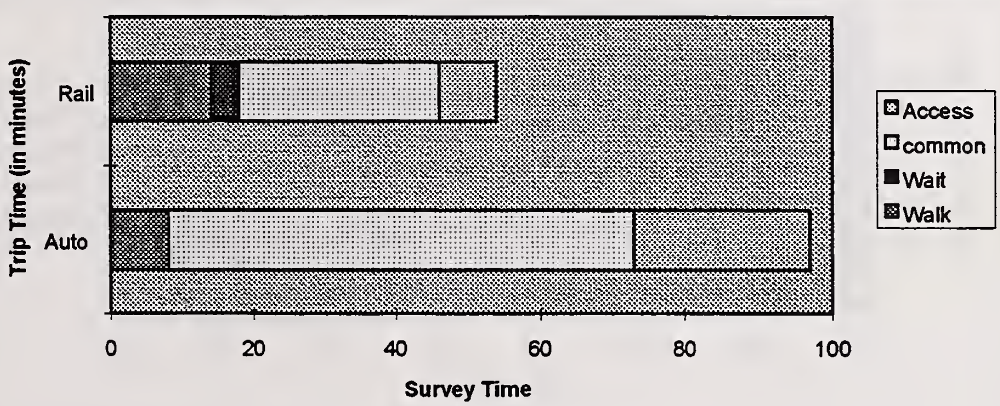


CORRIDOR: Midway Station - Chicago SUMMARY TABLE FOR ROUTE D-4: W. Randolph St. & N. State St. - 51st & Knox	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	53	62
In Common Segment	29	27
Outside Common Segment	16	19
Wait Time	0	6
Walk Time	8	10
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	14.7	12.1
In Common Segment	17.2	22.2
Outside Common Segment	17.6	7.9



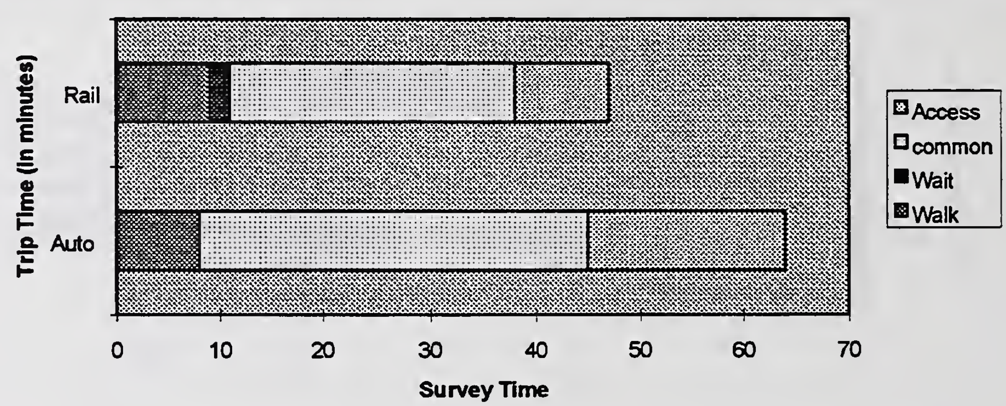
CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE E-5:
115 S. LaSalle & Monroe St. - 64th St. & Major

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	97	54
In Common Segment	65	28
Outside Common Segment	24	8
Wait Time	0	4
Walk Time	8	14
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	8.0	13.9
In Common Segment	7.7	21.4
Outside Common Segment	11.8	18.8



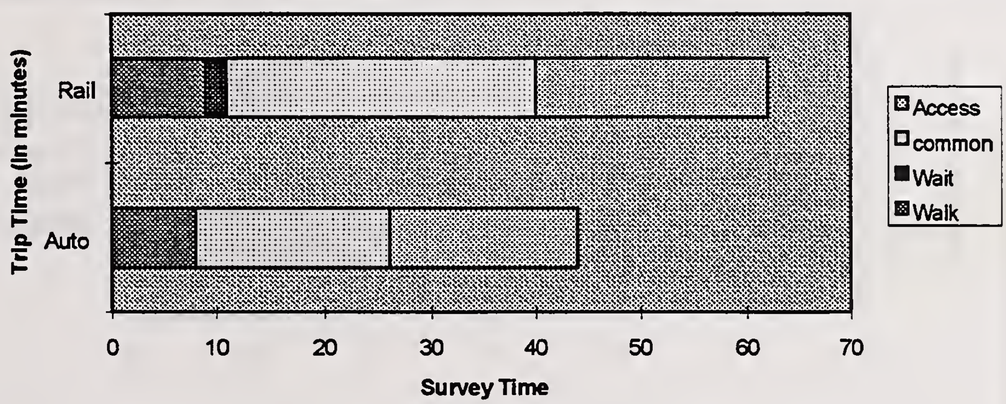
CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE F-6:
E. Adams St. & S. Michigan Ave. - 58th & Parkside

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	64	47
In Common Segment	37	27
Outside Common Segment	19	9
Wait Time	0	2
Walk Time	8	9
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	12.2	16.0
In Common Segment	13.5	22.2
Outside Common Segment	14.8	16.7

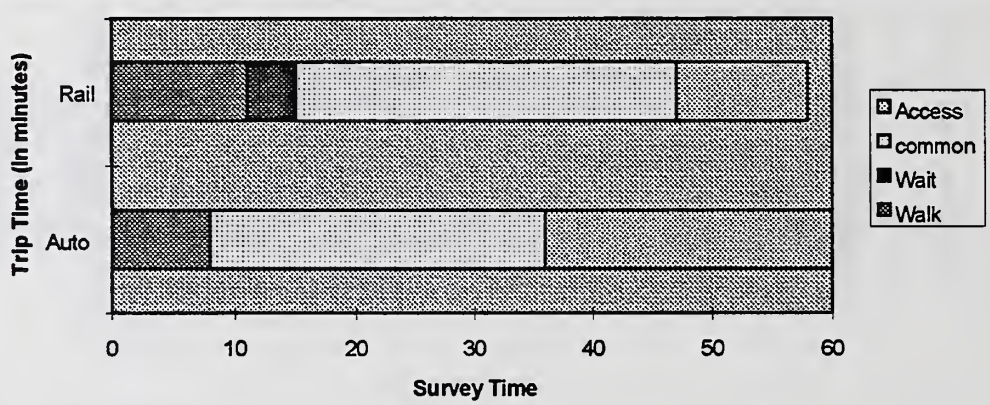


CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE G-7:
180 N. Wabash Ave. & W. Lake St. - 54th & Sayre

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	44	62
In Common Segment	18	29
Outside Common Segment	18	22
Wait Time	0	2
Walk Time	8	9
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	17.7	12.1
In Common Segment	27.7	20.7
Outside Common Segment	15.7	6.8

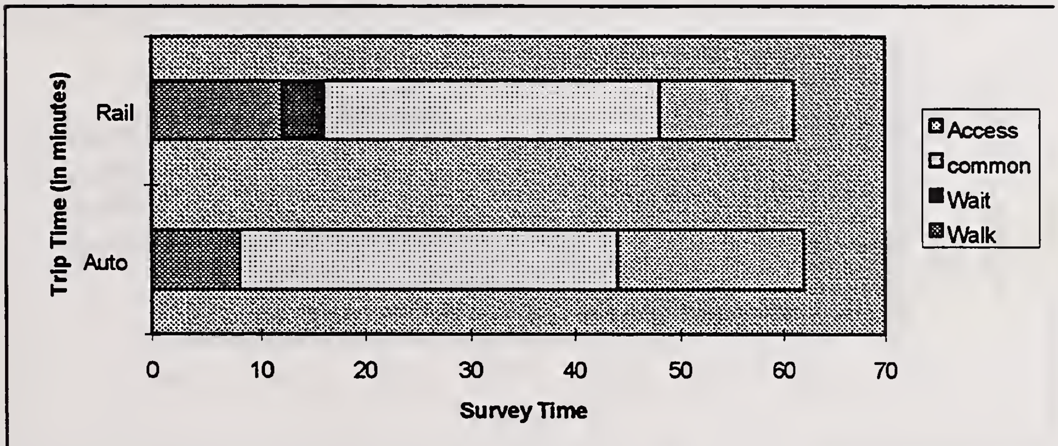


CORRIDOR: Midway Station - Chicago SUMMARY TABLE FOR ROUTE H-8: 69 W. Washington Blvd. & N. Dearborn St. - 49th & Lotus	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	60	58
In Common Segment	28	32
Outside Common Segment	24	11
Wait Time	0	4
Walk Time	8	11
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	13.0	12.9
In Common Segment	17.8	18.8
Outside Common Segment	11.8	13.6

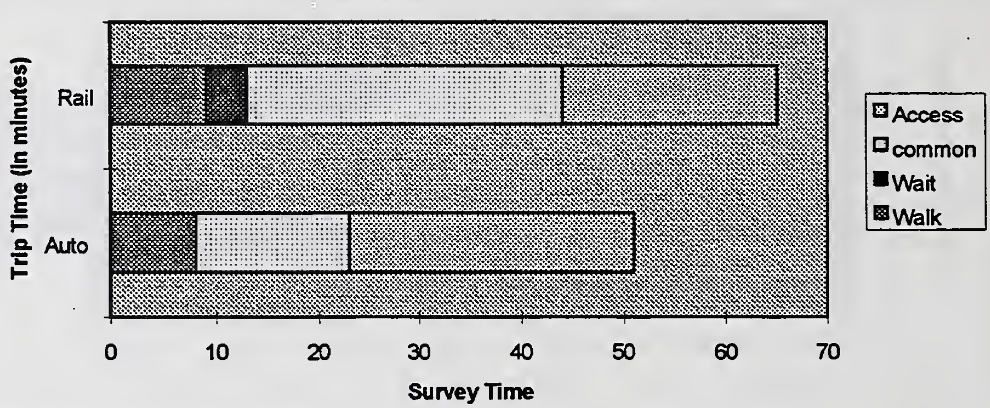


CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE I-9:
W. Randolph St. & N. Wells St. - Midway Airport (US Air Departures)

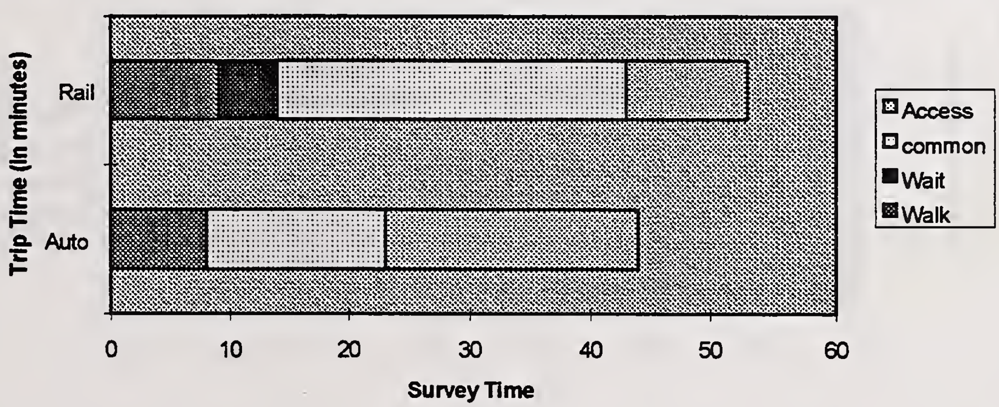
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	62	61
In Common Segment	36	32
Outside Common Segment	18	13
Wait Time	0	4
Walk Time	8	12
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	12.6	12.3
In Common Segment	13.8	18.8
Outside Common Segment	15.7	11.5



CORRIDOR: Midway Station - Chicago SUMMARY TABLE FOR ROUTE 1-B: 62nd & Karlov - W. Quincy St. & LaSalle	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	51	65
In Common Segment	15	31
Outside Common Segment	28	21
Wait Time	0	4
Walk Time	8	9
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	15.3	11.5
In Common Segment	33.2	19.4
Outside Common Segment	10.1	7.1

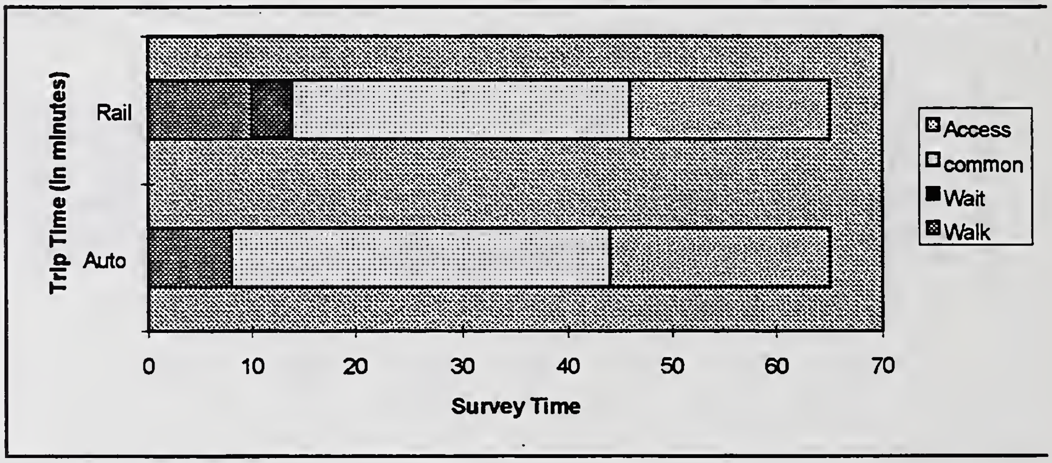


CORRIDOR: Midway Station - Chicago SUMMARY TABLE FOR ROUTE 2-C: Marquette & Kilpatrick - W. Monroe St. & S. Dearborn St.	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	44	53
In Common Segment	15	29
Outside Common Segment	21	10
Wait Time	0	5
Walk Time	8	9
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	17.7	14.2
In Common Segment	33.2	20.7
Outside Common Segment	13.4	15.0

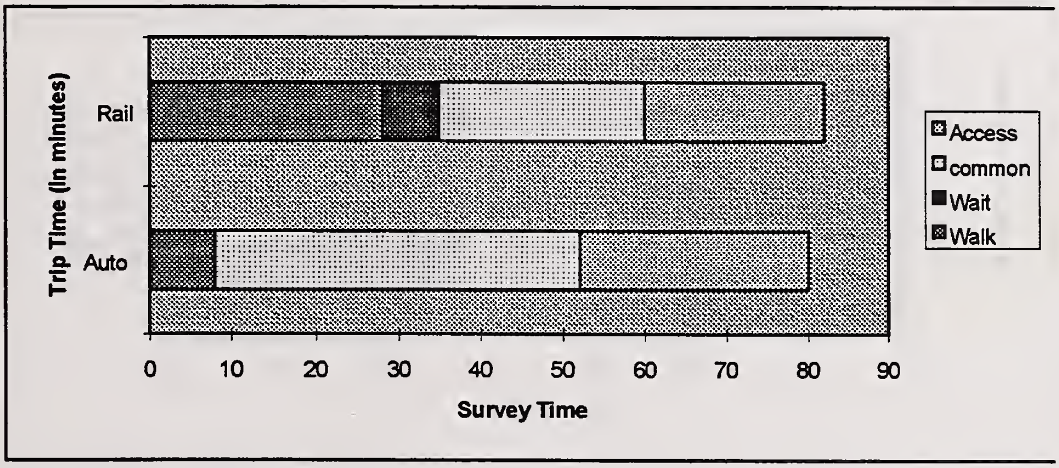


CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE 3-D:
53rd & Mulligan - W. Randolph St. & N. State St.

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	65	65
In Common Segment	36	32
Outside Common Segment	21	19
Wait Time	0	4
Walk Time	8	10
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	12.0	11.5
In Common Segment	13.8	18.8
Outside Common Segment	13.4	7.9

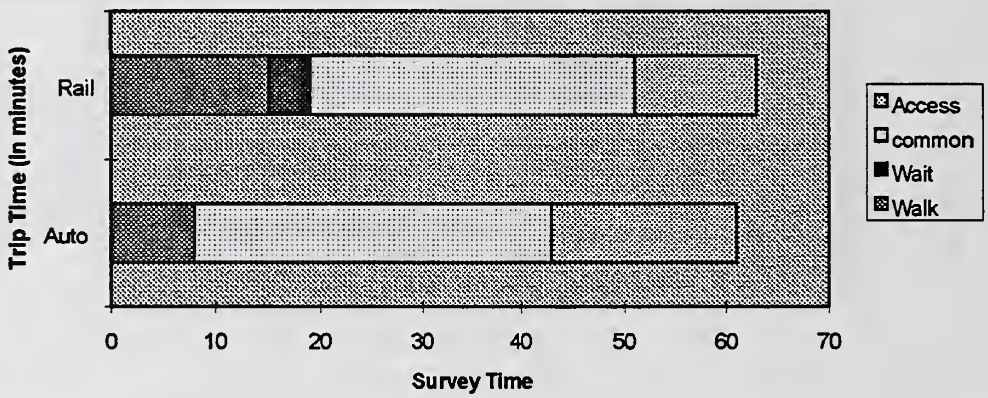


CORRIDOR: Midway Station - Chicago SUMMARY TABLE FOR ROUTE 4-E: 51st & Knox - 115 S. LaSalle & Monroe St.	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	80	82
In Common Segment	44	25
Outside Common Segment	28	22
Wait Time	0	7
Walk Time	8	28
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	9.8	9.1
In Common Segment	11.3	24.0
Outside Common Segment	10.1	6.8



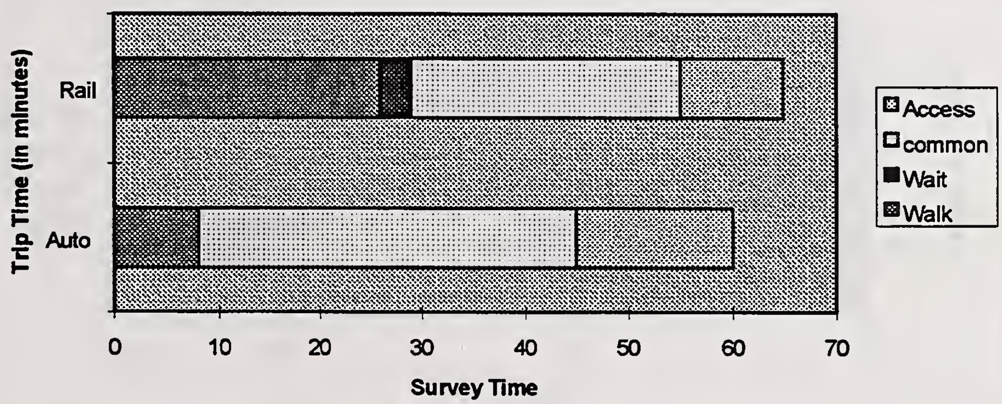
CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE 5-F:
64th & Major - E. Adams St. & S. Michigan Ave.

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	61	63
In Common Segment	35	32
Outside Common Segment	18	12
Wait Time	0	4
Walk Time	8	15
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	12.8	11.9
In Common Segment	14.2	18.8
Outside Common Segment	15.7	12.5



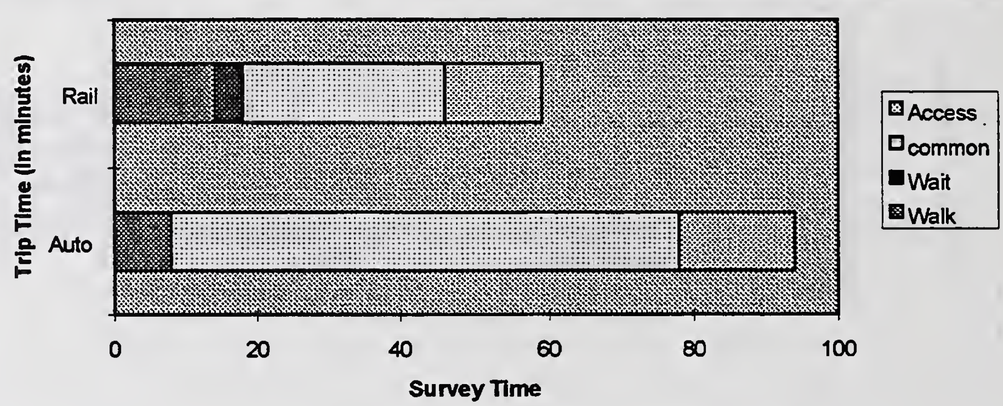
CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE 6-G:
58th & Parkside - 180 N. Wabash Ave. & W. Lake St.

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	60	65
In Common Segment	37	26
Outside Common Segment	15	10
Wait Time	0	3
Walk Time	8	26
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	13.0	11.5
In Common Segment	13.5	23.1
Outside Common Segment	18.8	15.0



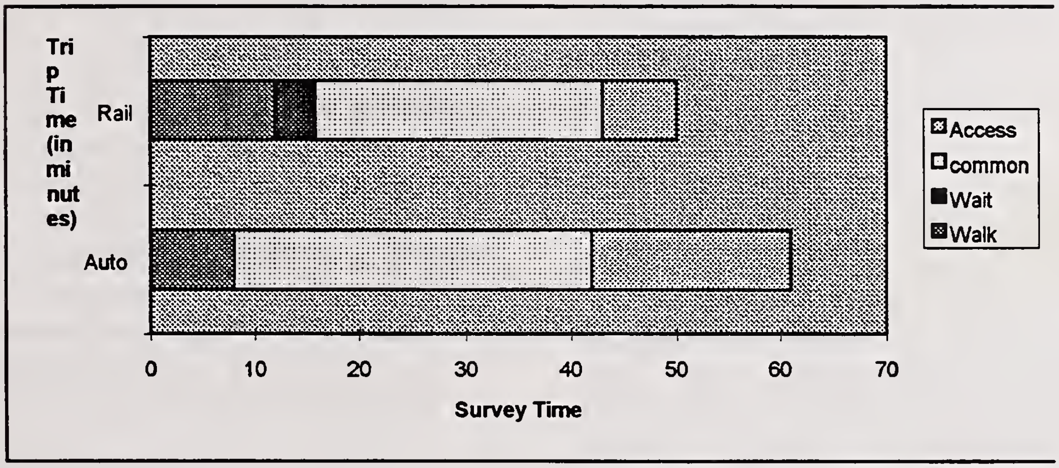
CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE 7-H:
54th & Sayre - 69 W. Washington Blvd. & N. Dearborn St.

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	94	59
In Common Segment	70	28
Outside Common Segment	16	13
Wait Time	0	4
Walk Time	8	14
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	8.3	12.7
In Common Segment	7.1	21.4
Outside Common Segment	17.6	11.5



CORRIDOR: Midway Station - Chicago
SUMMARY TABLE FOR
ROUTE 8-I:
49th & Lotus - W. Randolph St. & N. Wells St.

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	61	50
In Common Segment	34	27
Outside Common Segment	19	7
Wait Time	0	4
Walk Time	8	12
DISTANCE (miles)		
Route Distance	13.0	12.5
Common Segment Distance	8.3	10.0
SPEED (mph)		
Trip	12.8	15.0
In Common Segment	14.6	22.2
Outside Common Segment	14.8	21.4



Appendix 3. The North Hanley Light Rail Corridor Serving St. Louis

Executive Summary

Working Paper 1 (Subtask 1d, November 25, 1998) develops a theoretical and measurement framework within which the Mogridge-Lewis Convergence Hypothesis (MLC) can be employed in measuring the savings in highway delay attributable to transit and its equilibrating effect on the level of service in the corridor.

The framework also provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay without the need for repeated MLC surveys. The approach rests on the theoretical proposition, proven in Working Paper 1, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Purpose and Method

This Working Paper presents a case study of the methodology developed in Subtask 1c in application to the North Hanley – St. Louis corridor (the Metro Link light rail system). The methodology consists of calibrating the MLC-traffic model with

N.Hanley-St. Louis survey data. The model is then used to quantify delay savings attributable to Metro Link at present, and at alternative roadway traffic volumes (each for different user categories).

The study consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

The N. Hanley-St. Louis corridor was selected to measure the performance of the Metro Link light rail system connecting several residential areas with the Central Business District of St. Louis, Missouri. MLC theory predicts that the improved transit system will attract modal explorers, reduce congestion, and improve roadway travel times. As a result, we would expect to see improvements in both highway and transit door-to-door travel times

Principal Findings

The case study finds that based on the MLC model calibrated with 1999 survey data, the magnitude of peak-period delay savings per trip due to transit is about 3.89

minutes per door-to-door journey (Table A 3.1). These savings amount to about 11 percent of total door-to-door journey times and align with reasoned expectations.

HLB estimated the hours of delay savings for three different user groups: Metro riders (market benefits), users of the I-70 common segment (club benefits), and users of parallel highways (spillover benefits). Table A 3.4 also presents the estimated delay savings by category of user. Based on an assumed value of peak travel time of $15 per hour and an average of 250 working days per year, Table A 3.1 through Table A 3.3 show the benefits estimate by user category.

Table A 3.1 Daily Club Benefits

	Distance (miles)	Traffic Volume	Savings (hours)
	Common Segment		
I-70	11	61,167	1,826
	Access Segment		
(average)	2.5	37,000	251
Total	13.50		2,077

Table A 3.4 shows that the 1998 delay saving attributed to transit on the N.Hanley-St. Louis corridor is estimated at about $22.7 million. This can be translated to $1.7 million per rail mile.

These findings are surprisingly very similar to the ones found in the case study of the Gateway-Portland corridor. Although an intermodal travel time convergence of 11 minutes is sufficient to yield delay savings to highway users (as compared to the "without rail" case), full convergence would of course yield even greater savings.

Also, similar to the findings in Gateway-Portland Corridor, St. Louis's current parking structure in stations such as North Hanley Station ("horizontal" rather than "vertical" park-and-ride expansion) is not consistent with the maximization of transit's performance as a "regulator" of multi-modal corridor performance.

Table A 3.2 Daily Market Benefits

Station	West-bound Trips	East-bound Trips	Savings (hours)
N. Hanley	312	2,635	114.64
UMSL North	111	829	34.74
UMSL South	239	1,233	51.53
St. Charles Rock Road	482	1,207	55.85
Wellston	386	869	39.06
Delmar Blvd.	729	1,487	64.65
Forest Park	664	1,413	56.56
Central West End	1,907	1,539	87.13
Grand Avenue	1,680	1,080	64.42
Union Station	1,539	1,294	60.61
Kiel Center	828	385	21.23
Bush Stadium	603	355	14.91
8th and Pine	1,468	918	37.13
Convention Center	1,595	1,509	42.26
Total			745

Table A 3.3 Daily Spillover Benefits

Highways in the corridor:	Distance (miles)	Traffic Volume	Savings (hours)
W. Florissant Blvd.	5.95	19,000	276.07
Natural Bridge	7	22,800	389.75
Saint Louis Blvd.	3.85	12,650	92.50
Dr. Martin Luther King Blvd.	7	28,640	462.38
Delmar Blvd.	4.2	18,000	143.59
Page Street	5.95	16,040	181.27
College Lane/Lindell Boulevard	3.15	18,760	112.24
Forest Park Avenue	3.85	22,480	164.39
I-64/I-170	13.3	62,019	1,454.80
Total			3,277

Table A 3.4 Summary of Network Benefits

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	701	$ 10,519	$ 2,629,762
Club	2,077	$ 31,150	$ 7,787,481
Spillover	3,277	$ 49,155	$ 12,288,780
Total	6,055	$ 90,824	$ 22,706,023

Figure A 3.1 North Hanley Metro Link Station

Figure A 3.2 Convention Center Metro Link Station

Introduction

This report presents the results of the North Hanley – St. Louis corridor case study as part of Streamlined Strategic Corridor Travel Time Management study. The purpose of the study is to use the convergence measurement technique to derive a repeatable performance measurement for rail transit in congested corridors. This case study measures the performance of St. Louis' light rail system—known as Metro Link—using the methodology developed in Subtask 1c. The methodology consists of calibrating the Mogridge-Lewis Convergence Hypothesis (MLC) model with survey data and using the model to quantify delay savings attributable to transit at different roadway traffic volumes. The savings are estimated for three different user categories using highway traffic and light rail ridership data in this corridor.

Study Methodology

The study methodology consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor), and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

During the first step, HLB collected HPMS data, local arterials traffic data, and light rail ridership data from Bi-State Development Agency (the local transit authority), East-West Gateway Coordinating Council (the local MPO) and Missouri Department of Transportation. The data were used to estimate the model parameters.

For the second step, data were collected on the North Hanley - St. Louis corridor by a survey team. A corridor, as defined in this study, is a principal transportation artery into the central business district. Multiple transportation services are available to commuters who use this artery. Additionally, during the peak period a large number of commuters utilize this route in their door-to-door commute.

A statistical sample of trips was generated in the corridor by identifying random trip end point in the zones at either end of the corridor and joining them so that trips alternated between zones. These zones are catchment zones where travelers converge or diverge from either the transit station or the principal highway route. For this study these zones are defined as the access segment and the component of the corridor common to all trips for a given mode, regardless of trip end location, is defined as the common segment.

Survey crews were instructed to follow specific routes consisting of an access segment—dependent on the catchment zone considered for the trip—and a common segment. The data collected include start and arrival times for each segment, by mode of transportation, congestion level, seating availability, weather, road conditions, and travel costs for each segment.

Data were collected over a period of three consecutive days (Tuesday to Thursday) during the first week of March 1999. The days of the week were sampled to eliminate fluctuations in traffic patterns and volumes due to the day of week effects. Trips were validated to minimize the effects of unusual or circumstantial conditions. Sixty valid trips were selected to ensure a statistically adequate sample size. The study employed routes connecting several zones within a residential area to several points within St. Louis's central business district.

Step three consisted of estimating the "with transit" curve based on the traffic volume and the door to door travel time. Using the model developed in Subtask 1c, HLB derived the "without transit" curve and estimated the hours of delay saved due to transit. This performance metric is defined as the vertical difference between the two curves.

In step four, the hours of delay saved due to transit are aggregated into three user categories. Savings by common highway-segment users are estimated using the traffic volume on the segment. Savings by light rail riders are estimated using the ridership data for each station along the corridor. Savings by parallel highway users are estimated using traffic volume on parallel highways and arterials within the corridor. The magnitude of the savings decreases as the distance between the common segment and the parallel highway increases.

Plan of the Report

This report presents the results from the North Hanley -St. Louis corridor case study. Following this introduction, the first section presents an overview of the model and methodology to estimate the delay saving. It is followed by a discussion of the corridor characteristics and a description of the principal modes of transportation within the corridor. Then, we present the results from the 1999 door-to-door travel survey and the model estimation. This includes the hours of delay saved due to transit per person, per day; and the monetary value of the delay saved for the three user categories. Annexes provide maps of the residential area and the central business district as well as supporting data and supplementary route level results.

Methodology and Model Overview

The methodology consists of four steps:

1. Estimating the Corridor Performance Baseline
2. Estimating the Corridor Performance in the Absence of transit
3. Extrapolating Delay Savings Due to Transit
4. Estimation of Corridor Performance without Re-calibration

Estimating the Corridor Performance Baseline

The Model This model establishes a functional relationship between the person trip volume –all modes—and the average door to door travel time by auto in the corridor.

The door to door travel time by auto can be determined using a logistic function which calculates the door to door travel time in terms of travel time at free flow speed, trip time by high capacity rail mode, and the volume of trips in the corridor for all modes. The door to door travel time can be estimated as follows:

$$T = (T_c - T_{ff}) / (1 + e^{-(\delta + \varepsilon V1)}) + T_{ff} \quad (1)$$

Where T_{a1} is auto trip time,

Tc is trip time by high-capacity rail mode

T_{ff} is auto trip time at free-flow speed,

V is person trip volume in the corridor by auto, and

δ, ε are model parameters

Equation 1 implies that the door to door auto trip time is equal to the trip time at free-flow speed plus a delay which depends on transit travel time and the person trip volume in the corridor.

In other words, when the highway volume is close to zero, travel time is equal to travel time at free flow speed ($T = T_{ff}$). As the volume increases, the travel time is equal to T_{ff} plus a delay due to the high volume, but adjusted to the travel time by high capacity transit. That is the high capacity transit alleviates some of the highway trip delay as some trips shift to transit.

Equation 1 is transformed into a linear functional form before the parameters δ and ε can be estimated, the transformed equation will be:

$$U = \delta + \varepsilon V_1 \quad (2)$$

Where $U = \ln [(T_c - T_{ff}) / (T - T_{ff}) - 1]$

Equation 2 is estimated using Ordinary Least Squares regression.

Data The data required for the estimation of the above equations are:

person trip volume on the highway which can be calculated by dividing the traffic volume by the average vehicle occupancy (auto and buses). This data are available through HPMS data base and MPO's traffic data.

free flow trip time is a constant.

high capacity trip time is a constant.

The parameters δ and ε do not have to be re-estimated each year, they are both specific to the corridor and are relatively stable over the years. So periodically, the person trips volume can be inserted into Equation 1 to estimate the door to door travel time by auto.

Estimating the Corridor Performance in the Absence of transit

The Model This model represents the concept to quantify the role of transit in congestion management. In the absence of transit, the travel time Ta is estimated as:

$$\mathbf{T_a = T_{ff} \; * \; (1 + A\,(V^*)^{\beta})} \qquad \textbf{(3)}$$

Where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V^* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door to door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

- The existing auto and bus person trips on the highway.
- The percentage of person transit trips shifting to auto
- The percentage of person transit trips shifting to bus
- The number of additional cars in the highway
- The number of additional buses in the highway

The occupancy per vehicle in the absence of transit The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$\mathbf{V^* = V_1 + \alpha_1 V_c + \alpha_2 V_b} \qquad \textbf{(4)}$$

Where V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor, and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

Type 1: "Explorers" who are casual switchers and who will divert to Single Occupancy Vehicles in the absence of transit.

Type 2: Commuters with low elasticity of demand with respect to generalized cost and who will divert to use the bus or carpool.

Type 3: Commuters with high elasticity of demand with respect to generalized cost and who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher the shift of transit riders to cars and buses. Therefore, higher degree of convergence will lead to higher delay, which translates into higher savings due to transit.

In words, Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high which translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve (as the volume increases, travel time increases at an increasing rate). The figure below illustrates the relationship between the volume and travel time both in the presence and in the absence of transit.

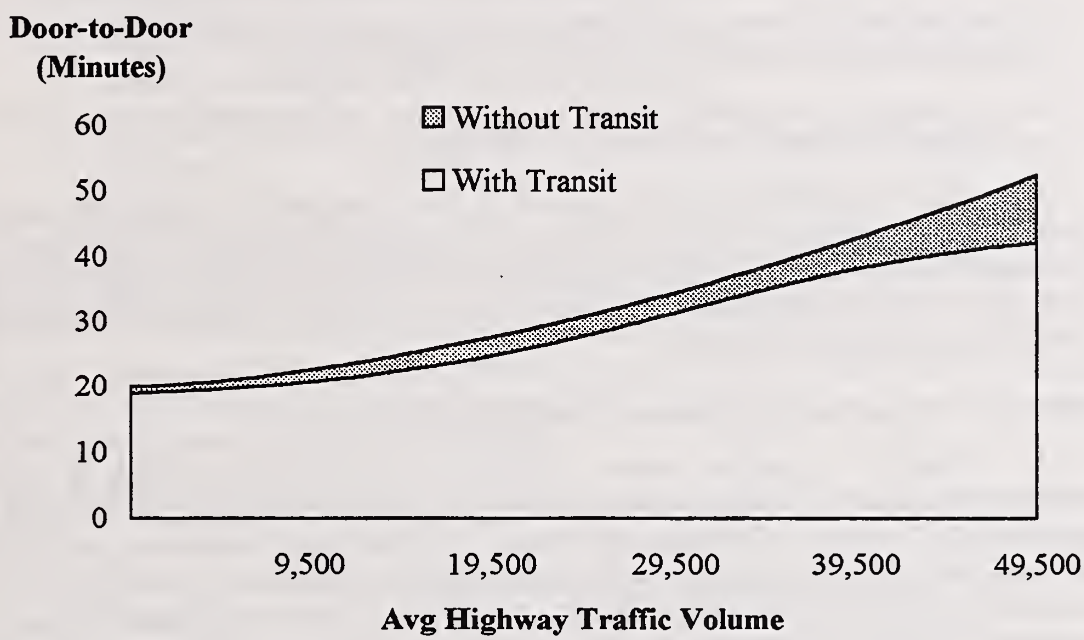


Figure A 3.3 Travel Times With and Without Transit

Data The data required to populate this model consist of:

Highway person trip volume (used in the previous model)

Transit ridership data

Fleet composition (cars and buses percentages out of the total traffic)

Cars and buses vehicle occupancy

Passenger car equivalent factor

Degree of convergence to determine the percentage person trips shifting to cars and buses

Free-flow travel time which is a constant

Equation 3 is specific to the corridor and do not need to be estimated each year. It will only be necessary to re-estimate them with an updated degree of convergence if a major change is made to the transit level of service or the highway structure.

Extrapolating Delay Savings Due to Transit

While the MLC hypothesis proves to be valid during the peak period only, the delay savings due to transit can be estimated during off-peak as well. This metric can be estimated as the vertical difference between the "without transit" curve and the "with transit" curve. That is at a specific person trip volume, the difference in travel times between the two cases can be defined as "the hours of delay saved due to transit".

The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by Metro riders (market benefits), savings by highway users (club benefits), and savings by users of parallel highways (spillover benefits).

The market benefits are estimated based on delay saved (which depends on the distance traveled) for each rider within the common segment.

The club benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution.

The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment. The spillover benefits are calculated by multiplying the traffic volume with a percentage of the delay savings. This percentage decreases as the distance between the common segment and the parallel highway increases.

Estimation of Corridor Performance without Re-calibration

The framework, presented above, provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay ***without*** the need for repeated MLC surveys. The approach rests on the theoretical proposition, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Corridor Overview

The North Hanley--St. Louis corridor is about 13 miles in length. It connects the residential area around North Hanley Station, which is located within ½ mile of the I-170 and I-70 Bypass with the CBD in St. Louis, Missouri. The residential catchment zone is centered around the North Hanley Transit Station. Trip end points within the residential zone are within a 20 minutes drive to the station. The downtown St. Louis, Missouri zone, centered around the Convention Center Light Rail Station, extends for a radius of .5 miles. App. Annex A1 provides maps of the residential and business district zones considered in this study. The North Hanley – Convention Center Metro Link light rail line is part of the 17.5-mile line connecting the Airport to the 5th street and Missouri Station in the Illinois side of the City of St. Louis. This line was opened on July, 1993.

Principal Travel Modes

The "principal travel mode" is defined as the mode used along the common segment of each individual trip. The main transportation modes serving the North Hanley – St. Louis Corridor are automobile and the light rail, Metro Link. The North Hanley - St. Louis line is a 13-mile segment which runs through the University of Missouri campus, the residential area of Forest Park, and the business center around Union Station.

Automobile routes can be broken into three distinct sections:

1. The route between the residential point and the intersection of I-70 and N. Hanley in the transit station area (Access1);
2. The route from the intersection of I-70 and N. Hanley to the I-70 Ramp Leading to Broadway (Common Segment); and
3. The route from the I-70 ramp leading to Broadway and the CBD point (Access2).

For a morning rush hour trip, survey drivers followed Access1 to the common segment. The common segment route originated at the intersection of I-70 and N. Hanley in North Hanley Transit Station area. Drivers followed I-70 East to downtown St. Louis and exited at the Broadway ramp. From the end of the common segment, survey drivers followed Access2 to the downtown points, at which time they parked at the closest parking lot and proceeded on foot to the end point. The evening rush hour trip covered the same progression in the opposite direction.

The routes for the Metro Link light rail mode can also be broken into three distinct sections:

1. The route between the residential point and the N.Hanley Transit Station (Access1);
2. The route between the N.Hanley Transit Station and the Convention Center Station (Common Segment); and
3. The route between the Convention Center Station and the CBD point (Access2).

For a morning rush hour trip, survey crews drove Access1 to the N.Hanley Transit Station parking lot and walked from the lot to the Metro Link station. The route taken for the common segment consisted of the light rail trip beginning at the N.Hanley Station and continued to the Convention Center Station. From the end of the common segment, the surveyor walked Access2 to the downtown points. The evening rush hour trip covered the same progression in the opposite direction. On average, trains run every 6 to 7 minutes during peak hours and 10 to 15 minutes during off-peak hours. Table A 3.5 displays some of the principal performance and service characteristics of the corridor.

Table A 3.5 Performance and Service Characteristics for N.Hanley-St.Louis Corridor

	Automobile	Light Rail
Number of stops	N/A	13
Number of Streets and Highways	1	N/A
Tolls/Fares for a one way (in dollars)	$0.00	$1.25

Figure A 3.4 and Figure A 3.5 show North Hanley--St. Louis corridor routes for the Metro Link and for automobile. In addition to taking daily commuters to work, the light rail system is also heavily used by University of Missouri students and by people going to Kiel Center (sports complex) or Busch Stadium. The line configuration made Metro Link a good multi-purpose transportation mode.

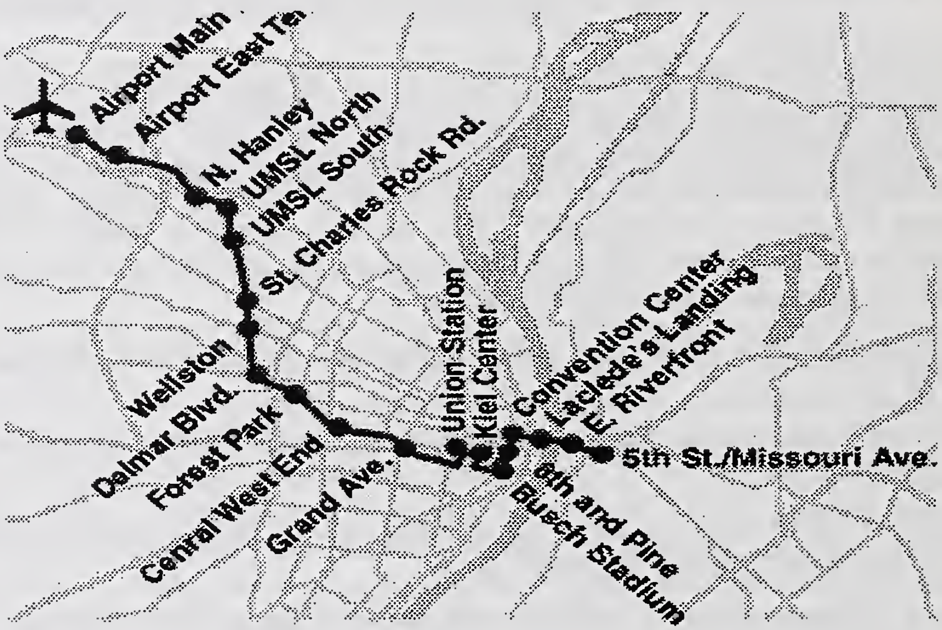


Figure A 3.4 North Hanley—St. Louis Light Rail Route

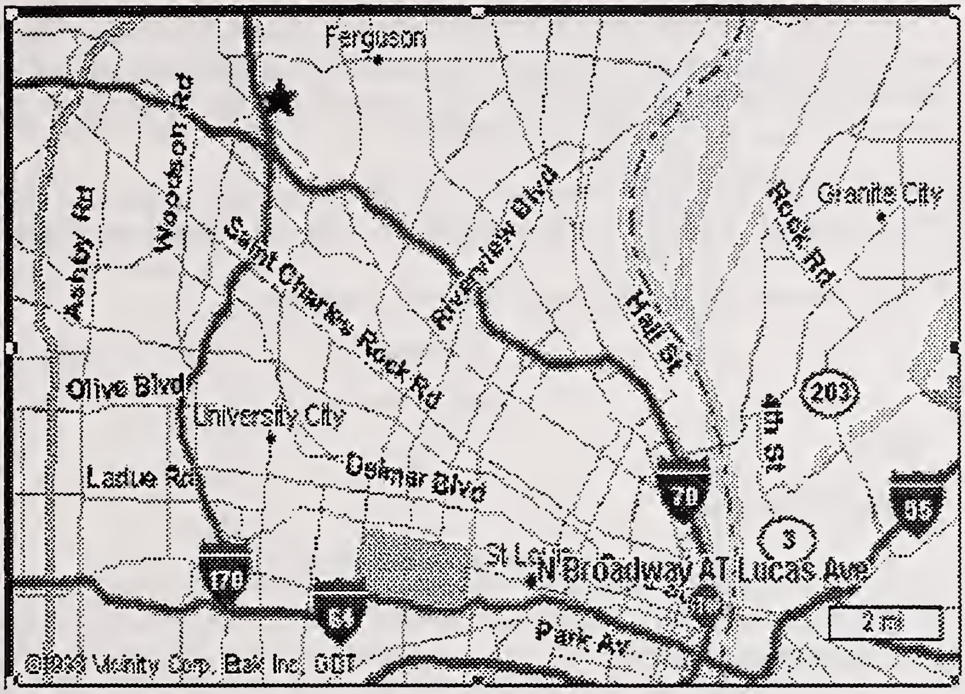


Figure A 3.5 N. Hanley--St.Louis Corridor Automobile Route

Principal Findings

This chapter first presents the results from the door-to-door travel survey conducted during the first week of March 1999. The travel survey data are used to derive the inter-modal convergence level in the North Hanley - St. Louis corridor. The chapter then presents the estimation of hours of delay saved due to transit for different user categories.

The Convergence Level

The starting point to estimate the "without transit" curve is to determine the convergence level based on the key findings from the 1999 door to door travel data.

The door to door travel survey for the N.Hanley-St.Louis Corridor found that:

- Average door-to-door travel times for auto and metro rail are 47.2 minutes by light rail and 36.1 minutes by auto (Table A 3.6).
- Travel time reliability, as represented by the standard deviation of average travel time is 5.3 for light rail mode and 7.3 for the auto mode (Table A 3.6).
- Commuters experienced similar travel times in the morning and in the evening reflecting the similar traffic dynamics of the inbound peak flow and the outbound peak flow in the corridor (Table A 3.7).
- Statistical analysis shows that the mean trip time by auto was at most 14 minutes longer with 95% confidence (Table A 3.8).

- The common segment travel time was greater for the light rail mode than for the transit mode, 27.5 minutes versus 15.7 minutes. The difference of 11.8 minutes between the two modes is due to lower congestion on the highways as more commuters use the light rail. (Table A 3.6).
- Access segment travel times indicate that auto commuters spent on average about the same time outside the common segment as transit commuters. (Table A 3.6).

Table A 3.6 Results for the N.Hanley-St.Louis Corridor

	Automobile	Light Rail -MAX
	Total Travel Time	
Mean	36.1	47.2
Standard Deviation	7.3	5.3
	Access Segment Travel Time	
Mean	20.4	19.7
Standard Deviation	4.5	5.0
	Common Segment Travel Time	
Mean	15.7	27.5
Standard Deviation	5.0	1.6
Sample Size	30	30

Table A 3.7 Comparison of AM and PM Trip Times by Modes

	Auto	Metro Rail
Inbound AM Average Trip Time	36.3	48.7
Outbound PM Average Trip Time	35.9	47.4

The results in Table A 3.8 indicate that light rail in the defined corridor has drawn door-to-door travel times by highway and light rail to within no more than 14 minutes of one another during congested roadway conditions (with 95 percent statistical confidence).

Although an inter-modal travel time convergence of 11 minutes (difference in mean travel times) is sufficient to yield delay savings to highway users (as compared to the "without rail" case – see below), full convergence would of course yield even greater savings. Why is the convergence level as high as 11 minutes? Stated differently, why is it that, even though door-to-door average peak-period roadway travel time is 14 minutes less than the average door-to-door travel time by light rail, light rail users are not re-exploring the roadway option by enough to "bid-up" roadway times any further?

Table A 3.8 Statistical Testing of Convergence Hypothesis

Difference in Mean Travel Times by Mode: (Auto- Metro Rail minutes)		11.1
Standard Error of the Difference of the Means (minutes):		1.65
Hypothesis: "The difference between the mean travel times by modes is at most..."	Significant at the 0.10 Level (90% Confidence)	Significant at the 0.05 Level (95% Confidence)
11 Minutes	NO	NO
12 Minutes	NO	NO
13 Minutes	NO	NO
14 Minutes	YES	NO
15 Minutes	YES	YES

The Mogridge-Lewis framework predicts that non-time related roadway travel costs (i.e, the non-time elements of "generalized cost" such as parking costs, fuel costs and so on) account for the "11 minute wedge." Light rail users are expected to re-explore the roadway option to the point at which the value of non-time generalized cost factors just equals the value of the travel time advantage offered by road. If non-time costs are moderate to high, travel time convergence will occur at a non-zero time differential between road and rail. Such is the case at-hand. In particular, parking costs in downtown St. Louis are at or above the national average. Parking capacity is low as a matter of land-use and transportation planning policy, which means that the time-related costs of finding parking and gaining walk-access to the final destination thereafter are higher than the national average. As well, low parking capacity drives the money cost of parking above the national average. The Mogridge-Lewis framework predicts convergence at a non-zero travel time differential in such circumstances. It also predicts convergence at a travel time differential that lies above the national average differential for corridors in convergence. Both predictions are borne out in the Portland case presented here.

Like the Gateway-Portland corridor case study, the design of expanded park-and-ride facilities in response to capacity constraints at existing stations will materially influence the extent and direction of inter-modal exploration. Designs that minimize auto-to-platform walking times (such as vertical structures rather than ground-level expansion) encourages auto users to explore light rail and discourages light rail users from exploring auto. This in-turn helps maximize light-rail's convergence-related benefits. St. Louis' current parking structure in stations such as North Hanley Station ("horizontal" rather than "vertical" park-and-ride expansion) is not consistent with the maximization of transit's performance as a "regulator" of multi-modal corridor performance.

Methodology Application on N. Hanley-St. Louis Corridor

Data HLB collected HPMS data, local arterials traffic data, and light rail ridership data from Bi-State Development Agency (the local transit authority), East-West Gateway Coordinating Council (the local MPO), and the Missouri Department of Transportation.

In addition door to door travel time survey was conducted to derive the corridor degree of convergence. HLB estimated the model, described in Section 1 using the obtained data.

Model Equation 1 is estimated as follows:

$$T_{a1} = (45 - 18) / (1 + e^{-(-3.28 + 0.00011\,(V))}) + 18 \quad (1)$$

Similarly, Equation 2 is estimated based on auto travel volume, transit ridership data, and convergence level estimate from the survey.

$$T_{a2} = 18 * (1 + 5.4E\text{-}08\,(V^*)^{1.59}) \quad (2)$$

The auto traffic volume in the absence of transit is determined by adding the auto volume in the presence of transit to the generated auto trips by transit riders. The generated results are based on:

- 31% of person transit trips will be forgone (determined by the corridor convergence level).
- The average vehicle occupancy (HOV and non-HOV) is 1.2 for cars and 40 for buses.
- Car trips will make about 90% of trips.

Benefit Estimation

To estimate the travel time saving (TTS) attributed to transit, the current traffic volume is inserted into Equation 1 and 2. An auto volume of 37,500 results into:

$$T_{a1} = 36.2,\ T_{a2} = 40.09,\ \text{and}.\ TTS = T_{a2} - T_{a1} = 3.89$$

That is on average, in N.Hanley-St.Louis corridor, transit saves about 3.89 minutes per auto trip (17 seconds per mile) during the peak period

Once the average travel time saving per vehicle is estimated, the savings are weighted to reflect the congestion level at each time of the day.

The benefits are calculated for three user groups:

1. Benefits to highway users (Club), these are the hours saved by the common segment user of the N.Hanley-St. Louis corridor (see Table A 3.9).
2. Benefits to Transit users (Market), these are the hours saved by the users of transit between N.Hanley TC and Convention Center Station (see Table A 3.10).
3. Benefits to the highway network users within the corridor (spillover), these are the hours saved by users of parallel and adjacent highways to the common segment within the corridor (see Table A 3.11).

Table A 3.9 through Table A 3.11 show the benefits estimate by user category.

Table A 3.9 Club Benefits

	Distance (miles)	Avg Daily Traffic Volume	Daily Savings (hours)
Common Segment			
I-70	11	61,167	1,826
Access Segment (on average)	2.5	37,000	251
Total	13.50		2,077

Table A 3.10 Market Benefits

Station	West-bound Trips	East-bound Trips	Daily Savings (hours)
N. Hanley	312	2,635	114.64
UMSL North	111	829	34.74
UMSL South	239	1,233	51.53
St. Charles Rock Road	482	1,207	55.85
Wellston	386	869	39.06
Delmar Blvd.	729	1,487	64.65
Forest Park	664	1,413	56.56
Central West End	1,907	1,539	87.13
Grand Avenue	1,680	1,080	64.42
Union Station	1,539	1,294	60.61
Kiel Center	828	385	21.23
Bush Stadium	603	355	14.91
8^{th} and Pine	1,468	918	37.13
Convention Center	1,595	1,509	42.26
Total			745

Table A 3.11 Spillover Benefits

Highways in the corridor:	Distance (miles)	AADT	Daily Savings (hours)
W. Florissant Blvd.	5.95	19,000	276.07
Natural Bridge	7	22,800	389.75
Saint Louis Blvd.	3.85	12,650	92.50
Dr. Martin Luther King Blvd.	7	28,640	462.38
Delmar Blvd.	4.2	18,000	143.59
Page Street	5.95	16,040	181.27
College Lane/Lindell Boulevard	3.15	18,760	112.24
Forest Park Avenue	3.85	22,480	164.39
I-64/I-170	13.3	62,019	1,454.80
Total			3,277

Table A 3.12 Summary of Benefits

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	701	$ 10,519	$ 2,629,762
Club	2,077	$ 31,150	$ 7,787,481
Spillover	3,277	$ 49,155	$ 12,288,780
Total	6,055	$ 90,824	$ 22,706,023

Table A 3.12 shows that the 1998 delay saving attributed to transit on the N.Hanley-St. Louis corridor is estimated at about $22.7 million. This can be translated to $1.7 million per rail mile.

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door to door travel time data should be collected to estimate an accurate performance metric.

Annex A 3.1 Views of the North Hanley Light Rail Corridor

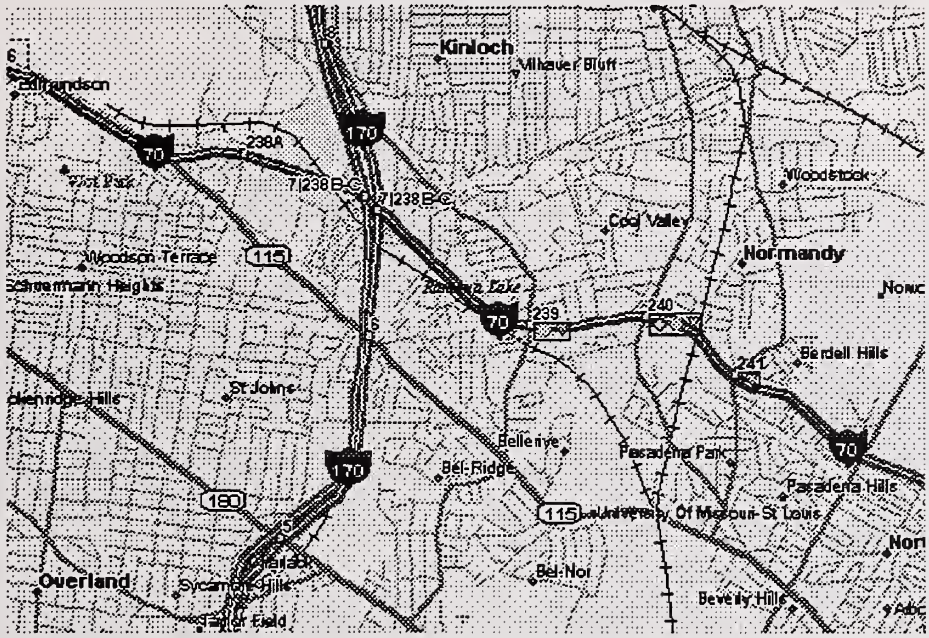


Figure A 3.6 Map of the Residential District

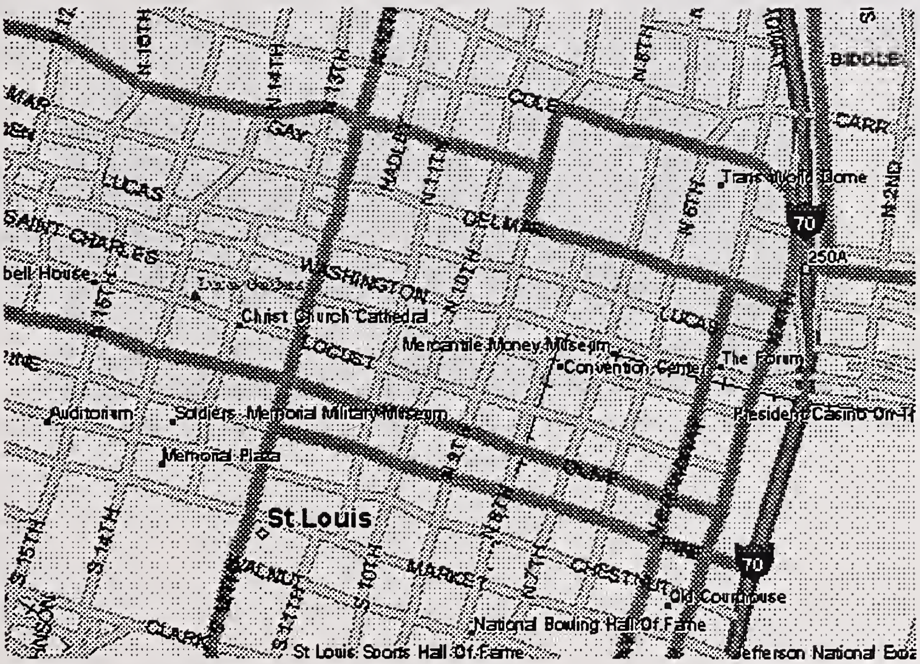
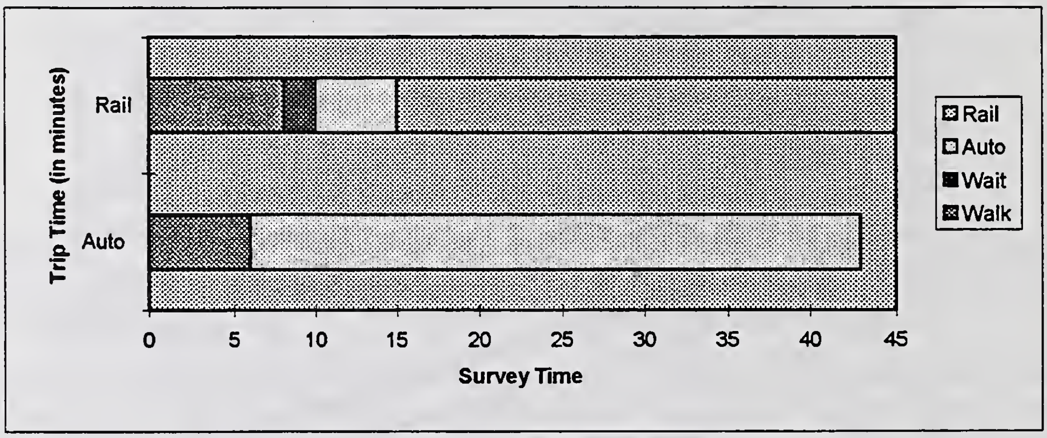


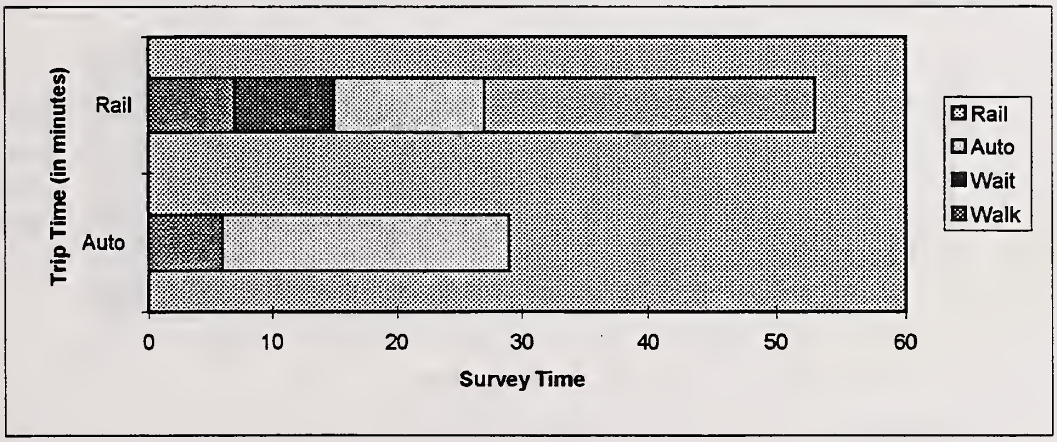
Figure A 3.7 Map of the Central Business District

Annex A 3.2 The Survey Findings by Route

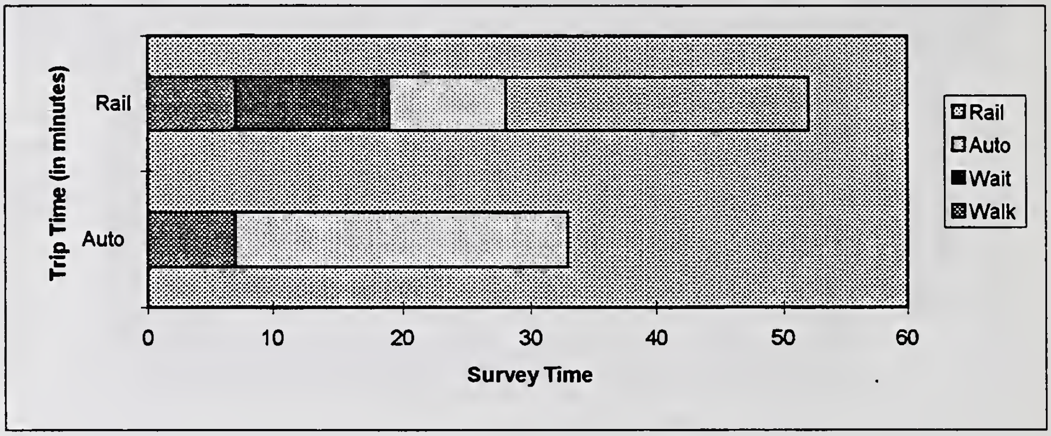
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE B-2: Prospect & Hern Road - Delmar & 10th Street	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	43	45
In Common Segment	20	30
Outside Common Segment	17	5
Wait Time	0	2
Walk Time	6	8
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	18.1	20.0
In Common Segment	33.0	24.0
Outside Common Segment	7.1	36.0



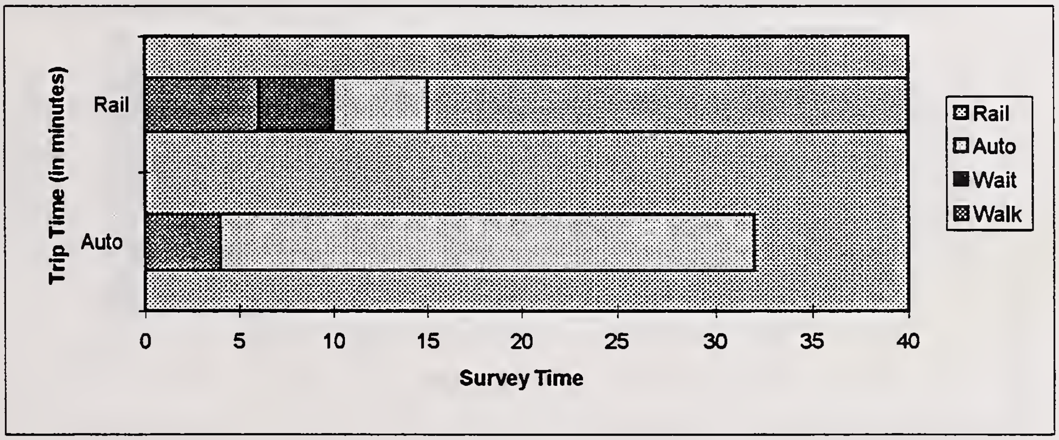
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE D-4: Albin & N Hanley Road - Carr & 10th Street	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	53
In Common Segment	11	26
Outside Common Segment	12	12
Wait Time	0	8
Walk Time	6	7
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	26.9	17.0
In Common Segment	60.0	27.7
Outside Common Segment	10.0	15.0



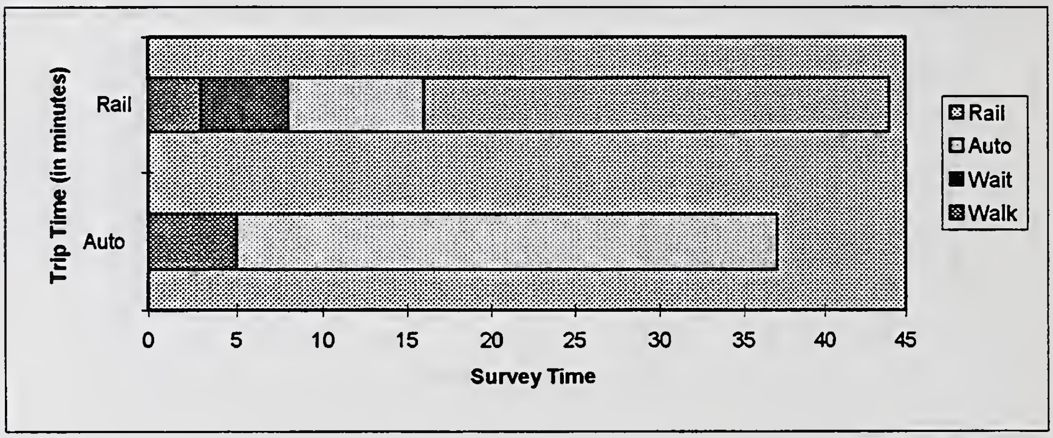
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE E-5: Monroe & N Hanley Road - Washington & 11th Street	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	33	52
In Common Segment	13	24
Outside Common Segment	13	9
Wait Time	0	12
Walk Time	7	7
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	23.6	17.3
In Common Segment	50.8	30.0
Outside Common Segment	9.2	20.0



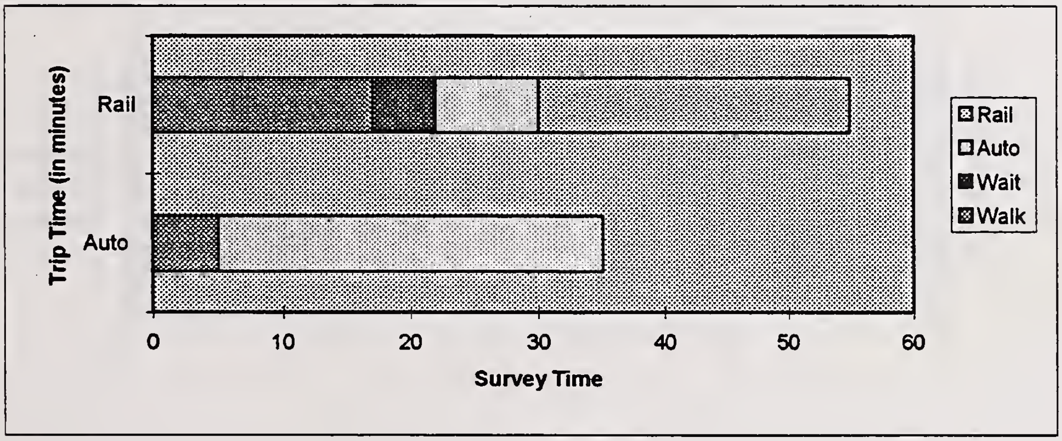
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE C-3: Randolph & S Florissant Road - Martin Luther King & 10th Street		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	32	40
In Common Segment	12	25
Outside Common Segment	16	5
Wait Time	0	4
Walk Time	4	6
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	24.4	22.5
In Common Segment	55.0	28.8
Outside Common Segment	7.5	36.0



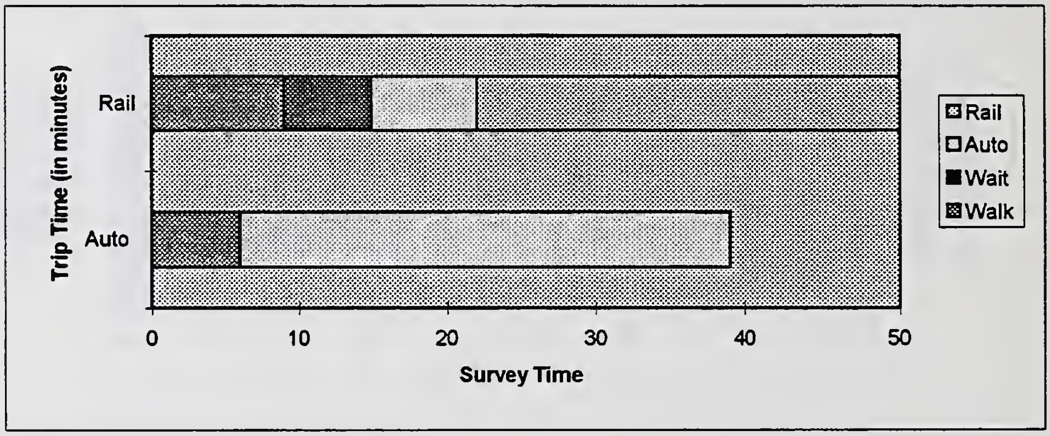
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 1-A: Broadway & Lucas Street - Monroe & Scudder Road		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	37	44
In Common Segment	27	28
Outside Common Segment	5	8
Wait Time	0	5
Walk Time	5	3
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	21.1	20.5
In Common Segment	24.4	25.7
Outside Common Segment	24.0	22.5



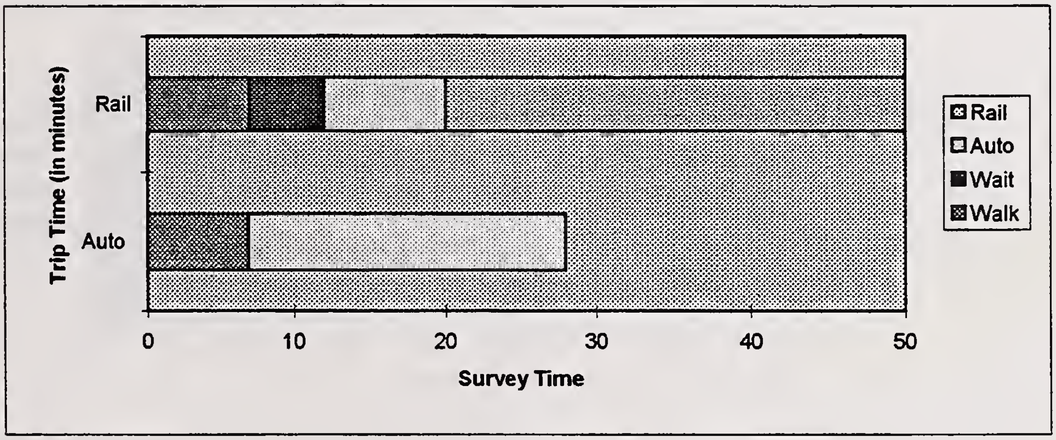
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 4-D: Carr & 10th Street - Albin & N Hanley Road	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	35	55
In Common Segment	15	25
Outside Common Segment	15	8
Wait Time	0	5
Walk Time	5	17
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	22.3	16.4
In Common Segment	44.0	28.8
Outside Common Segment	8.0	22.5



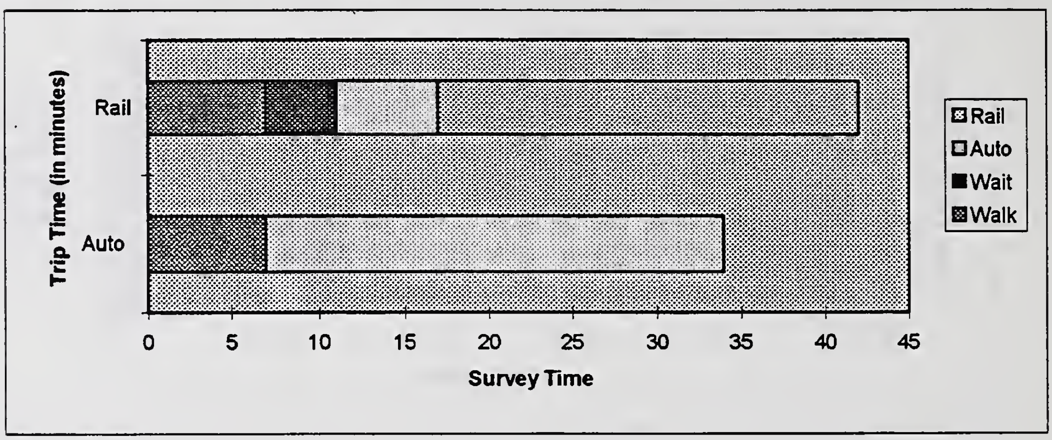
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 1-B: Broadway & Lucas Street - Prospect & Hern Road	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	39	50
In Common Segment	19	28
Outside Common Segment	14	7
Wait Time	0	6
Walk Time	6	9
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	20.0	18.0
In Common Segment	34.7	25.7
Outside Common Segment	8.6	25.7



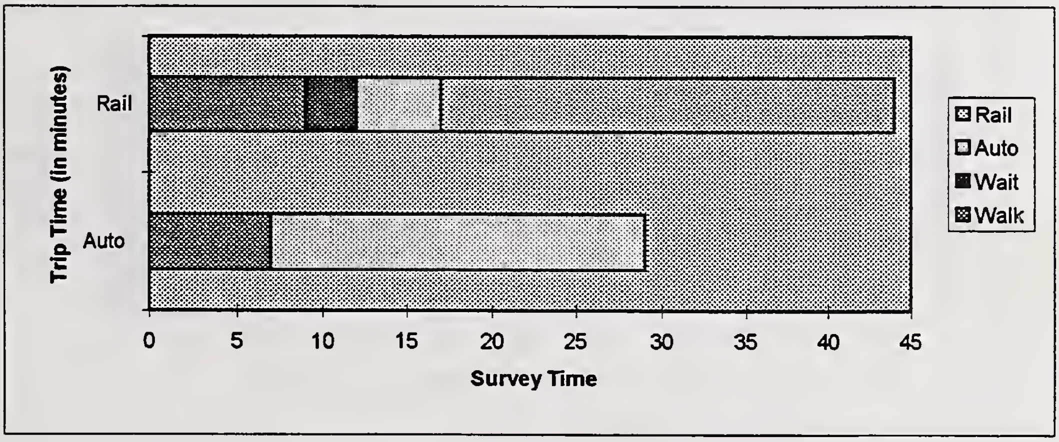
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 5-E: Washington & 11th Street - Monroe & N.Hanley Road		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	28	50
In Common Segment	10	30
Outside Common Segment	11	8
Wait Time	0	5
Walk Time	7	7
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	27.9	18.0
In Common Segment	66.0	24.0
Outside Common Segment	10.9	22.5



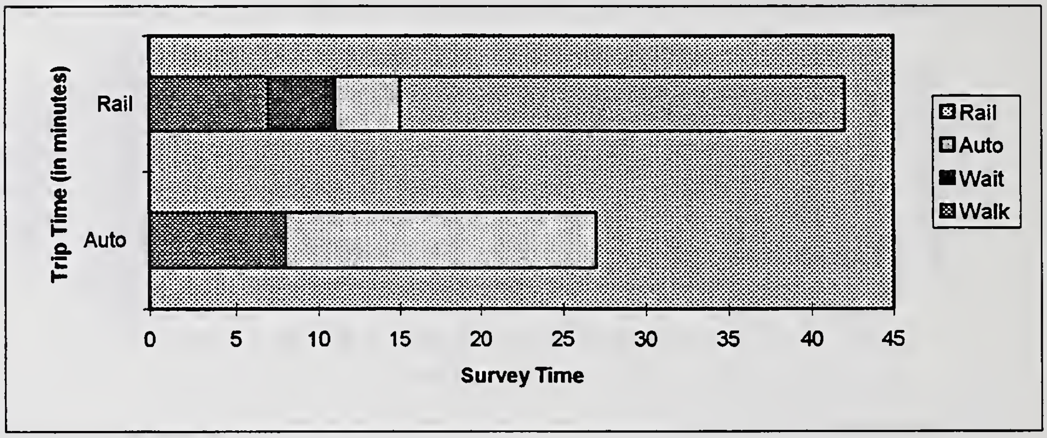
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 3-C: Martin Luther King & 10th Street - Randolph & S.Florissant Road		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	34	42
In Common Segment	13	25
Outside Common Segment	14	6
Wait Time	0	4
Walk Time	7	7
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	22.9	21.4
In Common Segment	50.8	28.8
Outside Common Segment	8.6	30.0



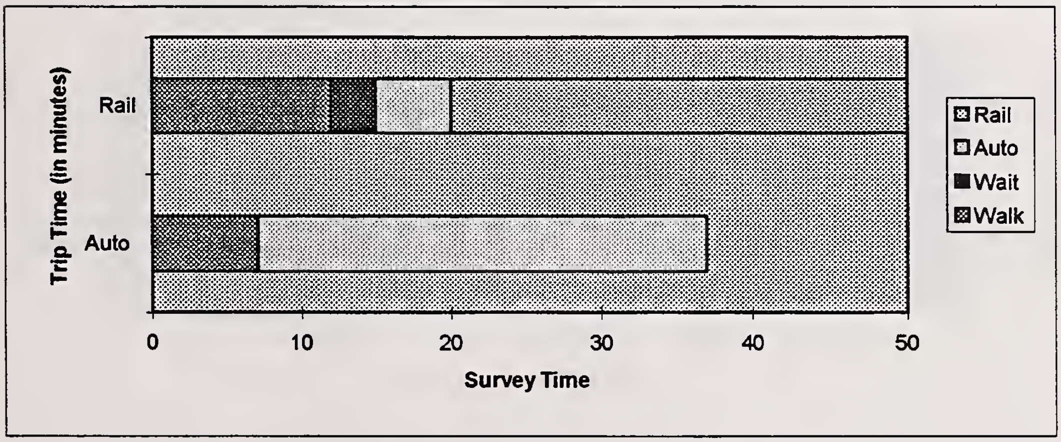
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE D-3: Albin & N.Hanley Road - Martin Luther King & 10th Street	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	44
In Common Segment	10	27
Outside Common Segment	12	5
Wait Time	0	3
Walk Time	7	9
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	26.9	20.5
In Common Segment	66.0	26.7
Outside Common Segment	10.0	36.0



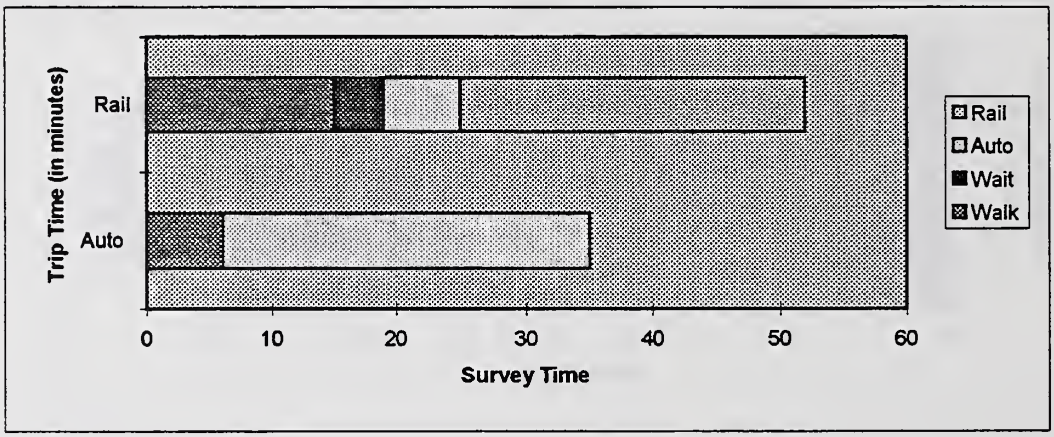
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE B-1: Prospect & Hern Road - Broadway & Lucas Street	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	27	42
In Common Segment	14	27
Outside Common Segment	5	4
Wait Time	0	4
Walk Time	8	7
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	28.9	21.4
In Common Segment	47.1	26.7
Outside Common Segment	24.0	45.0



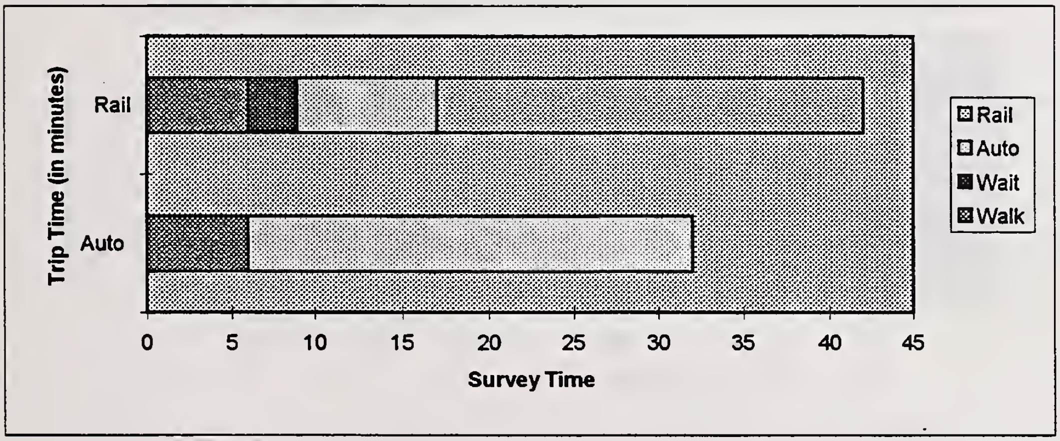
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE E-4: Monroe & N.Hanley Road - Carr & 10th Street	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	37	50
In Common Segment	15	30
Outside Common Segment	15	5
Wait Time	0	3
Walk Time	7	12
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	21.1	18.0
In Common Segment	44.0	24.0
Outside Common Segment	8.0	36.0



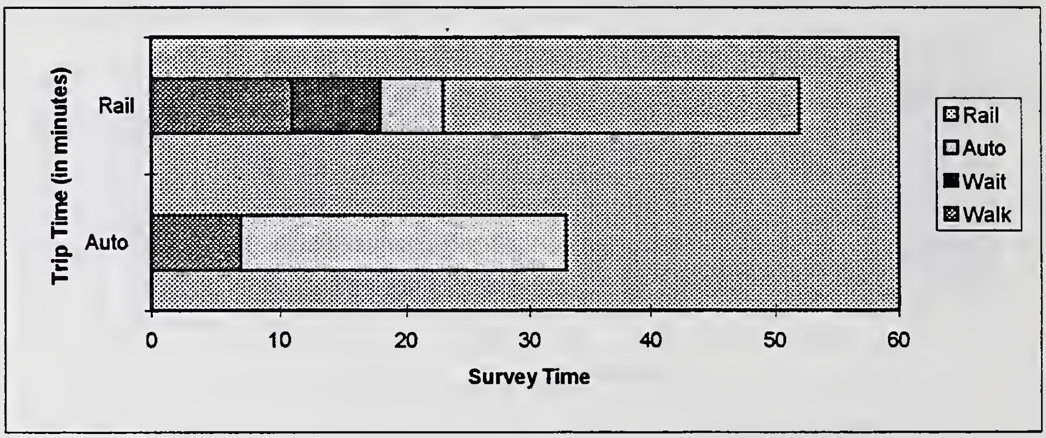
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE C-2: Randolph & S.Florissant Road - Delmar & 10th Street		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	35	52
In Common Segment	15	27
Outside Common Segment	14	6
Wait Time	0	4
Walk Time	6	15
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	22.3	17.3
In Common Segment	44.0	26.7
Outside Common Segment	8.6	30.0



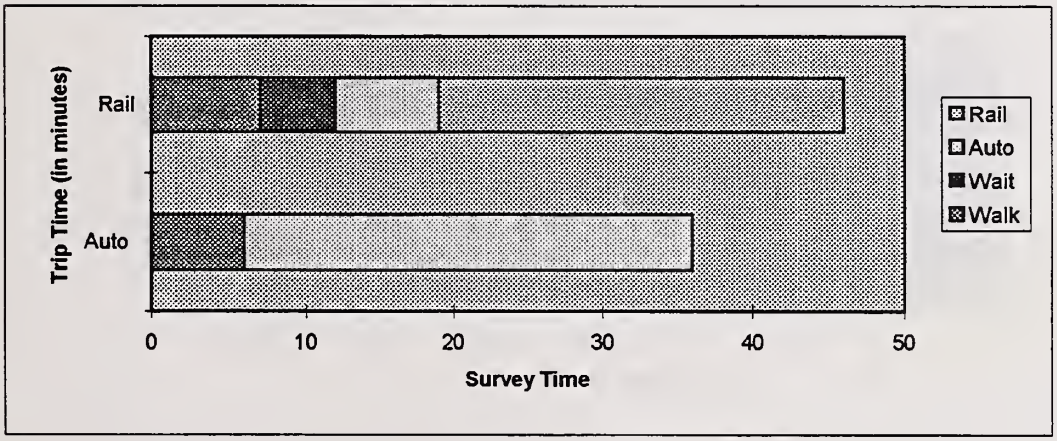
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE F-5: Midland & Brown Road - Washington & 11th Street		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	32	42
In Common Segment	11	25
Outside Common Segment	15	8
Wait Time	0	3
Walk Time	6	6
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	24.4	21.4
In Common Segment	60.0	28.8
Outside Common Segment	8.0	22.5



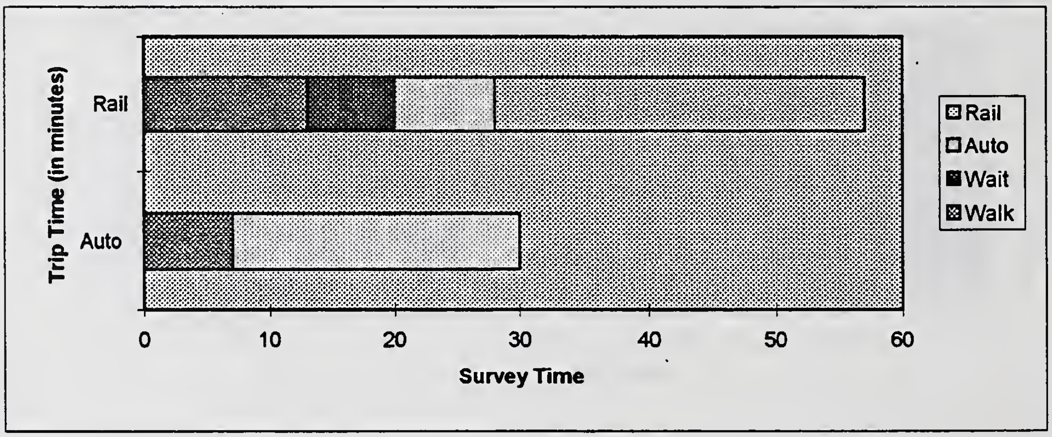
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 3-D: Martin Luther King & 10th Street - Albin & N Hanley Road	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	33	52
In Common Segment	14	29
Outside Common Segment	12	5
Wait Time	0	7
Walk Time	7	11
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	23.6	17.3
In Common Segment	47.1	24.8
Outside Common Segment	10.0	36.0



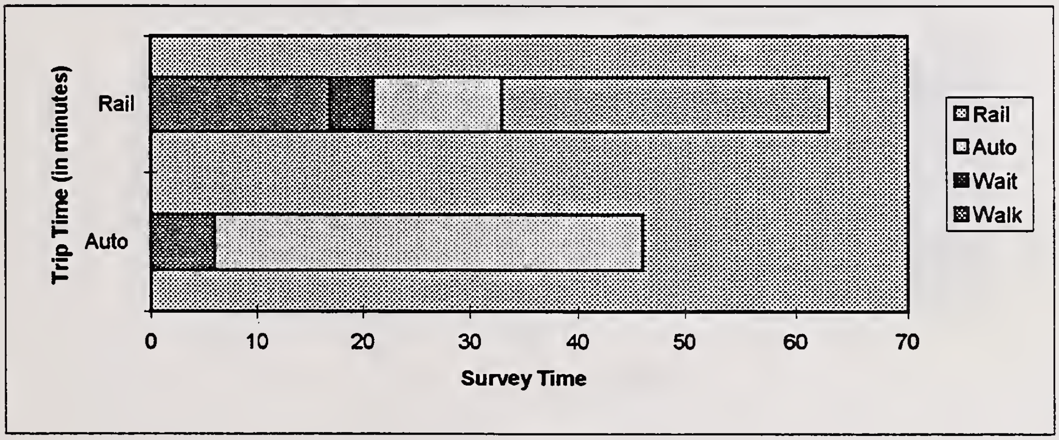
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 2-B: Delmar & 10th Street - Prospect & Hern Road		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	36	46
In Common Segment	16	27
Outside Common Segment	14	7
Wait Time	0	5
Walk Time	6	7
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	21.7	19.6
In Common Segment	41.3	26.7
Outside Common Segment	8.6	25.7



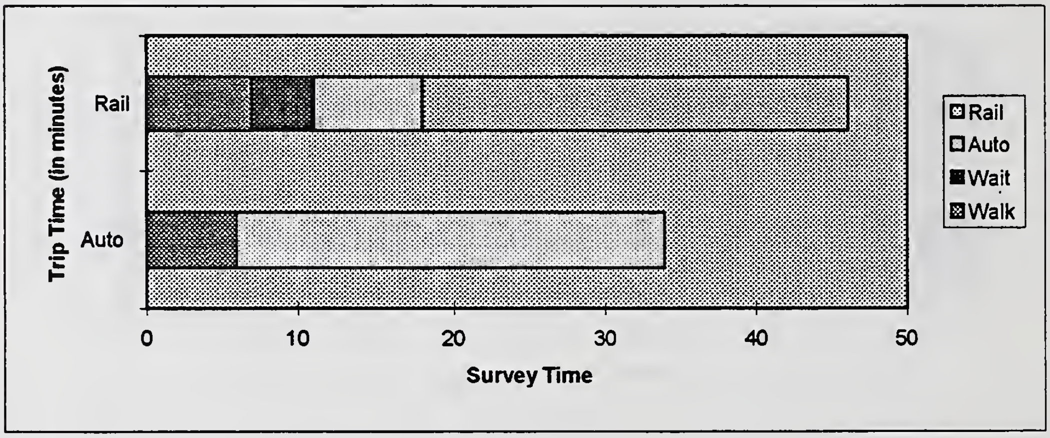
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 4-E: Carr & 10th Street - Monroe & N.Hanley Road	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	30	57
In Common Segment	15	29
Outside Common Segment	8	8
Wait Time	0	7
Walk Time	7	13
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	26.0	15.8
In Common Segment	44.0	24.8
Outside Common Segment	15.0	22.5



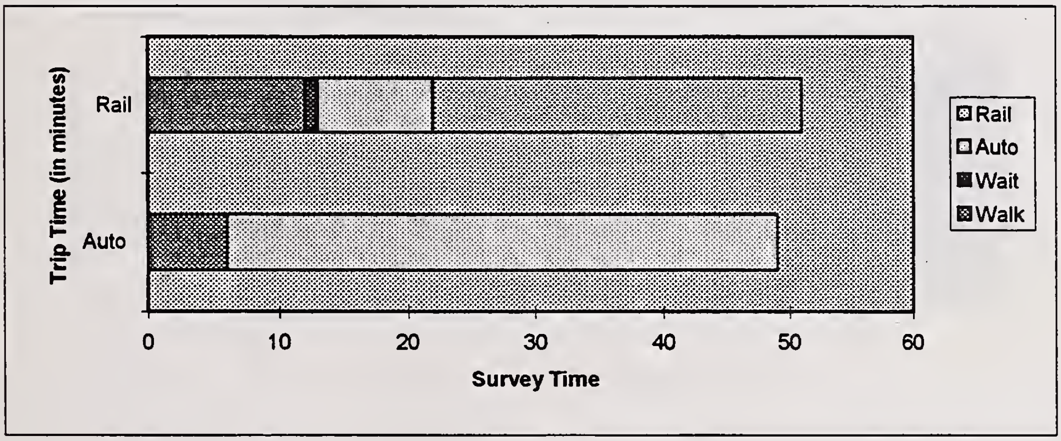
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 2-C: Delmar & 10th Street - Randolph & S.Florissant Road		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	46	63
In Common Segment	24	30
Outside Common Segment	16	12
Wait Time	0	4
Walk Time	6	17
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	17.0	14.3
In Common Segment	27.5	24.0
Outside Common Segment	7.5	15.0



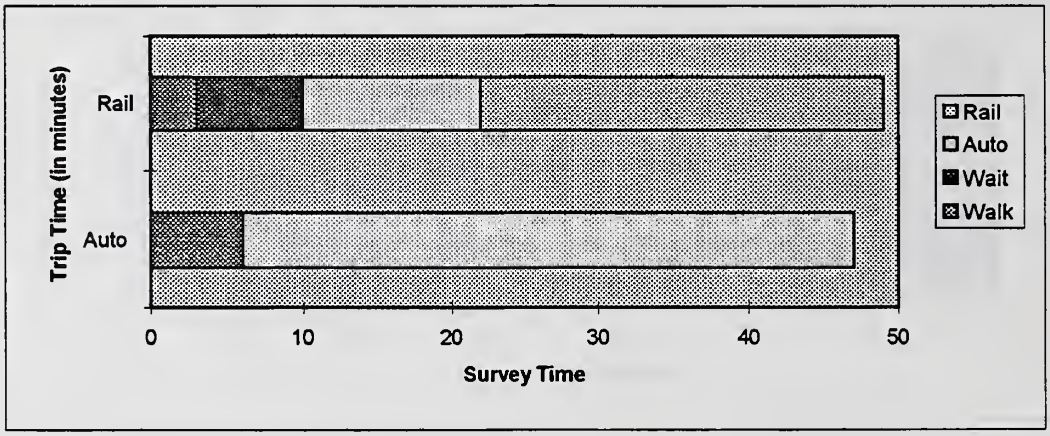
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE 5-F: Washington & 11th Street - Midland & Brown Road		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	34	46
In Common Segment	12	28
Outside Common Segment	16	7
Wait Time	0	4
Walk Time	6	7
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	22.9	19.6
In Common Segment	55.0	25.7
Outside Common Segment	7.5	25.7



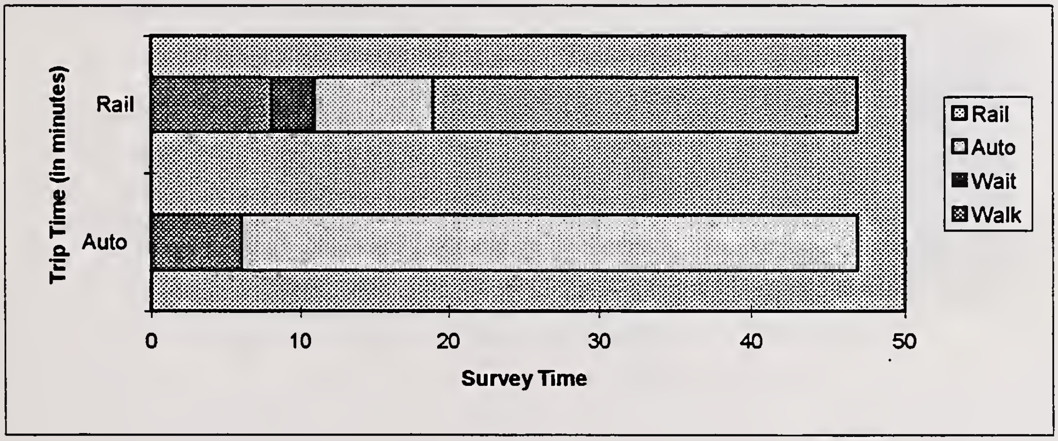
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE F-6: Midland & Brown Road - Locust & 11th Street		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	49	51
In Common Segment	20	29
Outside Common Segment	23	9
Wait Time	0	1
Walk Time	6	12
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	15.9	17.6
In Common Segment	33.0	24.8
Outside Common Segment	5.2	20.0



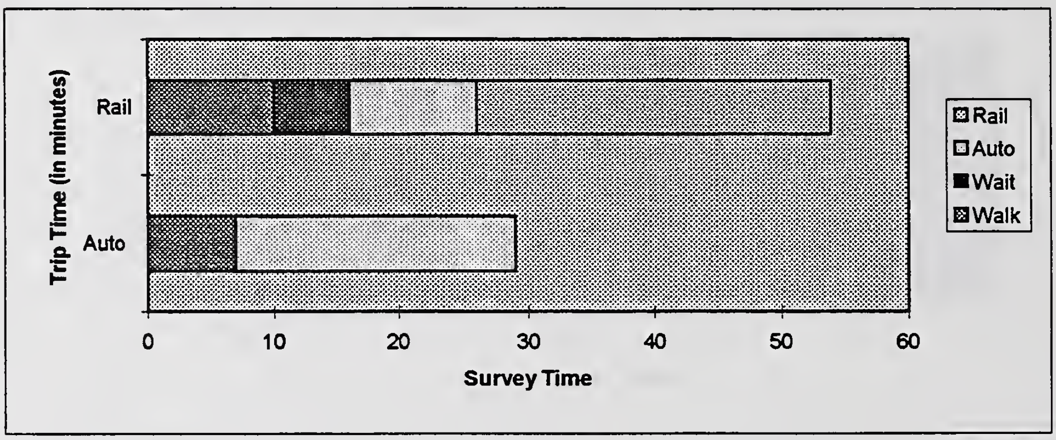
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE G-7: Boswell & North Road - Pine & 10th Street		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	47	49
In Common Segment	20	27
Outside Common Segment	21	12
Wait Time	0	7
Walk Time	6	3
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	16.6	18.4
In Common Segment	33.0	26.7
Outside Common Segment	5.7	15.0



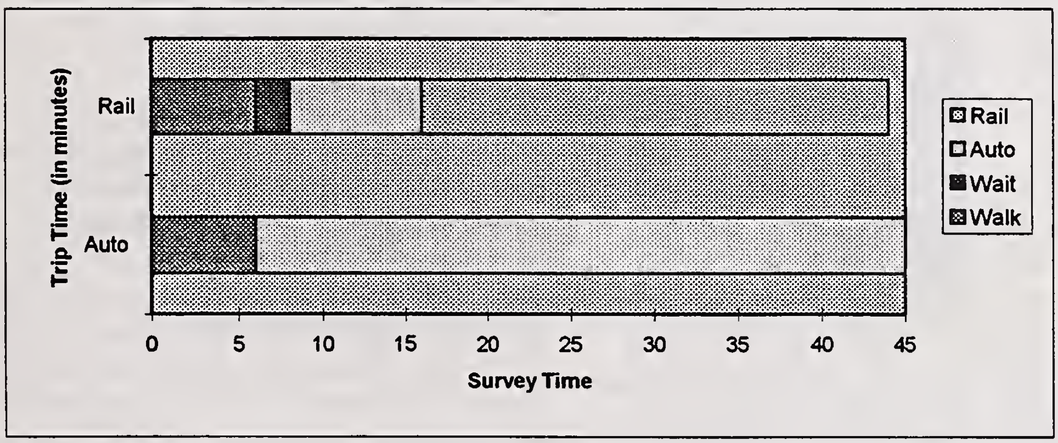
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE H-8: Boswell & Harold Road - Broadway & Olive Street		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	47	47
In Common Segment	20	28
Outside Common Segment	21	8
Wait Time	0	3
Walk Time	6	8
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	16.6	19.1
In Common Segment	33.0	25.7
Outside Common Segment	5.7	22.5



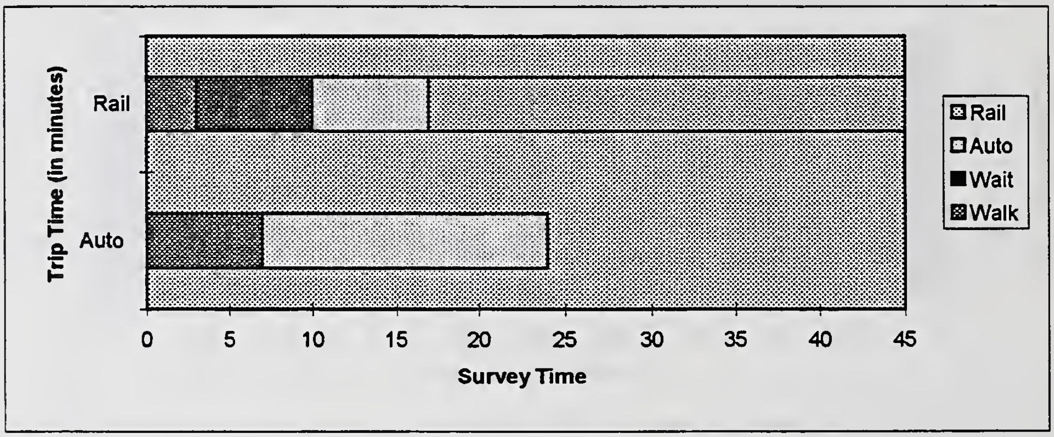
CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE I-9: Lucas and Hunt & Route 115 - Locust & 4th Street		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	54
In Common Segment	11	28
Outside Common Segment	11	10
Wait Time	0	6
Walk Time	7	10
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	26.9	16.7
In Common Segment	60.0	25.7
Outside Common Segment	10.9	18.0



CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE J-10: Clearview & Audrain - Saint Charles & Broadway		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	45	44
In Common Segment	16	28
Outside Common Segment	23	8
Wait Time	0	2
Walk Time	6	6
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	17.3	20.5
In Common Segment	41.3	25.7
Outside Common Segment	5.2	22.5



CORRIDOR: North Hanley - St. Louis SUMMARY TABLE FOR ROUTE A-1: Monroe & Scudder Road - Broadway & Lucas Avenue		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	24	45
In Common Segment	11	28
Outside Common Segment	6	7
Wait Time	0	7
Walk Time	7	3
DISTANCE (miles)		
Route Distance	13.0	15.0
Common Segment Distance	11.0	12.0
SPEED (mph)		
Trip	32.5	20.0
In Common Segment	60.0	25.7
Outside Common Segment	20.0	25.7



Appendix 4. The Butterfield Light Rail Corridor Serving Sacramento

Executive Summary

Working Paper 1 (Subtask 1d, November 25, 1998) develops a theoretical and measurement framework within which the Mogridge-Lewis Convergence Hypothesis (MLC) can be employed in measuring the savings in highway delay attributable to transit and its equilibrating effect on the level of service in the corridor.

The framework also provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay without the need for repeated MLC surveys. The approach rests on the theoretical proposition, proven in Working Paper 1, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Purpose and Method

This Working Paper presents a case study of the methodology developed in Subtask 1c in application to the Butterfield-Sacramento corridor. The methodology consists of calibrating the MLC-traffic model with survey data. The model is then used to quantify delay savings attributable to light rail at present, and at alternative roadway traffic volumes (each for different user categories).

The study consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

The Butterfield-Sacramento corridor was selected to measure the performance of the light rail system connecting several residential areas with the Central Business District of Sacramento, California. MLC theory predicts that the improved transit system will attract modal explorers, reduce congestion, and improve roadway travel times. As a result, we would expect to see improvements in both highway and transit door-to-door travel times

Principal Findings

The case study finds that based on the MLC model calibrated with 1999 survey data, the magnitude of peak-period delay savings per trip due to transit is about 1.25 minutes per door-to-door trip (about 11

about 4 percent of total door-to-door journey times and align with reasoned expectations.

HLB estimated the hours of delay savings for three different user groups: Metro riders (market benefits), users of the US-50 common segment (club benefits), and users of parallel highways (spillover benefits). Table A 4.1 presents the estimated delay savings by category of user. Based on an assumed value of peak travel time of $15 per hour and an average of 250 working days per year. Table A 4.1 indicates aggregate peak delay savings due to transit of $7 million for 1999. The savings can be translated to $0.6 million per rail mile.

Table A 4.1 Benefits Summary for the Butterfield-Sacramento Corridor

Benefit Category	Daily Savings In Hours	Daily Savings In Dollars	Yearly Savings In Dollars
Market	128	$ 1,920	$ 480,007
Club	1,269	$ 19,042	$ 4,760,480
Spillover	483	$ 7,247	$ 1,811,851
Total	1,881	$ 28,209	$ 7,052,338

The summary table shows that 67% of the savings are club savings while only 7% are market savings. These results illustrate the relative low ridership and the high use of automobile in the corridor.

Figure A 4.1 displays the "with-" and "without transit" curves using 1999 convergence data. The vertical difference between the "with-" and "without transit" curves represents the delay savings due to transit at different volumes of US-50 traffic.

The curves indicate that in the absence of major infrastructure improvements or radical traffic growth, the performance metric will remain stable.

Although an intermodal travel time convergence of 15 minutes in this corridor is sufficient to yield delay savings to highway users (as compared to the "without rail" case), full convergence would of course yield even greater savings. The Mogridge-Lewis framework predicts that non-time related roadway travel costs (ie, the non-time elements of "generalized cost" such as parking costs, fuel costs and so on) account for the "15 minute wedge." Light rail users are expected to re-explore the roadway option to the point at which the value of non-time generalized cost factors just equals the value of the travel time advantage offered by road. If non-time costs are moderate to high, travel time convergence will occur at a non-zero time differential between road and rail. Such is the case at-hand.

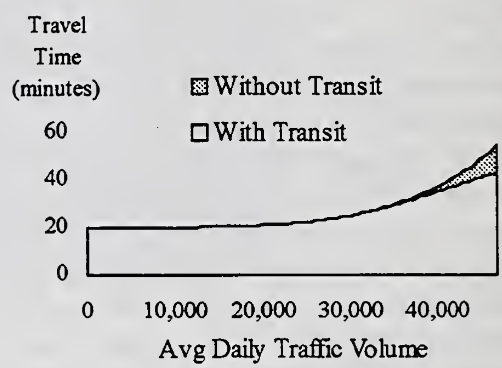


Figure A 4.1 Illustration of the "With" and "Without Transit" curves for the Butterfield-Sacramento Corridor

Introduction

This report presents the results for the Butterfield-Sacramento corridor case study as part of Streamlined Strategic Corridor Travel Time Management study. The purpose of the study is to use the convergence measurement technique to derive a repeatable performance measurement for rail transit in congested corridors. This case study measures the performance of Sacramento's light rail system using the methodology developed in Subtask 1c. The methodology consists of calibrating the Mogridge-Lewis Convergence Hypothesis (MLC) model with survey data and using the model to quantify delay savings attributable to transit at different roadway traffic volumes. The savings are estimated for three different user categories using highway traffic data and light rail ridership in the corridor.

Study Methodology

The study methodology consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

During the first step, HLB collected HPMS data, local arterials traffic data, and light rail ridership data from Sacramento Area Council of Governments (the local MPO) and Sacramento Regional Transit (the local transit authority). The data were used to estimate the model parameters.

For the second step, data was collected on site by a survey team. A corridor, as defined in this study, is a principal transportation artery into the central business district. Multiple transportation services are available to commuters who use this artery. Additionally, during the peak period a large number of commuters utilize this route in their door-to-door commute.

A statistical sample of trips was generated in the corridor by identifying random trip end point in the zones at either end of the corridor and joining them so that trips alternated between zones. These zones are catchment zones where travelers converge or diverge from either the transit station or the principal highway route. In this study these zones are defined as the access segment and the component of the corridor common to all trips for a given mode, regardless of trip end location, is defined as the common segment.

Survey crews were instructed to follow specific routes that consisted of an access segment—dependent on the catchment zone considered for the trip—and a common segment. The data collected include start times and arrival times for each segment, by mode, congestion level, seating availability, weather, road conditions, and travel costs for each segment.

Data were collected over a period of three consecutive days (Tuesday to Thursday) during the first week of May 1999. The days of the week were sampled to eliminate fluctuations in traffic patterns and volumes due to the day of week effects. Trips were validated to minimize the effects of unusual or circumstantial conditions. Sixty valid trips were selected to ensure a statistically adequate sample size. The study employed the maps and routes connecting several zones within a residential area to several points within Sacramento's central business district.

Step three consisted of estimating the "with transit" curve based on the traffic volume and the door to door travel time. Using the model developed in Subtask 1c, HLB derived the "without transit" curve and estimated the hours of delay saved due to transit. This performance metric is defined as the vertical difference between the two curves.

In step four, the hours of delay saved due to transit are aggregated into three user categories. Savings by common highway-segment users are estimated using the traffic volume on the segment. Savings by light rail riders are estimated using the ridership data for each station along the corridor. Savings by parallel highway users are estimated using traffic volume on parallel highways and arterials within the corridor. The magnitude of the savings decreases as the distance between the common segment and the arterial increases.

Plan of the Report

This report presents the results from the Butterfield-Sacramento corridor case study. Following this introduction, Chapter 2 presents an overview of the model and methodology to estimate the delay saving. Chapter 3 displays the corridor characteristics and a description of the principal modes of transportation within the corridor. Chapter 4 presents the results from the 1999 door-to-door travel survey and shows the model estimation results. The chapter estimates the hours of delay saved due to transit per person per day, and provides a monetary value of the delay saved for three user categories. Appendices provide maps of the residential area and the central business district as well as supporting data and supplementary results on the survey findings by route.

Methodology and Model Overview

The methodology consists of four steps:

1. Estimating the Corridor Performance Baseline
2. Estimating the Corridor Performance in the Absence of transit
3. Extrapolating Delay Savings Due to Transit
4. Estimation of Corridor Performance without Re-calibration

Estimating the Corridor Performance Baseline

The Model This model establishes a functional relationship between the person trip volume –all modes—and the average door to door travel time by auto in the corridor.

The door to door travel time by auto can be determined using a logistic function which calculates the door to door travel time in terms of travel time at free flow speed, trip time by high capacity rail mode, and the volume of trips in the corridor for all modes. The door to door travel time can be estimated as follows:

$$\mathbf{T = (T_c - T_{ff}) / (1 + e^{-(\delta + \varepsilon V1)}) \quad + T_{ff}} \qquad \mathbf{(1)}$$

Where T_{a1} is auto trip time,

Tc is trip time by high-capacity rail mode

T_{ff} is auto trip time at free-flow speed,

V is person trip volume in the corridor by auto, and

δ, ε are model parameters

Equation 1 implies that the door to door auto trip time is equal to the trip time at free-flow speed plus a delay which depends on transit travel time and the person trip volume in the corridor.

In other words, when the highway volume is close to zero, travel time is equal to travel time at free flow speed.($T = T_{ff}$). As the volume increases, the travel time is equal to T_{ff} plus a delay due to the high volume, but adjusted to the travel time by high capacity transit. That is the high capacity transit alleviates some of the highway trip delay as some trips shift to transit.

Equation 1 is transformed into a linear functional form before the parameters δ and ε can be estimated, the transformed equation will be:

$$\mathbf{U = \delta + \varepsilon V_1} \qquad \mathbf{(2)}$$

Where $U = \ln [(T_c - T_{ff}) / (T - T_{ff}) - 1]$

Equation 2 is estimated using Ordinary Least Squares regression.

Data The data required for the estimation of the above equations are:

- person trip volume on the highway which can be calculated by dividing the traffic volume by the average vehicle occupancy (auto and buses). This data are available through HPMS data base and MPO's traffic data.
- free flow trip time is a constant.
- high capacity trip time is a constant.

The parameters δ and ε do not have to be re-estimated each year, they are both specific to the corridor and are relatively stable over the years. So periodically, the person trips volume can be inserted into Equation 1 to estimate the door to door travel time by auto.

Estimating the Corridor Performance in the Absence of transit

The Model This model represents the concept to quantify the role of transit in congestion management. In the absence of transit, the travel time Ta is estimated as:

$$\mathbf{T_a = T_{ff} \ * \ (1 + A\,(V^*)^{\beta})} \qquad \mathbf{(3)}$$

Where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V^* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door to door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

- The existing auto and bus person trips on the highway.
- The percentage of person transit trips shifting to auto
- The percentage of person transit trips shifting to bus
- The number of additional cars in the highway
- The number of additional buses in the highway
- The occupancy per vehicle in the absence of transit The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$V^* = V_1 + \alpha_1 V_c + \alpha_2 V_b \tag{4}$$

Where V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

4. α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor, and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

Type 1: “Explorers” who are casual switchers and who will divert to Single Occupancy Vehicles in the absence of transit.

Type 2: Commuters with low elasticity of demand with respect to generalized cost and who will divert to use the bus or carpool.

Type 3: Commuters with high elasticity of demand with respect to generalized cost and who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher the shift of transit riders to cars and buses. Therefore, higher degree of convergence will lead to higher delay, which translates into higher savings due to transit.

In words, Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high which translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve (as the volume increases, travel time increases at an increasing rate). The figure below illustrates the relationship between the volume and travel time both in the presence and in the absence of transit.

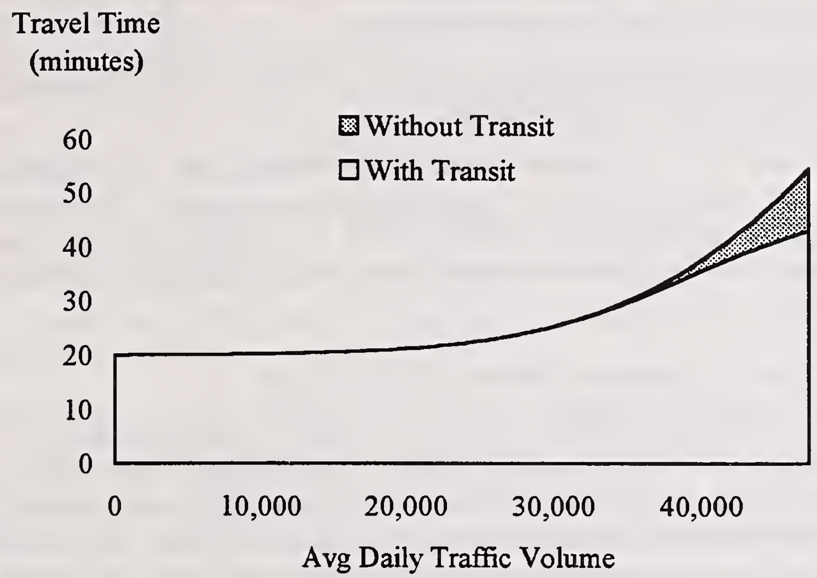


Figure A 4.1 Corridor Travel Times With and Without Transit

Data The data required to populate this model consist of:

- Highway person trip volume (used in the previous model)
- Transit ridership data
- Fleet composition (cars and buses percentages out of the total traffic)
- Cars and buses vehicle occupancy
- Passenger car equivalent factor
- Degree of convergence to determine the percentage person trips shifting to cars and buses
- Free-flow travel time which is a constant

Equation 3 is specific to the corridor and do not need to be estimated each year. It will only be necessary to re-estimate them with an updated degree of convergence if a major change is made to the transit level of service or the highway structure.

Extrapolating Delay Savings Due to Transit

While the MLC hypothesis proves to be valid during the peak period only, the delay savings due to transit can be estimated during off-peak as well. This metric can be estimated as the vertical difference between the "without transit" curve and the "with transit" curve. That is at a specific person trip volume, the difference in travel times between the two cases can be defined as "the hours of delay saved due to transit".

The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by Metro riders (market benefits), savings by highway users (club benefits), and savings by users of parallel highways (spillover benefits).

The market benefits are estimated based on delay saved (which depends on the distance traveled) for each rider within the common segment.

The club benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution.

The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment. The spillover benefits are calculated by multiplying the traffic volume with a percentage of the delay savings. This percentage decreases as the distance between the common segment and the parallel highway increases.

Estimation of Corridor Performance without Re-calibration

The framework, presented above, provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay without the need for repeated MLC surveys. The approach rests on the theoretical proposition, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Corridor Overview

The Butterfield-Sacramento corridor is about 11.6 miles in length and connects the residential area around Bradshaw Road and the central business district, downtown Sacramento. The residential catchment zone is centered around Butterfield Metro Station. Trip end points within the residential zone are no more than a 15-minute drive to the station. The downtown Sacramento CBD zone, centered around 9th and K street light rail station, extends for a radius of .5 miles. App. Annex A1 provides maps of the residential and business district zones considered in this study. The Butterfield-Sacramento light rail line is part of the 12-mile line connecting Downtown and Butterfield, east of Sacramento.

Principal Travel Modes

The "principal travel mode" is defined as the mode used during the common segment of each individual trip. The main transportation modes serving the Butterfield-Sacramento Corridor are automobile and the light rail. Automobile routes can be broken into three distinct sections:

1. The route between the residential point and the intersection of US-50 and Bradshaw Road (Access1);
2. The route from the intersection of US-50 and Bradshaw Road to the US-50/ I-5 Bypass (Common Segment); and
3. The route from the intersection of US-50/I-5 Bypass to the CBD destination point (Access 2).

For a morning rush hour trip, survey drivers followed Access 1 to the common segment. The common segment route originated at the intersection of US-50 and Bradshaw Road in Butterfield Station area. Drivers followed US-50 to I-5 Bypass. From the end of the common segment, survey drivers followed Access 2 to the downtown points, at which time they parked at the closest parking lot and proceeded on foot to the end point. The evening rush hour trip covered the same progression in the opposite direction.

The routes for the light rail mode riders can be broken into three distinct sections:

1. The route between the residential point and the Butterfield Station (Access1);
2. The route between the Butterfield Station and the 9th and K Street Station (Common Segment); and
3. The route between the 9th and K Street Station and the CBD point (Access2).

For a morning rush hour trip, survey crews drove Access 1 to the Butterfield Station parking lot and walked from the lot to the MAX station. The route taken for the common segment consisted of a light rail trip which began at the Butterfield Station and continued to the 9th and K Street Station. From the end of the common segment, the surveyor walked Access2 to the downtown points. The evening rush hour trip covered the same progression in the opposite direction. On average, trains run every 10 minutes during peak hours. Table A 4.2 displays some of the principal performance and service characteristics of the corridor.

Table A 4.2 Performance and Service Characteristics for Butterfield-Sacramento Corridor

	Automobile	Light Rail
Number of stops	N/A	16
Number of Streets and Highways	1	N/A
Tolls/Fares for a one way (in dollars)	$0.00	$1.25

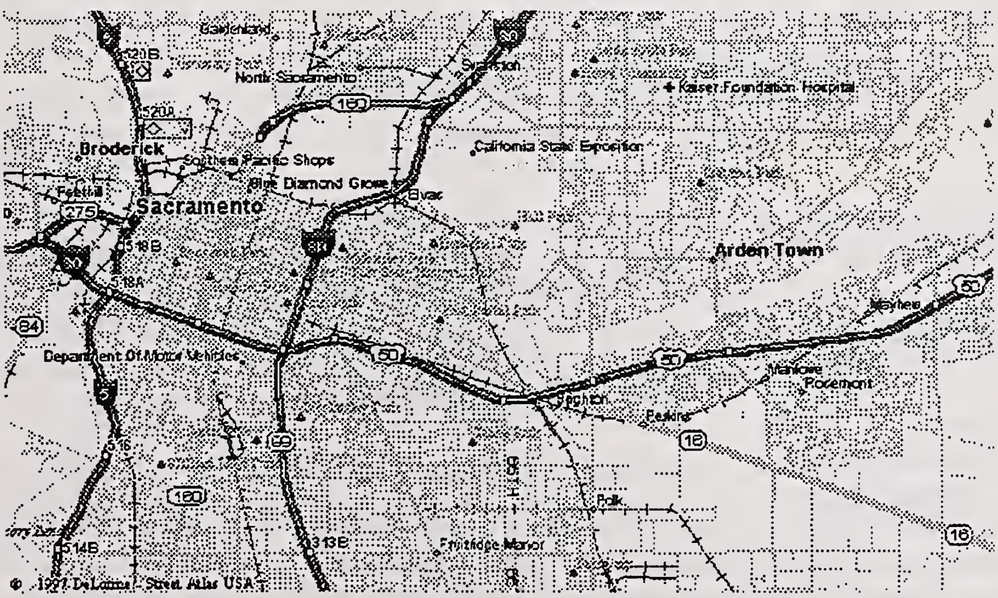


Figure A 4.2 Map of the Butterfield-Sacramento Corridor

Principal findings

This chapter starts by presenting the results from the door-to-door travel survey conducted during the first week of May 1999. The travel survey data are used to derive the inter-modal convergence level in the Butterfield-Sacramento corridor. The chapter then presents the estimation of the hours of delay saved due to transit for different user categories.

The Convergence Level

The starting point to estimate the "without transit" curve is to determine the convergence level based on the key findings from the 1999 door to door travel data.

The door to door travel survey for the Butterfield-Sacramento Corridor found that:

- Average door-to-door travel times for auto and metro rail, are not similar, 46.0 minutes by light rail versus 30.8 minutes by auto (Table A 4.2).
- Travel time reliability, as represented by the standard deviation of average travel time, is similar, 3.4 for light rail mode compared and 2.8 for the auto mode (Table A 4.3).
- Commuters experienced similar travel times in the morning and in the evening reflecting the similar traffic dynamics of the inbound peak flow versus the outbound peak flow in the corridor (Table A 4.4).
- Statistical analysis shows that the mean trip time by auto was at most 17 minutes longer with 95% confidence (Table A 4.5).
- The common segment travel time was greater for the light rail mode than for the transit mode, 28.4 minutes versus 13.1 minutes. The difference of 15.3 minutes between the two modes is due to the several stops of the light rail (16 stops) while the common segment for auto consisted of one highway (Table A 4.3).
- Access segment travel times was similar between auto commuters and transit commuters (Table A 4.3).

Table A 4.3 Results for the Butterfield-Sacramento Corridor

	Automobile	Light Rail
	Total Travel Time	
Mean	30.8	46.0
Standard Deviation	2.8	3.4
	Access Segment Travel Time	
Mean	17.7	17.6
Standard Deviation	2.6	1.5
	Common Segment Travel Time	
Mean	13.1	28.4
Standard Deviation	1.5	1.5
Sample Size	30	30

Table A 4.4 Comparison of AM and PM Trip Times by Modes

	Auto	Metro Rail
Inbound AM Average Trip Time	30.5	47.0
Outbound PM Average Trip Time	31.1	45.1

Table A 4.5 Statistical Testing of Convergence Hypothesis

Difference in Mean Travel Times by Mode (Auto- Metro Rail minutes)		15.2
Standard Error of the Difference of the Means (minutes)		0.80
Hypothesis: "The difference between the mean travel times by modes is at most..."	Significant at the 0.10 Level (90% Confidence)	Significant at the 0.05 Level (95% Confidence)
14 Minutes	NO	NO
15 Minutes	NO	NO
16 Minutes	NO	NO
17 Minutes	YES	YES
18 Minutes	YES	YES

The results in Table A 4.5 indicate that light rail in the defined corridor has drawn door-to-door travel times by highway and light rail to within 16 minutes of one another during congested roadway conditions (with 95 percent statistical confidence).

Although an inter-modal travel time convergence of 16 minutes is sufficient to yield delay savings to highway users (as compared to the "without rail" case – see below), full convergence would of course yield even greater savings. Why is the convergence level as high as 16 minutes? Stated differently, why is it that, even though door-to-door average peak-period roadway travel time is 16 minutes less than the average door-to-door travel time by light rail, light rail users are not re-exploring the roadway option by enough to "bid-up" roadway times any further?

The Mogridge-Lewis framework predicts that non-time related roadway travel costs (i.e, the non-time elements of "generalized cost" such as parking costs, fuel costs and so on) account for the "16 minute wedge." Light rail users are expected to re-explore the roadway option to the point at which the value of non-time generalized cost factors just equals the value of the travel time advantage offered by road. If non-time costs are moderate to high, travel time convergence will occur at a non-zero time differential between road and rail

Methodology Application on Butterfield-Sacramento Corridor

Data HLB obtained traffic volume data (HPMS data) from the regional MPO Sacramento Area Council of Governments. The ridership data were obtained from the Sacramento Regional Transit. In addition, door to door travel time survey was conducted to derive the degree of convergence in the corridor.

Model The traffic volume and travel time data were used to populate the model, Equation 1 is estimated as follows:

$$T_{a1} = (50 - 20) / (1 + e^{-(-6.817 + 0.00016 (V))}) + 20 \tag{1}$$

When V is equal to 0, the travel time is equal the travel time at free flow speed (20 minutes). For an auto traffic volume of 40,000 between Bradshaw Road and Downtown Sacramento (based on SACOG 1998 O-D tables), the travel time is equal to 28.05 minutes.

Similarly, Equation 2 is estimated based on auto travel volume, transit ridership data, and convergence level estimate from the survey.

$$T_{a2} = 50 * (1 + 1.22E\text{-}21 (V^*)^{4.5}) \tag{2}$$

The auto traffic volume in the absence of transit is determined by adding the auto volume in the presence of transit to the generated auto trips by transit riders. The generated is based on:

- About 40% of person transit trips will be forgone (determined by the corridor convergence level).
- The average vehicle occupancy (HOV and non-HOV) is 1.2 for cars and 40 for buses.
- Car trips will make about 90% of trips.

Benefit Estimation

To estimate the travel time saving (TTS) attributed to transit, the current traffic volume is inserted into Equation 1 and 2. An auto volume of 37,500 results into:

$$T_{a1} = 33.72,\ T_{a2} = 34.97, \text{ and . } TTS = T_{a2} - T_{a1} = 1.25$$

That is on average, on Butterfield-Sacramento corridor, transit saves about 1.25 minutes per auto trip (6.5 seconds per mile) during the peak period.

Once the average travel time saving per vehicle is estimated, the savings are weighted to reflect the congestion level at each time of the day. The Avg Traffic Volume by time of the day is shown below:

Feeding the volume levels for 1999, for the Butterfield-Sacramento corridor into equation (1) and (2), HLB estimated the hours of delay saved due to transit for 1999. The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by Metro riders (market benefits), savings by US-50 common segment users (club benefits), and savings by users of parallel highways (spillover benefits).

The market benefits are estimated based on delay saved (which depends on the distance traveled) by each rail rider within the common segment (Table A 4.6). The club benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution (Table A 4.7). The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment (Table A 4.8). The magnitude of savings by the commuters on these highways decreases with the distance to the common segment.

Table A 4.6 Market Benefits for Butterfield-Sacramento Corridor

Station	In-bound Trips	Out-bound Trips	Daily Savings (hours)
Butterfield	2393	-	32.41
Tiber	142	42	2.37
Starfire	270	137	4.96
Watt/Manlove	913	205	12.87
College Greens	431	228	7.14
Power Inn	575	116	7.02
65th St.	973	807	16.87
59th St	221	123	3.03
48th St	153	55	1.69
39th St	191	147	2.52
29th Street	1428	809	18.18
23rd St	520	464	8.66
16th St	401	364	7.25
13th St	112	188	3.05
Archives Pl	314	494	8.75
8th & O	543	803	15.49
7th & Capitol	440	460	10.97
Total	8,723	3,685	128

Table A 4.7 Club Benefits for Butterfield-Sacramento Corridor

	Distance (miles)	Avg Traffic Volume	Daily Savings (hours)
Common Segment (US 50)	9.6	85,750	1,153.19
Access Segment (average)	2	41,500	116.27
Total	11.60		1,269.46

Table A 4.9 shows the summary of benefits by category. The results indicate that the delay saving due to transit is about 1.25 minutes per trip one way (about 6 seconds per mile). Using a travel time value of $15 per hour and an average of 250 working days per year, the yearly delay saving can be valued at $7 million in 1999, this can be translated into a $ 0.6 million per rail mile in the Butterfield-Sacramento Corridor. The summary table shows that 67% of the savings are club savings while only 7% are market savings. These results illustrate the relative low ridership and the high use of automobile in the corridor.

Table A 4.8 Spillover Benefits for Butterfield-Sacramento Corridor

Highways in the corridor	Distance (miles)	Avg Traffic Volume	Daily Savings (hours)
Folsom Street	10	11,237	125.93
Fair Oaks	7	6,997	65.18
Hurley Way	7	6,158	56.16
Arden Way	6	8,053	61.60
Keifer Blvd.	5	9,934	59.14
Broadway	4	8,205	36.78
S Street	4	5,156	21.67
U Street	4	5,156	20.22
V Street	4	5,156	20.22
M Street	3	5,156	16.25
Total			483.16

Table A 4.9 Benefits Summary

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	128	$ 1,920	$ 480,007
Club	1,269	$ 19,042	$ 4,760,480
Spillover	483	$ 7,247	$ 1,811,851
Total	1,881	$ 28,209	$ 7,052,338

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door to door travel time data should be collected to estimate an accurate performance metric.

Annex A 4.1 Views of the Sacramento Butterfield Light Rail Corridor

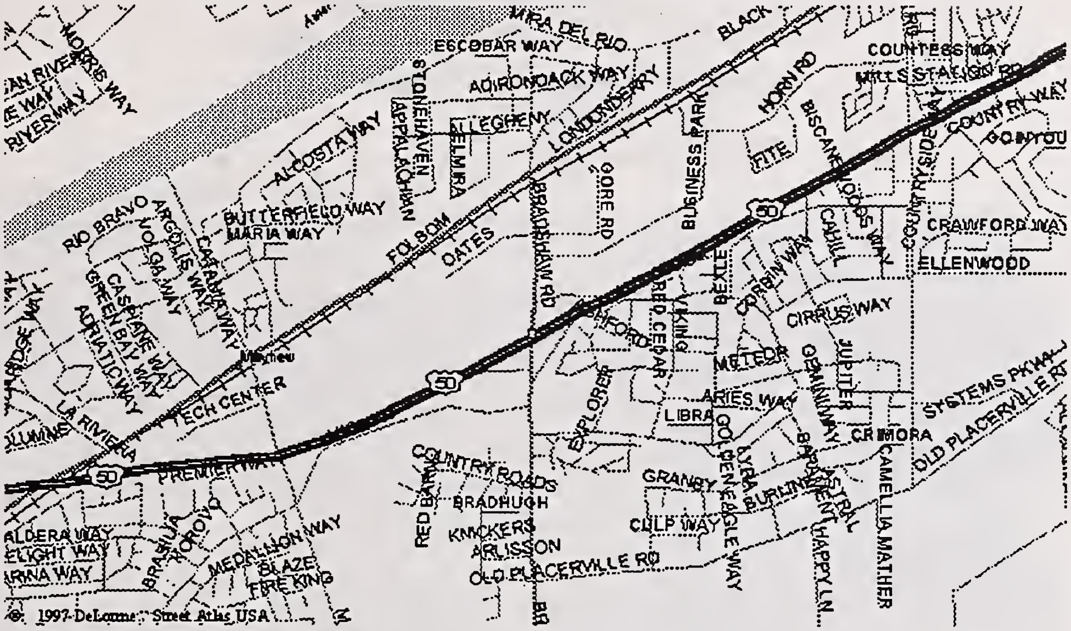
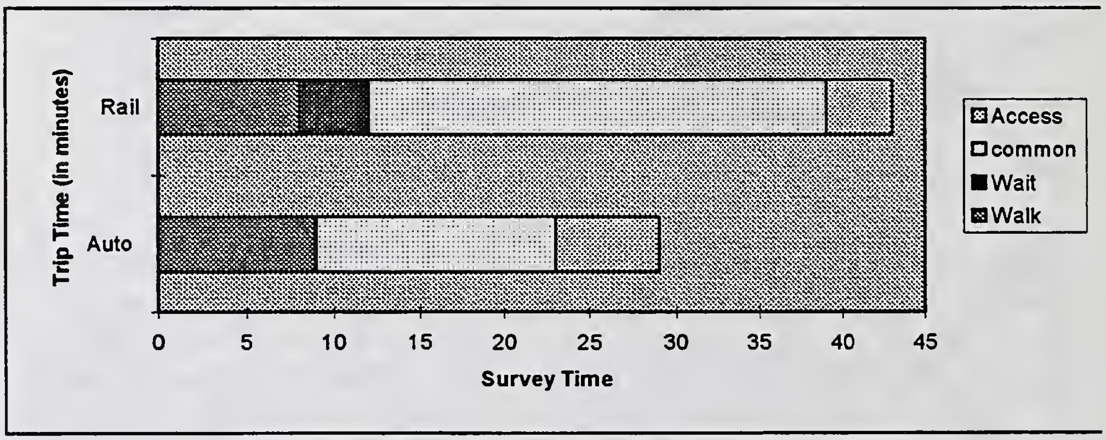


Figure A 4.3 Map of the residential district

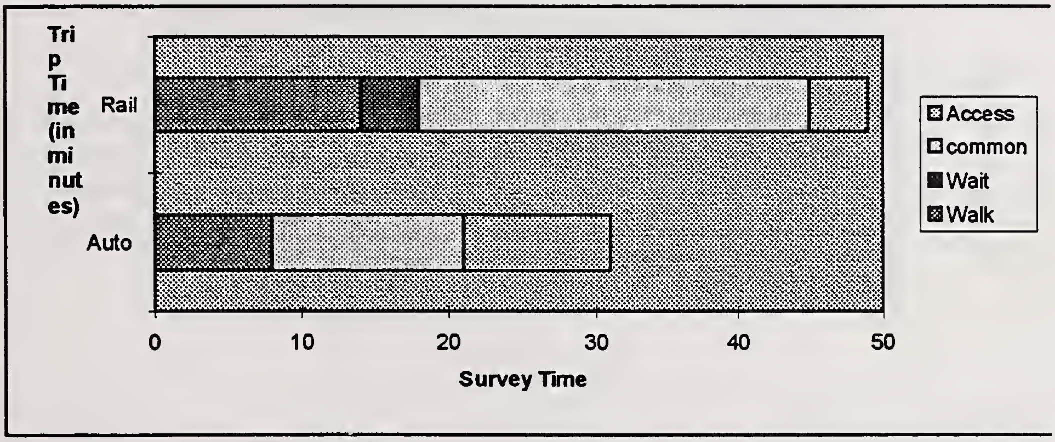
Figure A 4.4 Map of the central business district

Annex A 4.2 The survey findings by route

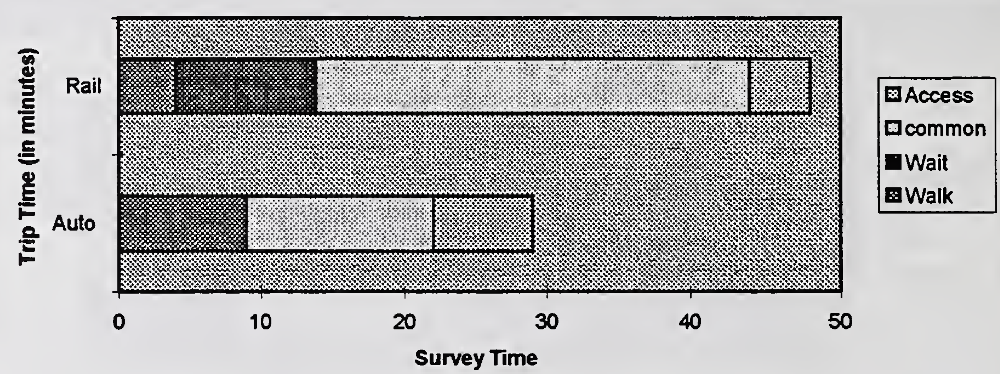
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE A1: Old Placerville & Happy Ln - 3rd & K		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	43
In Common Segment	14	27
Outside Common Segment	6	4
Wait Time	0	4
Walk Time	9	8
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	20.9
In Common Segment	41.1	26.7
Outside Common Segment	20.0	45.0



CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE B2: Old Placerville & Routier Rd - 3rd & L	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	31	49
In Common Segment	13	27
Outside Common Segment	10	4
Wait Time	0	4
Walk Time	8	14
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	22.5	18.4
In Common Segment	44.3	26.7
Outside Common Segment	12.0	45.0

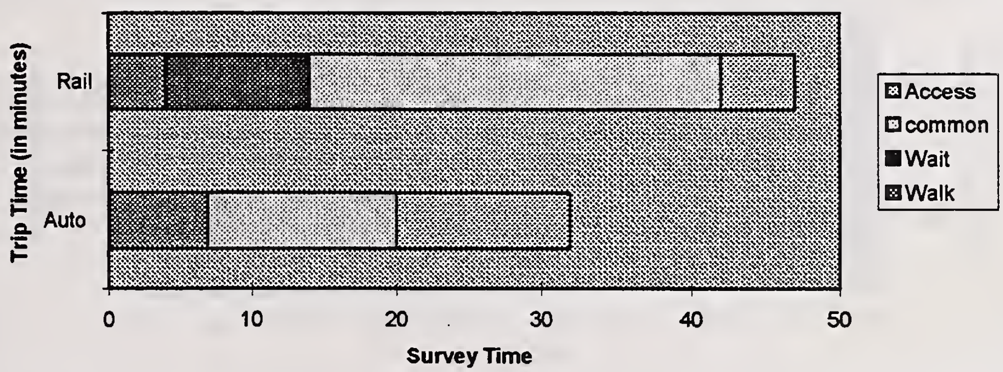


CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE C3: Mira del Rio & Escobar Way - 5th & L	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	48
In Common Segment	13	30
Outside Common Segment	7	4
Wait Time	0	10
Walk Time	9	4
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	18.8
In Common Segment	44.3	24.0
Outside Common Segment	17.1	45.0

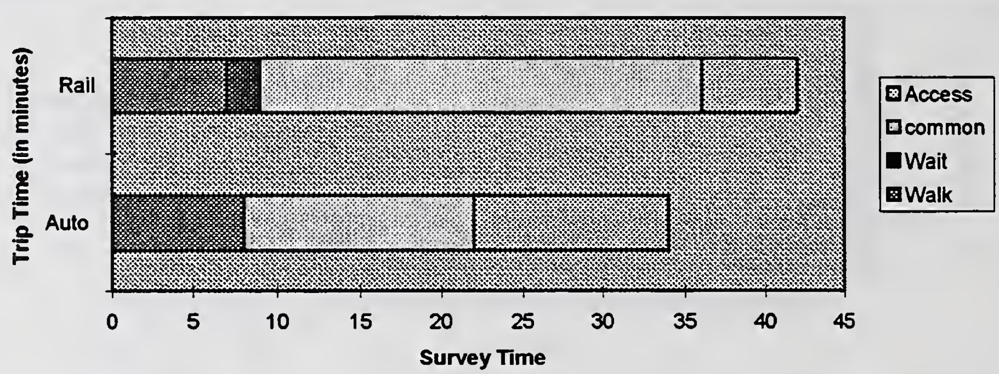


CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE D4:
Bradshaw & Mira del Rio - 3rd & Capital

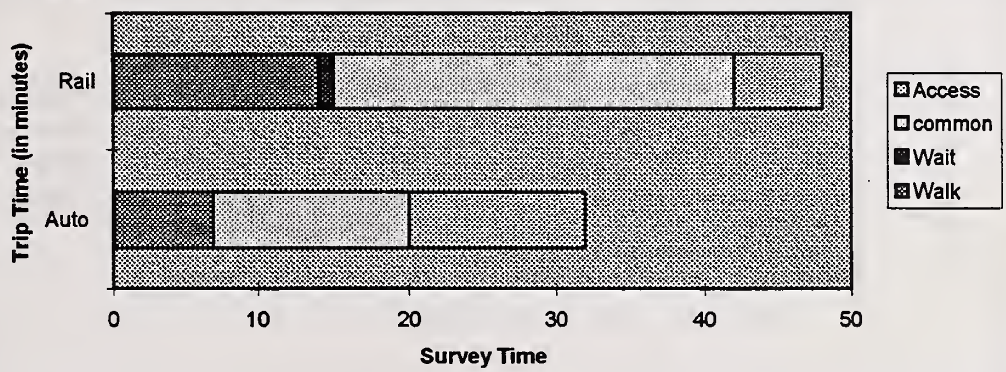
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	32	47
In Common Segment	13	28
Outside Common Segment	12	5
Wait Time	0	10
Walk Time	7	4
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	21.8	19.1
In Common Segment	44.3	25.7
Outside Common Segment	10.0	36.0



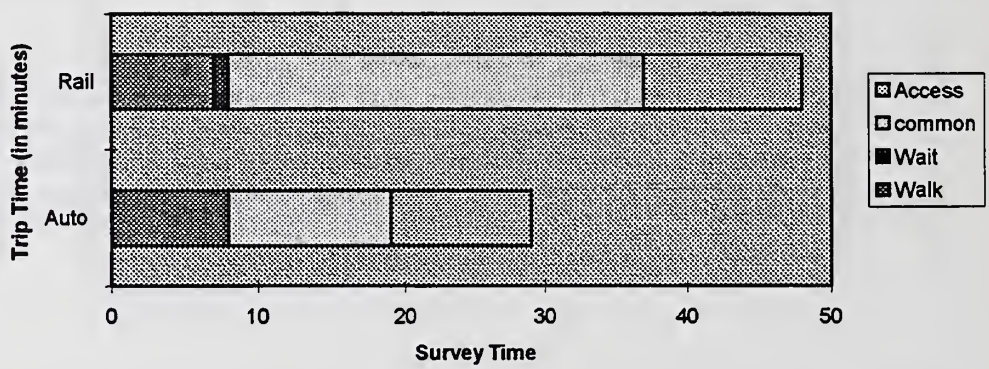
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE E5: Bradshaw & Old Placerville - 4th & J	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	34	42
In Common Segment	14	27
Outside Common Segment	12	6
Wait Time	0	2
Walk Time	8	7
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	20.5	21.4
In Common Segment	41.1	26.7
Outside Common Segment	10.0	30.0



CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 1A: 3rd & K - Old Placerville & Happy Ln	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	32	48
In Common Segment	13	27
Outside Common Segment	12	6
Wait Time	0	1
Walk Time	7	14
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	21.8	18.8
In Common Segment	44.3	26.7
Outside Common Segment	10.0	30.0

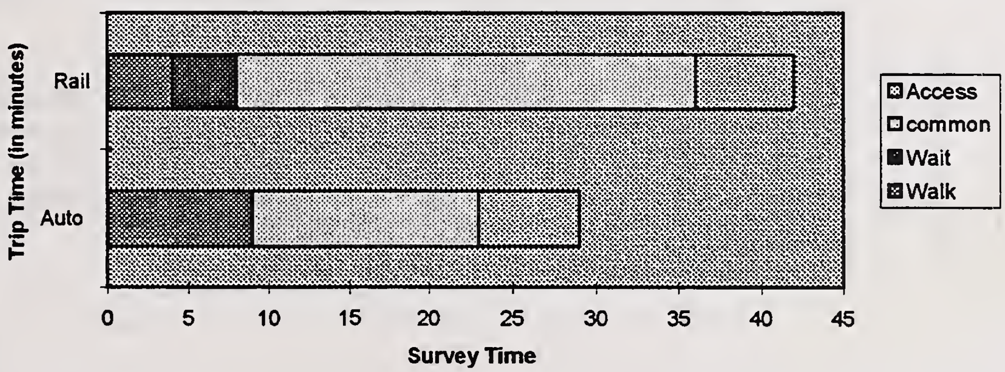


CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 2B: 3rd & L - Old Placerville & Routier Rd.	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	48
In Common Segment	11	29
Outside Common Segment	10	11
Wait Time	0	1
Walk Time	8	7
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	18.8
In Common Segment	52.4	24.8
Outside Common Segment	12.0	16.4

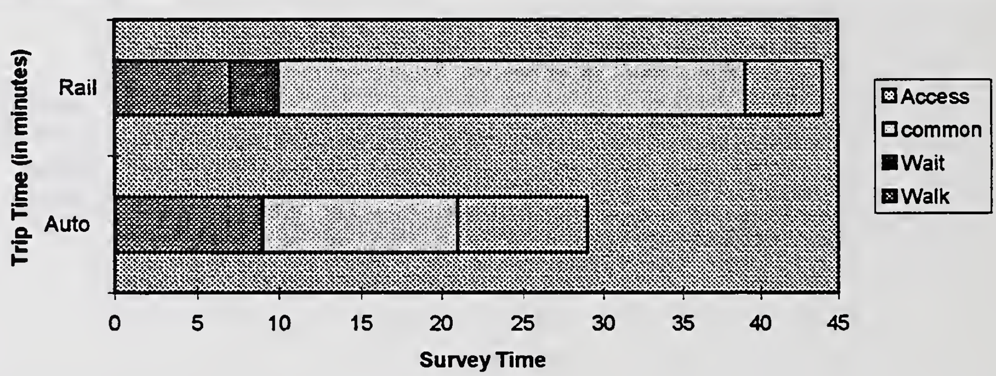


CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE 3C:
5th & L - Mira del Rio & Escobar

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	42
In Common Segment	14	28
Outside Common Segment	6	6
Wait Time	0	4
Walk Time	9	4
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	21.4
In Common Segment	41.1	25.7
Outside Common Segment	20.0	30.0

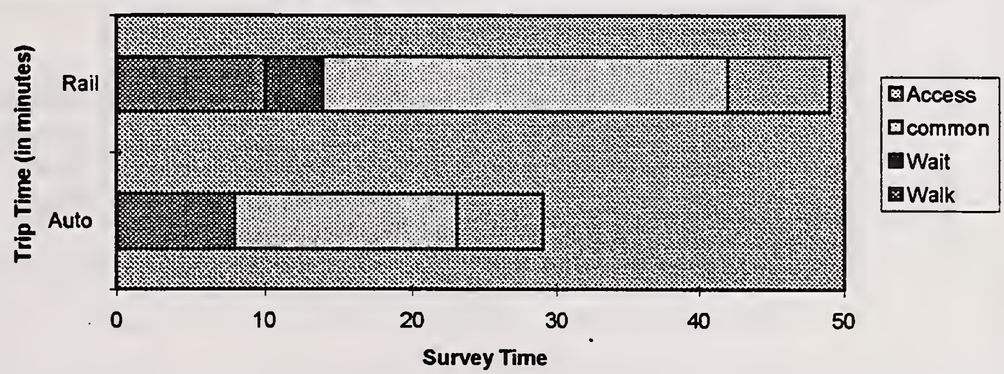


CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 4D: 3rd & Capital - Bradshaw & Mira del Rio	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	44
In Common Segment	12	29
Outside Common Segment	8	5
Wait Time	0	3
Walk Time	9	7
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	20.5
In Common Segment	48.0	24.8
Outside Common Segment	15.0	36.0

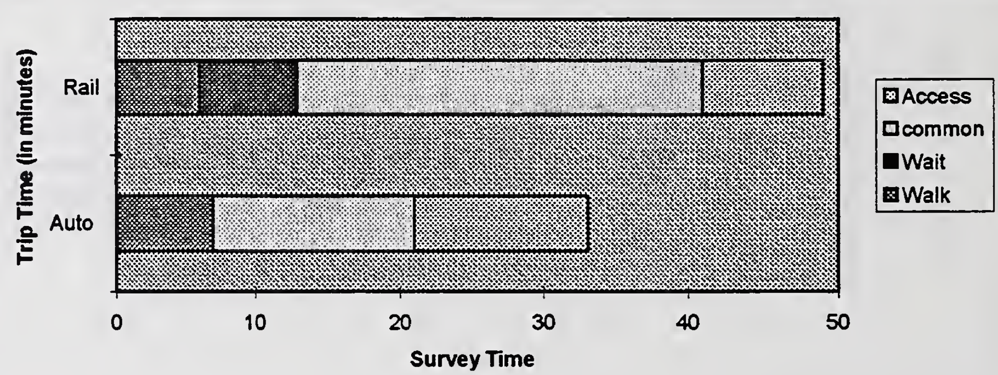


CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE 5E:
4th & J - Bradshaw & Old Placerville

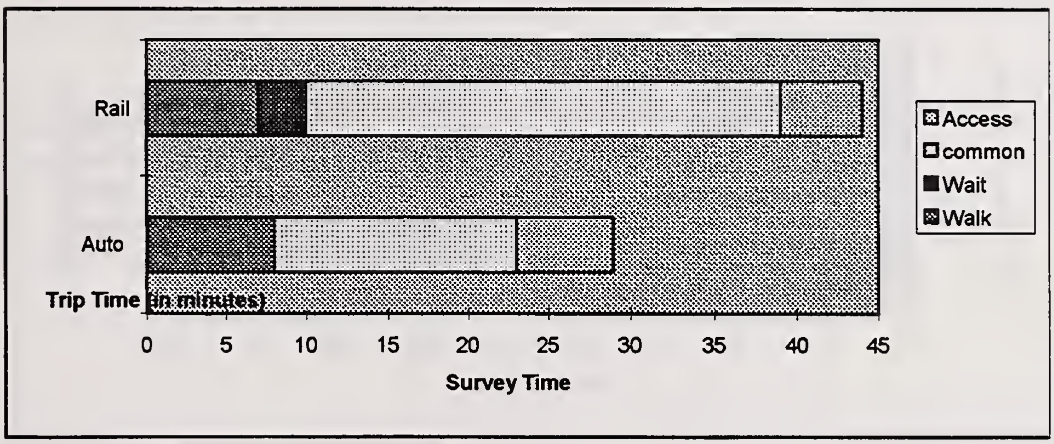
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	49
In Common Segment	15	28
Outside Common Segment	6	7
Wait Time	0	4
Walk Time	8	10
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	18.4
In Common Segment	38.4	25.7
Outside Common Segment	20.0	25.7



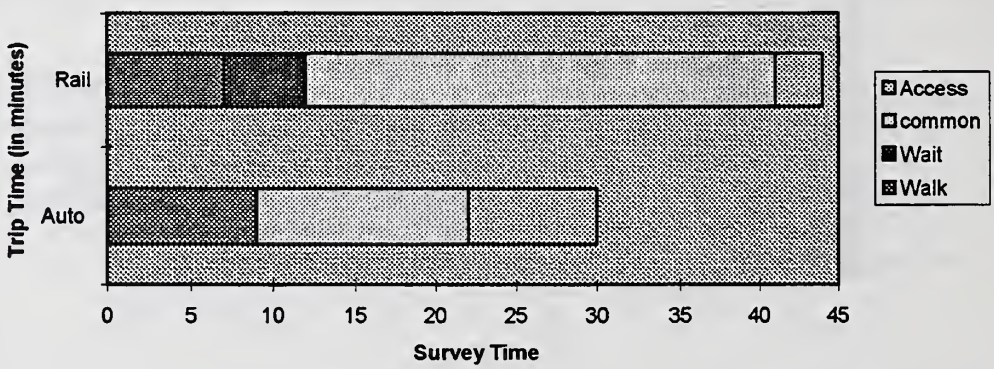
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE B1: Old Placerville & Routier Rd - 3rd & K	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	33	49
In Common Segment	14	28
Outside Common Segment	12	8
Wait Time	0	7
Walk Time	7	6
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	21.1	18.4
In Common Segment	41.1	25.7
Outside Common Segment	10.0	22.5



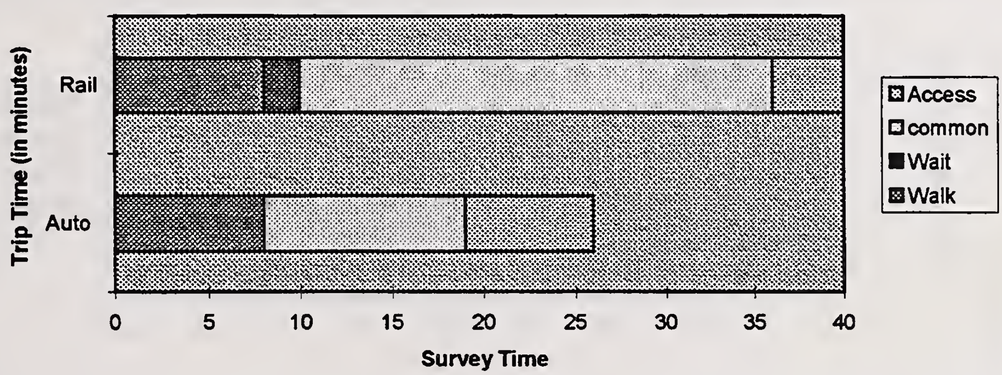
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE ROUTE C2 Mira del Rio & Escobar Way - 3rd & L	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	29	44
In Common Segment	15	29
Outside Common Segment	6	5
Wait Time	0	3
Walk Time	8	7
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	20.5
In Common Segment	38.4	24.8
Outside Common Segment	20.0	36.0



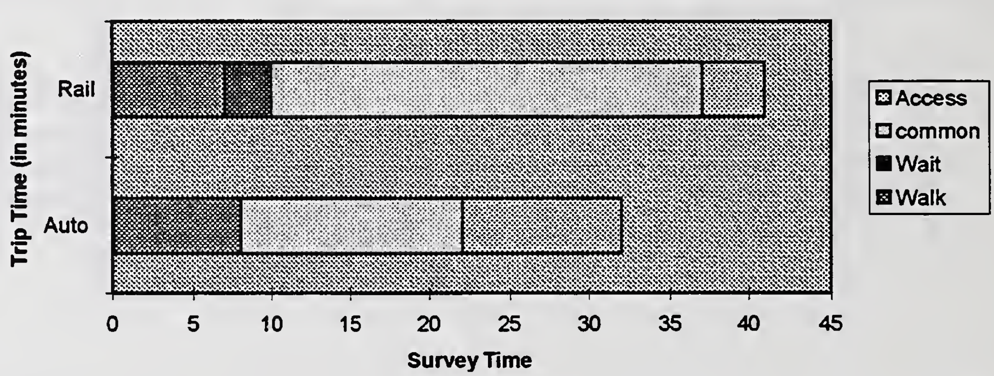
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE D3: Bradshaw & Mira del Rio - 5th & L	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	30	44
In Common Segment	13	29
Outside Common Segment	8	3
Wait Time	0	5
Walk Time	9	7
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	23.2	20.5
In Common Segment	44.3	24.8
Outside Common Segment	15.0	60.0



CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE E4: Bradshaw & Old Placerville - 3rd & Capital	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	26	40
In Common Segment	11	26
Outside Common Segment	7	4
Wait Time	0	2
Walk Time	8	8
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	26.8	22.5
In Common Segment	52.4	27.7
Outside Common Segment	17.1	45.0

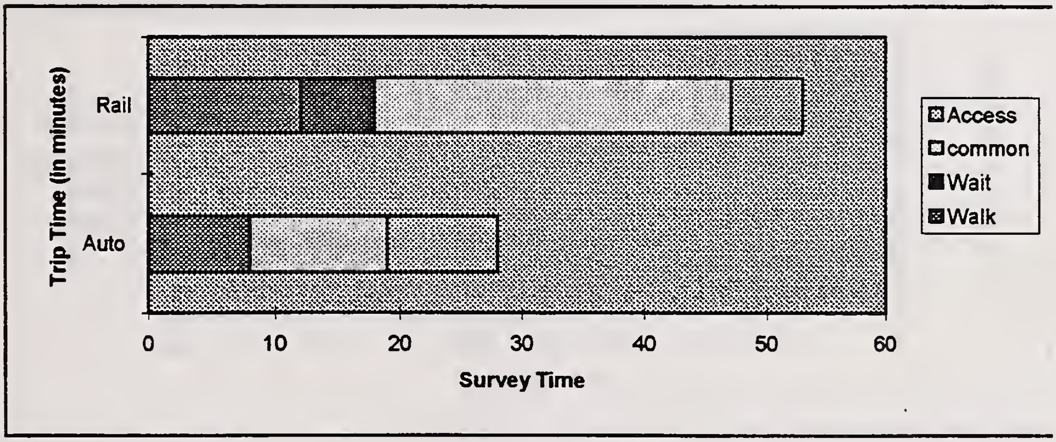


CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE F5: Mayhew & Keifer - 4th & J	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	32	41
In Common Segment	14	27
Outside Common Segment	10	4
Wait Time	0	3
Walk Time	8	7
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	21.8	22.0
In Common Segment	41.1	26.7
Outside Common Segment	12.0	45.0



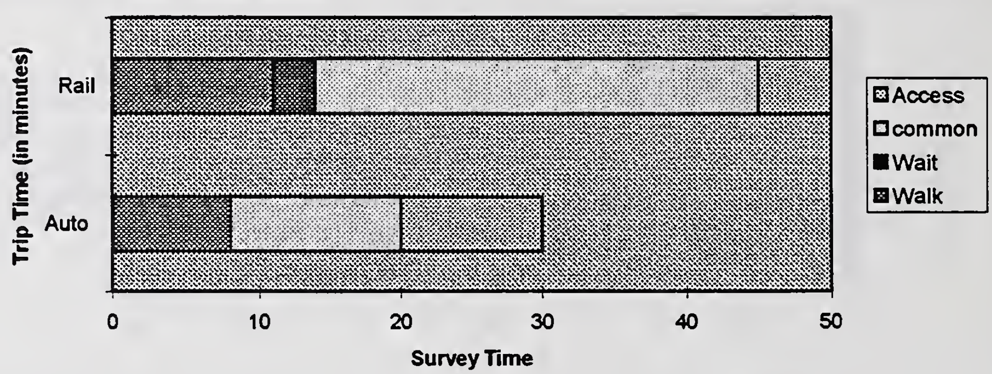
CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE 1B:
3rd & K - Routier & Old Placerville

	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	28	53
In Common Segment	11	29
Outside Common Segment	9	6
Wait Time	0	6
Walk Time	8	12
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.9	17.0
In Common Segment	52.4	24.8
Outside Common Segment	13.3	30.0

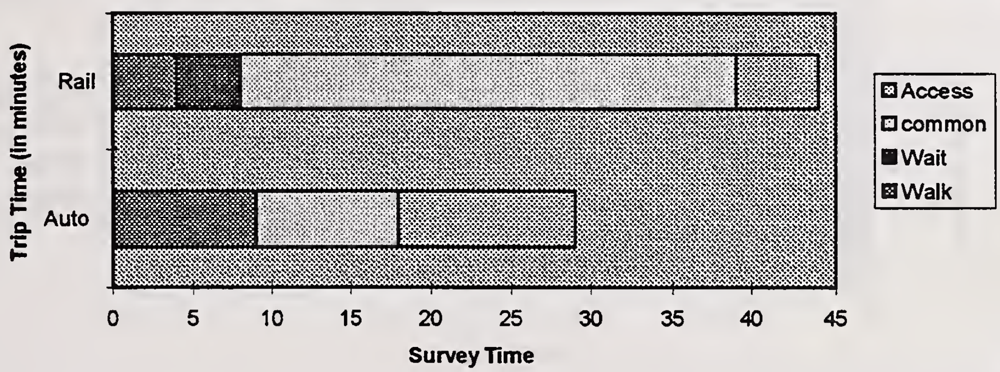


CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE 2C:
3rd & L - Mira del Rio & Escobar Way

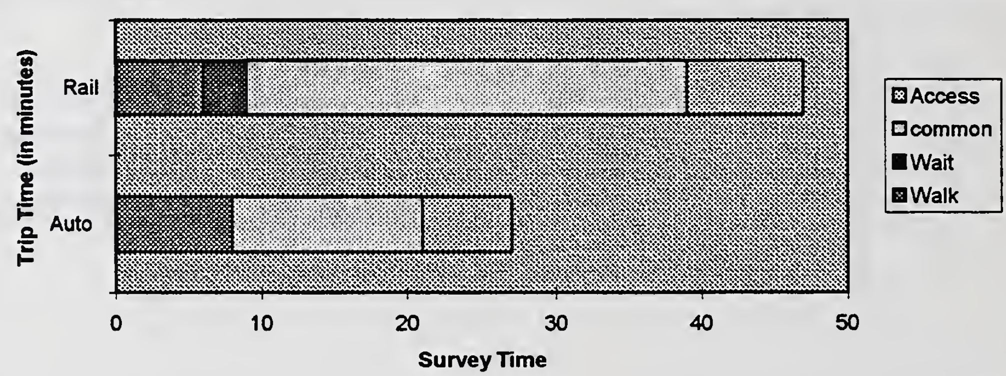
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	30	50
In Common Segment	12	31
Outside Common Segment	10	5
Wait Time	0	3
Walk Time	8	11
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	23.2	18.0
In Common Segment	48.0	23.2
Outside Common Segment	12.0	36.0



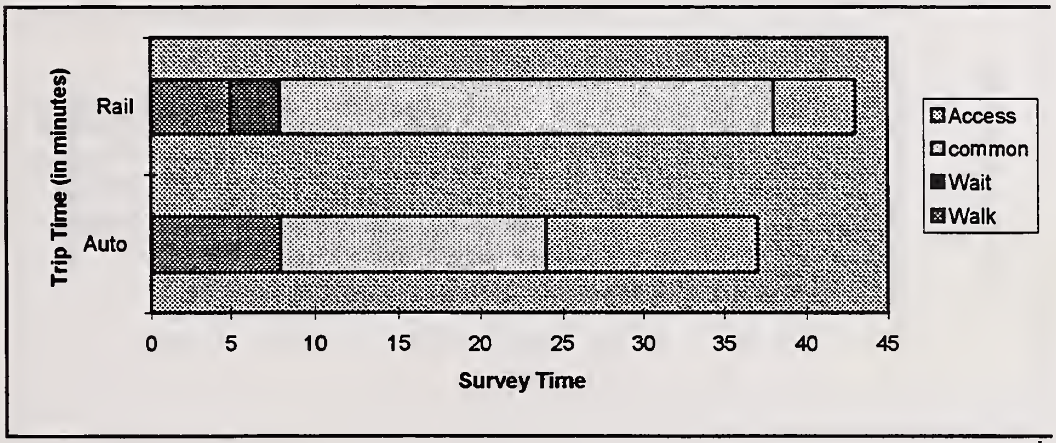
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 3D: 5th & L - Bradshaw & Mira del Rio	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	44
In Common Segment	9	31
Outside Common Segment	11	5
Wait Time	0	4
Walk Time	9	4
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	20.5
In Common Segment	64.0	23.2
Outside Common Segment	10.9	36.0



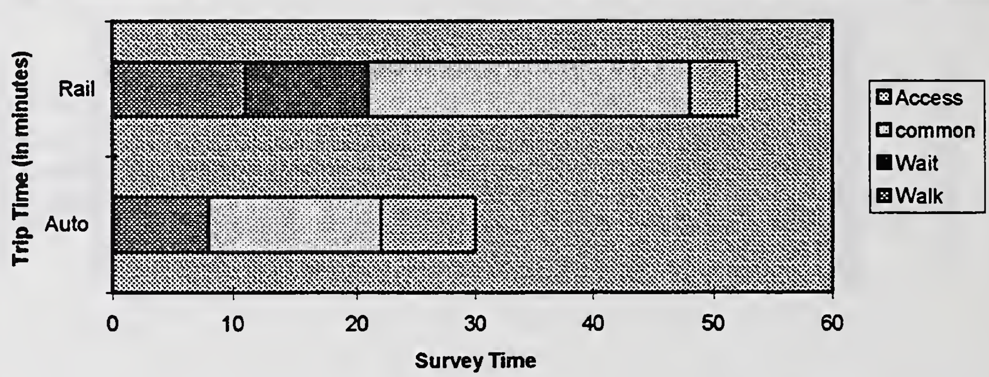
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 4E: 3rd & Capital - Bradshaw & Old Placerville	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	27	47
In Common Segment	13	30
Outside Common Segment	6	8
Wait Time	0	3
Walk Time	8	6
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	25.8	19.1
In Common Segment	44.3	24.0
Outside Common Segment	20.0	22.5



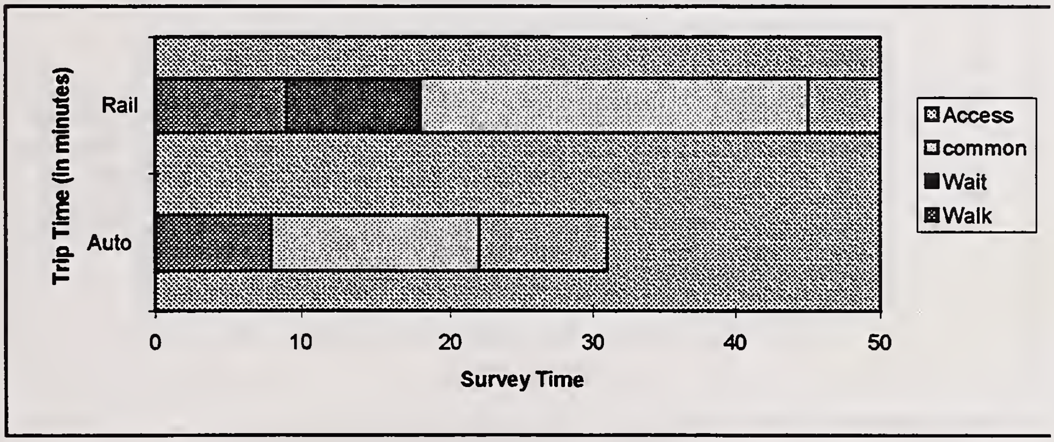
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 5F: 4th & J - Mayhew & Keifer	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	37	43
In Common Segment	16	30
Outside Common Segment	13	5
Wait Time	0	3
Walk Time	8	5
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	18.8	20.9
In Common Segment	36.0	24.0
Outside Common Segment	9.2	36.0



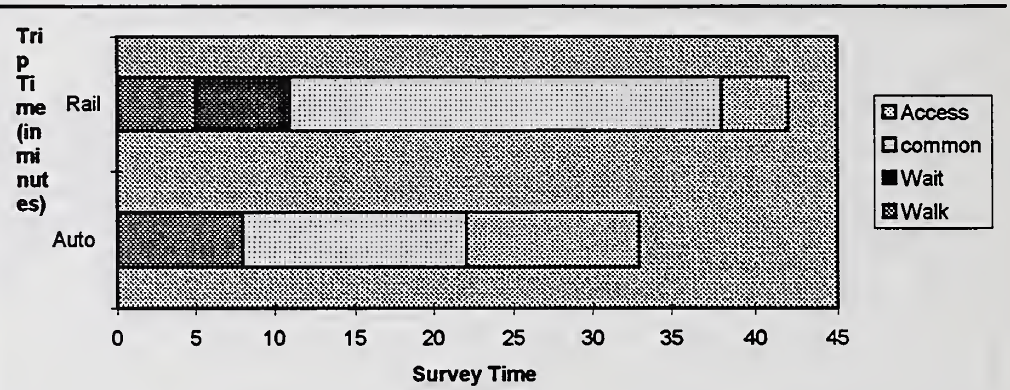
CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE F6: Mayhew & Keifer - 6th & H	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	30	52
In Common Segment	14	27
Outside Common Segment	8	4
Wait Time	0	10
Walk Time	8	11
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	23.2	17.3
In Common Segment	41.1	26.7
Outside Common Segment	15.0	45.0



CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE G7: Keifer & Bradshaw - 8th & H	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	31	50
In Common Segment	14	27
Outside Common Segment	9	5
Wait Time	0	9
Walk Time	8	9
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	22.5	18.0
In Common Segment	41.1	26.7
Outside Common Segment	13.3	36.0

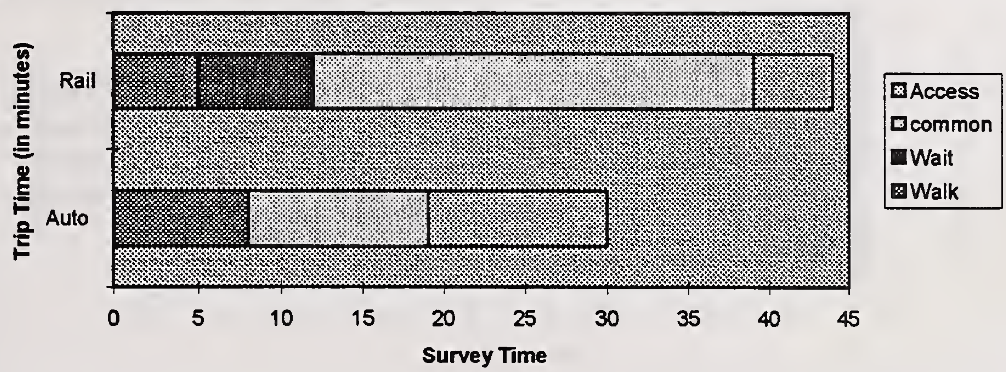


CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE H8: Rosemont & Huntsman - 9th & I	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	33	42
In Common Segment	14	27
Outside Common Segment	11	4
Wait Time	0	6
Walk Time	8	5
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	21.1	21.4
In Common Segment	41.1	26.7
Outside Common Segment	10.9	45.0



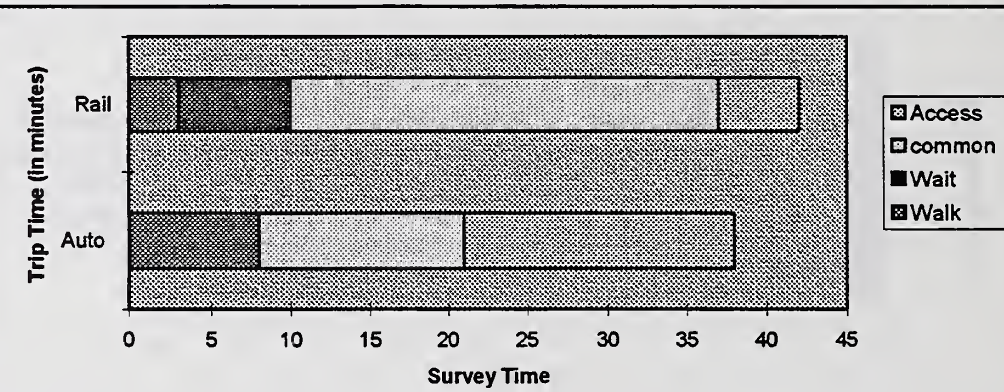
CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE I9:
Keifer & Huntsman - 7th & I

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	30	44
In Common Segment	11	27
Outside Common Segment	11	5
Wait Time	0	7
Walk Time	8	5
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	23.2	20.5
In Common Segment	52.4	26.7
Outside Common Segment	10.9	36.0



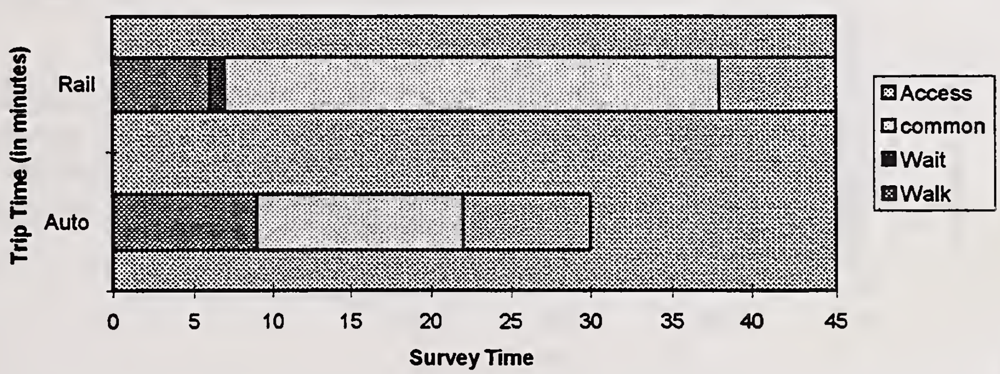
CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE J10:
Folsom & Routier - 9 & L

	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	38	42
In Common Segment	13	27
Outside Common Segment	17	5
Wait Time	0	7
Walk Time	8	3
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	18.3	21.4
In Common Segment	44.3	26.7
Outside Common Segment	7.1	36.0

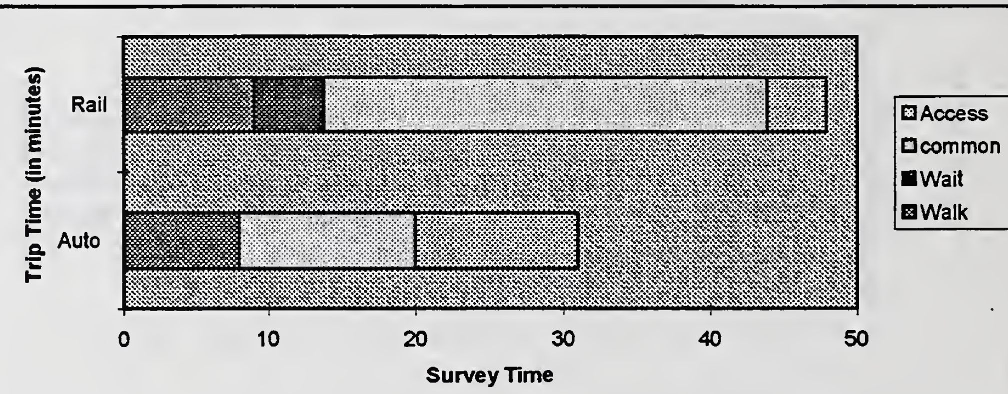


CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE 6G:
6th & H - Keifer & Bradshaw

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	30	45
In Common Segment	13	31
Outside Common Segment	8	7
Wait Time	0	1
Walk Time	9	6
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	23.2	20.0
In Common Segment	44.3	23.2
Outside Common Segment	15.0	25.7

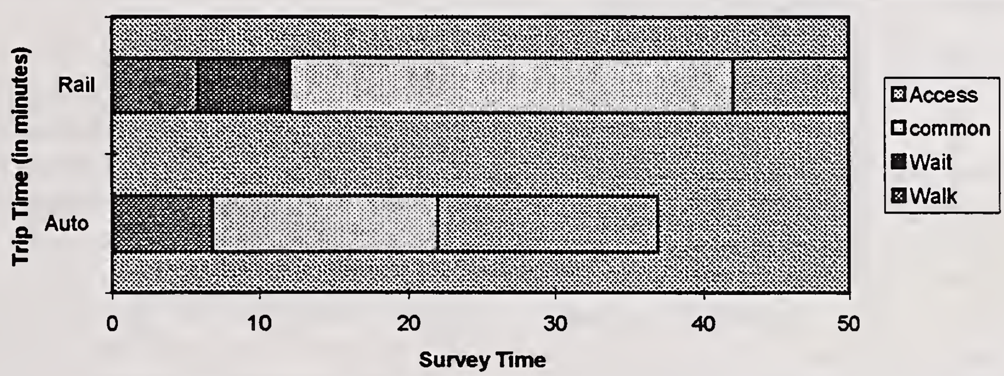


CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 7H: 8th & H - Rosemont & Huntsman	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	31	48
In Common Segment	12	30
Outside Common Segment	11	4
Wait Time	0	5
Walk Time	8	9
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	22.5	18.8
In Common Segment	48.0	24.0
Outside Common Segment	10.9	45.0

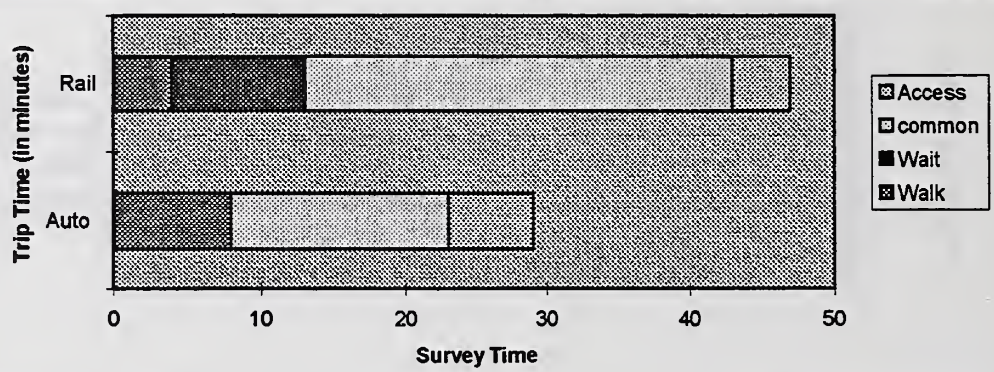


CORRIDOR: Butterfield - Sacramento
SUMMARY TABLE FOR
ROUTE 8I:
9th & I - Keifer & Huntsman

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	37	50
In Common Segment	15	30
Outside Common Segment	15	8
Wait Time	0	6
Walk Time	7	6
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	18.8	18.0
In Common Segment	38.4	24.0
Outside Common Segment	8.0	22.5



CORRIDOR: Butterfield - Sacramento SUMMARY TABLE FOR ROUTE 9J: 7th & I - Folsom & Routier	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	29	47
In Common Segment	15	30
Outside Common Segment	6	4
Wait Time	0	9
Walk Time	8	4
DISTANCE (miles)		
Route Distance	11.6	15.0
Common Segment Distance	9.6	12.0
SPEED (mph)		
Trip	24.0	19.1
In Common Segment	38.4	24.0
Outside Common Segment	20.0	45.0



Appendix 5. The Park Lane Light Rail Corridor Serving Dallas

Executive summary

Working Paper 1 (Subtask 1d, November 25, 1998) develops a theoretical and measurement framework within which the Mogridge-Lewis Convergence Hypothesis (MLC) can be employed in measuring the savings in highway delay attributable to transit and its equilibrating effect on the level of service in the corridor.

The framework also provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay *without* the need for repeated MLC surveys. The approach rests on the theoretical proposition, proven in Working Paper 1, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Purpose and Method

This Working Paper presents a case study of the methodology developed in Subtask 1c in application to the Park Lane-Dallas corridor. The methodology consists of calibrating the MLC-traffic model with survey data. The model is then used to quantify delay savings attributable to light rail at present, and at alternative roadway traffic volumes (each for different user categories).

The study consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

The Park Lane-Dallas corridor was selected to measure the performance of the light rail system connecting several residential areas with the Central Business District of Dallas, Texas. MLC theory predicts that the improved transit system will attract modal explorers, reduce congestion, and improve roadway travel times. As a result, we would expect to see improvements in *both* highway and transit door-to-door travel times

Principal Findings

The case study finds that based on the MLC model calibrated with 1999 survey data, the magnitude of peak-period delay savings per trip due to transit is about 3.54 minutes per door-to-door trip (about 18 seconds per mile). These savings amount to about 8 percent of total door-to-door journey times and align with reasoned expectations.

HLB estimated the hours of delay savings for three different user groups: Light rail riders (market benefits), users of the US-75 common segment (club benefits), and users of parallel highways (spillover benefits). Table A 5.1 presents the estimated delay savings by category of user. Based on an assumed value of peak travel time of $15 per hour and an average of 250 working days per year, Table A 5.1 indicates aggregate peak delay savings due to transit of $36.8 million for 1999. The savings can be translated to $2.8 million per rail mile.

Table A 5.1 Benefits Summary for the Park Lane-Dallas Corridor

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	4,311	64,672	16,167,962
Club	1,990	29,855	7,463,708
Spillover	3,532	52,984	13,246,016
Total	9,834	147,511	36,877,686

The summary table shows that 44% of the savings are market savings. These results illustrate the relative high ridership and the high reliability on light rail in the corridor.

Figure A 5.1 displays the "with-" and "without transit" curves using 1999 convergence data. The vertical difference between the "with-" and "without transit" curves represents the delay savings due to transit at different volumes of US-75 traffic. The curves indicate that in the absence of major infrastructure improvements or radical traffic growth, the performance metric will remain stable.

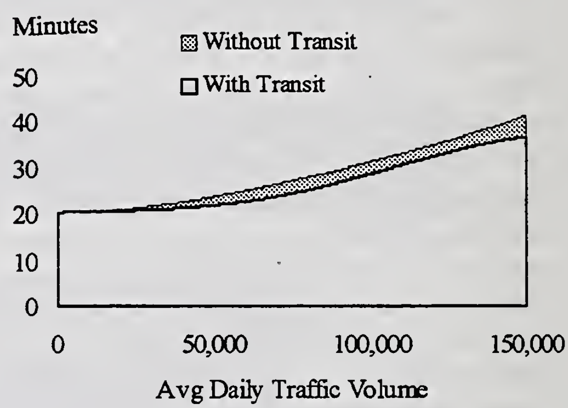


Figure A 5.1 Illustration of the "With-" and "Without Transit" curves for the Park Lane - Dallas Corridor

Introduction

This report presents the results for the Park Lane-Dallas corridor case study as part of Streamlined Strategic Corridor Travel Time Management study. The purpose of the study is to use the convergence measurement technique to derive a repeatable performance measurement for rail transit in congested corridors. This case study measures the performance of Dallas's light rail system using the methodology developed in Subtask 1c. The methodology consists of calibrating the Mogridge-Lewis Convergence Hypothesis (MLC) model with survey data and using the model to quantify delay savings attributable to transit at different roadway traffic volumes. The savings are estimated for three different user categories using highway traffic data and light rail ridership in the corridor.

Study Methodology

The study methodology consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

During the first step, HLB collected HPMS data, local arterials traffic data, and light rail ridership data from The City of Dallas, Transportation Planning Department (the local MPO) and Dallas Area Rapid Transit-DART (the local transit authority). The data were used to estimate the model parameters.

For the second step, data was collected on site by a survey team. A corridor, as defined in this study, is a principal transportation artery into the central business district. Multiple transportation services are available to commuters who use this artery. Additionally, during the peak period a large number of commuters utilize this route in their door-to-door commute.

A statistical sample of trips was generated in the corridor by identifying random trip end point in the zones at either end of the corridor and joining them so that trips alternated between zones. These zones are catchment zones where travelers converge or diverge from either the transit station or the principal highway route. In this study these zones are defined as the access segment and the component of the corridor common to all trips for a given mode, regardless of trip end location, is defined as the common segment.

Survey crews were instructed to follow specific routes that consisted of an access segment—dependent on the catchment zone considered for the trip—and a common segment. The data collected include start times and arrival times for each segment, by mode, congestion level, seating availability, weather, road conditions, and travel costs for each segment.

Data were collected over a period of three consecutive days (Tuesday to Thursday) during the third week of September 1999. The days of the week were sampled to eliminate fluctuations in traffic patterns and volumes due to the day of week effects. Trips were validated to minimize the effects of unusual or circumstantial conditions. Sixty valid trips were selected to ensure a statistically adequate sample size. The study employed the maps and routes connecting several zones within a residential area to several points within Dallas's central business district.

Step three consisted of estimating the "with transit" curve based on the traffic volume and the door-to-door travel time. Using the model developed in Subtask 1c, HLB derived the "without transit" curve and estimated the hours of delay saved due to transit. This performance metric is defined as the vertical difference between the two curves.

In step four, the hours of delay saved due to transit are aggregated into three user categories. Savings by common highway-segment users are estimated using the traffic volume on the segment. Savings by light rail riders are estimated using the ridership data for each station along the corridor. Savings by parallel highway users are estimated using traffic volume on parallel highways and arterials within the corridor. The magnitude of the savings decreases as the distance between the common segment and the arterial increases.

Plan of the Report

This report presents the results from the Park Lane-Dallas corridor case study. Following this introduction, Chapter 2 presents an overview of the model and methodology to estimate the delay saving. Chapter 3 displays the corridor characteristics and a description of the principal modes of transportation within the corridor. Chapter 4 presents the results from the 1999 door-to-door travel survey and shows the model estimation results. The chapter estimates the hours of delay saved due to transit per person per day, and provides a monetary value of the delay saved for three user categories. Appendices provide maps of the residential area and the central business district as well as supporting data and supplementary results on the survey findings by route.

Methodolgy and Model Overview

The methodology consists of four steps:

1. Estimating the Corridor Performance Baseline
2. Estimating the Corridor Performance in the Absence of transit
3. Extrapolating Delay Savings Due to Transit
4. Estimation of Corridor Performance without Re-calibration

Estimating the Corridor Performance Baseline

The Model This model establishes a functional relationship between the person trip volume – all modes—and the average door-to-door travel time by auto in the corridor.

The door to door travel time by auto can be determined using a logistic function which calculates the door to door travel time in terms of travel time at free flow speed, trip time by high capacity rail mode, and the volume of trips in the corridor for all modes. The door-to-door travel time can be estimated as follows:

5. $T = (T_c - T_{ff}) / (1 + e^{-(\delta + \varepsilon V1)}) + T_{ff}$ (1)

Where T_{a1} is auto trip time,

Tc is trip time by high-capacity rail mode

T_{ff} is auto trip time at free-flow speed,

V is person trip volume in the corridor by auto, and

δ, ε are model parameters

Equation 1 implies that the door-to-door auto trip time is equal to the trip time at free-flow speed plus a delay that depends on transit travel time and the person trip volume in the corridor.

In other words, when the highway volume is close to zero, travel time is equal to travel time at free flow speed.($T = T_{ff}$). As the volume increases, the travel time is equal to T_{ff} plus a delay due to the high volume, but adjusted to the travel time by high capacity transit. That is the high capacity transit alleviates some of the highway trip delay as some trips shift to transit.

Equation 1 is transformed into a linear functional form before the parameters δ and ε can be estimated, the transformed equation will be:

$$U = \delta + \varepsilon V_1 \quad (2)$$

Where $U = \ln [(T_c - T_{ff}) / (T - T_{ff}) - 1]$

Equation 2 is estimated using Ordinary Least Squares regression.

Data The data required for the estimation of the above equations are:

- Person trip volume on the highway that can be calculated by dividing the traffic volume by the average vehicle occupancy (auto and buses). This data are available through HPMS database and MPO's traffic data.
- Free flow trip time is a constant.
- High capacity trip time is a constant.

The parameters δ and ε do not have to be re-estimated each year, they are both specific to the corridor and are relatively stable over the years. So periodically, the person trips volume can be inserted into Equation 1 to estimate the door to door travel time by auto.

Estimating the Corridor Performance in the Absence of transit

The Model This model represents the concept to quantify the role of transit in congestion management. In the absence of transit, the travel time Ta is estimated as:

$$T_a = T_{ff} * (1 + A (V^*)^{\beta}) \quad (3)$$

Where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V^* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door-to-door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

- The existing auto and bus person trips on the highway.
- The percentage of person transit trips shifting to auto
- The percentage of person transit trips shifting to bus
- The number of additional cars in the highway
- The number of additional buses in the highway

The occupancy per vehicle in the absence of transit The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$V^* = V_1 + \alpha_1 V_c + \alpha_2 V_b \tag{4}$$

Where V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor, and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

Type 1: "Explorers" who are casual switchers and who will divert to Single Occupancy Vehicles in the absence of transit.

Type 2: Commuters with low elasticity of demand with respect to generalized cost and who will divert to use the bus or carpool.

Type 3: Commuters with high elasticity of demand with respect to generalized cost and who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher the shift of transit riders to cars and buses. Therefore, higher degree of convergence will lead to higher delay, which translates into higher savings due to transit.

In words, Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high which translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve (as the volume increases, travel time increases at an increasing rate). Figure A 5.2 illustrates the relationship between the volume and travel time both in the presence and in the absence of transit.

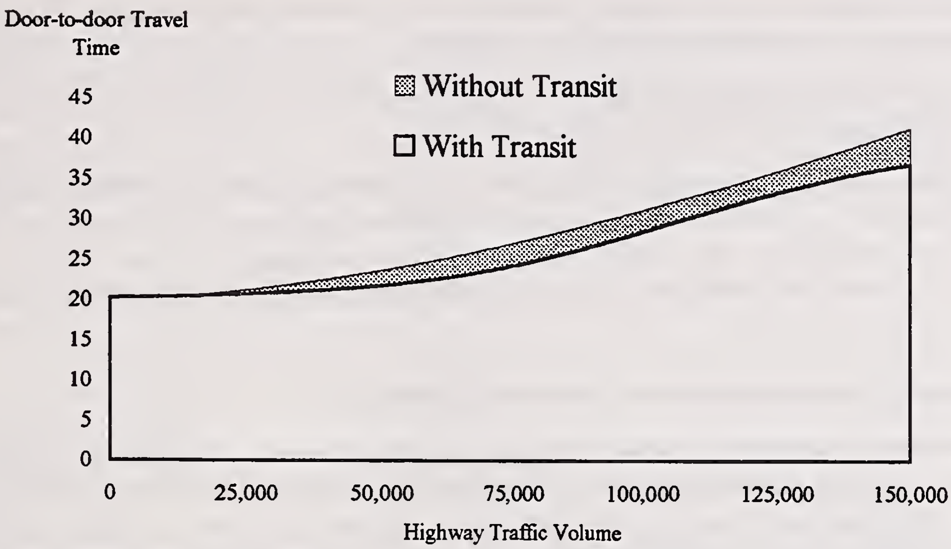


Figure A 5.2 Travel Time With and Without Transit.

Data The data required to populate this model consist of:

- Highway person trip volume (used in the previous model)
- Transit ridership data
- Fleet composition (cars and buses percentages out of the total traffic)
- Cars and buses vehicle occupancy
- Passenger car equivalent factor
- Degree of convergence to determine the percentage person trips shifting to cars and buses
- Free-flow travel time which is a constant

Equation 3 is specific to the corridor and do not need to be estimated each year. It will only be necessary to re-estimate them with an updated degree of convergence if a major change is made to the transit level of service or the highway structure.

Extrapolating Delay Savings Due to Transit

While the MLC hypothesis proves to be valid during the peak period only, the delay savings due to transit can be estimated during off-peak as well. This metric can be estimated as the vertical difference between the "without transit" curve and the "with transit" curve. That is at a specific person trip volume, the difference in travel times between the two cases can be defined as "the hours of delay saved due to transit".

The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by light rail riders (market benefits), savings by highway users (club benefits), and savings by users of parallel highways (spillover benefits).

The market benefits are estimated based on delay saved (which depends on the distance traveled) for each rider within the common segment.

The club benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution.

The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment. The spillover benefits are calculated by multiplying the traffic volume with a percentage of the delay savings. This percentage decreases as the distance between the common segment and the parallel highway increases.

Estimation of Corridor Performance without Re-calibration

The framework presented above provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay *without* the need for repeated MLC surveys. The approach rests on the theoretical proposition, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Corridor Overview

The Park Lane-Dallas corridor is about 13.0 miles in length and connects the residential area around I-75 and Northwest Parkway to the central business district, downtown Dallas. The residential catchment zone is centered around Park Lane Light Rail Station. Trip end points within the residential zone are no more than a 15-minute drive to the station. The downtown Dallas CBD zone, centered around West End Light Rail station, extends for a radius of .6 miles. App. Annex A1 provides maps of the residential and business district zones considered in this study. The Park Lane-Dallas light rail line (Red Line) is part of the line connecting Park Lane to Westmoreland, southwest of Dallas.

Principal Travel Modes

The "principal travel mode" is defined as the mode used during the common segment of each individual trip. The main transportation modes serving the Park Lane-Dallas Corridor are automobile and light rail. Automobile routes can be broken into three distinct sections:

1. The route between the residential point and the intersection of US-75 and Northwest Parkway (Access1);
2. The route from the intersection of US-75 and Northwest Parkway to Alamo street (Common Segment); and
3. The route from the intersection Alamo Street and McKinney to the CBD destination point (Access2).

For a morning rush hour trip, survey drivers followed Accessl to the common segment. The common segment route originated at the intersection of US-75 and Northwest Parkway close to Park Lane Station area. Drivers followed US-750 to Knox Street, then drive south on Cole Street to the intersection of McKinney and Alamo Street. From the end of the common segment, survey drivers followed Access2 to the downtown points, at which time they parked at the closest parking lot and proceeded on foot to the end point. The evening rush hour trip covered the same progression in the opposite direction.

The routes for the light rail mode riders can be broken into three distinct sections

1. The route between the residential point and the Park Lane Station (Access1);
2. The route between the Park Lane Station and the West End Station (Common Segment); and
3. The route between the West End Station and the CBD point (Access2).

For a morning rush hour trip, survey crews drove Access1 to the Park Lane Station parking lot and walked from the lot to the light rail station. The route taken for the common segment consisted of a light rail trip that begins at the Park Lane Station and continues to the West End Station Station. From the end of the common segment, the surveyor walked Access2 to the downtown points. The evening rush hour trip covered the same progression in the opposite direction. On average, trains run every 8 to 12 minutes during peak hours. Table A 5.2 displays some of the principal performance and service characteristics of the corridor. Figure A 5.3 shows the Park Lane-Dallas corridor and the main highways and arterials in the area.

Table A 5.2 Performance and Service Characteristics for Park Lane-Dallas Corridor

	Automobile	Light Rail
Number of stops	N/A	6
Number of Streets and Highways	3	N/A
Tolls/Fares for a one way (in dollars)	\$0.00	\$1.00

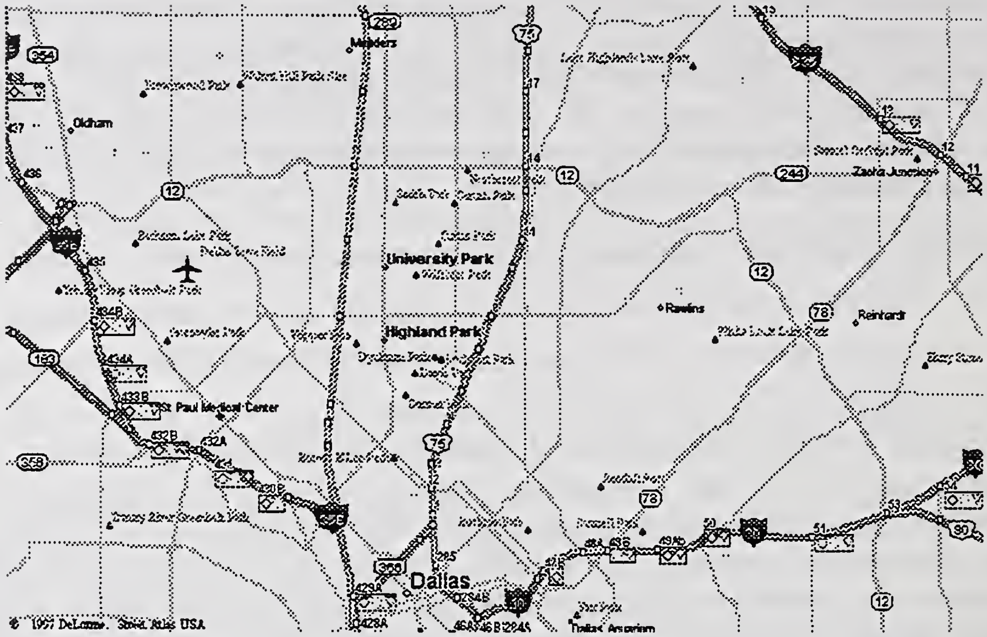


Figure A 5.3 Map of the Park Lane--Dallas Corridor

Principal findings

This chapter starts by presenting the results from the door-to-door travel survey conducted during the third week of September 1999. The travel survey data are used to derive the inter-modal convergence level in the Park Lane-Dallas corridor. The chapter then presents the estimation of the hours of delay saved due to transit for different user categories.

The Convergence Level

The starting point to estimate the "without transit" curve is to determine the convergence level based on the key findings from the 1999 door to door travel data.

The door-to-door travel survey for the Park Lane-Dallas Corridor found that:

Average door-to-door travel times for auto and metro rail, are similar, 52.36 minutes by light rail versus 46.5 minutes by auto (Table A 5.3).

Travel time reliability, as represented by the standard deviation of average travel time is 4.28 for light rail mode and 7.06 for the auto mode (Table A 5.3).

Commuters experienced similar travel times in the morning and in the evening reflecting the similar traffic dynamics of the inbound peak flow versus the outbound peak flow in the corridor (Table A 5.4).

Statistical analysis shows that the mean trip time by auto was at most 9 minutes longer with 95% confidence (Table A 5.5).

The common segment travel time was slightly higher for the light rail mode than for the transit mode, 21.47 minutes versus 19.4 minutes. The slight difference of 2.03 minutes between the two modes is due to the fewer stops of the light rail (6 stops) while the common segment for auto consisted of three roadways (Table A 5.3).

Similarly, access segment travel times was similar between auto commuters (27.06 minutes) and transit commuters (30.9 minutes) (Table A 5.3).

Table A 5.3 Results for the Park Lane-Dallas Corridor

	Automobile	Light Rail
	Total Travel Time	
Mean	46.5	52.4
Standard Deviation	7.06	4.28
	Access Segment Travel Time	
Mean	27.1	30.9
Standard Deviation	7.7	4.7
	Common Segment Travel Time	
Mean	19.4	21.47
Standard Deviation	4.7	3.18
Sample Size	30	30

Table A 5.4 Comparison of AM and PM Trip Times by Modes

	Auto	Metro Rail
Inbound AM Average Trip Time	48.1	53.1
Outbound PM Average Trip Time	44.0	51.4

Table A 5.5 Statistical Testing of Convergence Hypothesis

Difference in Mean Travel Times by Mode: (Auto- Metro Rail minutes)		5.87
Standard Error of the Difference of the Means (minutes):		1.51
Hypothesis: "The difference between the mean travel times by modes is at most..."	Significant at the 0.10 Level (90% Confidence)	Significant at the 0.05 Level (95% Confidence)
6 Minutes	NO	NO
7 Minutes	NO	NO
8 Minutes	NO	NO
9 Minutes	YES	YES
10 Minutes	YES	YES

The results in Table A 5.5 indicate that light rail in the defined corridor has drawn door-to-door travel times by highway and light rail to within 9 minutes of one another during congested roadway conditions (with 95 percent statistical confidence).

Although an inter-modal travel time convergence of 9 minutes is sufficient to yield delay savings to highway users (as compared to the "without rail" case – see below), full convergence would of course yield even greater savings

The Mogridge-Lewis framework predicts that non-time related roadway travel costs (i.e, the non-time elements of "generalized cost" such as parking costs, fuel costs and so on) account for the "9 minute wedge." Light rail users are expected to re-explore the roadway option to the point at which the value of non-time generalized cost factors just equals the value of the travel time advantage offered by road. If non-time costs are moderate to high, travel time convergence will occur at a non-zero time differential between road and rail

Methodology Application on Park Lane - Dallas Corridor

Data HLB obtained traffic volume data (HPMS data) from the City of Dallas, Transportation Planning Department. The ridership data were obtained from the Dallas Area Rapid Transit. In addition, door-to-door travel time survey was conducted to derive the degree of convergence in the corridor.

Model The traffic volume and travel time data were used to populate the model. Equation 1 is estimated as follows:

$$\mathbf{T_{a1} = (40 - 20) / (1 + e^{-(-4.255 + 3.983\,E\text{-}05\,(V))}) + 20} \qquad (1)$$

When V is equal to 0, the travel time is equal the travel time at free flow speed (20 minutes). For an auto traffic volume of 122,600 between Park Lane and Downtown Dallas (based on 1998 O-D tables), the travel time is equal to 35 minutes.

Similarly, Equation 2 is estimated based on auto travel volume, transit ridership data, and convergence level estimate from the survey.

$$\mathbf{T_{a2} = 40 * (1 + 7.2178E\text{-}09\,(V^*)^{1.58})} \qquad (2)$$

The auto traffic volume in the absence of transit is determined by adding the auto volume in the presence of transit to the generated auto trips by transit riders. The generated is based on:

About 40% of person transit trips will be forgone (determined by the corridor convergence level).

The average vehicle occupancy (HOV and non-HOV) is 1.2 for cars and 40 for buses.

Car trips will make about 90% of trips.

Benefit Estimation To estimate the travel time saving (TTS) attributed to transit, the current traffic volume is inserted into Equation 1 and 2. An auto volume of 144,500 results into:

$$\mathbf{T_{a1} = 36.35,\ T_{a2} = 40.25, \text{and . } TTS = T_{a2} - T_{a1} = 3.54}$$

That is on average, on Park Lane-Dallas corridor, transit saves about 4 minutes per auto trip (18 seconds per mile) during the peak period. Once the average travel time saving per vehicle is estimated, the savings are weighted to reflect the congestion level at each time of the day.

Feeding the volume levels for 1999, for the Park Lane-Dallas corridor into equation (1) and (2), HLB estimated the hours of delay saved due to transit for 1999. The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by light rail riders (market benefits), savings by US-75 common segment users (club benefits), and savings by users of parallel highways (spillover benefits).

The market benefits are estimated based on delay saved (which depends on the distance traveled) by each rail rider within the common segment (Table A 5.6). The club benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution (

Table A 5.7). The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment (Table A 5.8). The magnitude of savings by the commuters on these highways decreases with the distance to the common segment.

Table A 5.9 shows the summary of benefits by category. The results indicate that the delay saving due to transit is about 3.54 minutes per trip one way (about 18 seconds per mile). Using a travel time value of $15 per hour and an average of 250 working days per year, the yearly delay saving can be valued at $36.9 million in 1999, this can be translated into a $ 2.8 million per rail mile in the Park Lane-Dallas Corridor. The summary table shows that 44% of the savings are light rail riders savings. These results illustrate the relative high ridership and the high reliability of the light rail in the corridor.

Table A 5.6 Market Benefits for Park Lane-Dallas Corridor

Station	In-bound Trips	Out-bound Trips	Daily Savings (hours)
Park Lane	109727	0	1,283.81
Lovers Lane	30419	6406	333.01
Mockingbird	28320	6139	326.45
Pearl	27577	20062	371.58
St. Paul	21528	23067	351.84
Akard	42068	47874	731.74
West End	85466	58527	913.02
Total	345,105	162,075	4,311

Table A 5.7 Club Benefits for Park Lane-Dallas Corridor

	Distance (miles)	Avg Daily Traffic Volume	Daily Savings (hours)
Common Segment			
US 75	4	158,000	1,232
Knox Street	1	19,546	61
Cole Street/McKinney	5	12,045	211
Access Segment (on average)	3	41,500	486
Total	13		1,990

Table A 5.8 Spillover Benefits for Park Lane-Dallas Corridor

Highways in the corridor:	Distance (miles)	Avg Daily Traffic Volume	W	Daily Savings (hours)
US 75	5	126,000	0.8	1,965.60
Hillcrest	6	6,997	0.6	98.24
Boedecker	4	6,158	0.8	76.85
Cole/McKinney	8	11,683	0.91	331.70
Preston	4	9,934	0.4	61.99
Bryan	3	8,205	0.8	76.80
Woodall Rodgers Freeway	6	15,156	0.5	177.33
Northwest	1	52,440	0.6	122.71
Park Lane	1	16,790	0.6	39.29
Akard	1	12,668	0.6	29.64
Pacific	1	14,500	0.8	45.24
Ross	4	7,525	0.6	70.43
San Jacinto	4	7,580	0.7	82.77
Greenville	5	24,183	0.75	353.68
Total				3,532.27

Table A 5.9 Benefits Summary

Benefit Category	Daily Savings In Hours	Daily Savings In Dollars	Yearly Savings In Dollars
Market	4,311	$ 64,672	$ 16,167,962
Club	1,990	$ 29,855	$ 7,463,708
Spillover	3,532	$ 52,984	$ 13,246,016
Total	9,834	$ 147,511	$ 36,877,686

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door to door travel time data should be collected to estimate an accurate performance metric.

Annex A 5.1 Views of the Park Lane Light Rail Corridor Serving Dallas

Figure A 5.4 Map of the Residential Area Around Park Lane

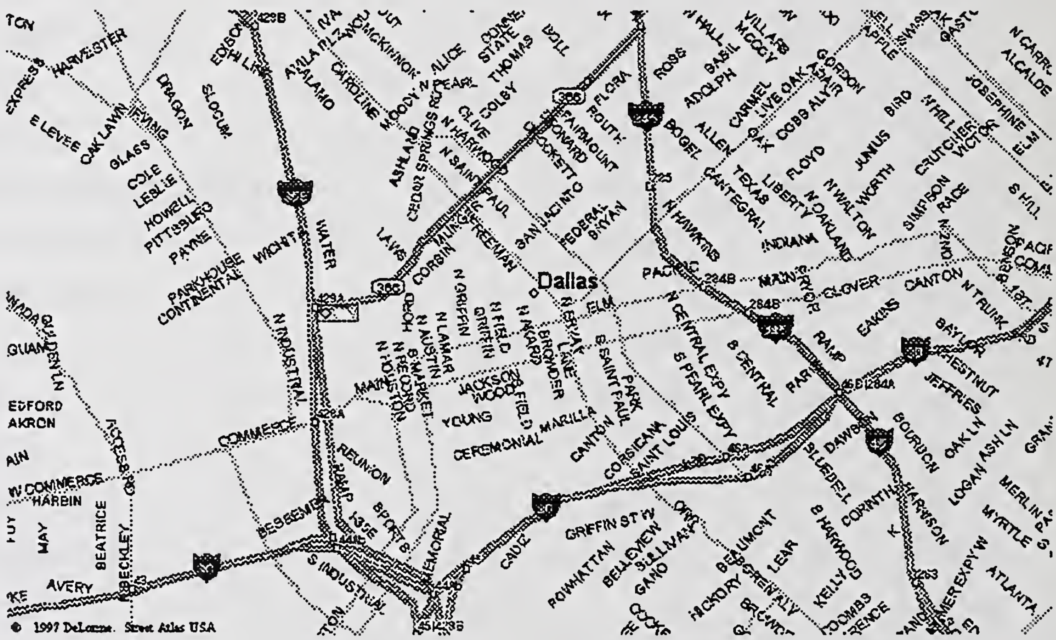
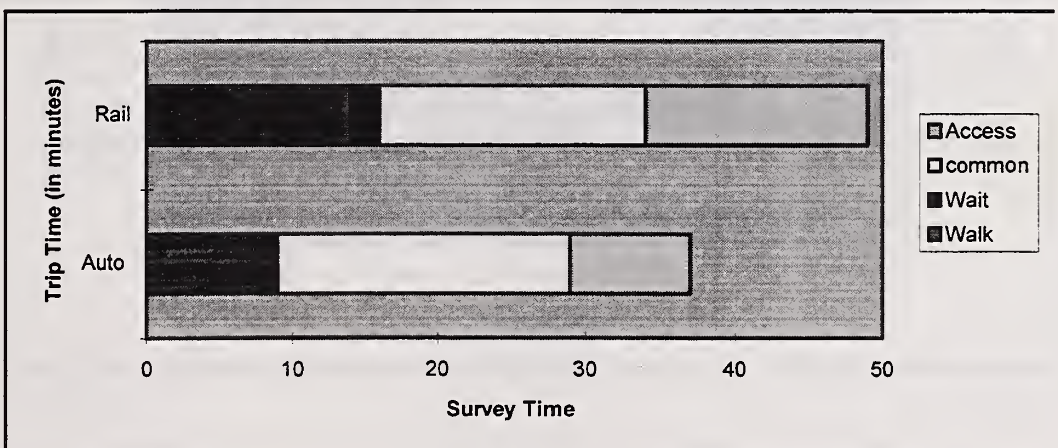


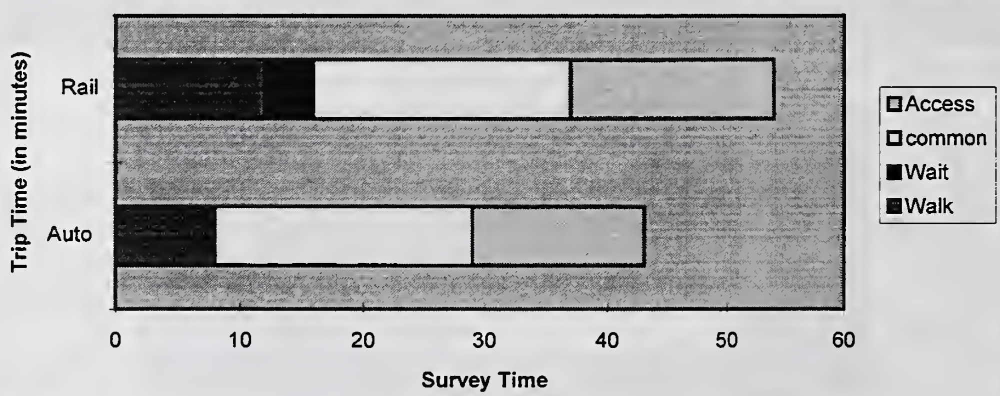
Figure A 5.5 Map of the Central Business District

Annex A 5.2 The survey findings by route

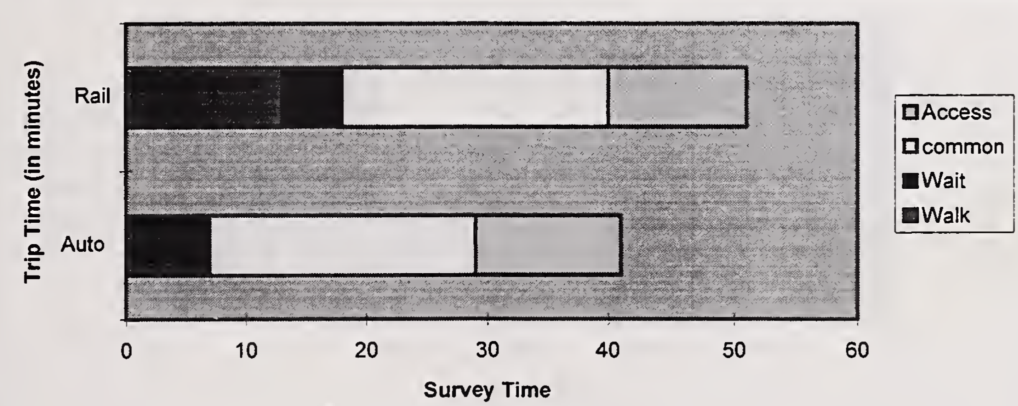
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE A1: Deloache & Edgemere - McKinney & N. Lamar		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	37	49
In Common Segment	20	18
Outside Common Segment	8	15
Wait Time	0	2
Walk Time	9	14
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	21.1	15.9
In Common Segment	25.5	33.3
Outside Common Segment	33.8	12.0



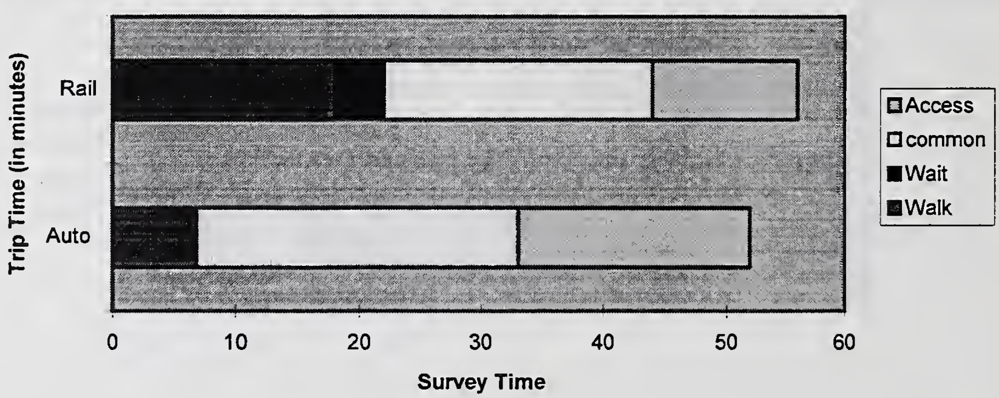
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE A12: Deloache & Edgemere - Elm & S. Record		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	43	54
In Common Segment	21	21
Outside Common Segment	14	17
Wait Time	0	4
Walk Time	8	12
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	18.1	14.4
In Common Segment	24.3	28.6
Outside Common Segment	19.3	10.6



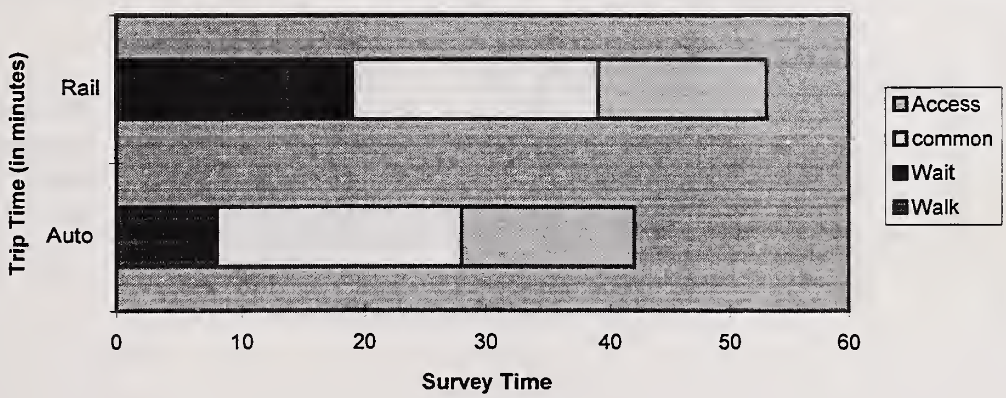
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE B2: Wentwood & Thackery - McKinney & N. Griffin	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	41	51
In Common Segment	22	22
Outside Common Segment	12	11
Wait Time	0	5
Walk Time	7	13
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	19.0	15.3
In Common Segment	23.2	27.3
Outside Common Segment	22.5	16.4



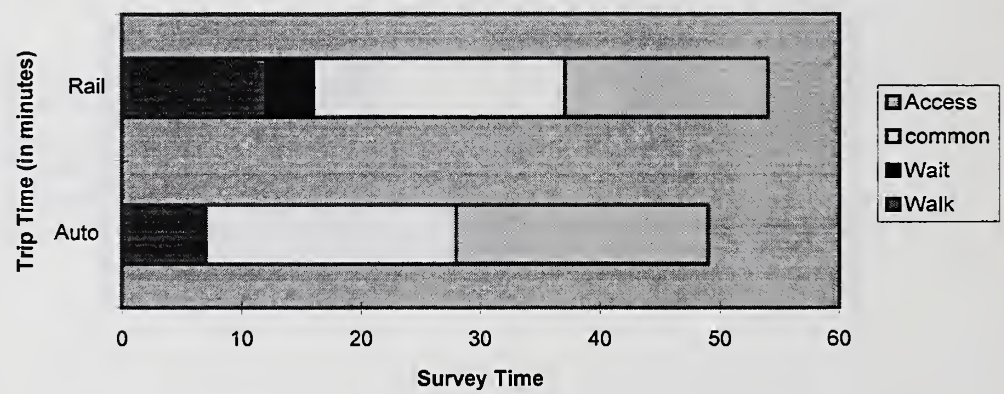
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE B13: Wentwood & Thackery - Corbin & S. Record		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	52	56
In Common Segment	26	22
Outside Common Segment	19	12
Wait Time	0	4
Walk Time	7	18
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	15.0	13.9
In Common Segment	19.6	27.3
Outside Common Segment	14.2	15.0



CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE C1: Douglas & Luther - McKinney & N. Lamar	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	42	53
In Common Segment	20	20
Outside Common Segment	14	14
Wait Time	0	5
Walk Time	8	14
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	18.6	14.7
In Common Segment	25.5	30.0
Outside Common Segment	19.3	12.9

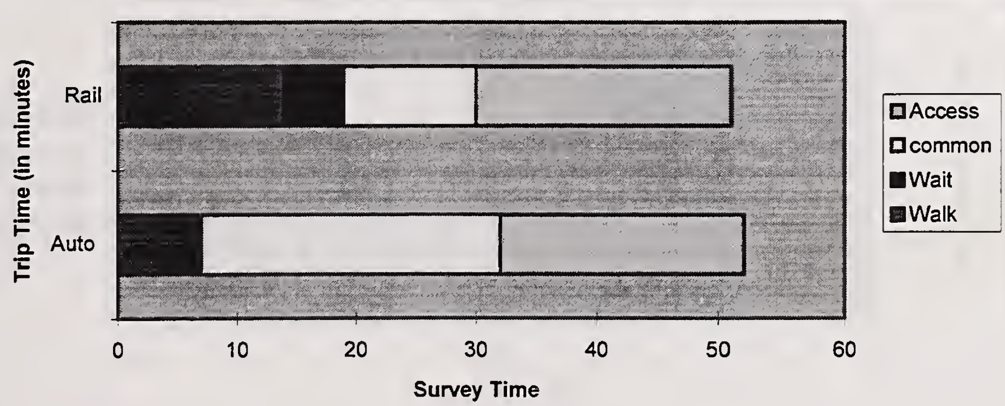


CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE C3: Douglas & Luther - Corbin & N. Griffin	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	49	54
In Common Segment	21	21
Outside Common Segment	21	17
Wait Time	0	4
Walk Time	7	12
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	15.9	14.4
In Common Segment	24.3	28.6
Outside Common Segment	12.9	10.6

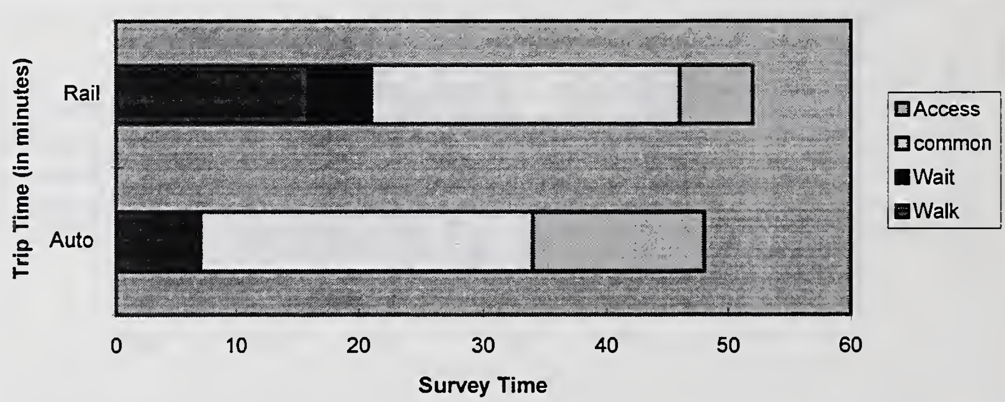


CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE D2:
Park Lane & Dougkas - McKinney & N. Griffin

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	52	51
In Common Segment	25	11
Outside Common Segment	20	21
Wait Time	0	5
Walk Time	7	14
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	15.0	15.3
In Common Segment	20.4	54.5
Outside Common Segment	13.5	8.6

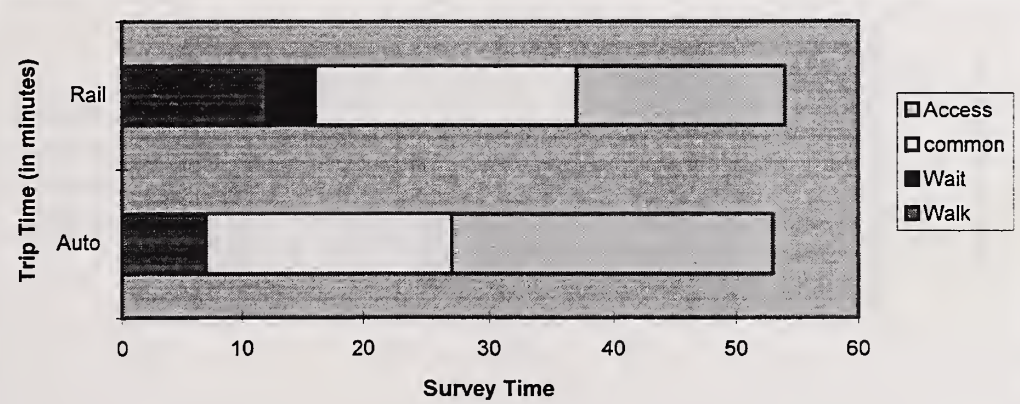


CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE D4: Park Lane & Dougkas - Ross & Freeman	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	48	52
In Common Segment	27	25
Outside Common Segment	14	6
Wait Time	0	5
Walk Time	7	16
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	16.3	15.0
In Common Segment	18.9	24.0
Outside Common Segment	19.3	30.0

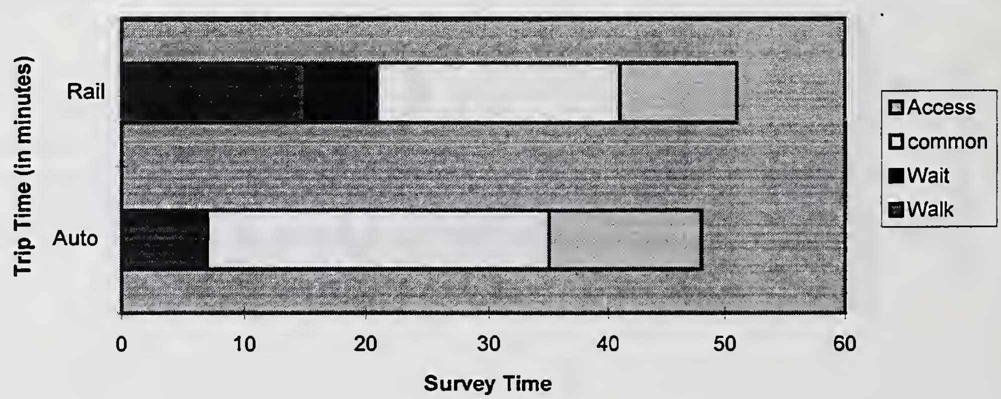


CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE E2:
Aberdeen & Tibbs - McKinney & N. Griffin

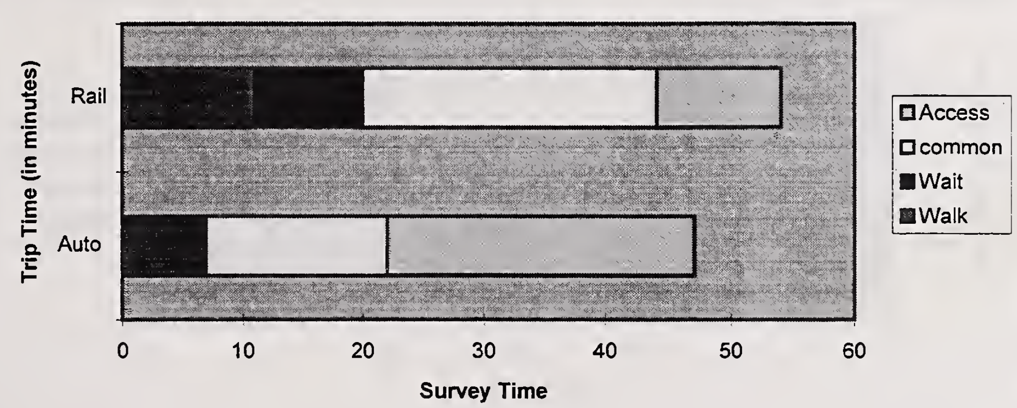
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	53	54
In Common Segment	20	21
Outside Common Segment	26	17
Wait Time	0	4
Walk Time	7	12
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	14.7	14.4
In Common Segment	25.5	28.6
Outside Common Segment	10.4	10.6



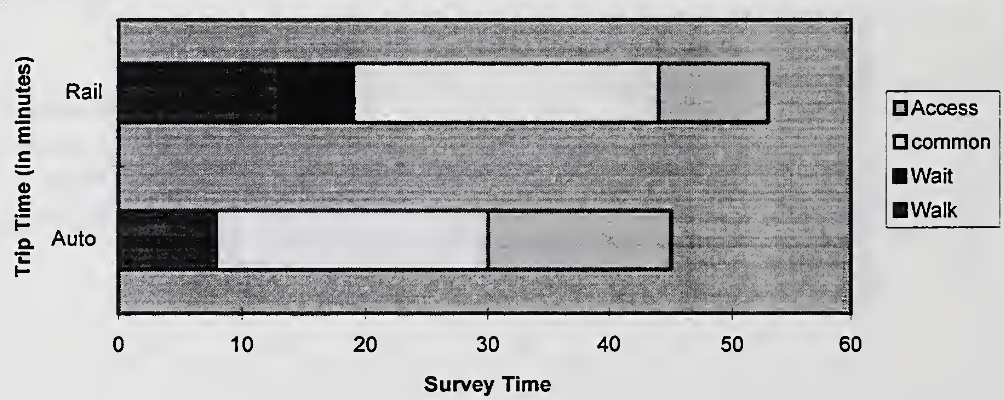
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE E5: Aberdeen & Tibbs - San Jacinto & N. Akard	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	48	51
In Common Segment	28	20
Outside Common Segment	13	10
Wait Time	0	6
Walk Time	7	15
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	16.3	15.3
In Common Segment	18.2	30.0
Outside Common Segment	20.8	18.0



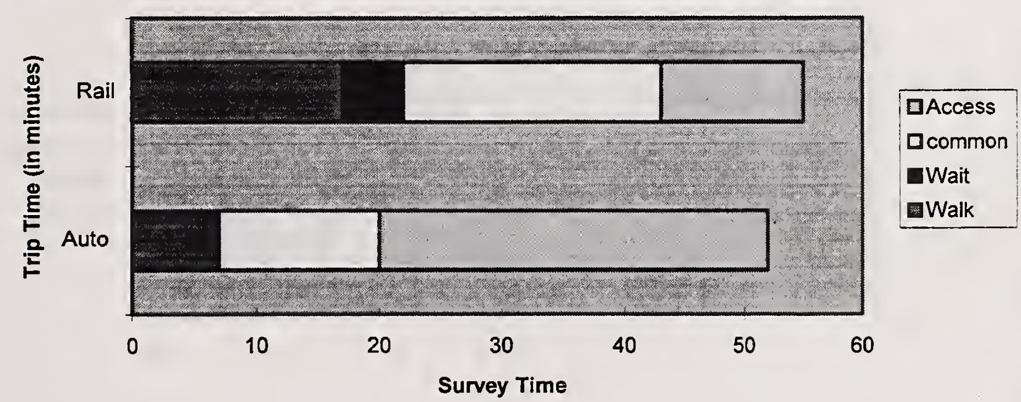
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE F6: Thackery & Norway - Bullington & Bryan		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	47	54
In Common Segment	15	24
Outside Common Segment	25	10
Wait Time	0	9
Walk Time	7	11
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	16.6	14.4
In Common Segment	34.0	25.0
Outside Common Segment	10.8	18.0



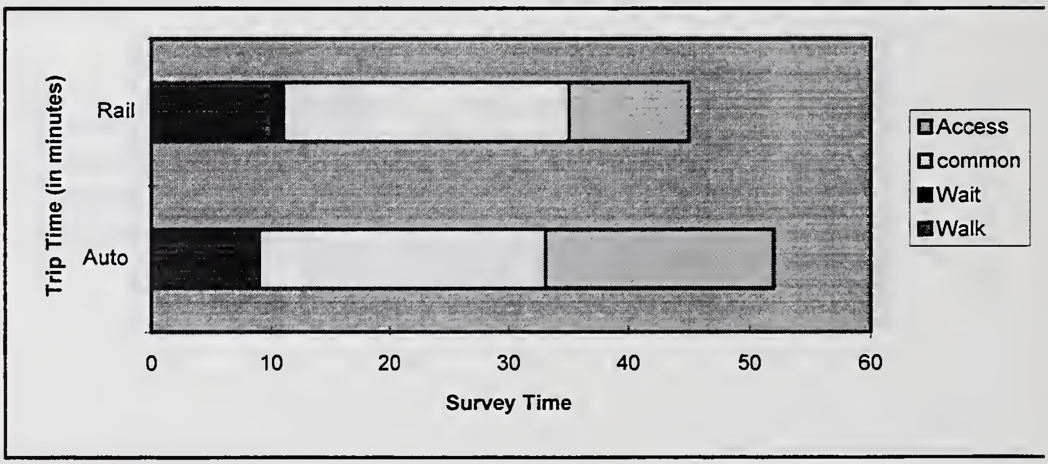
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE G7: Bodeker & Lakehurst - Elm & Stone		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	45	53
In Common Segment	22	25
Outside Common Segment	15	9
Wait Time	0	6
Walk Time	8	13
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	17.3	14.7
In Common Segment	23.2	24.0
Outside Common Segment	18.0	20.0



CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE I9: Kingsley & Fieldcrest - Wood & S. Field	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	52	55
In Common Segment	13	21
Outside Common Segment	32	12
Wait Time	0	5
Walk Time	7	17
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	15.0	14.2
In Common Segment	39.2	28.6
Outside Common Segment	8.4	15.0

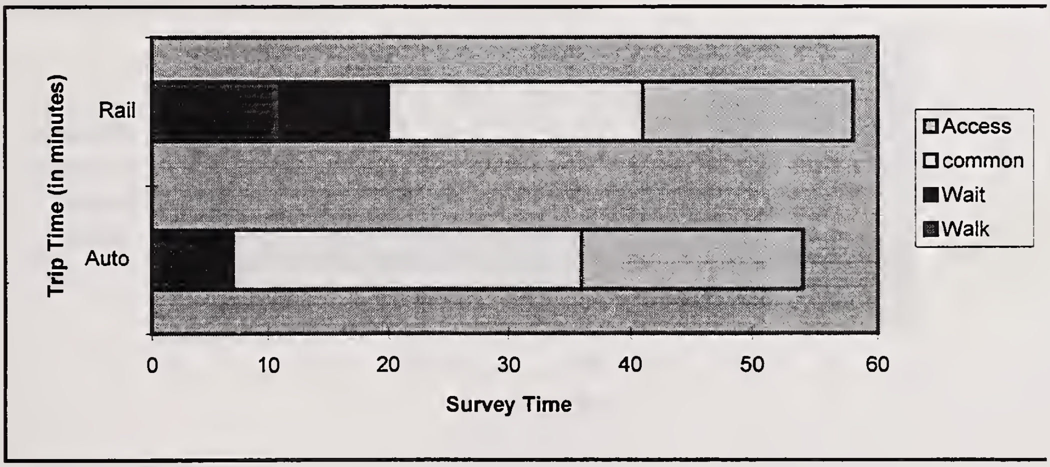


CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE J10: Wild Valley & Larmanda - Wood & S. Lamar	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	52	45
In Common Segment	24	24
Outside Common Segment	19	10
Wait Time	0	1
Walk Time	9	10
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	15.0	17.3
In Common Segment	21.3	25.0
Outside Common Segment	14.2	18.0

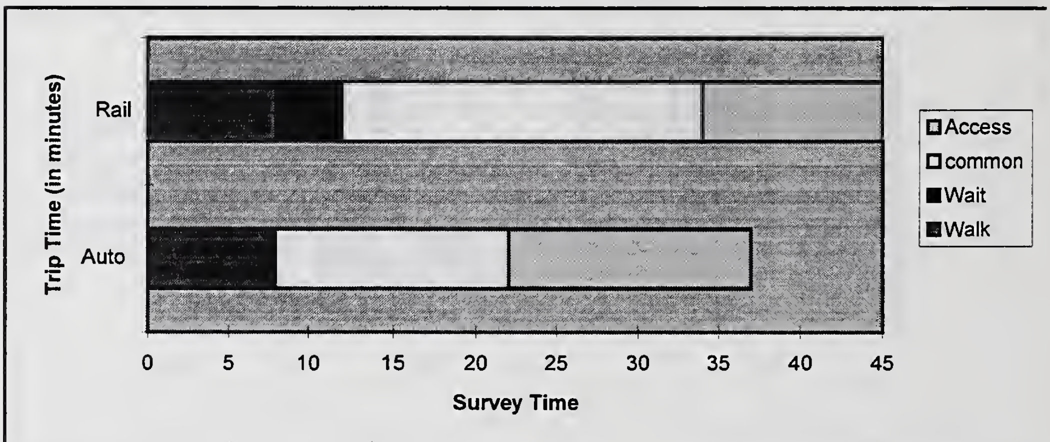


CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE K11:
Berryhill & Town North - Commerce & S. Record

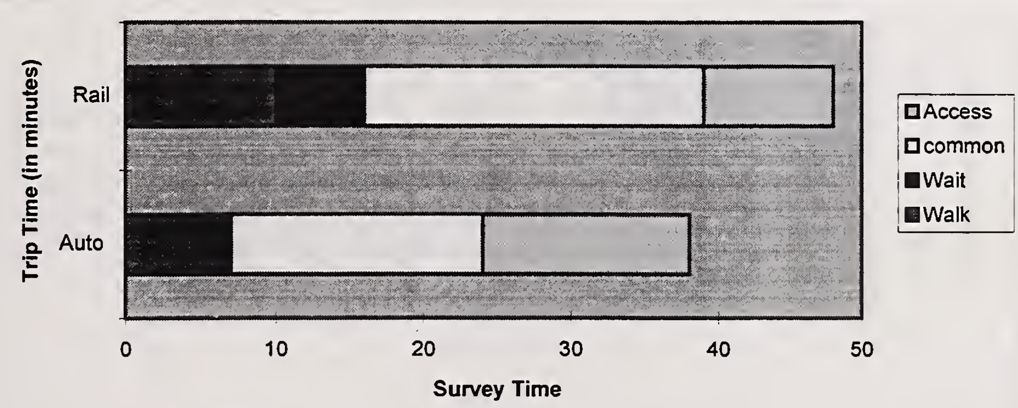
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	54	58
In Common Segment	29	21
Outside Common Segment	18	17
Wait Time	0	9
Walk Time	7	11
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	14.4	13.4
In Common Segment	17.6	28.6
Outside Common Segment	15.0	10.6



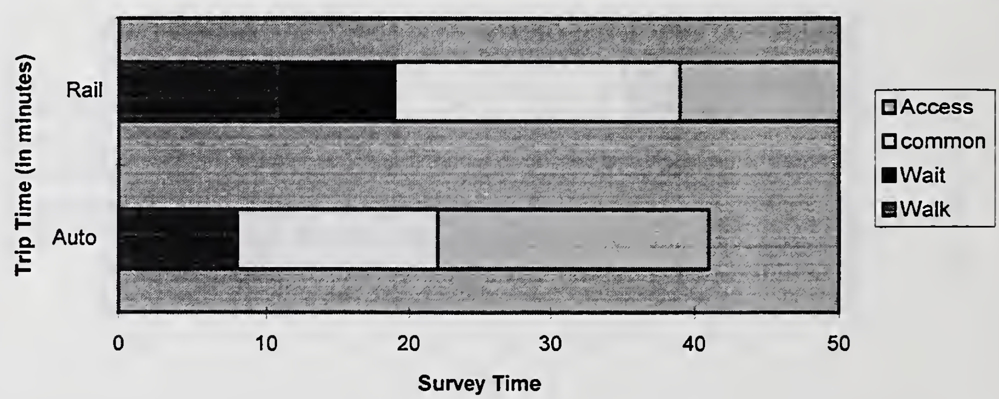
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 1B: McKinney & N. Lamar - Westwood & Thackery	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	37	45
In Common Segment	14	22
Outside Common Segment	15	11
Wait Time	0	4
Walk Time	8	8
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	21.1	17.3
In Common Segment	36.4	27.3
Outside Common Segment	18.0	16.4



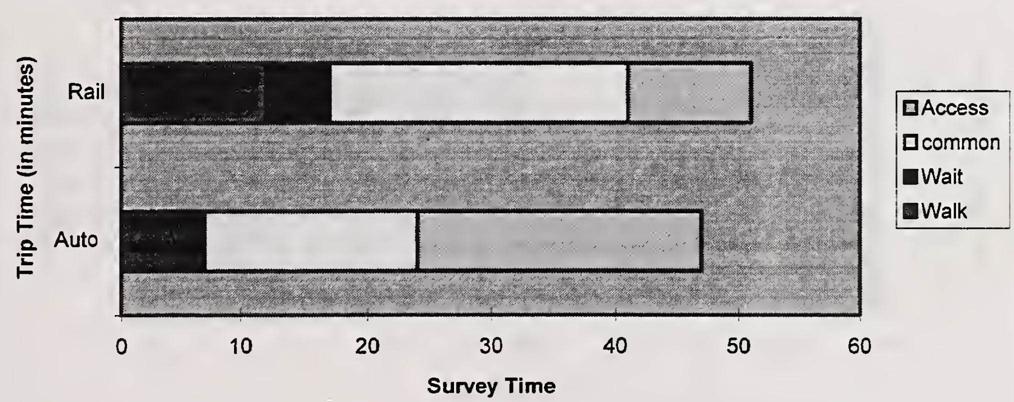
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 1D: McKinney & N. Lamar - Park Lane & Douglas	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	38	48
In Common Segment	17	23
Outside Common Segment	14	9
Wait Time	0	6
Walk Time	7	10
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	20.5	16.3
In Common Segment	30.0	26.1
Outside Common Segment	19.3	20.0



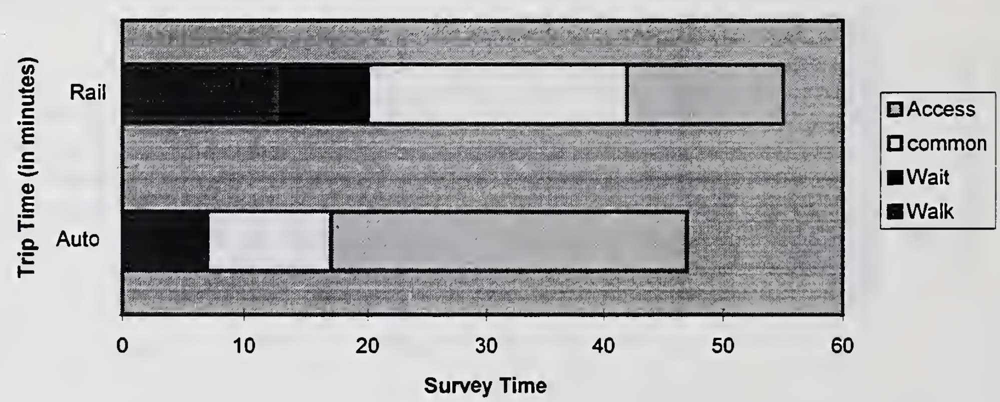
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 2C McKinney & N. Griffin - Douglas & Luther	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	41	50
In Common Segment	14	20
Outside Common Segment	19	11
Wait Time	0	8
Walk Time	8	11
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	19.0	15.6
In Common Segment	36.4	30.0
Outside Common Segment	14.2	16.4



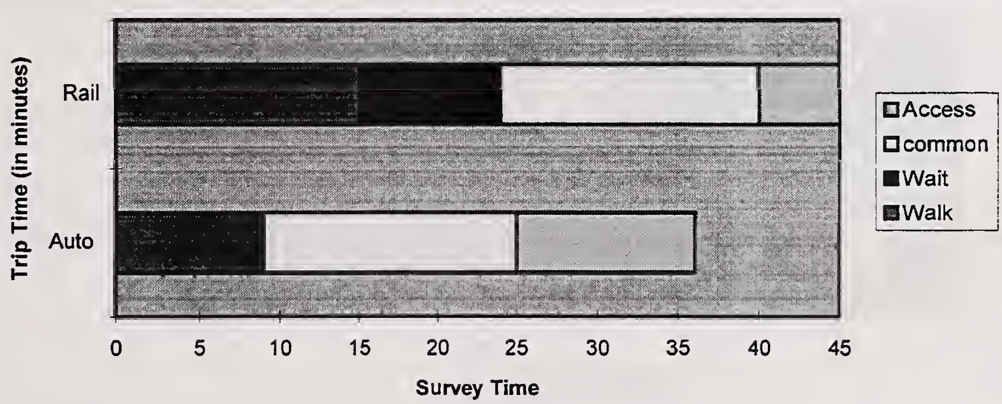
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 2E McKinney & N. Griffin -Aberdeen & Tibbs	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	47	51
In Common Segment	17	24
Outside Common Segment	23	10
Wait Time	0	5
Walk Time	7	12
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	16.6	15.3
In Common Segment	30.0	25.0
Outside Common Segment	11.7	18.0



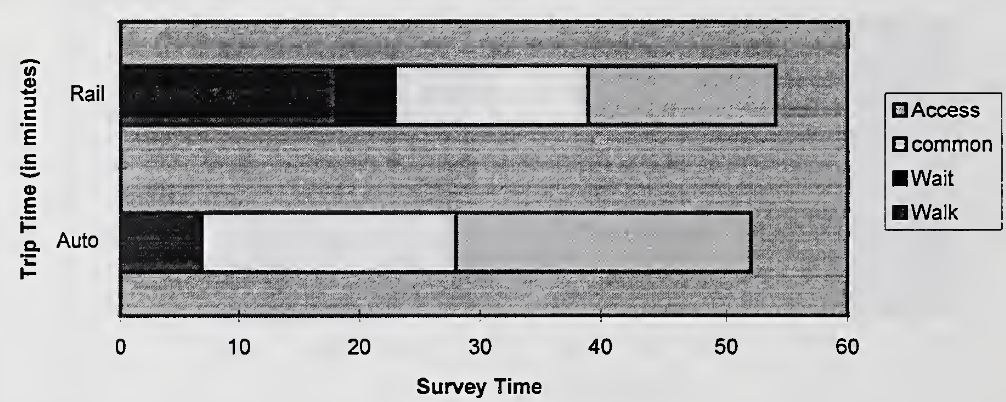
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 3D Corbin & N. Griffin - Park Lane & Douglas	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	47	55
In Common Segment	10	22
Outside Common Segment	30	13
Wait Time	0	7
Walk Time	7	13
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	16.6	14.2
In Common Segment	51.0	27.3
Outside Common Segment	9.0	13.8



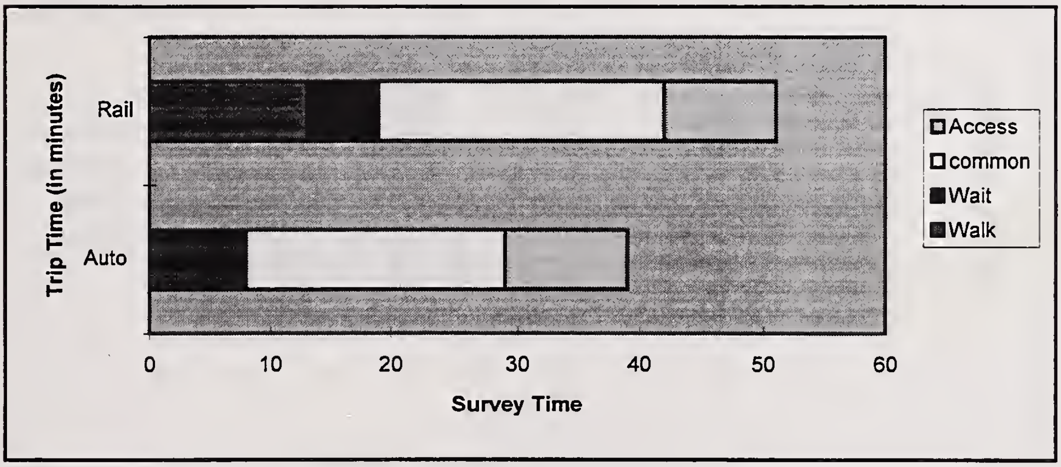
CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 4E Ross & Freeman - Aberdeen & Tibbs	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	36	45
In Common Segment	16	16
Outside Common Segment	11	5
Wait Time	0	9
Walk Time	9	15
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	21.7	17.3
In Common Segment	31.9	37.5
Outside Common Segment	24.5	36.0



CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 5F San Jacinto & N. Akard - Thackery & Norway	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	52	54
In Common Segment	21	16
Outside Common Segment	24	15
Wait Time	0	5
Walk Time	7	18
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	15.0	14.4
In Common Segment	24.3	37.5
Outside Common Segment	11.3	12.0

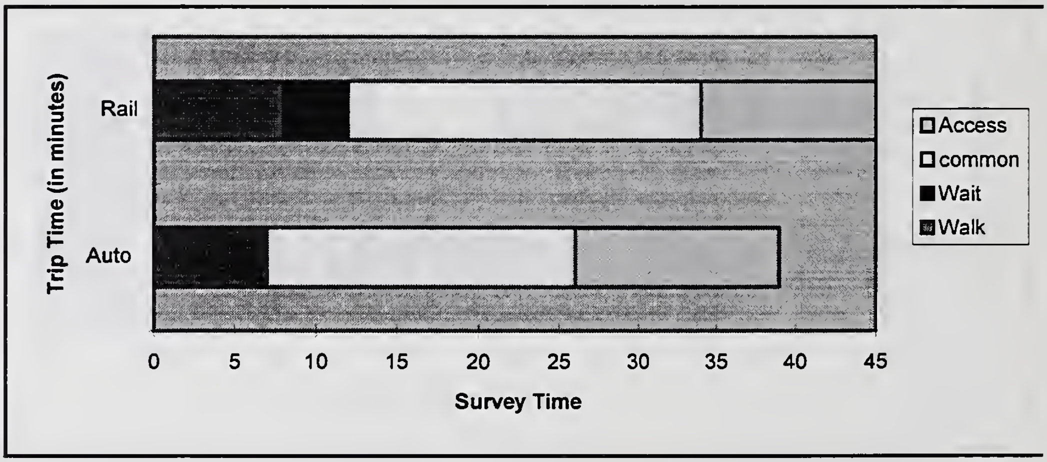


CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 6G Bullington & Bryan - Bordeker & Lakehurst	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	39	51
In Common Segment	21	23
Outside Common Segment	10	9
Wait Time	0	6
Walk Time	8	13
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	20.0	15.3
In Common Segment	24.3	26.1
Outside Common Segment	27.0	20.0



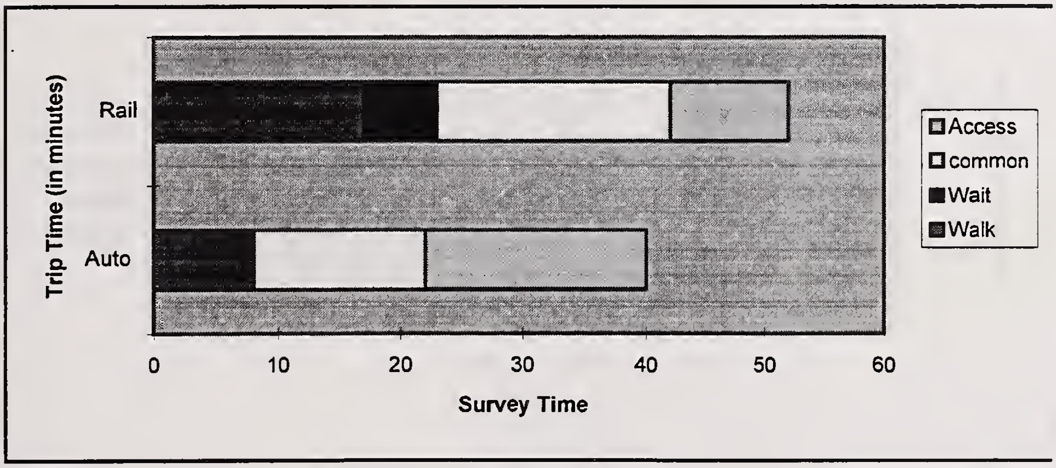
CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE 7H
Elm & Stone - Church & Arborgate

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	39	45
In Common Segment	19	22
Outside Common Segment	13	11
Wait Time	0	4
Walk Time	7	8
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	20.0	17.3
In Common Segment	26.8	27.3
Outside Common Segment	20.8	16.4

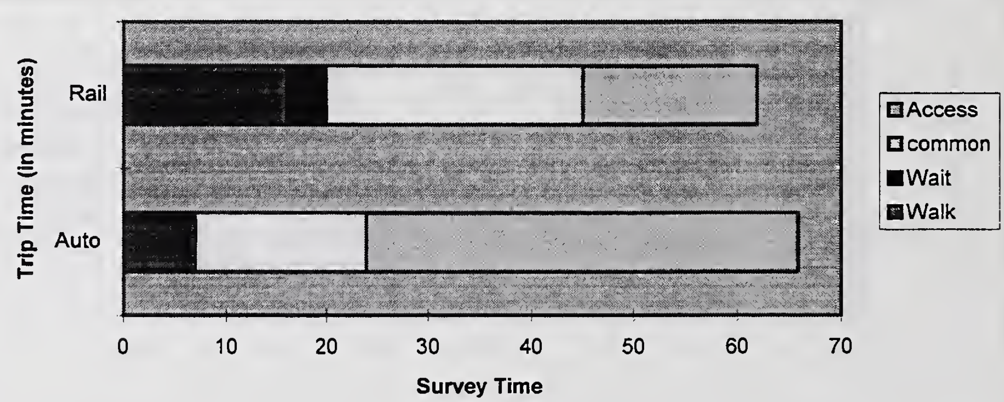


CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE 8I
Commerce & S. Akard - Kingsley & Fieldcrest

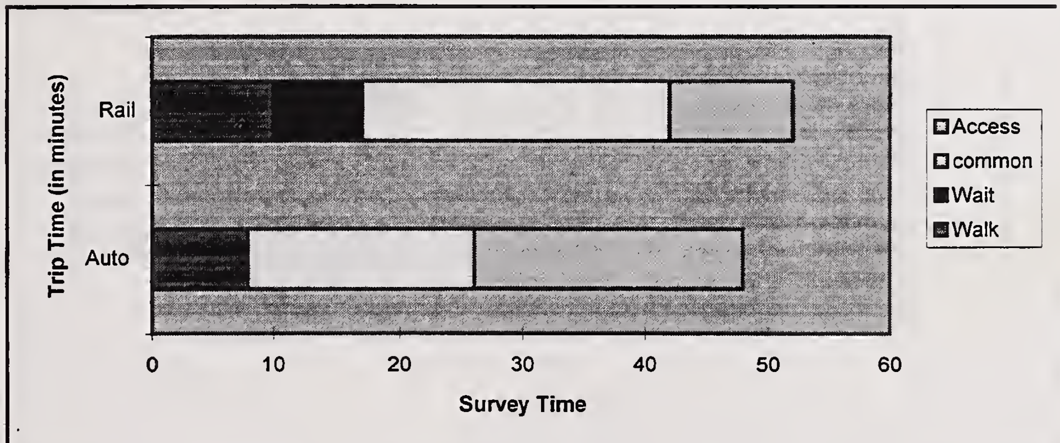
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	40	52
In Common Segment	14	19
Outside Common Segment	18	10
Wait Time	0	6
Walk Time	8	17
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	19.5	15.0
In Common Segment	36.4	31.6
Outside Common Segment	15.0	18.0



CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 9J Wood & S. Field - Wild Valley & Larmanda	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	66	62
In Common Segment	17	25
Outside Common Segment	42	17
Wait Time	0	4
Walk Time	7	16
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	11.8	12.6
In Common Segment	30.0	24.0
Outside Common Segment	6.4	10.6

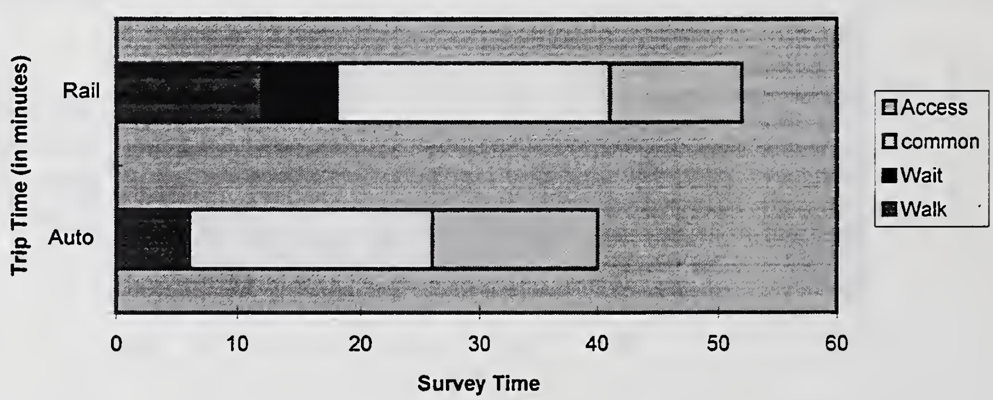


CORRIDOR: Park Lane - Dallas SUMMARY TABLE FOR ROUTE 10K Wood & S. Lamar - Berryhill & Town North	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	48	52
In Common Segment	18	25
Outside Common Segment	22	10
Wait Time	0	7
Walk Time	8	10
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	16.3	15.0
In Common Segment	28.3	24.0
Outside Common Segment	12.3	18.0



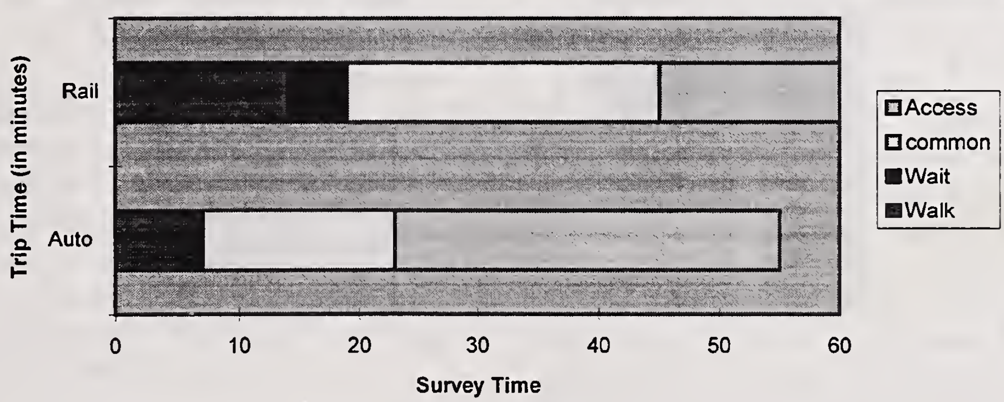
CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE 11A:
Commerce & S. Record - Deloache & Edgemere

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	40	52
In Common Segment	20	23
Outside Common Segment	14	11
Wait Time	0	6
Walk Time	6	12
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	19.5	15.0
In Common Segment	25.5	26.1
Outside Common Segment	19.3	16.4



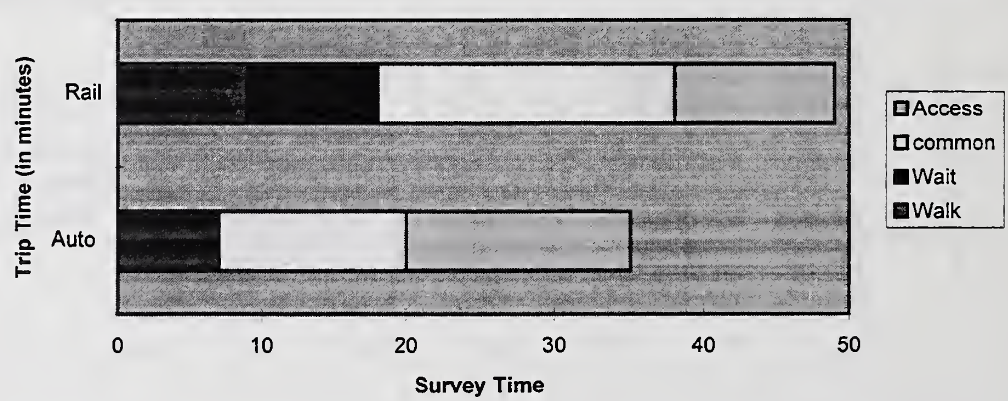
CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE 12B:
Elm & S. Record - Westwood & Thackery

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	55	60
In Common Segment	16	26
Outside Common Segment	32	15
Wait Time	0	5
Walk Time	7	14
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	14.2	13.0
In Common Segment	31.9	23.1
Outside Common Segment	8.4	12.0



CORRIDOR: Park Lane - Dallas
SUMMARY TABLE FOR
ROUTE 13C:
Corbin & S. Record - Douglas & Luther

	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	35	49
In Common Segment	13	20
Outside Common Segment	15	11
Wait Time	0	9
Walk Time	7	9
DISTANCE (miles)		
Route Distance	13.0	13.0
Common Segment Distance	8.5	10.0
SPEED (mph)		
Trip	22.3	15.9
In Common Segment	39.2	30.0
Outside Common Segment	18.0	16.4



Appendix 6. The Gateway Light Rail Corridor Serving Portland, Oregon

Executive Summary

Working Paper 1 (Subtask 1d, November 25, 1998) develops a theoretical and measurement framework within which the Mogridge-Lewis Convergence Hypothesis (MLC) can be employed in measuring the savings in highway delay attributable to transit and its equilibrating effect on the level of service in the corridor.

The framework also provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay <u>without</u> the need for repeated MLC surveys. The approach rests on the theoretical proposition, proven in Working Paper 1, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Purpose and Method

This Working Paper presents a case study of the methodology developed in Subtask 1c in application to the Gateway-Portland corridor (the MAX light rail system). The methodology consists of calibrating the MLC-traffic model with Gateway-Portland survey data. The model is then used to quantify delay savings attributable to MAX at present, and at alternative roadway traffic volumes (each for different user categories).

The study consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

The Gateway-Portland corridor was selected to measure the performance of the MAX light rail system connecting several residential areas with the Central Business District of Portland, Oregon. MLC theory predicts that the improved transit system will attract modal explorers, reduce congestion, and improve roadway travel times. As a result, we would expect to see improvements in <u>both</u> highway and transit door-to-door travel times

Principal Findings

The case study finds that based on the MLC model calibrated with 1999 survey data, the magnitude of peak-period delay savings per trip due to transit is about 3.05 minutes per door-to-door journey. These

savings amount to about 11 percent of total door-to-door journey times and align with reasoned expectations.

HLB estimated the hours of delay savings for three different user groups: Metro riders (market benefits), users of the I-84 common segment (club benefits), and users of parallel highways (spillover benefits). Table A 6.1 through Table A 6.4 present the estimated delay savings by category of user. Based on an assumed value of peak travel time of $15 per hour and an average of 250 working days per year, Table A 6.4 indicates an aggregate peak delay savings due to transit of $20.8 million for 1999.

Table A 6.1 Daily Club Benefits for Gateway-Portland Corridor

	Distance (miles)	Daily Volume	Savings (hours)
Common Segment			
I-84	6.11	53,425	1,161.36
I-5	1.07	44,738	170.31
Morrison Bridge	0.25	20,763	18.47
Access Segment			
(on average)	2	20,763	147.74
Total	9.43		1,497.88

Table A 6.2 Daily Market Benefits for Gateway Portland Corridor

Station	In-bound Trips	Out-bound Trips	Savings (hours)
Gateway TC	1,833	2,032	108.08
NE 82nd Avenue]	1,533	1,889	90.89
NE 60th Avenue	1,617	2,048	92.22
Hollywood/NE 42nd TC	1,542	2,173	88.27
Lloyd Center/NE 11th Ave.	1,867	2,063	87.89
NE 7th Avenue	2,983	1,774	99.76
Convention Center	3,167	1,669	94.64
Rose Quarter TC	1,542	2,173	67.50
Old Town/Chinatown	1,867	2,063	65.92
Skidmore Fountain	2,983	1,774	73.16
Oak Street/SW 1st Ave.	3,167	1,669	60.84
SW 3rd Avenue/Yamhill	2,533	1,568	45.86
Mall/SW 5th-/SW 4 th Ave.	2,717	1,347	39.76
Pionner Square N/S	2,567	1,348	32.84
Total			1,048

Table A 6.3 Daily Spillover Benefits for Gateway-Portland Corridor

Highways in the Corridor	Distance (miles)	Daily Traffic Volume	Savings (hours)
NE Halsey Street	7.5	11,525	276.77
NE Glisan Street	11	15,450	544.18
SE Stark Street	9	7,650	195.96
E Burnside Street	11	16,050	533.91
NE Sandy Boulevard	12.5	18,475	575.14
Broadway Avenue	6	21,738	324.82
Weidler Street	3.25	31,425	254.35
Multnumah Street	3	13,425	100.30
Holladay Boulevard	2	1,046	5.21
Yamhill Street	11.5	6,425	184.01
Total			2,995

Table A 6.4 Network Benefits Summary

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	1,048	$ 15,714	$ 3,928,622
Club	1,498	$ 22,468	$ 5,617,034
Spillover	2,995	$ 44,920	$ 11,229,998
Total	5,540	$ 83,103	$ 20,775,654

Table A 6.4 shows that the 1998 delay saving attributed to transit on the Gateway-Portland corridor is estimated at about $20.8 million. This can be translated to $2.2 million per rail mile.

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door to door travel time data should be collected to estimate an accurate performance metric.

Figure A 6.1 displays the "with-" and "without transit" curves using 1999 convergence data. The vertical difference between the "with-" and "without transit" curves represents the delay savings due to transit at different volumes of the common segment traffic. The curves indicate that in the absence of major infrastructure improvements or radical traffic growth, the performance metric will remain stable.

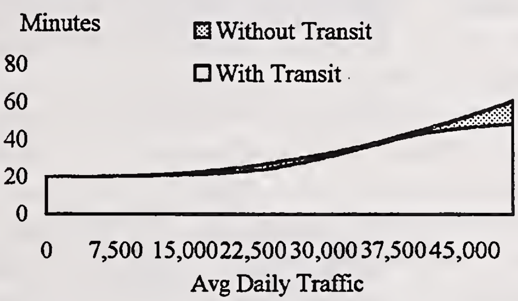


Figure A 6.1 "With-" and "Without Transit" Curves

Although an intermodal travel time convergence of 13 minutes is sufficient to yield delay savings to highway users (as compared to the "without rail" case), full convergence would of course yield even greater savings. Why is the convergence level as high as 13 minutes? Stated differently, why is it that, even though door-to-door average peak-period roadway travel time is 13 minutes less than the average door-to-door travel time by light rail, light rail users are not re-exploring the roadway option by enough to "bid-up" roadway times any further?

The Mogridge-Lewis framework predicts that non-time related roadway travel costs (ie, the non-time elements of "generalized cost" such as parking costs, fuel costs and so on) account for the "13 minute wedge." Light rail users are expected to re-explore the roadway option to the point at which the value of non-time generalized cost factors just equals the value of the travel time advantage offered by road. If non-time costs are moderate to high, travel time convergence will occur at a non-zero time differential between road and rail. Such is the case at-hand. In particular, parking costs in downtown Portland are well above the national average. Parking capacity is low as a matter of land-use and transportation planning policy, which means that the time-related costs of finding parking and gaining walk-access to the final destination thereafter are higher than the national average. Also, low parking capacity drives the money cost of parking above the national average. The Mogridge-Lewis framework predicts convergence at a non-zero travel time differential in such circumstances. It also predicts convergence at a travel time differential that lies above the national average differential for corridors in convergence. Both predictions are borne out in the Portland case presented here.

The design of expanded park-and-ride facilities in response to capacity constraints at existing stations will materially influence the extent and direction of inter-modal exploration. Designs that minimize auto-to-platform walking times (such as vertical structures rather than ground-level expansion) encourages auto users to explore light rail and discourages light rail users from exploring auto. This in-turn helps maximize light-rail's convergence-related benefits. Portland's current parking structure in stations such as Gateway Station ("horizontal" rather than "vertical" park-and-ride expansion) is not consistent with the maximization of transit's performance as a "regulator" of multi-modal corridor performance.

Figure A 6.2 MAX light Rail running through transit-dedicated streets in Downtown Portland

Figure A 6.3 MAX Light rail servicing a residential area in north Portland

Introduction

This report presents the results for the Gateway-Portland corridor case study as part of Streamlined Strategic Corridor Travel Time Management study. The purpose of the study is to use the convergence measurement technique to derive a repeatable performance measurement for rail transit in congested corridors. This case study measures the performance of Portland's light rail system—known as MAX—using the methodology developed in Subtask 1c. The methodology consists of calibrating the Mogridge-Lewis Convergence Hypothesis (MLC) model with survey data and using the model to quantify delay savings attributable to transit at different roadway traffic volumes. The savings are estimated for three different user categories using highway traffic data and light rail ridership in the corridor.

Study Methodology

The study methodology consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and light rail ridership data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) light rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

During the first step, HLB collected HPMS data, local arterials traffic data, and light rail ridership data from METRO (the local MPO) and Tri-Met (the Tri-County Metropolitan Transportation District of Oregon). The data were used to estimate the model parameters.

For the second step, data was collected on site—Gateway-Portland corridor—by a survey team. A corridor, as defined in this study, is a principal transportation artery into the central business district. Multiple transportation services are available to commuters who use this artery. Additionally, during the peak period a large number of commuters utilize this route in their door-to-door commute.

A statistical sample of trips was generated in the corridor by identifying random trip end point in the zones at either end of the corridor and joining them so that trips alternated between zones. These zones are catchment zones where travelers converge or diverge from either the transit station or the principal highway route. In this study these zones are defined as the access segment and the component of the corridor common to all trips for a given mode, regardless of trip end location, is defined as the common segment.

Survey crews were instructed to follow specific routes that consisted of an access segment—dependent on the catchment zone considered for the trip—and a common segment. The data collected include start times and arrival times for each segment, by mode, congestion level, seating availability, weather, road conditions, and travel costs for each segment.

Data were collected over a period of three consecutive days (Tuesday to Thursday) during the first week of February 1999. The days of the week were sampled to eliminate fluctuations in traffic patterns and volumes due to the day of week effects. Trips were validated to minimize the effects of unusual or circumstantial conditions. Sixty valid trips were selected to ensure a statistically adequate sample size. The study employed the maps and routes connecting several zones within a residential area to several points within Portland's central business district.

Step three consisted of estimating the "with transit" curve based on the traffic volume and the door to door travel time. Using the model developed in Subtask 1c, HLB derived the "without transit" curve and estimated the hours of delay saved due to transit. This performance metric is defined as the vertical difference between the two curves.

In step four, the hours of delay saved due to transit are aggregated into three user categories. Savings by common highway-segment users are estimated using the traffic volume on the segment. Savings by light rail riders are estimated using the ridership data for each station along the corridor. Savings by parallel highways users are estimated using traffic volume on parallel highways and arterials within the corridor. The magnitude of the savings decreases as the distance between the common segment and the arterial increases.

Plan of the Report

This report presents the results from the Gateway-Portland corridor case study. Following this introduction, Chapter 2 presents an overview of the model and methodology to estimate the delay saving. Chapter 3 displays the corridor characteristics and a description of the principal modes of transportation within the corridor. Chapter 4 presents the results from the 1999 door-to-door travel survey and shows the model estimation results. The chapter estimates the hours of delay saved due to transit per person per day, and provides a monetary value of the delay saved for three user categories. Appendices provide maps of the residential area and the central business district as well as supporting data and supplementary results on the survey findings by route.

Methodology and Model Overview

The methodology consists of four steps:

1. Estimating the Corridor Performance Baseline
2. Estimating the Corridor Performance in the Absence of transit
3. Extrapolating Delay Savings Due to Transit
4. Estimation of Corridor Performance without Re-calibration

Estimating the Corridor Performance Baseline

The Model This model establishes a functional relationship between the person trip volume –all modes—and the average door to door travel time by auto in the corridor.

The door to door travel time by auto can be determined using a logistic function which calculates the door to door travel time in terms of travel time at free flow speed, trip time by high capacity rail mode, and the volume of trips in the corridor for all modes. The door to door travel time can be estimated as follows:

$$\mathbf{T = (T_c - T_{ff}) / (1 + e^{-(\delta + \varepsilon V1)}) \quad + T_{ff}} \qquad \mathbf{(1)}$$

Where T_{a1} is auto trip time,

Tc is trip time by high-capacity rail mode

T_{ff} is auto trip time at free-flow speed,

V is person trip volume in the corridor by auto, and

δ, ε are model parameters

Equation 1 implies that the door to door auto trip time is equal to the trip time at free-flow speed plus a delay which depends on transit travel time and the person trip volume in the corridor.

In other words, when the highway volume is close to zero, travel time is equal to travel time at free flow speed.($T = T_{ff}$). As the volume increases, the travel time is equal to T_{ff} plus a delay due to the high volume, but adjusted to the travel time by high capacity transit. That is the high capacity transit alleviates some of the highway trip delay as some trips shift to transit.

Equation 1 is transformed into a linear functional form before the parameters δ and ε can be estimated, the transformed equation will be:

$$\mathbf{U = \delta + \varepsilon V_1} \qquad \mathbf{(2)}$$

Where $U = \ln [(T_c - T_{ff}) / (T - T_{ff}) - 1]$

Equation 2 is estimated using Ordinary Least Squares regression.

Data The data required for the estimation of the above equations are:

person trip volume on the highway which can be calculated by dividing the traffic volume by the average vehicle occupancy (auto and buses). This data are available through HPMS data base and MPO's traffic data.

free flow trip time is a constant.

high capacity trip time is a constant.

The parameters δ and ε do not have to be re-estimated each year, they are both specific to the corridor and are relatively stable over the years. So periodically, the person trips volume can be inserted into Equation 1 to estimate the door to door travel time by auto.

Estimating the Corridor Performance in the Absence of transit

The Model This model represents the concept to quantify the role of transit in congestion management. In the absence of transit, the travel time Ta is estimated as:

$$\mathbf{T_a = T_{ff} * (1 + A (V^*)^{\beta})} \quad \mathbf{(3)}$$

Where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V^* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door to door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

The existing auto and bus person trips on the highway.

The percentage of person transit trips shifting to auto

The percentage of person transit trips shifting to bus

The number of additional cars in the highway

The number of additional buses in the highway

The occupancy per vehicle in the absence of transit

The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$\mathbf{V^* = V_1 + \alpha_1 V_c + \alpha_2 V_b} \quad \mathbf{(4)}$$

Where : V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor, and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

1. Type 1: "Explorers" who are casual switchers and who will divert to Single Occupancy Vehicles in the absence of transit.
2. Type 2: Commuters with low elasticity of demand with respect to generalized cost and who will divert to use the bus or carpool.
3. Type 3: Commuters with high elasticity of demand with respect to generalized cost and who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher the shift of transit riders to cars and buses. Therefore, higher degree of convergence will lead to higher delay, which translates into higher savings due to transit.

In words, Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high which translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve (as the volume increases, travel time increases at an increasing rate). Figure A 6.4 illustrates the relationship between the volume and travel time both in the presence and in the absence of transit.

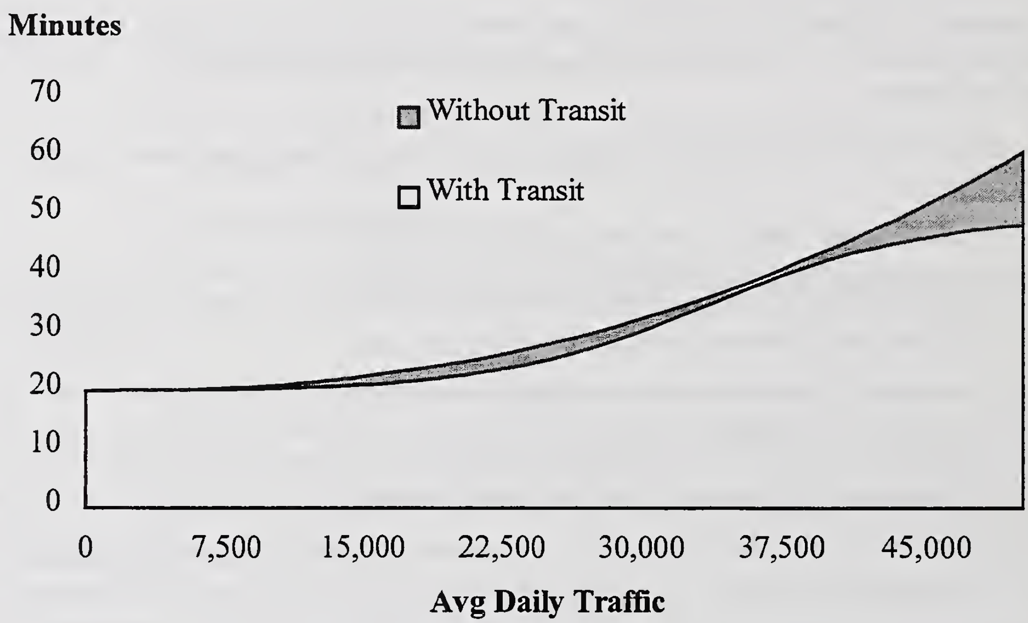


Figure A 6.4 Travel time both in the presence and in the absence of transit

Data The data required to populate this model consist of:

Highway person trip volume (used in the previous model)

Transit ridership data

Fleet composition (cars and buses percentages out of the total traffic)

Cars and buses vehicle occupancy

Passenger car equivalent factor

Degree of convergence to determine the percentage person trips shifting to cars and buses

Free-flow travel time which is a constant

Equation 3 is specific to the corridor and do not need to be estimated each year. It will only be necessary to re-estimate them with an updated degree of convergence if a major change is made to the transit level of service or the highway structure.

Extrapolating Delay Savings Due to Transit

While the MLC hypothesis proves to be valid during the peak period only, the delay savings due to transit can be estimated during off-peak as well. This metric can be estimated as the vertical difference between the "without transit" curve and the "with transit" curve. That is at a specific person trip volume, the difference in travel times between the two cases can be defined as "the hours of delay saved due to transit".

The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by Metro riders (market benefits), savings by highway users (club benefits), and savings by users of parallel highways (spillover benefits).

The market benefits are estimated based on delay saved (which depends on the distance traveled) for each rider within the common segment.

The club benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution.

The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment. The spillover benefits are calculated by multiplying the traffic volume with a percentage of the delay savings. This percentage decreases as the distance between the common segment and the parallel highway increases.

Estimation of Corridor Performance without Re-calibration

The framework, presented above, provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay without the need for repeated MLC surveys. The approach rests on the theoretical proposition, that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

Corridor Overview

The Gateway-Portland corridor is about 8 miles in length and connects the residential area east of I-205 and I-84 Bypass with the CBD in Portland, Oregon. The residential catchment zone is centered around the Gateway/NE 99th Avenue Transit Center. Trip end points within the residential zone are no more than a 15 minutes drive or bus ride to the station. The downtown Portland, Oregon zone, centered around the Pioneer Square Light Rail Station, extends for a radius of .6 miles. App. Annex A1 provides maps of the residential and business district zones considered in this study. The Gateway-Portland MAX light rail line is part of the 15-mile line connecting Downtown Portland with the City of Gresham, East of Portland. This line was opened on September 5th, 1986.

Principal Travel Modes

The “principal travel mode” is defined as the mode used during the common segment of each individual trip. The main transportation modes serving the Gateway-Portland Corridor are automobile and the light rail, MAX. The Gateway-Portland MAX line is a 6.16-mile segment of the 15-mile Eastside MAX line serving the area between downtown Portland and the city of Gresham.

Automobile routes can be broken into three distinct sections:

1. The route between the residential point and the intersection of I-84 and NE Halsey in Gateway TC area (Access1);
2. The route from the intersection of I-84 and NE Halsey in Gateway TC area to the intersection of SW Washington Street and Second Avenue (Common Segment); and
3. The route from the intersection of SW Washington Street and Second Avenue and the CBD point (Access2).

For a morning rush hour trip, survey drivers followed Accessl to the common segment. The common segment route originated at the intersection of I-84 and NE Halsey in Gateway TC area. Drivers followed I-84 West to I-5 South to northwest on Morrison Bridge, up to SW Washington and Second Avenue. From the end of the common segment, survey drivers followed Access2 to the downtown points, at which time they parked at the closest parking lot and proceeded on foot to the end point. The evening rush hour trip covered the same progression in the opposite direction.

The routes for the MAX light rail mode can also be broken into three distinct sections:

1. The route between the residential point and the Gateway Transit Center (Access1);
2. The route between the Gateway Transit Center and the Pioneer Square North light rail station (Common Segment); and
3. The route between the Pioneer Square North light rail station and the CBD point (Access2).

For a morning rush hour trip, survey crews rode the bus or drove Accessl to the Gateway Transit Center Metro Station parking lot and walked from the lot (or the bus stop) to the MAX station. The route taken for the common segment consisted of a light rail trip which began at the Gateway TC and continued to the Pioneer Square North MAX Station. From the end of the common segment, the surveyor walked Access2 to the downtown points. The evening rush hour trip covered the same progression in the opposite direction. On average, trains run every 6 minutes during peak hours. Table A 6.5 displays some of the principal performance and service characteristics of the corridor.

Table A 6.5 Performance and Service Characteristics for Gateway-Portland Corridor

	Automobile	Light Rail
Number of stops	N/A	13
Number of Streets and Highways	3	N/A
Tolls/Fares for a one way (in dollars)	$0.00	$1.40

One of the main characteristics The Gateway-Portland corridor is that the MAX light rail line and the I-84 common segment are side-by- side for about 5.5 miles from Gateway TC/99th Avenue to the Lloyd Center/ NE 11th Avenue. Figure A 6.5 shows the Gateway-Portland corridor and the main highways and arterials in the area.

Another feature of the MAX line is that it runs through a sport complex—Rose Garden Arena—and nearby High-Schools around Hollywood TC and 42nd Avenue. This line configuration made MAX a good transportation choice not only for daily commuters but for sport fans and students as well.

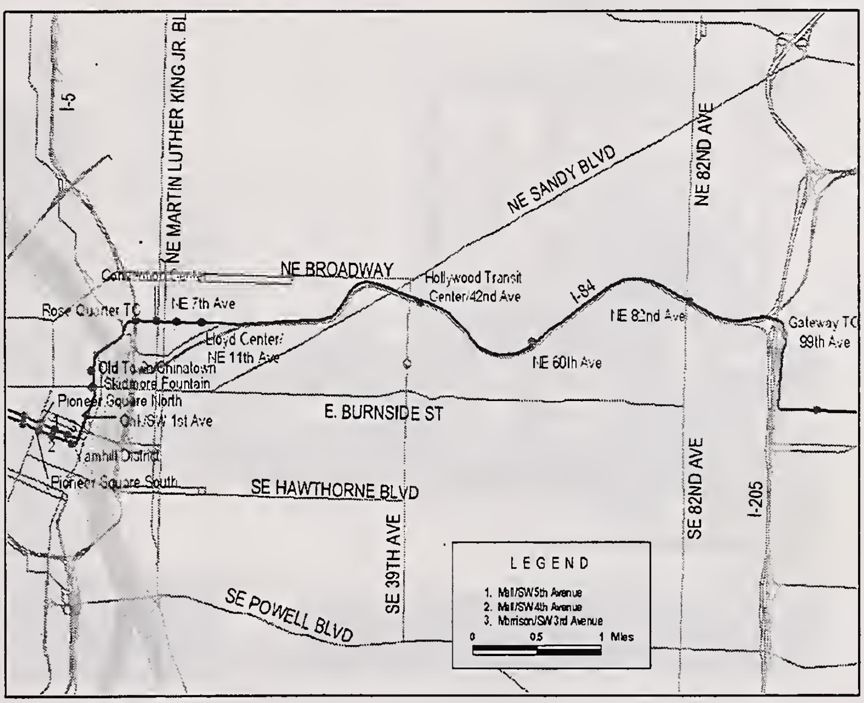


Figure A 6.5 Map of the Gateway-Portland Corridor

Figure A 6.6 Transit Station (Park and Ride facility) for Bus and Light Rail located south of Portland

Figure A 6.7 Max Light rail sharing the streets of Downtown Portland

Principal findings

This chapter starts by presenting the results from the door-to-door travel survey conducted during the first week of February 1999. The travel survey data are used to derive the inter-modal convergence level in the Gateway-Portland corridor. The chapter then presents the estimation of the hours of delay saved due to transit for different user categories.

The Convergence Level

The starting point to estimate the "without transit" curve is to determine the convergence level based on the key findings from the 1999 door to door travel data. The door to door travel survey for the Gateway-Portland Corridor found that:

- Average door-to-door travel times for auto and metro rail, are not similar, 38.3 minutes by light rail versus 27.3 minutes by auto (Table A 6.6).
- Travel time reliability, as represented by the standard deviation of average travel time, is similar, 5.6 for light rail mode compared and 4.2 for the auto mode (Table A 6.6).
- Commuters experienced similar travel times in the morning and in the evening reflecting the similar traffic dynamics of the inbound peak flow versus the outbound peak flow in the corridor (Table A 6.7).
- Statistical analysis shows that the mean trip time by auto was at most 13 minutes longer with 95% confidence (Table A 6.8).
- The common segment travel time was greater for the light rail mode than for the transit mode, 23.3 minutes versus 15.9 minutes. The difference of 7.4 minutes between the two modes is due to lower congestion on the highways as more commuters use the light rail[1]. (Table A 6.6).
- Access segment travel times indicate that auto commuters spent 4 minutes on average less outside the common segment than transit commuters. The difference is mainly due to the waiting time for the light rail (Table A 6.6).
- Access segment travel time for commuters who rode the bus to and from the light rail station was 3.5 minutes higher than for commuters who drove to and from the station. This is mainly due to the wait for at the bus stop.

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1 In 1997, 72% of Tri-Met customers have a car, but prefer to ride Tri-Met, and during Fiscal Year 1997 MAX experienced an 8.8% increase in Ridership.
Source: Tri-Met Attitude & Awareness Survey, August 1997.

Table A 6.6 Results for the Gateway-Portland Corridor

	Automobile	Light Rail -MAX
Total Travel Time		
Mean	27.3	38.3
Standard Deviation	4.2	5.6
Access Segment Travel Time		
Mean	11.4	15.0
Standard Deviation	2.1	4.2
Common Segment Travel Time		
Mean	15.9	23.3
Standard Deviation	4.5	2.9
Sample Size	30	30

Table A 6.7 Comparison of AM and PM Trip Times by Modes

	Auto	Metro Rail
Inbound AM Average Trip Time	27	37.8
Outbound PM Average Trip Time	26.3	37.6

Table A 6.8 Statistical Testing of Convergence Hypothesis

Difference in Mean Travel Times by Mode (Auto- Metro Rail minutes)		11.1
Standard Error of the Difference of the Means (minutes)		1.28
Hypothesis: "The difference between the mean travel times by modes is at most..."	Significant at the 0.10 Level (90% Confidence)	Significant at the 0.05 Level (95% Confidence)
10 Minutes	NO	NO
11 Minutes	NO	NO
12 Minutes	NO	NO
13 Minutes	YES	YES
14 Minutes	YES	YES

The results in Table A 6.8 indicate that light rail in the defined corridor has drawn door-to-door travel times by highway and light rail to within no more than 13 minutes of one another during congested roadway conditions (with 95 percent statistical confidence).

Although an inter-modal travel time convergence of 13 minutes is sufficient to yield delay savings to highway users (as compared to the "without rail" case – see below), full convergence would of course yield even greater savings. Why is the convergence level as high as 13 minutes? Stated differently, why is it that, even though door-to-door average peak-period roadway travel time is 13 minutes less than the average door-to-door travel time by light rail, light rail users are not re-exploring the roadway option by enough to "bid-up" roadway times any further?

The Mogridge-Lewis framework predicts that non-time related roadway travel costs (i.e, the non-time elements of "generalized cost" such as parking costs, fuel costs and so on) account for the "13 minute wedge." Light rail users are expected to re-explore the roadway option to the point at which the value of non-time generalized cost factors just equals the value of the travel time advantage offered by road. If non-time costs are moderate to high, travel time convergence will occur at a non-zero time differential between road and rail. Such is the case at-hand. In particular, parking costs in downtown Portland are well above the national average. Parking capacity is low as a matter of land-use and transportation planning policy, which means that the time-related costs of finding parking and gaining walk-access to the final destination thereafter are higher than the national average. As well, low parking capacity drives the money cost of parking above the national average. The Mogridge-Lewis framework predicts convergence at a non-zero travel time differential in such circumstances. It also predicts convergence at a travel time differential that lies above the national average differential for corridors in convergence. Both predictions are borne out in the Portland case presented here.

The design of expanded park-and-ride facilities in response to capacity constraints at existing stations will materially influence the extent and direction of inter-modal exploration. Designs that minimize auto-to-platform walking times (such as vertical structures rather than ground-level expansion) encourages auto users to explore light rail and discourages light rail users from exploring auto. This in-turn helps maximize light-rail's convergence-related benefits. Portland's current parking structure in stations such as Gateway Station ("horizontal" rather than "vertical" park-and-ride expansion) is not consistent with the maximization of transit's performance as a "regulator" of multi-modal corridor performance.

Methodology Application on Gateway-Portland Corridor

Data HLB collected HPMS data, local arterials traffic data, and light rail ridership data from METRO (the local MPO) and Tri-Met (the Tri-County Metropolitan Transportation District of Oregon). In addition door to door travel time survey was conducted to derive the corridor degree of convergence. HLB estimated the model, described in Section 1 using the obtained data.

Model Equation 1 is estimated as follows:

$$\mathbf{T_{a1} = (60 - 15) / (1 + e^{-(-9.14 + 0.000174 (V))}) + 15} \quad (1)$$

Similarly, Equation 2 is estimated based on auto travel volume, transit ridership data, and convergence level estimate from the survey.

$$\mathbf{T_{a2} = 15 * (1 + 3.49E\text{-}18 (V^*)^{3.7})} \quad (2)$$

The auto traffic volume in the absence of transit is determined by adding the auto volume in the presence of transit to the generated auto trips by transit riders. The generated results are based on:

- About 40% of person transit trips will be forgone (determined by the corridor convergence level).
- The average vehicle occupancy (HOV and non-HOV) is 1.2 for cars and 40 for buses.
- Car trips will make about 90% of trips.

Benefit Estimation

To estimate the travel time saving (TTS) attributed to transit, the current traffic volume is inserted into Equation 1 and 2. An auto volume of 37,500 results into:

$$T_{a1} = 25.10,\ T_{a2} = 28.15,\ \text{and}.\ TTS = T_{a2} - T_{a1} = 3.05$$

That is on average, in Gateway-Portland corridor, transit saves about 3.05 minutes per auto trip (6 seconds per mile) during the peak period. Once the average travel time saving per vehicle is estimated, the savings are weighted to reflect the congestion level at each time of the day.

The benefits are calculated for three user groups:

1. Benefits to highway users (Club), these are the hours saved by the common segment user of the Gateway-Portland corridor (see Table A 6.9).
2. Benefits to Transit users (Market), these are the hours saved by the users of transit between Gateway TC and Pioneer Square Station (see Table A 6.10).
3. Benefits to the highway network users within the corridor (spillover), these are the hours saved by users of parallel and adjacent highways to the common segment within the corridor (see Table A 6.11).

Table A 6.9 Club Benefits for Gateway-Portland Corridor

	Distance (miles)	Avg Daily Traffic Volume	Daily Savings (hours)
Common Segment			
I-84	6.11	53,425	1,161.36
I-5	1.07	44,738	170.31
Morrison Bridge	0.25	20,763	18.47
Access Segment (average)	2	20,763	147.74
Total	9.43		1,497.88

Table A 6.10 Market Benefits for Gateway-Portland Corridor

Station	In-bound Trips	Out-bound Trips	Daily Savings (hours)
Gateway TC	1,833	2,032	108.08
NE 82nd Avenue]	1,533	1,889	90.89
NE 60th Avenue	1,617	2,048	92.22
Hollywood/NE 42nd TC	1,542	2,173	88.27
Lloyd Center/NE 11th Ave.	1,867	2,063	87.89
NE 7th Avenue	2,983	1,774	99.76
Convention Center	3,167	1,669	94.64
Rose Quarter TC	1,542	2,173	67.50
Old Town/Chinatown	1,867	2,063	65.92
Skidmore Fountain	2,983	1,774	73.16
Oak Street/SW 1st Ave.	3,167	1,669	60.84
SW 3rd Avenue/Yamhill	2,533	1,568	45.86
Mall/SW 5th-/SW 4 th Ave.	2,717	1,347	39.76
Pionner Square N/S	2,567	1,348	32.84
Total			1,048

Table A 6.11 Spillover Benefits for Gateway-Portland Corridor

Highways in the corridor	Distance (miles)	Avg Daily Traffic Volume	Daily Savings (hours)
NE Halsey Street	7.5	11,525	276.77
NE Glisan Street	11	15,450	544.18
SE Stark Street	9	7,650	195.96
E Burnside Street	11	16,050	533.91
NE Sandy Boulevard	12.5	18,475	575.14
Broadway Avenue	6	21,738	324.82
Weidler Street	3.25	31,425	254.35
Multnumah Street	3	13,425	100.30
Holladay Boulevard	2	1,046	5.21
Yamhill Street	11.5	6,425	184.01
Total			2,995

Table A 6.12 Benefits Summary

	Daily Savings		Yearly Savings
Benefit Category	In Hours	In Dollars	In Dollars
Market	1,048	$ 15,714	$ 3,928,622
Club	1,498	$ 22,468	$ 5,617,034
Spillover	2,995	$ 44,920	$ 11,229,998
Total	5,540	$ 83,103	$ 20,775,654

Table A 6.12 shows that the 1998 delay saving attributed to transit on the Gateway-Portland corridor is estimated at about $20.8 million. This can be translated to $2.2 million per rail mile.

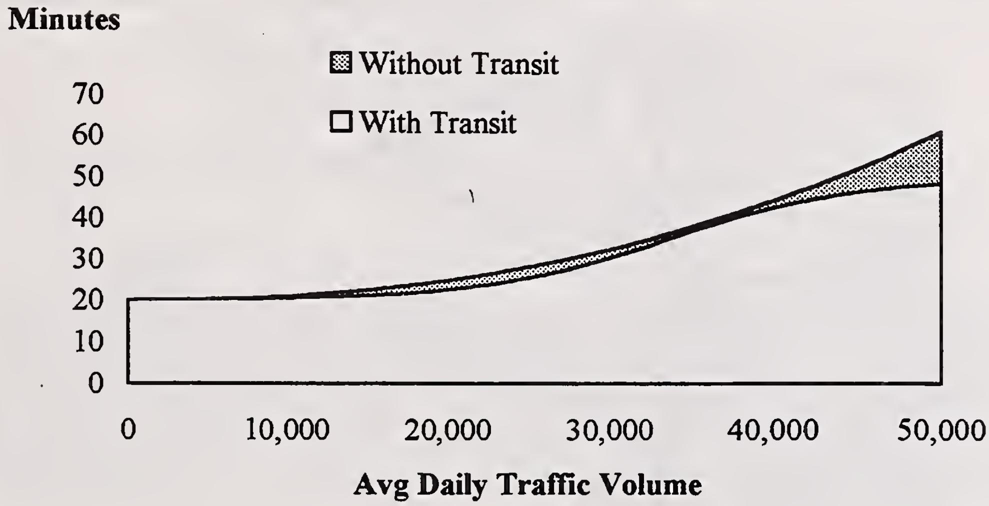


Figure A 6.8 Illustration of the "With-" and "Without Transit" Curves for Portland

The methodology implies that in the absence of major infrastructure improvements or strong growth in volume of traffic the performance metric will remain stable. So, it should suffice to gather corridor travel time—degree of convergence—once every several years. In the case of major infrastructure improvement or a change in the transit service, however, door to door travel time data should be collected to estimate an accurate performance metric.

Annex A 6.1 Views of The Gateway Light Rail Corridor

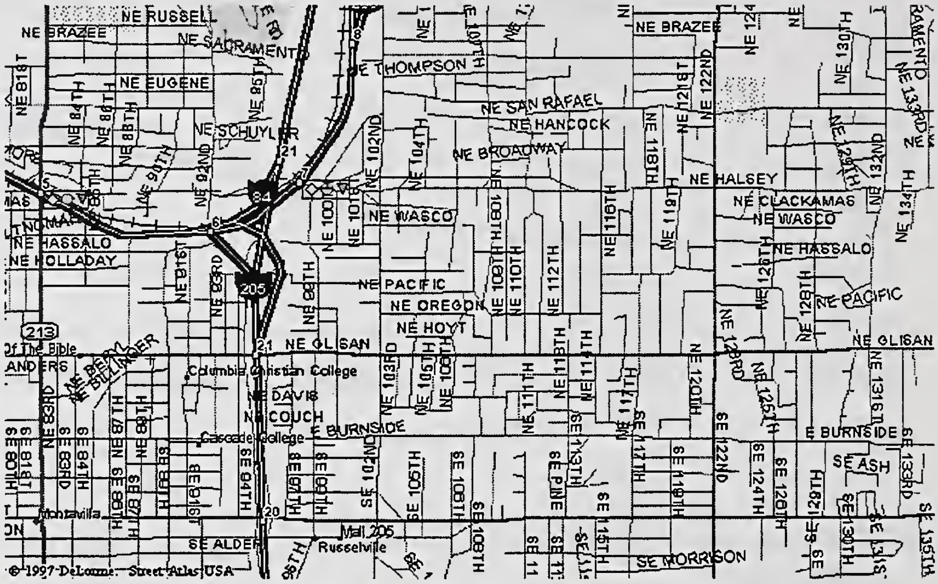


Figure A 6.9 Map of the Residential District

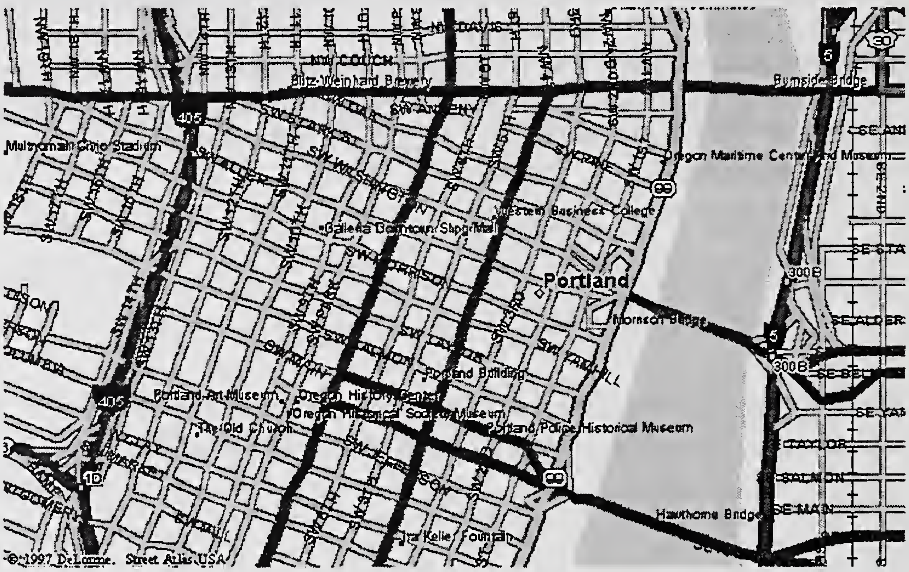
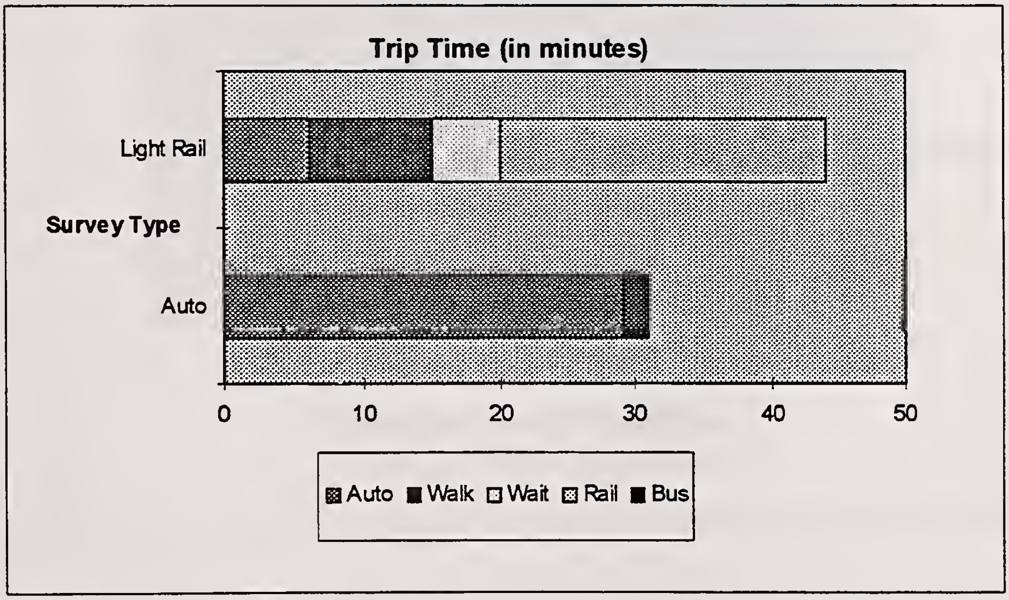


Figure A 6.10 Map of the Central Business District

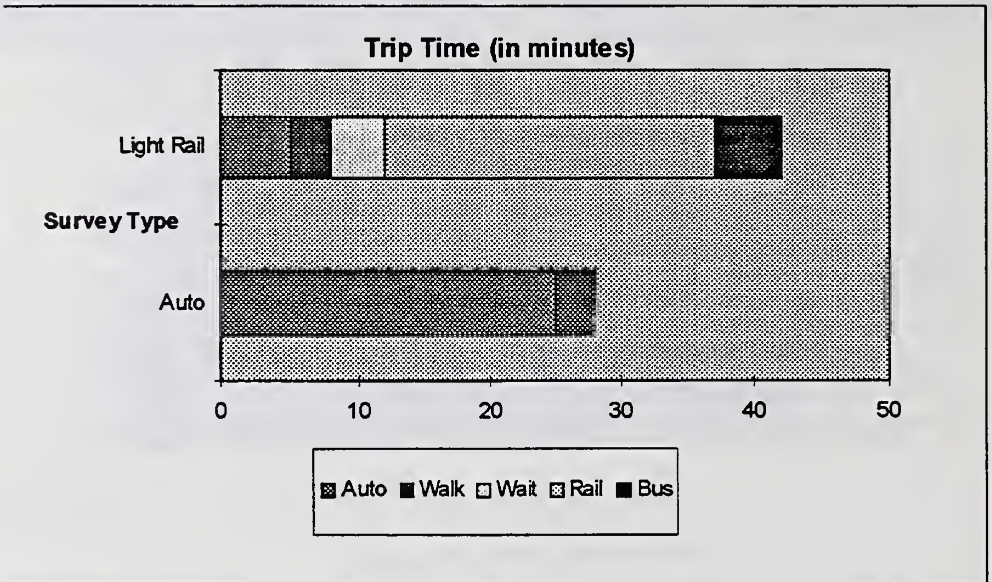
Annex A 6.2 The Survey Findings by Route

CORRIDOR: GATEWAY - PORTLAND
SUMMARY TABLE FOR
ROUTE 1-B:
NE Thompson & 108th Avenue - SW 4th & Madison

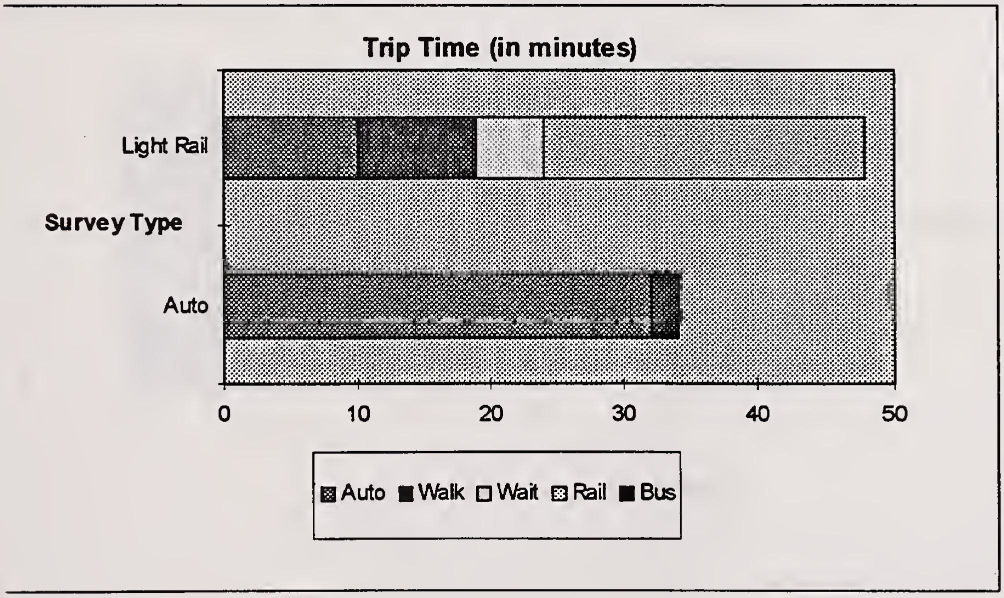
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	31	44
In Common Segment	19	24
Outside Common Segment	12	20
Wait Time	0	5
Walk Time	2	9
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	17.8	12.0
In Common Segment	23.4	17.6
Outside Common Segment	9.0	5.3



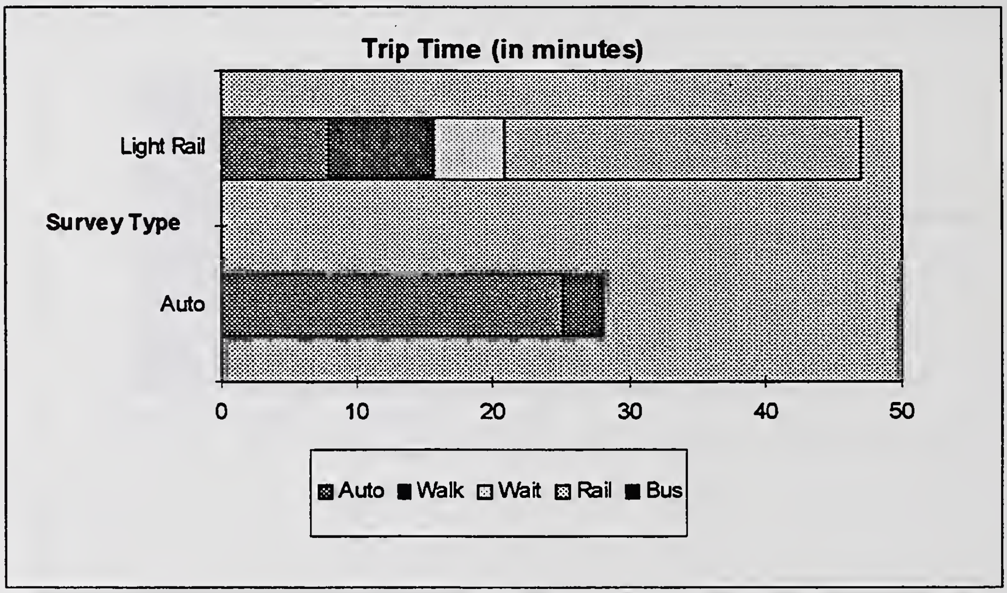
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 2-C: NE Hancock & 111th Avenue - SW 5th & Main	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	28	37
In Common Segment	19	25
Outside Common Segment	9	12
Wait Time	0	4
Walk Time	3	3
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	19.7	14.3
In Common Segment	23.4	16.9
Outside Common Segment	12.0	8.8



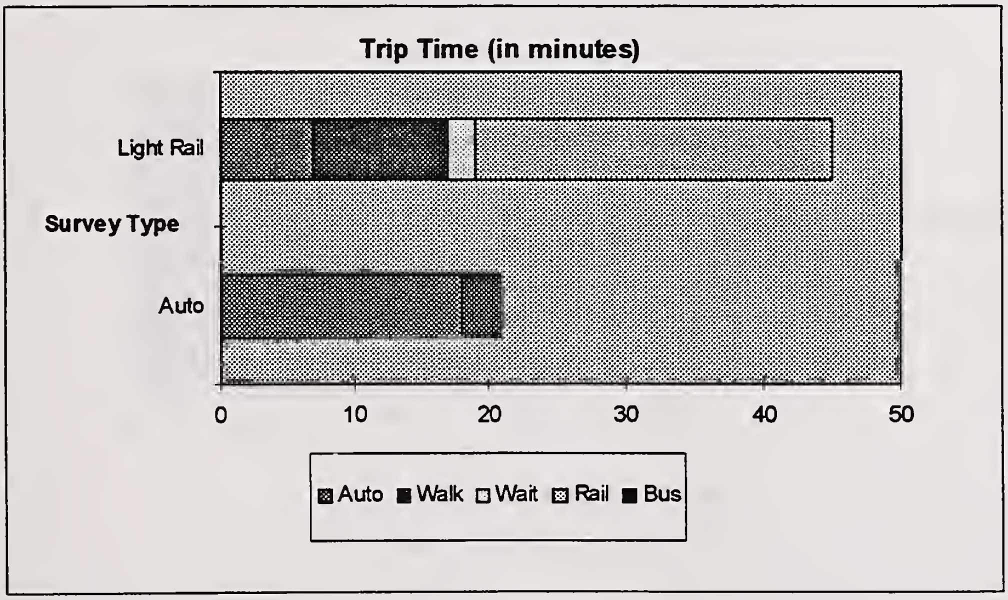
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 6-G: NE Glisan & 113th Avenue - SW Park & SW Alder	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	34	48
In Common Segment	24	24
Outside Common Segment	10	24
Wait Time	0	5
Walk Time	2	9
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	16.2	11.0
In Common Segment	18.5	17.6
Outside Common Segment	10.8	4.4



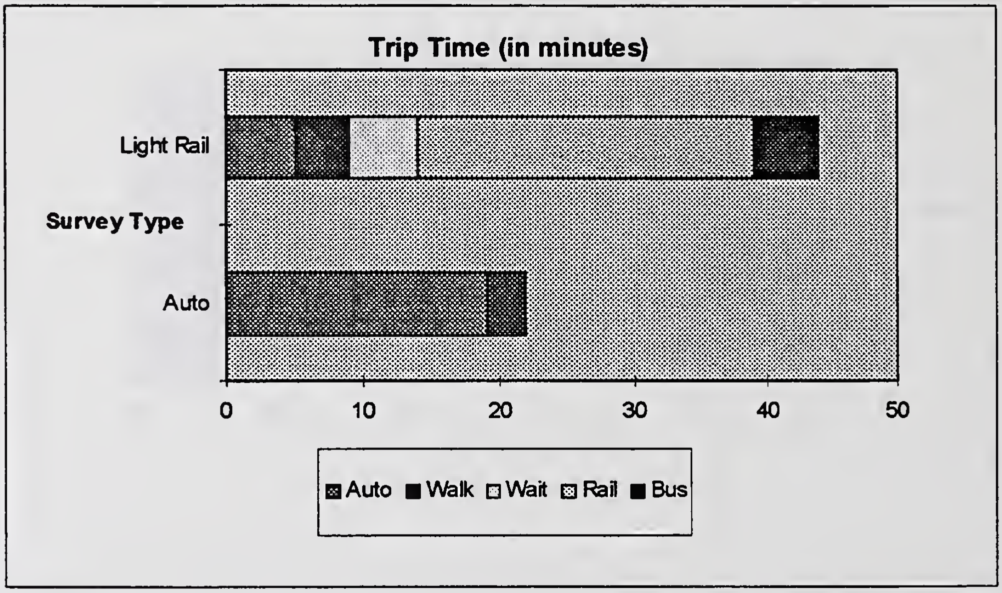
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 8-I: NE Burnside & 109th Avenue - SW Washington & 5th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	28	47
In Common Segment	20	26
Outside Common Segment	8	21
Wait Time	0	5
Walk Time	3	8
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	19.7	11.2
In Common Segment	22.2	16.2
Outside Common Segment	13.5	5.0



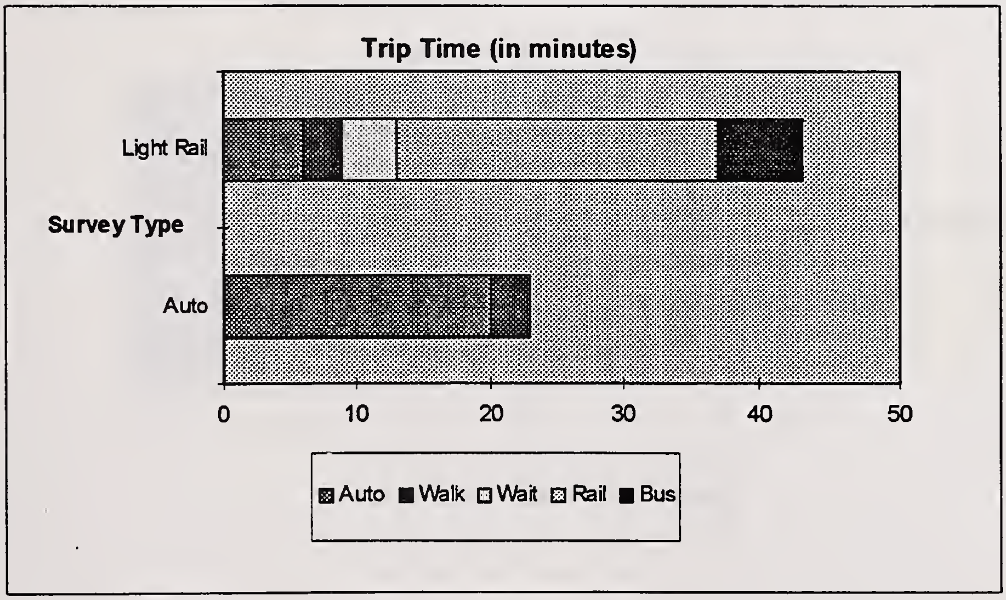
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE B-2: SW 4th & Madison Avenue - NE Hancock & 111th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	21	45
In Common Segment	10	26
Outside Common Segment	11	19
Wait Time	0	2
Walk Time	3	10
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	26.3	11.7
In Common Segment	44.4	16.2
Outside Common Segment	9.8	5.6



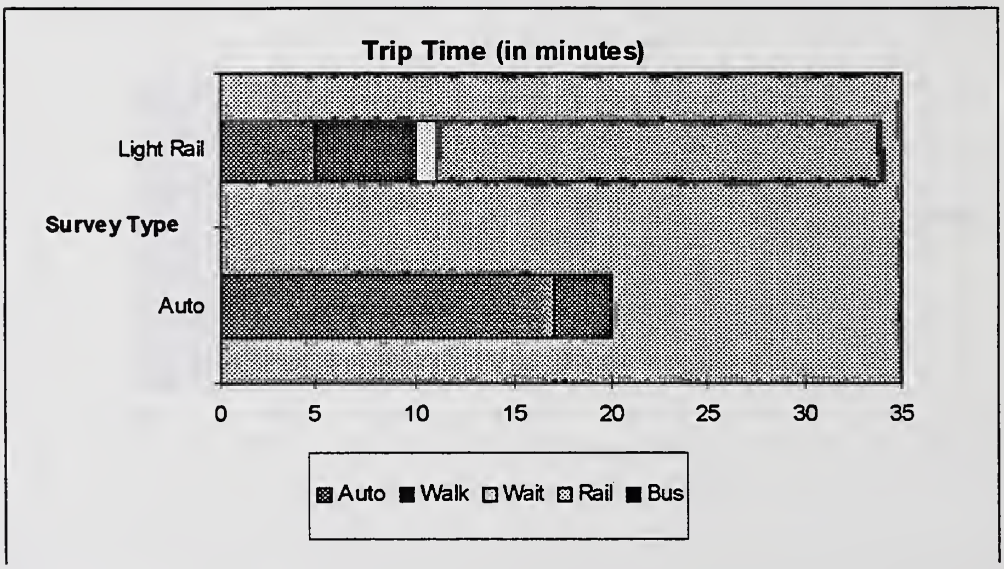
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE C- 3: SW 5th & Main - NE Halsey & 114th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	22	39
In Common Segment	9	25
Outside Common Segment	13	14
Wait Time	0	5
Walk Time	3	4
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	25.1	13.5
In Common Segment	49.3	16.9
Outside Common Segment	8.3	7.5



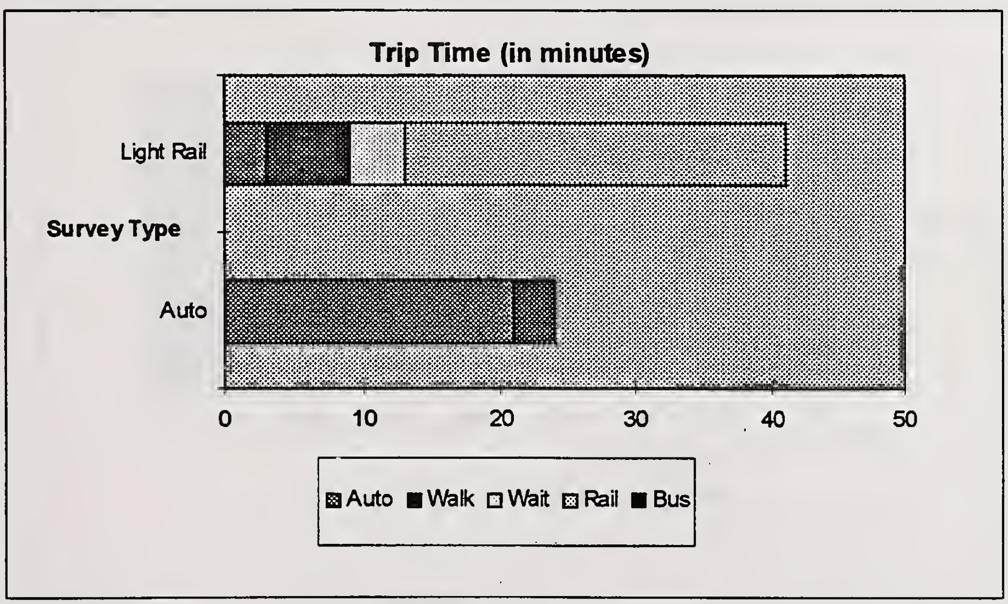
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE D- 4: SW 6th & Salmon - NE Pacific & 117th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	23	37
In Common Segment	9	24
Outside Common Segment	14	13
Wait Time	0	4
Walk Time	3	3
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	24.0	14.3
In Common Segment	49.3	17.6
Outside Common Segment	7.7	8.1



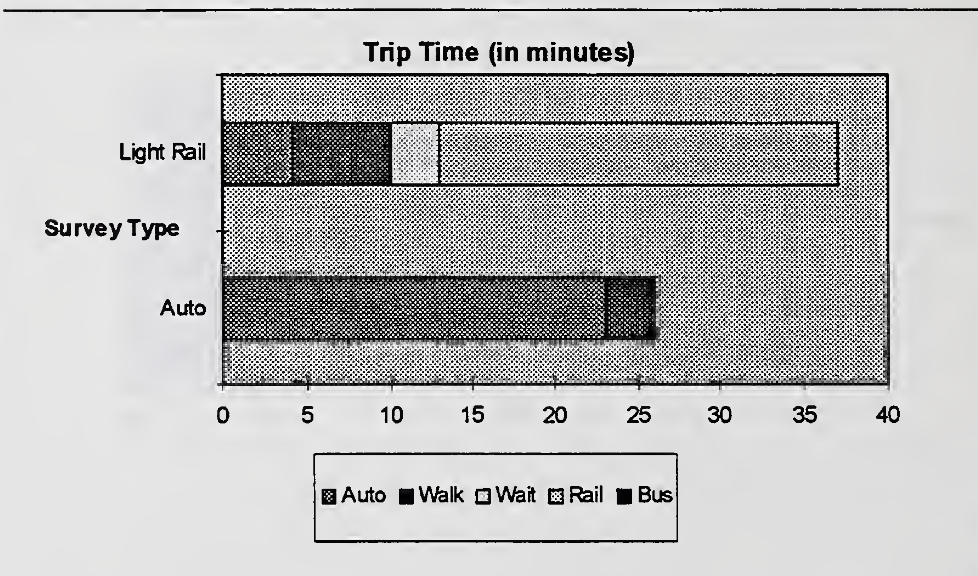
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE G-7: SW Park & Alder - NE Glisan & 106th Avenue		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	20	34
In Common Segment	10	23
Outside Common Segment	10	11
Wait Time	0	1
Walk Time	3	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	27.6	15.5
In Common Segment	44.4	18.4
Outside Common Segment	10.8	9.6



CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE I- 9: SW Washington & 5th Avenue - SE Burnside & 102nd Avenue	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	24	41
In Common Segment	11	28
Outside Common Segment	13	13
Wait Time	0	4
Walk Time	3	6
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	23.0	12.9
In Common Segment	40.4	15.1
Outside Common Segment	8.3	8.1

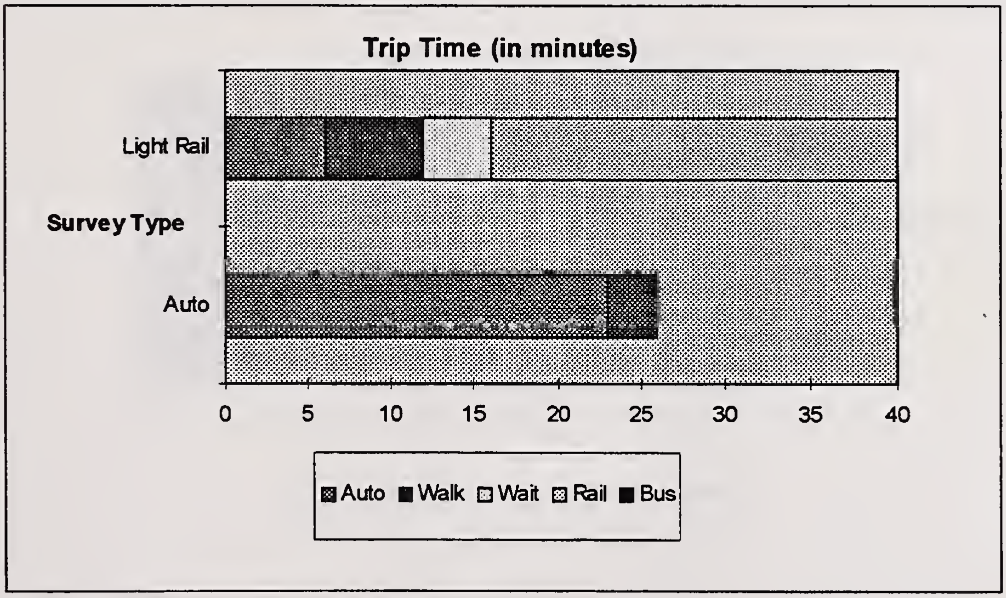


CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 4- E: NE Pacific & 117th Avenue - SW Broadway & Taylor	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	26	37
In Common Segment	16	24
Outside Common Segment	10	13
Wait Time	0	3
Walk Time	3	6
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	21.2	14.3
In Common Segment	27.8	17.6
Outside Common Segment	10.8	8.1

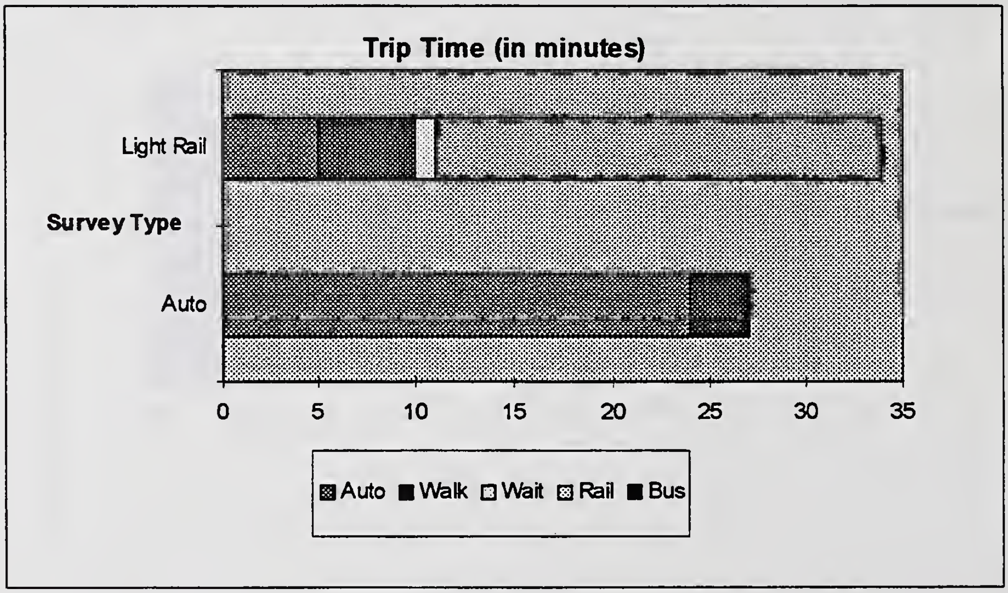


CORRIDOR: GATEWAY - PORTLAND
SUMMARY TABLE FOR
ROUTE 5- F:
NE Oregon & 114th Avenue - SW Park & Yamhill

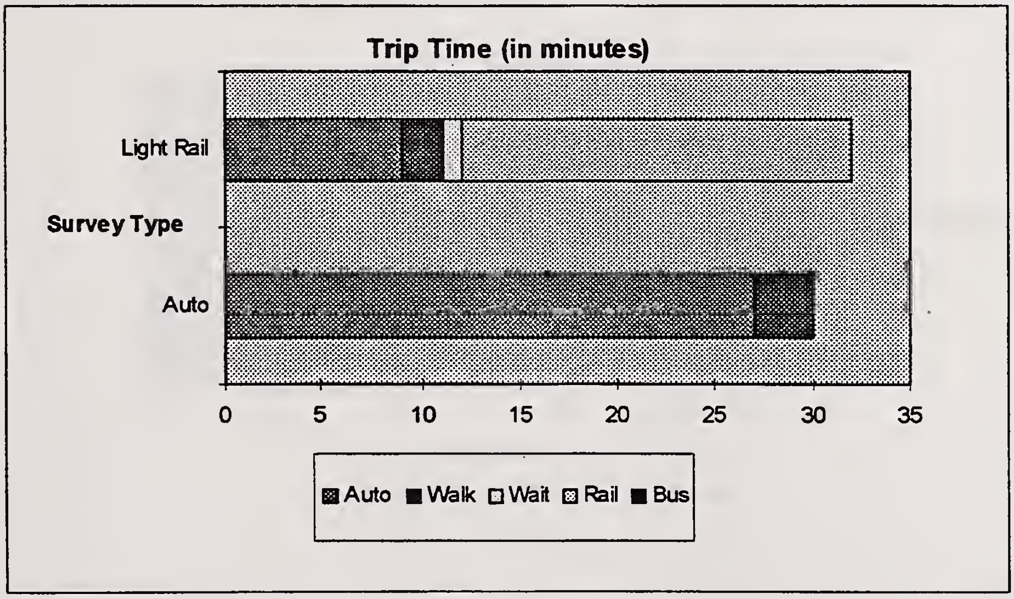
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	26	40
In Common Segment	13	24
Outside Common Segment	13	16
Wait Time	0	4
Walk Time	3	6
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	21.2	13.2
In Common Segment	34.2	17.6
Outside Common Segment	8.3	6.6



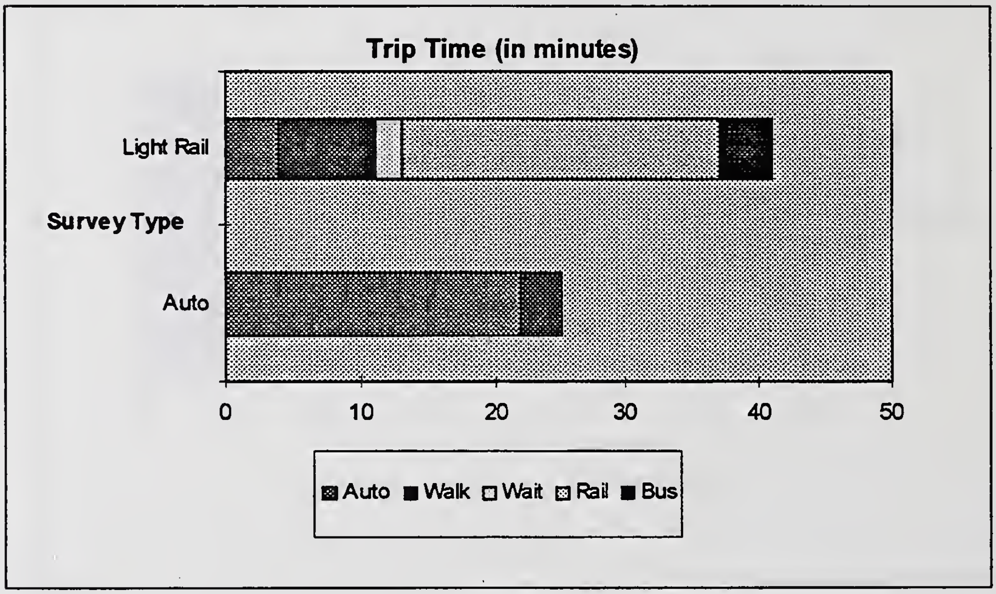
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 7- H: NE Glisan & 106th Avenue - SW Washington & 6th Avenue	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	27	34
In Common Segment	20	23
Outside Common Segment	7	11
Wait Time	0	1
Walk Time	3	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	20.4	15.5
In Common Segment	22.2	18.4
Outside Common Segment	15.4	9.6



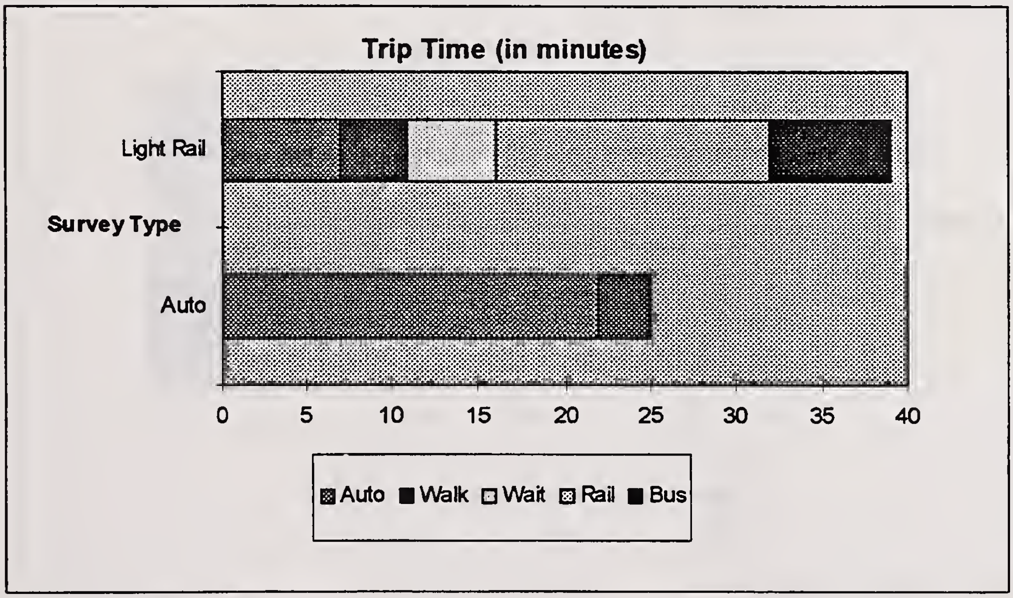
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 9- J: SE Burnside & 102nd Avenue - SW Stark & 6th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	30	32
In Common Segment	22	20
Outside Common Segment	8	12
Wait Time	0	1
Walk Time	3	2
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	18.4	16.5
In Common Segment	20.2	21.1
Outside Common Segment	13.5	8.8



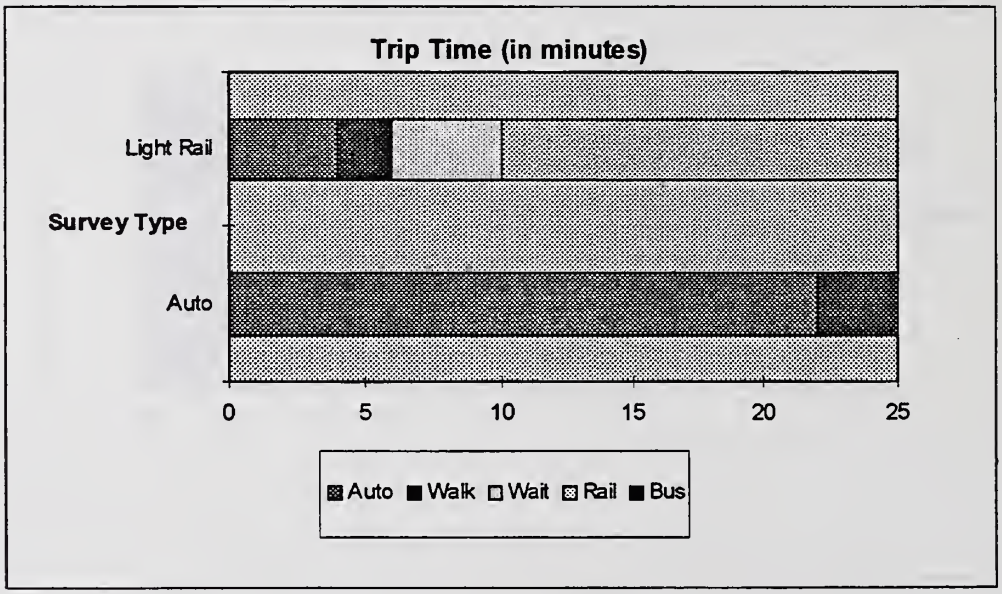
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 10- A: SE Stark & 99th Avenue - SW 3rd Avenue & Main	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	25	37
In Common Segment	15	24
Outside Common Segment	10	13
Wait Time	0	7
Walk Time	3	2
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	22.1	14.3
In Common Segment	29.6	17.6
Outside Common Segment	10.8	8.1



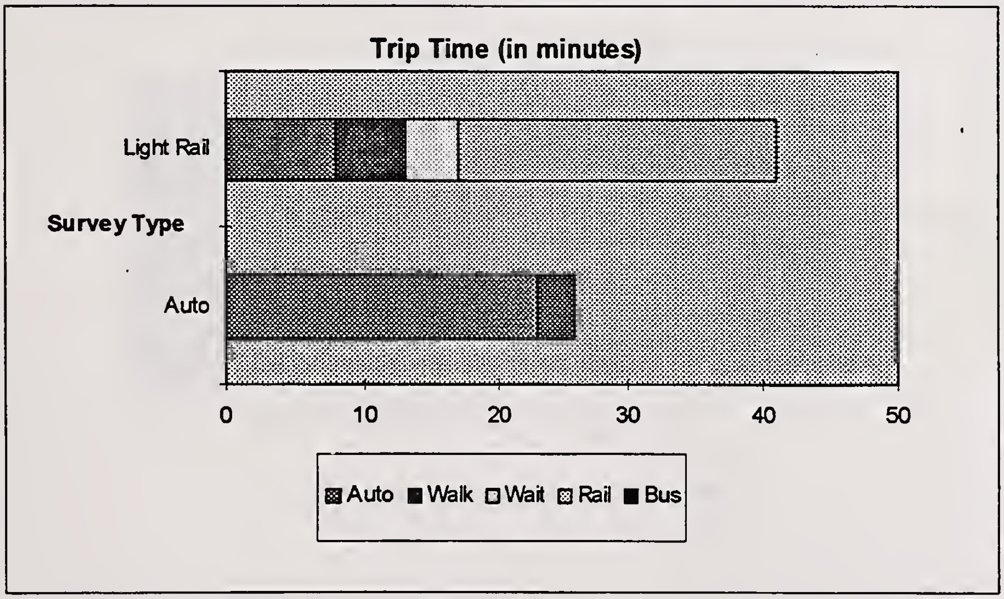
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE E- 5: SW Broadway & Taylor Avenue - NE Oregon & 114th Avenue	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	25	32
In Common Segment	13	16
Outside Common Segment	12	16
Wait Time	0	5
Walk Time	3	4
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	22.1	16.5
In Common Segment	34.2	26.4
Outside Common Segment	9.0	6.6



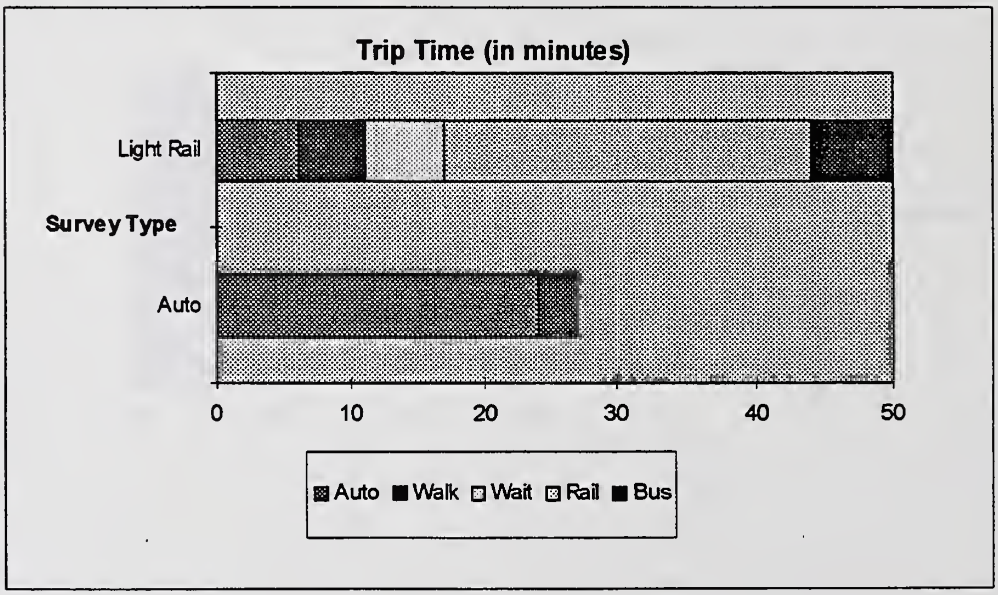
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE F- 6: SW Park & Yamhill Avenue - NE Glisan & 113th Avenue		
	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	25	25
In Common Segment	12	15
Outside Common Segment	13	10
Wait Time	0	4
Walk Time	3	2
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	22.1	21.1
In Common Segment	37.0	28.2
Outside Common Segment	8.3	10.6



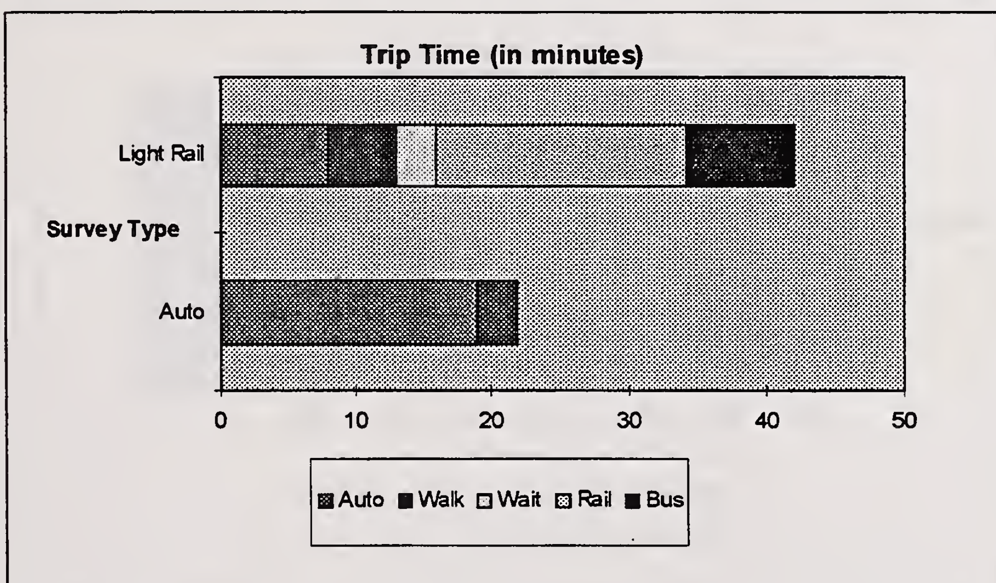
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE H- 8: SW Washington & 6th Avenue - NE Burnside & 109th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	26	41
In Common Segment	12	24
Outside Common Segment	14	17
Wait Time	0	4
Walk Time	3	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	21.2	12.9
In Common Segment	37.0	17.6
Outside Common Segment	7.7	6.2



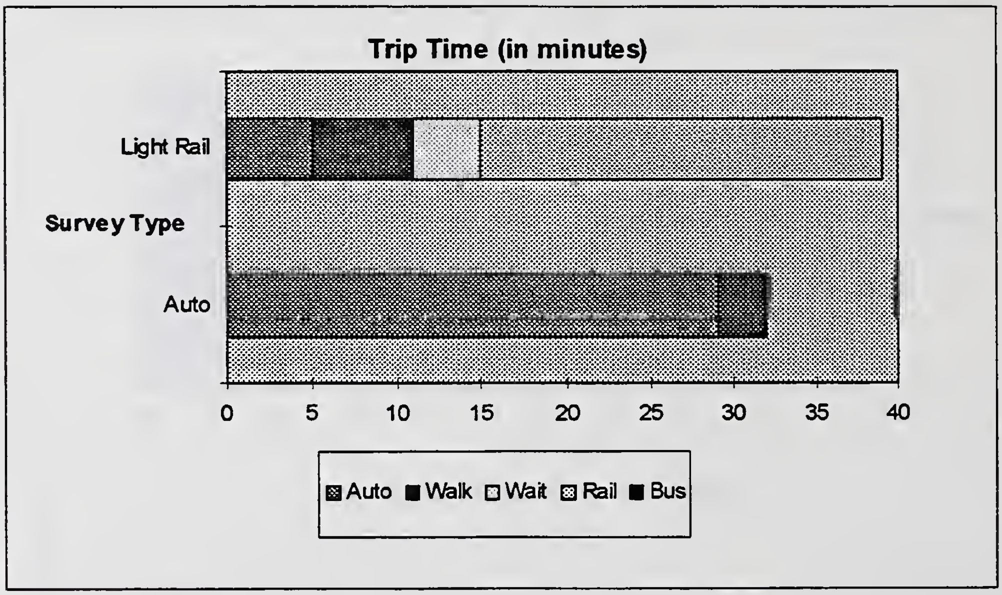
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE J- 10: SW 4th Avenue and Stark - SE Stark & 99th Avenue	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	27	44
In Common Segment	15	27
Outside Common Segment	12	17
Wait Time	0	6
Walk Time	3	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	20.4	12.0
In Common Segment	29.6	15.6
Outside Common Segment	9.0	6.2



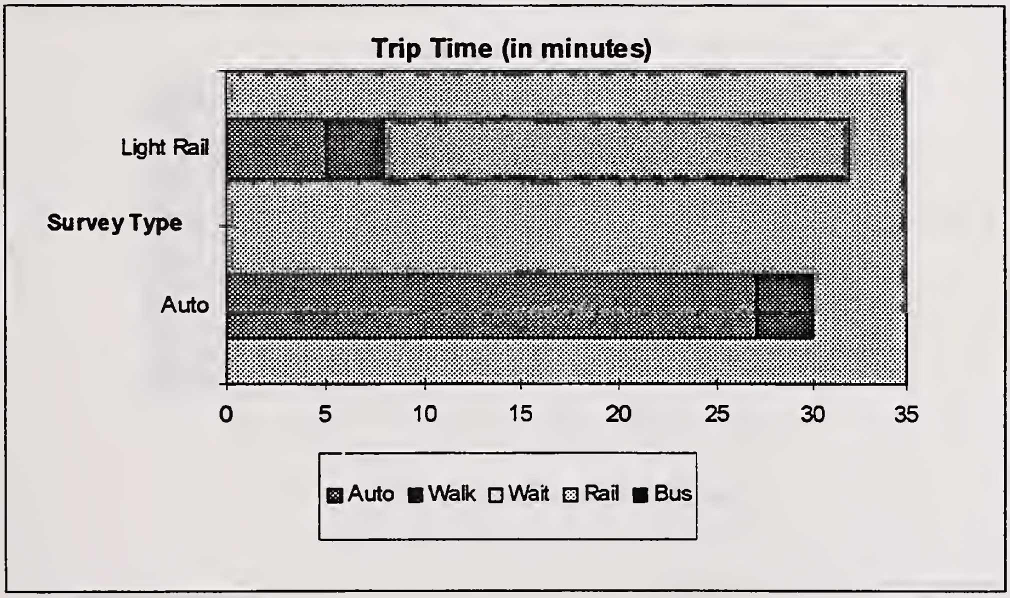
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE A- 1: SW 3rd Avenue and Main - NE Thompson & 108th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	22	34
In Common Segment	12	18
Outside Common Segment	10	16
Wait Time	0	3
Walk Time	3	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	25.1	15.5
In Common Segment	37.0	23.5
Outside Common Segment	10.8	6.6



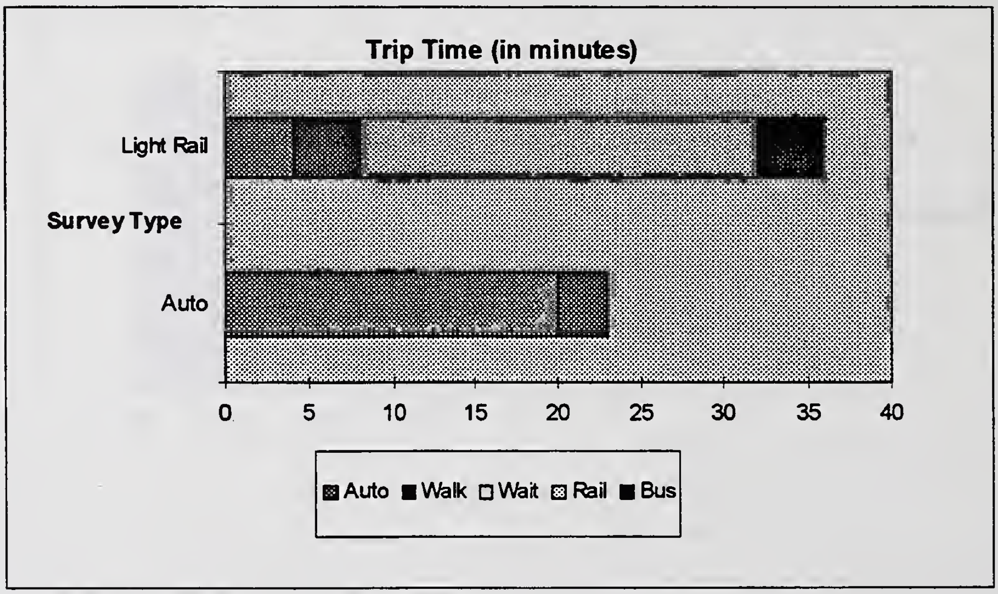
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 8- B: NE Burnside & 109th Avenue - SW 4th Avenue & Madison	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	32	39
In Common Segment	19	24
Outside Common Segment	13	15
Wait Time	0	4
Walk Time	3	6
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	17.3	13.5
In Common Segment	23.4	17.6
Outside Common Segment	8.3	7.0



CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 9- C: SE Burnside & 102nd Avenue - SW 5th Avenue & Main	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	30	32
In Common Segment	16	24
Outside Common Segment	14	8
Wait Time	0	0
Walk Time	3	3
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	18.4	16.5
In Common Segment	27.8	17.6
Outside Common Segment	7.7	13.2

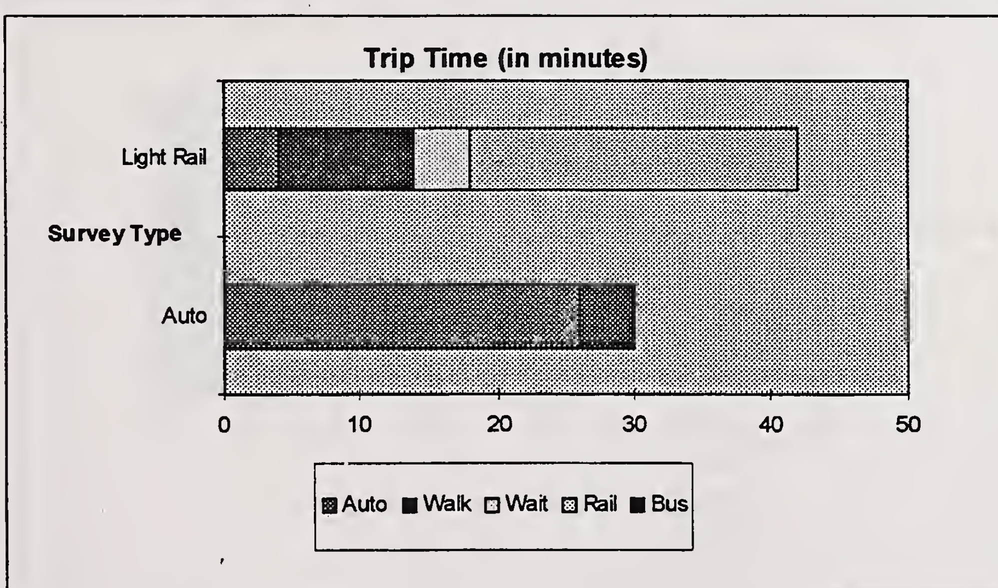


CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 10- D: SE Stark & 99th Avenue - SW 6th Avenue & Salmon	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	23	32
In Common Segment	14	24
Outside Common Segment	9	8
Wait Time	0	0
Walk Time	3	4
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	24.0	16.5
In Common Segment	31.7	17.6
Outside Common Segment	12.0	13.2

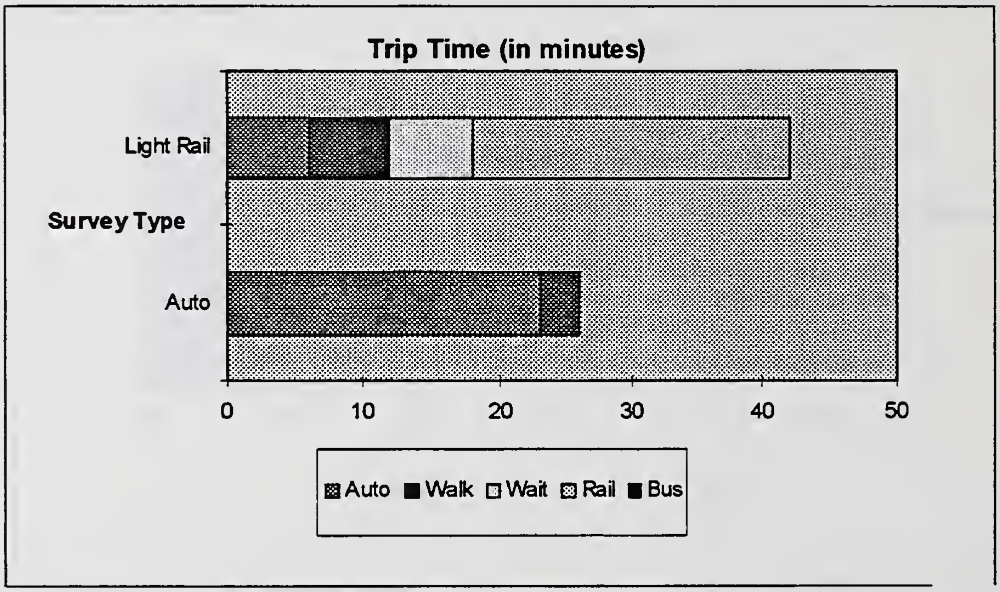


CORRIDOR: GATEWAY - PORTLAND
SUMMARY TABLE FOR
ROUTE 2- I:
NE Hancock & 111th Avenue - SW Washington & 5th Avenue

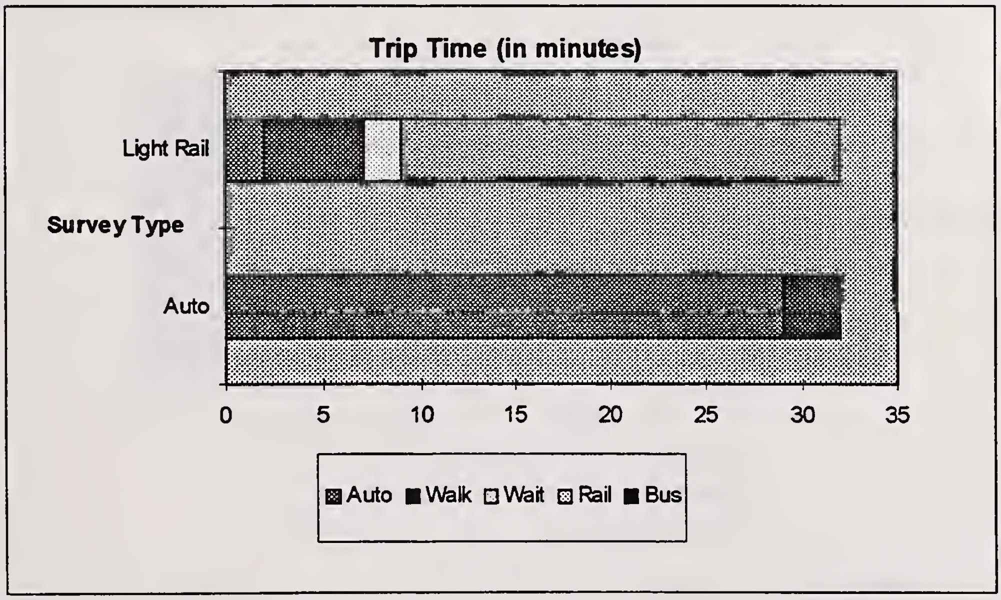
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	30	42
In Common Segment	17	24
Outside Common Segment	13	18
Wait Time	0	4
Walk Time	4	10
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	18.4	12.6
In Common Segment	26.1	17.6
Outside Common Segment	8.3	5.9



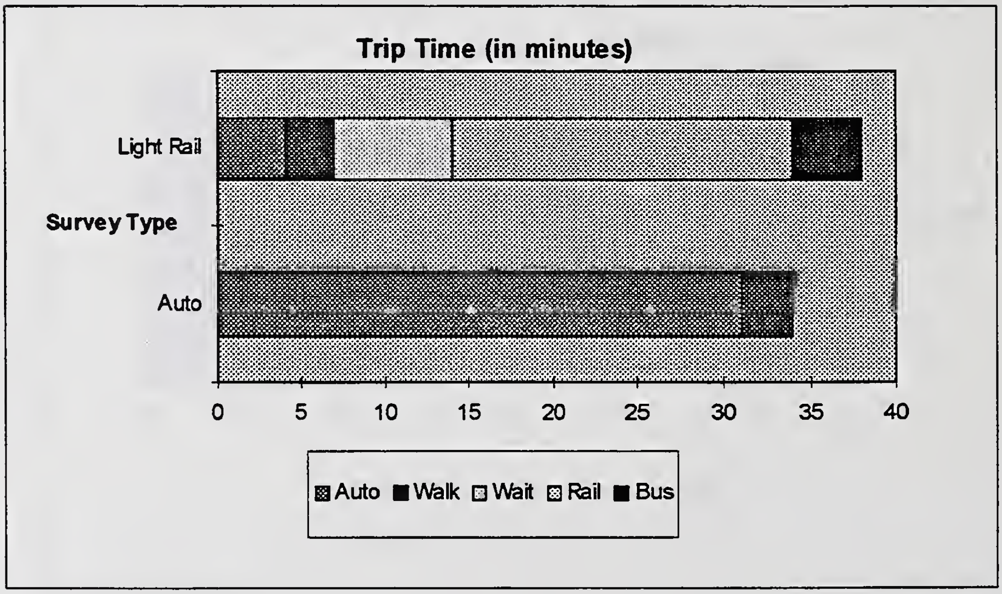
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE 1- H: NE Thompson & 108th Avenue - SW Washington & 6th Avenue		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	26	42
In Common Segment	15	24
Outside Common Segment	11	18
Wait Time	0	6
Walk Time	3	6
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	21.2	12.6
In Common Segment	29.6	17.6
Outside Common Segment	9.8	5.9



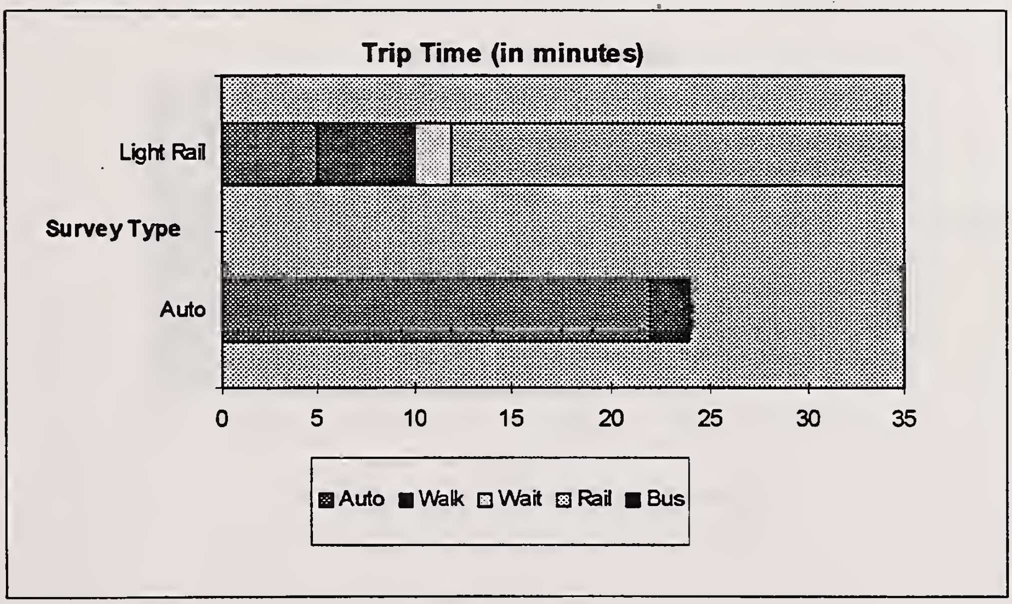
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE B- 9: SW 4th & Madison Avenue - SE Burnside & 102th Avenue	SURVEY TYPE	
TIME (minutes)	Auto	Light Rail
Trip	32	32
In Common Segment	17	23
Outside Common Segment	15	9
Wait Time	0	2
Walk Time	3	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	17.3	16.5
In Common Segment	26.1	18.4
Outside Common Segment	7.2	11.7



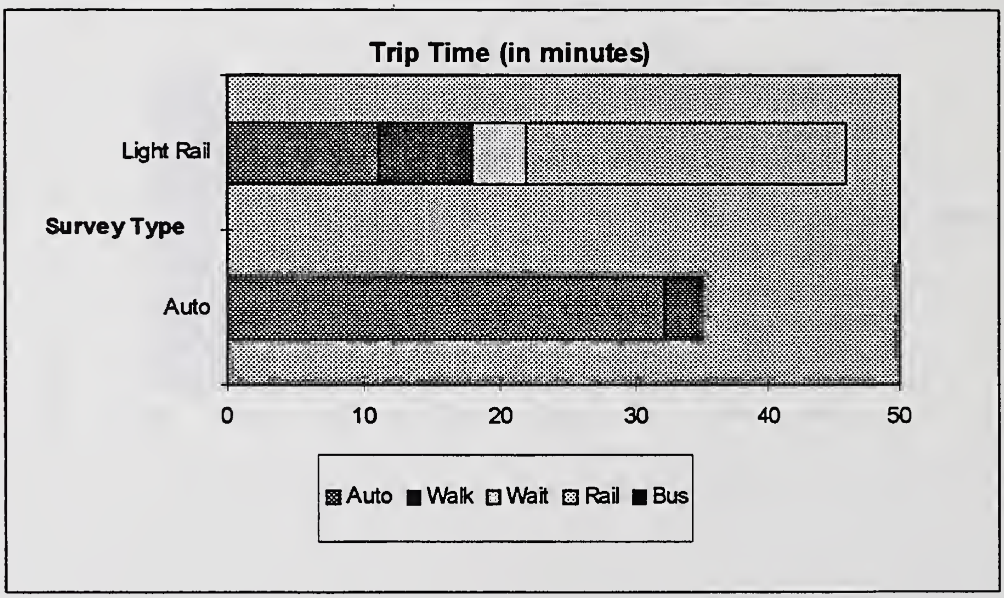
CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE C- 10: SW 5th Avenue & Main - SE Stark & 99th Avenue		
	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	34	34
In Common Segment	22	20
Outside Common Segment	12	14
Wait Time	0	7
Walk Time	3	3
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	16.2	15.5
In Common Segment	20.2	21.1
Outside Common Segment	9.0	7.5



CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE I- 2: SW Washington & 5th Avenue - NE Hancock & 111th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	24	35
In Common Segment	12	23
Outside Common Segment	12	12
Wait Time	0	2
Walk Time	2	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	23.0	15.1
In Common Segment	37.0	18.4
Outside Common Segment	9.0	8.8



CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE A- 8: SW 3rd Avenue & Main - NE Burnside & 109th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	35	46
In Common Segment	21	24
Outside Common Segment	14	22
Wait Time	0	4
Walk Time	3	7
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	15.8	11.5
In Common Segment	21.1	17.6
Outside Common Segment	7.7	4.8



CORRIDOR: GATEWAY - PORTLAND SUMMARY TABLE FOR ROUTE J- 1: SW 4th Avenue & Stark - NE Thompson & 108th Avenue	SURVEY TYPE	
	Auto	Light Rail
TIME (minutes)		
Trip	34	46
In Common Segment	25	25
Outside Common Segment	9	21
Wait Time	0	8
Walk Time	3	5
DISTANCE (miles)		
Route Distance	9.2	8.8
Common Segment Distance	7.4	7.0
SPEED (mph)		
Trip	16.2	11.5
In Common Segment	17.8	16.9
Outside Common Segment	12.0	5.0