Title

An Automobile/Transit Emissions Evaluation of Southern California's Metrolink

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Publication Date

1995-07-01

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Working Paper
UCTC No. 279

The University of California Transportation Center

University of California
Berkeley, CA 94720

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An Automobile/Transit Emissions Evaluation of Southern California's Metrolink

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Working Paper
July 1995

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Preface

This report has been prepared for the University of California Transportation Center, contract number UCB DOT DTR S92 G0009, entitled "An Automobile/Transit Emissions Evaluation of Southern California's Metrolink". This report covers the work that has been performed during the contract period, August 1, 1994 to July 31, 1995. Contributions to this report have been made by Matthew Barth, Ramakrishna Tadi, Theodore Younglove, Mike Todd, Eric Johnston, and Feng An. The assistance received from Peter Hidalgo of Metrolink and his staff, Hideo Sugita and Susan Cornelison of RCTC, James Ortner of OCTA, and the SCAG Inland Empire office is greatly appreciated.

Executive Summary

In order to alleviate traffic congestion and obtain better air quality in the South Coast Air Basin, the Southern California Regional Rail Authority (SCRRA) began constructing a new commuter train system called Metrolink in October 1992. There are currently five lines in operation: the Riverside Line, San Bernardino Line, Santa Clarita Line, Ventura County Line, and the Fullerton Line. The system is still expanding and when complete, Metrolink will form the nation's sixth largest commuter rail system, with construction costs exceeding $500 million. Metrolink commuter trains connect suburban communities with centers of business, such as Burbank, Glendale, Industry, and downtown Los Angeles. The SCRRA monitors the passenger ridership counts of each line closely, from which the amount of congestion mitigation can be determined. However, there have been no detailed studies on the direct air quality impact of Metrolink since its inception.

The purpose of this research project is to estimate total pollutant emissions associated with a single Metrolink line, specifically the Riverside line. The Riverside line, which began operation in 1993, runs from downtown Riverside and continues to downtown Los Angeles' Union Station with stops in Pedley, East Ontario, and the City of Industry. In this study, emissions associated with two commuting scenarios are compared. An emissions estimation is first made for commutes from Riverside to downtown Los Angeles using the Metrolink system. This is then compared to the emissions associated with the same set of commutes made by automobile, as if the Metrolink system did not exist. Based on trip conditions recorded in November, 1994, this study attempts to predict the breakpoint, i.e., the minimum amount of Metrolink ridership required to get a net air quality benefit from the system.

Several key emission sources were identified and incorporated into this analysis. For a Metrolink-based trip, we consider:

- cold start and running emissions of automobiles during the home to Riverside Metrolink station trip; and
- running emissions of the diesel locomotive traveling from origin station (Riverside) to Los Angeles' Union Station.

For the non-Metrolink-based trip scenario, only cold start and running emissions of automobiles were considered during the Riverside to downtown Los Angeles commute.

Essential data for the automobile emissions modeling process were obtained through a survey of Metrolink passengers and through remote emissions sensing of Metrolink passenger vehicles.

Train emissions were estimated using emission rate data provided by recent diesel locomotive studies. Results indicated that at current ridership levels there is a reduction in total amount of all four pollutants combined through Metrolink commuting. On a pollutant by pollutant basis, it was estimated that the Metrolink commuting scenario reduces the emissions of carbon monoxide (CO) and hydrocarbons (HC) relative to the automobile-only commuting scenario, however it increases the emissions of oxides of nitrogen (NOx) and particulate matter (PM).

The number of passengers necessary for the Riverside Metrolink commute to break even varies by pollutant and season. Some general conclusions for the current diesel powered Metrolink trains are:

- Fewer than 100 riders are necessary for the Riverside Metrolink commute to break even on CO and HC;
- Approximately 2000 riders are necessary for the Riverside Metrolink commute to break even on PM;
- Between 1500 and 2200 riders are necessary for the Riverside Metrolink commute to break even on NOx.

Table of Contents

List of Figures

List of Tables

1 Introduction

In order to alleviate traffic congestion and obtain better air quality in the South Coast Air Basin (SCAB), the Southern California Regional Rail Authority (SCRRA) began constructing a new commuter train system called Metrolink in October 1992. There are currently five lines in operation: the Riverside Line, San Bernardino Line, Santa Clarita Line, Ventura County Line, and the Fullerton Line, as shown in Figure 1.1. The system is still expanding and when complete, Metrolink will form the nation's sixth largest commuter rail system, with construction costs exceeding $500 million [Clarke, 1995]. Metrolink commuter trains connect suburban communities with centers of business, such as Burbank, Glendale, Industry, and downtown Los Angeles. The SCRRA monitors the passenger ridership counts of each line closely, from which the amount of congestion mitigation can be determined [SCRRA, 1992]. However, there have been no detailed studies on the direct air quality impact of Metrolink since its inception.

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For the non-Metrolink-based trip scenario, only cold start and running emissions of automobiles were considered during the Riverside to downtown Los Angeles commute.

Ridership and vehicle data were collected through a survey that was conducted simultaneously with a remote sensing emissions experiment at the Riverside Metrolink station. This data collection process is described in more detail below. Emission data for the Metrolink diesel locomotives were obtained from recent technical reports produced for the Southern California Regional Railroad Authority [SCRRA, 1992] and the Southwest Research Institute [Fritz, 1992]. Cold start emissions and running emissions for automobiles were based on the EMFAC7F emissions model developed at the California Air Resources Board (CARB) [CARB, 1991,1992]. For this study, four emission species are considered: carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), and particulate matter (PM).

It is important to point out that this study is done purely from an air quality standpoint, and does not deal with operating cost and revenue aspects of Metrolink or traffic congestion and stress aspects of the auto commuters. Further, the comparisons are made only for the single Riverside Metrolink line, and the conclusions may not necessarily be applied to the entire Metrolink system.

Prior to a description of the data collection process performed for this study, we briefly provide background information on Metrolink's Riverside line. Chapter 2 then describes various trip statistics derived from the data collection phase. Chapter 3 then discusses the methodology and results of the emissions analysis. Finally, chapter 4 discusses various conclusions from the study.

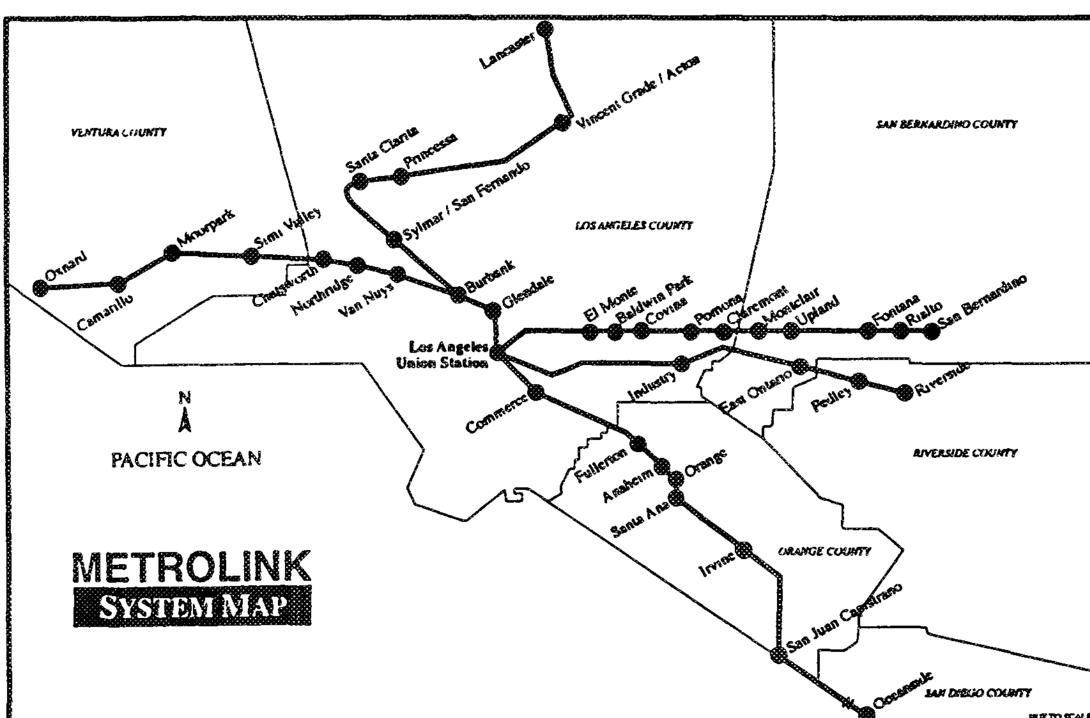


Figure 1.1. Southern California's Metrolink commuter rail system (Source: SCRRA).

1.1 METROLINK: RIVERSIDE LINE

The downtown Riverside Metrolink Station is located on approximately 11 acres in the Marketplace redevelopment area in Riverside, California (see Figure 1.2). The Riverside County Transportation Commission (RCTC) maintains and operates the station. The station consists of a dual-sided platform and parking for 390 automobiles. At the time of the data collection for the study, six commuter trains between Riverside and Los Angeles served the station, along with Amtrak connecting buses, and Riverside Transit Agency (RTA) feeder bus service. Table 1.1 shows the operating schedule (November, 1994) for the Riverside Metrolink line. For study purposes, only AM peak period commuting trips have been considered i.e., trains leaving at 5:00 AM, 6:10 AM, 6:43 AM and 7:35 AM from the Riverside station. The average duration of these AM trips between Riverside station and Los Angeles Union Station is approximately one hour and eight minutes, with the trains operating at speeds ranging from 25 to 60 mph (maximum speed is 75 mph).

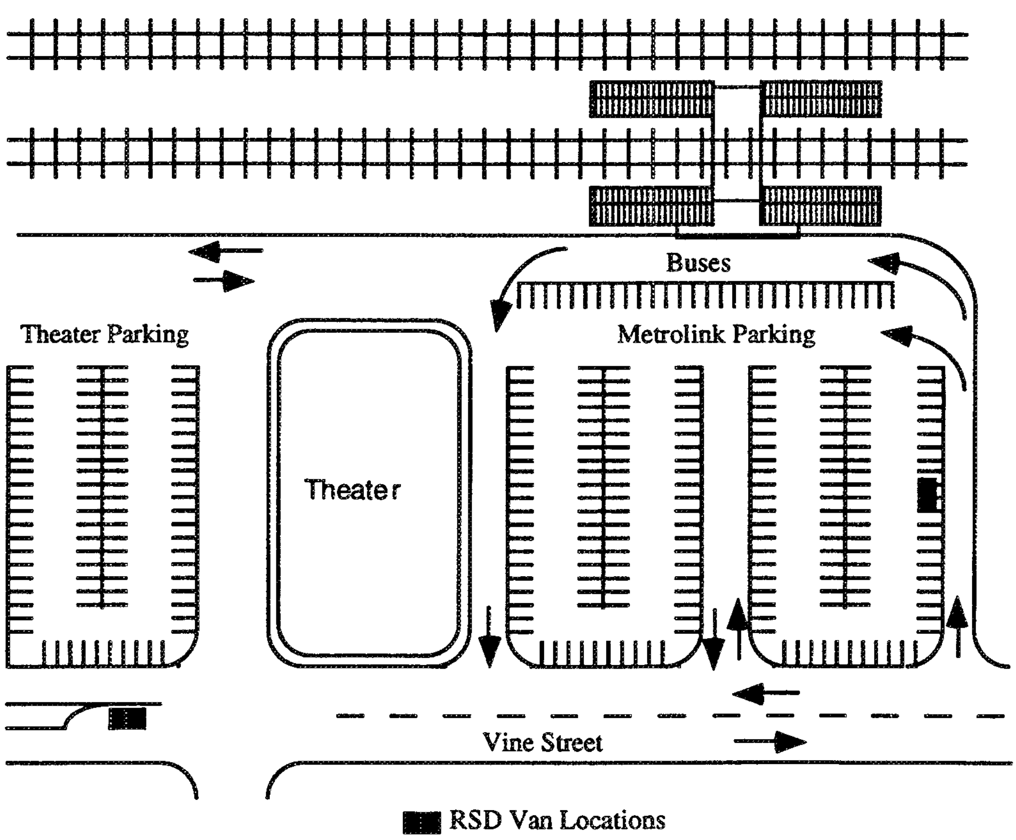


Figure 1.2 Riverside Metrolink Station Layout (Not to Scale)

To Los Angeles (Read Down)

TRAIN NUMBERS	401	403	405	407	409	411
Riverside-Downtown	5:00A	6:10A	6:43A	7:35A	2:47P	5:29P
The Pedley Station	5:10A	6:20A	6:50A	7:44A	2:57P	
East Ontario	5:19A	6:29A	6:59A	7:53A	3:05P	
Industry	5:36A	6:46A	7:16A	8:11A	3:24P	
L.A. Union Station	6:08A	7:18A	7:48A	8:43A	4:02P	7:09P

Table 1.1 Riverside Line Metrolink Schedule (November, 1994)

1.2 METHODOLOGY: DATA COLLECTION

To evaluate and compare total pollutant emissions, two different commuting trip scenarios have been considered: 1) Metrolink-based commute trips, and 2) automobile-only commute trips, i.e., Metrolink passengers commuting instead by automobile. In order to perform this analysis, various data were collected:

1.2.1 Passenger Survey Data

Ridership travel characteristics along the Metrolink's Riverside line were obtained through a passenger survey conducted during a typical weekday (Wednesday, November 16, 1994). A copy of the survey form is shown in Appendix A. The data collected during the survey included:

- trip origin/destination/purpose information;
- length, time, and mode of home to Riverside Metrolink station trip;
- model year and make of vehicle used to travel to Riverside Metrolink station;
- length, time, and mode of drop-off station to final destination trip;
- miscellaneous information such as reason for choosing rail, prior travel mode, etc.

A total of eight people (four staff and four student assistants) conducted the passenger survey in cooperation with SCRRA and RCTC. Passengers were informed of the survey by the train conductor between the Ontario and Riverside stations the previous day. Blank survey forms were distributed by two student assistants to all passengers boarding the Metrolink at the Riverside Station. These same students also boarded the train and traveled to East Ontario station to answer any questions the passengers may have had regarding the survey questionnaire. They also collected the completed survey forms before disembarking in Ontario. Those passengers who could not / did not want to complete the forms on board the train and wished to complete the forms at a latter time were provided with self-addressed stamped envelopes. This procedure was conducted for AM departures at 5:00 AM, 6:10 AM, 6:43 AM and 7:35 AM.

Out of a total of 362 survey forms that were distributed to adult passengers who boarded the four morning trains (outbound to LA) at the Riverside Metrolink Station, 297 passengers completed the survey. This includes 9 of the 15 distributed mailback survey forms. 65 survey forms were never returned for an overall 82% response rate.

The information gathered in the surveys not only provided origin / destination information needed by the emission models, but also helped to establish vehicle mix profiles and a probability density of cold start emissions modes. A more detailed analysis of the data and the emission results are presented in subsequent chapters.

1.2.2 Remotely Sensed Emissions Data

Remote sensing emissions instrumentation was set up on the same day as the survey, as well as the following day (November 16 - 17, 1994). This remote sensing instrumentation measures CO_2, CO and HC by using a continuous infrared (IR) beam directly perpendicular to the path of passing vehicles. Instantaneous CO and HC measurements are taken when a vehicle passes through and breaks the IR beam. In addition to these instantaneous emission measurements, license plate information, vehicle speed and acceleration data are obtained. The license plate information is obtained with a video camera and subsequent image digitization. The remote sensing measurement sites at the Riverside Metrolink station are shown in Figure 1.2.

This remote sensing emissions data are used in the analysis to estimate the percentage of high emitting vehicles (using a 4% CO threshold) and to corroborate cold start percentage data derived from the survey forms. Further details on the remotely sensed emissions data and its use in this study are provided in chapter 3.

1.2.3 Miscellaneous Data

Data were also collected regarding the number of passengers arriving at the station by RTA buses and those who were dropped by someone else during the time of the survey. These results are presented in Table 1.2.

Time	Train Number	Passengers Arriving by Bus		Passengers Dropped Off	
		Wed (11/16/94)	Thurs (11/17/94)	Wed (11/16/94)	Thurs (11/17/94)
5:00A	401	10	6	12	7
6:10A	403	9	11	23	20
6:43A	405	3	5	14	7
7:35A	407	2	3	14	14

Table 1.2. Passenger Counts

2 Ridership Travel Characteristics

Although the main purpose of this study is to analyze the emissions impact of Metrolink, a rich set of ridership data was obtained during the Metrolink survey conducted during the data collection phase. This set of data provides the basis of the emissions analysis and is also of general interest. A total of 362 survey forms were handed out on the four AM Riverside to LA Metrolink trains on 11/16/94 and 297 (82%) were returned for compilation. The results are summarized below.

2.1 HOME ZIP CODES

One of the items on the survey form was the rider's home zip code. There were 38 distinct home ZIP codes for the 173 who responded to this question. One hundred and fourteen of these were from six ZIP code areas (Table 2.1)

Home ZIP	City	Frequency
92557	Moreno Valley	36
92553	Moreno Valley	23
92506	Riverside	17
92571	Perris	16
92551	Moreno Valley	12
92507	Riverside	10
92324	Colton	6
92346	East Highlands	6
92555	Moreno Valley	5
92374	Redlands	4
92223	Beaumont	3
92504	Riverside	3
92508	Riverside	3
91719	Corona	2
92220	Banning	2
92313	Grand Terrace	2
92554	Moreno Valley	2
21 Others	Various	1 each

Table 2.1 Home ZIP Code Frequency

Examination of the ZIP codes indicates that the majority of the riders boarding the Metrolink in Riverside are from the City of Moreno Valley followed by the City of Riverside. Of the 173 ZIP code responses, 94 (54%) were from Moreno Valley and 35 (20%) were from Riverside, accounting for 74.5% of the total.

2.2 MODE OF TRAVEL TO METROLINK STATION

Based on a survey question regarding mode of travel from home to the Metrolink station, the dominant mode was driving alone (194 out of 288, 67%). The next largest category was those who were dropped off with 43 (15%) responses, followed by those that traveled by carpool with 29 (10%) responses. 21 (7%) indicated that they arrived by bus and one walked. The results are presented graphically in Figure 2.1. A total of 266 of the 288 respondents arrived by car, generating approximately 251 vehicle trips if we assume that there are slightly more than 2 carpoolers per carpool vehicle. If this percentage holds for the entire rider population, the 362 survey respondents would generate approximately 315 vehicle trips to the Riverside Metrolink station.

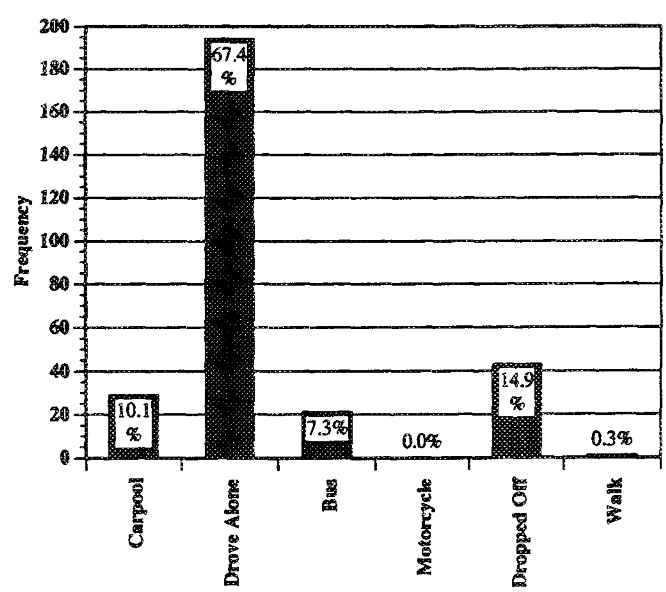


Figure 2.1 Method Of Travel To Riverside Metrolink Station.

2.3 TRAVEL TIME & DISTANCE FROM HOME TO METROLINK STATION

The mean time for a trip from home to the Riverside Metrolink station derived from the survey was 17.4 minutes. The minimum trip time given on the survey was 1.5 minutes and the maximum was 80 minutes. The mean trip distance was 13.4 miles with a minimum of 0.5 miles and a maximum of 76 miles. A detailed examination of the time and distance data indicates that approximately 20% of the riders live within 6 miles of the station and approximately 13% drive less than 10 minutes to reach the station (Table 2.2). Nearly 40% drive more than 19 minutes on average while only 5% travel more than 38 miles to the Metrolink station.

Distance to Station (Miles)	Cumulative Percent	Time to Station (minutes)	Cumulative Percent
0.0 - 1.9	2.0	0.0 - 0.9	0.0
2.0 - 3.9	10.4	1.0 - 1.9	0.4
4.0 - 5.9	20.9	2.0 - 2.9	0.4
6.0 - 7.9	25.3	3.0 - 3.9	0.7
8.0 - 9.9	34.1	4.0 - 4.9	1.8
10.0 - 11.9	51.0	5.0 - 5.9	6.0
12.0 - 13.9	62.2	6.0 - 6.9	7.0
14.0 - 15.9	75.5	7.0 - 7.9	10.2
16.0 - 17.9	79.5	8.0 - 8.9	12.3
18.0 - 19.9	82.7	9.0 - 9.9	13.4
20.0 - 21.9	88.8	10.0 - 10.9	29.6
22.0 - 23.9	89.6	11.0 - 11.9	29.9
24.0 - 25.9	92.4	12.0 - 12.9	34.2
26.0 - 27.9	93.6	13.0 - 13.9	35.6
28.0 - 29.9	93.6	14.0 - 14.9	35.9
30.0 - 31.9	95.2	15.0 - 15.9	56.0
32.0 - 33.9	95.2	16.0 - 16.9	56.3
34.0 - 35.9	95.2	17.0 - 17.9	57.7
36.0 - 37.9	95.2	18.0 - 18.9	58.1
38.0 +	100.0	19.0 +	100.0

Table 2.2 Cumulative Percent Of Distance And Time To Riverside Metrolink Station

2.4 VEHICLE MODEL YEAR

A critical question on the survey form was vehicle model year, an important input to the subsequent emissions analysis. No significant differences were found between vehicle model year distributions for the four AM train departure times. A significant difference would have indicated differences in the age of vehicles used for commuting at different times of the morning. With no significant difference for the 4 trains, the overall vehicle age profile is all that is necessary for the emissions modeling component of the project. The survey vehicle age profile is presented in Figure 2.2a and is similar to the Southern California vehicle age distribution in Figure 2.2b (based on data from the California Department of Transportation (CALTRANS, [Ochoa, 1993]). The age profiles differ primarily due to the small number of pre-1975 vehicles in the Metrolink population.

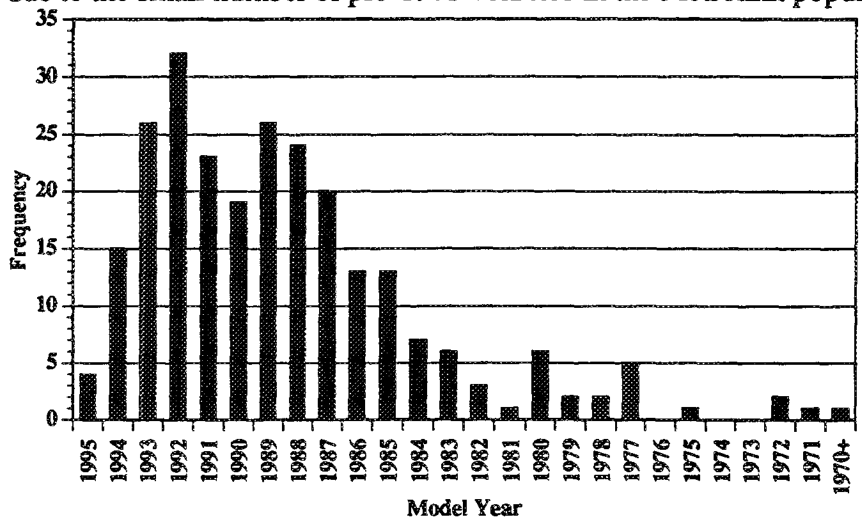


Figure 2.2a Proportion of vehicles by model year at Metrolink-Riverside from survey data.

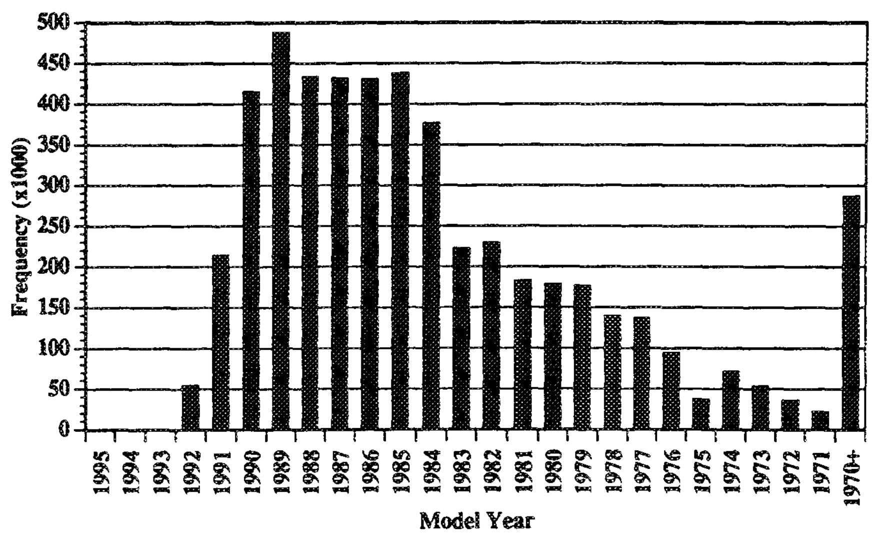


Figure 2.2b Proportion of vehicles by model year in the SCAG region from CALTRANS [Ochoa, 1993].

2.5 VEHICLE MAKE

Thirty-one vehicle makes were represented in the survey of Metrolink riders (Table 2.3). The top five makes were Toyota (45), Honda (33), Ford (30), Chevrolet (22), and Nissan (19). Based on the above information, a "typical" Riverside-Metrolink rider can be described as driving alone in a 1990's car from Moreno Valley approximately 13 miles taking about 17 minutes to reach the Riverside Metrolink station.

Make	Frequency	Make	Frequency
Toyota	45	Datsun	3
Honda	33	Plymouth	3
Ford	30	Cadillac	2
Chevrolet	22	Isuzu	2
Nissan	19	Saturn	2
Mazda	11	Subaru	2
Dodge	9	Buick	1
Oldsmobile	9	Daihatsu	1
Pontiac	7	Geo	1
BMW	7	GMC	1
Acura	5	International	1
Mitsubishi	5	Mercedes	1
Volkswagen	5	Mercury	1
Chrysler	4	Porsche	1
Hyundai	4	Suzuki	1
Volvo	4		

Table 2.3 Survey Vehicle Frequency by Make.

2.6 DESTINATION STATION

The survey results indicated that 260 (90.3%) of the riders boarding in Riverside were heading to the LA Union Station (LAUS). The Industry station was the second most common destination with 19 (6.6%) responses. The remaining responses were Glendale 5 (1.7%), Burbank 2 (0.7%), Pedley 1 (0.3%), and Van Nuys 1 (0.3%). The Industry and Pedley riders are the only respondents who did not travel to the LA Union station because all of the other destination stations are on different lines of the Metrolink and require a transfer at LAUS. Only the riders traveling from Riverside to LA were accounted for in the emissions analysis.

2.7 FINAL DESTINATION CITY AND ZIP CODE

The final destination city for the majority of the riders was Los Angeles with 219 (75.3%) of the 291 responses to this question. Most of the rest of the destination cities given were in the general Los Angeles area. Six responses (2.1%) identified destination cities located either in northern California or out of state—these riders were assumed to be traveling by air from the Los Angeles area. The destination city for the one remaining rider was given as Perris, a city which lies in Riverside county in the opposite direction from Los Angeles. There were 220 responses covering 74 destination ZIP codes given with the top three being 90012 with 38 (17.3%), 90017 with 36 (16.4%), and 90071 with 23 (10.5%).

2.8 MODE OF TRAVEL TO FINAL DESTINATION

The mode of travel from the drop-off station to the final destination was primarily by bus (31.8%) and rail (24.0%) (summarized in Figure 2.3). A significant fraction (15%) used non-polluting bike and walk modes. A similar number (16.4%) used the highest polluting drive alone mode.

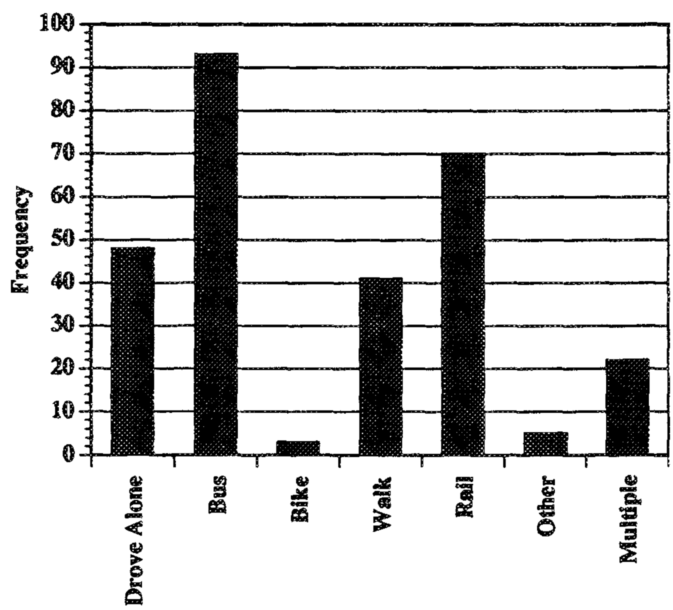


Figure 2.3 Mode of Travel from Drop Off Station to Final Destination.

2.9 DISTANCE AND TIME FROM DROP-OFF STATION TO DESTINATION

The mean distance from the drop-off station to the final destination was 7.96 miles with the mean time to the destination 18.86 minutes. The skewed distribution of both these variables shown in Figures 2.4a and 2.4b makes the mean somewhat misleading. The median (50th percentile) distance from the station to the final destination was 5 miles. The median time to the final destination was 15 minutes.

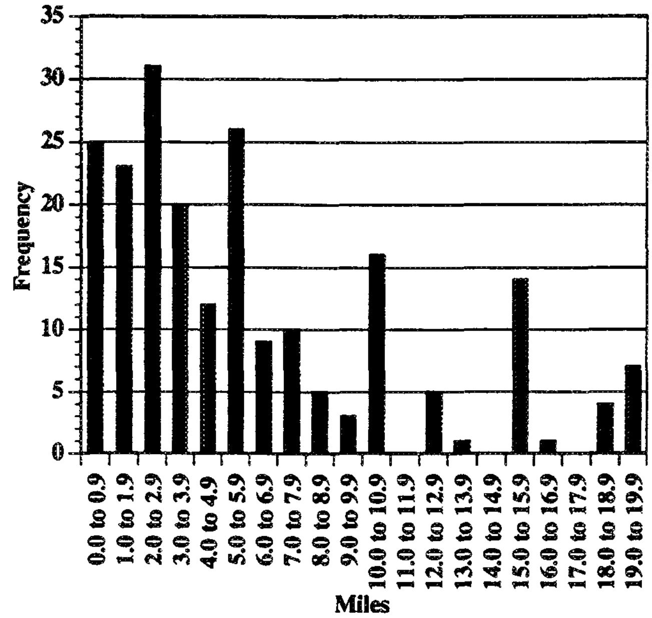


Figure 2.4a Histogram of Distance From Drop Off Station to Final Destination.

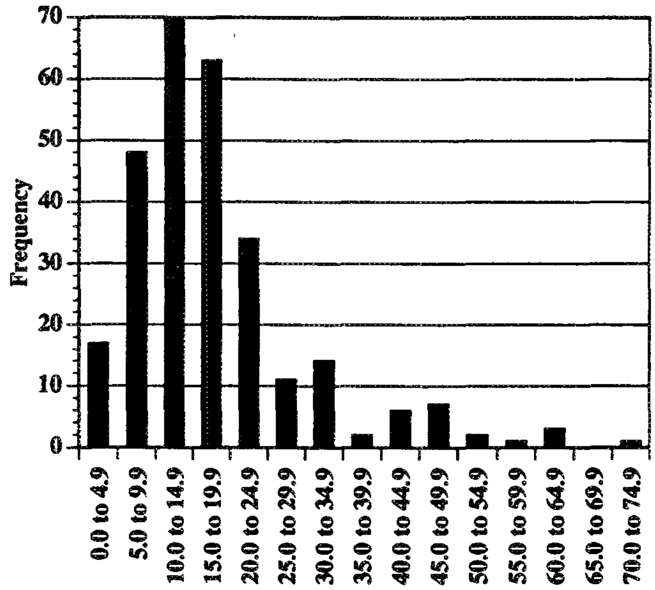


Figure 2.4b Histogram of Time (in minutes) From Drop Off Station to Final Destination.

2.10 TRIP PURPOSE

The riders were surveyed for information regarding the purpose of their trip. Of the majority of the 294 responses, 272 (92.5%) were for work. Eleven (3.7%) were traveling home, 7 (2.4%) were riding for pleasure, 2 (0.6%) for shopping, and 2 (0.6%) Other. From these results it is apparent that the dominant trip purpose of the riders is traveling to work.

2.11 PRIMARY REASON FOR CHOOSING METROLINK

Almost two thirds of the survey respondents indicated that they chose to use Metrolink because of convenience (Figure 2.5). The responses in descending order of importance were: Convenience with 185 (63.4%), Economy with 32 (11.0%), No Other Choice with 26 (8.9%), and Air Quality with 17 (5.8%). A number of riders selected multiple answers for this question with Convenience and Air Quality the most frequent combination with 13 (4.5%) of the responses followed by Economy and Convenience with 10 (3.4%).

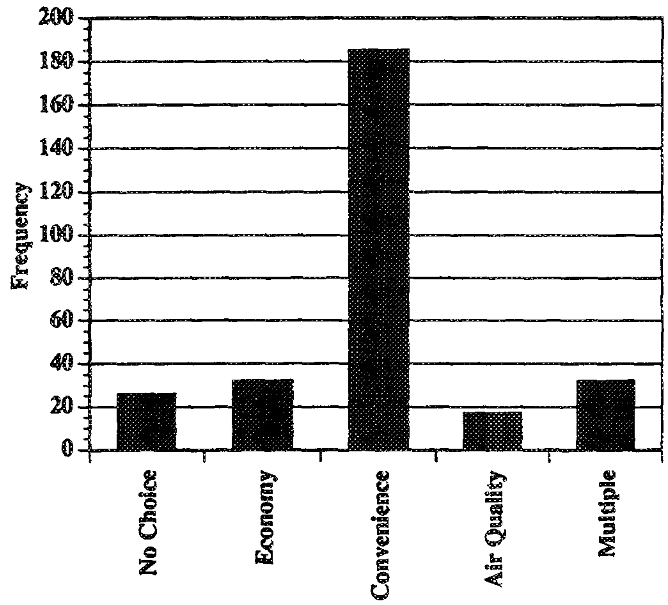


Figure 2.5 Primary Reason for Choosing Metrolink.

2.12 PREVIOUS MODE OF TRAVEL

Driving alone was the most frequent response on the Previous Mode of Travel question with 186 (63.9%) responses (Figure 2.6). These results are similar to results obtained by Metrolink recently on other lines [Pound, 1994]. Less than half as many riders previously used multiple occupancy modes with 44 (15.1%) using carpools and 24 (8.2%) using bus.

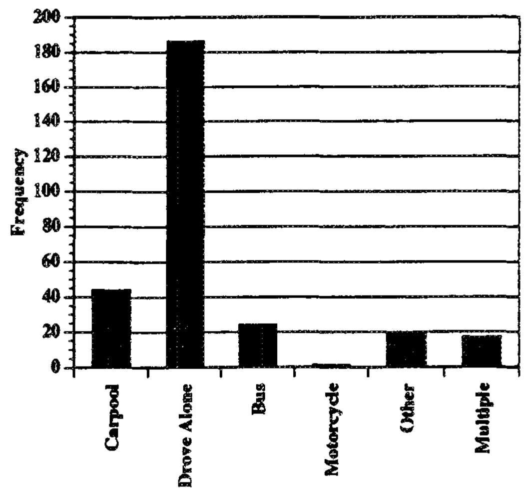


Figure 2.6 Previous Modes of Travel

2.13 AVAILABILITY OF OTHER TRANSPORTATION MODES

The frequencies were similar to the previous mode of transportation for the available alternative modes of transportation with additional responses spread out in the multiple mode responses (Figure 2.7).

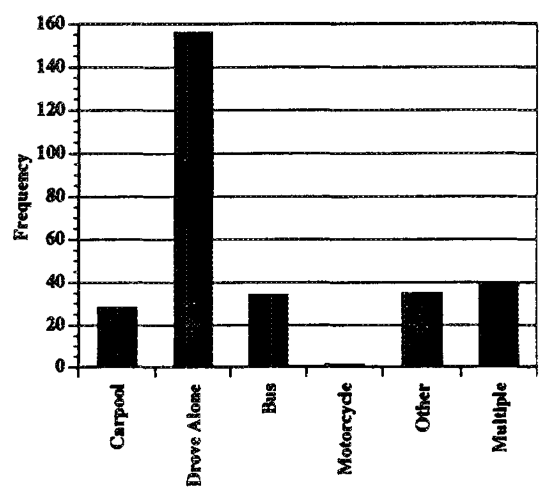


Figure 2.7 Availability of Alternative Modes of Transportation

2.14 FREQUENCY OF METROLINK RIDERSHIP

The survey results indicate that the majority of the passengers ride Metrolink on a regular basis (Figure 2.8). There were 184 (63%) of the 292 responses who indicated that they rode the Metrolink 5 times per week, 51 (17.5%) who rode 4 times per week, 21 (7.2%) at 3 times per week, 14 (4.8%) at 2 times per week, and 11 (3.8%) each at 1 and 0 times per week.

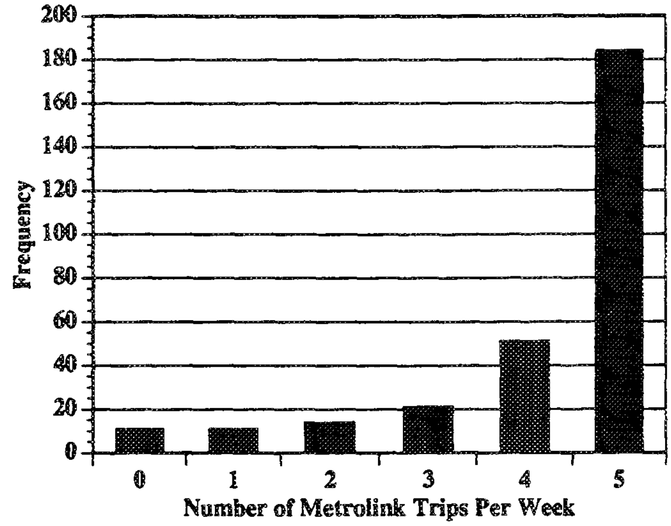


Figure 2.8 Weekly Number of Metrolink Trips by Survey Respondents.

The following emissions analysis chapter uses these survey results to determine the proper inputs to the detailed emissions models.

3 Estimation of Pollutant Emissions

As described in the Introduction, the primary purpose of this study is to estimate the total pollutant emissions from two commuting scenarios, a Metrolink-based commute and an automobile commute, traveling from Riverside to downtown Los Angeles. In order to estimate the total emissions associated with a Metrolink-based commute, it was necessary to estimate:

1) the vehicle emissions created by travel from the home to the Riverside station, and

2) the diesel locomotive emissions of a Metrolink train traveling from Riverside to Los Angeles.

The last leg of this commute, i.e., traveling from the Los Angeles Union Station to the final destination, was not considered in this emissions analysis since it was too difficult to estimate the emissions from the wide variety of travel modes, and their contribution is likely to be small. There was not a dominant mode like there was in the trips to the Riverside Metrolink station. Fifteen percent of the riders used non-polluting bike and walk modes while 55.8% used either Bus or Rail. Only 16.4% of the riders used the drive alone mode, with an unknown portion of these in the lower emissions hot start conditions. The contribution to the emissions total of the last segment of the commute is likely to be small because the drive alone mode is the only mode which significantly contributes to the emission load, and its percentage is low.

For the automobile Riverside to Los Angeles commute, only the trip from home to downtown Los Angeles was considered. For all automobile trips, the cold start portion of the total emissions was accounted for. It was assumed for all automobile trips that there were no stops during the commute.

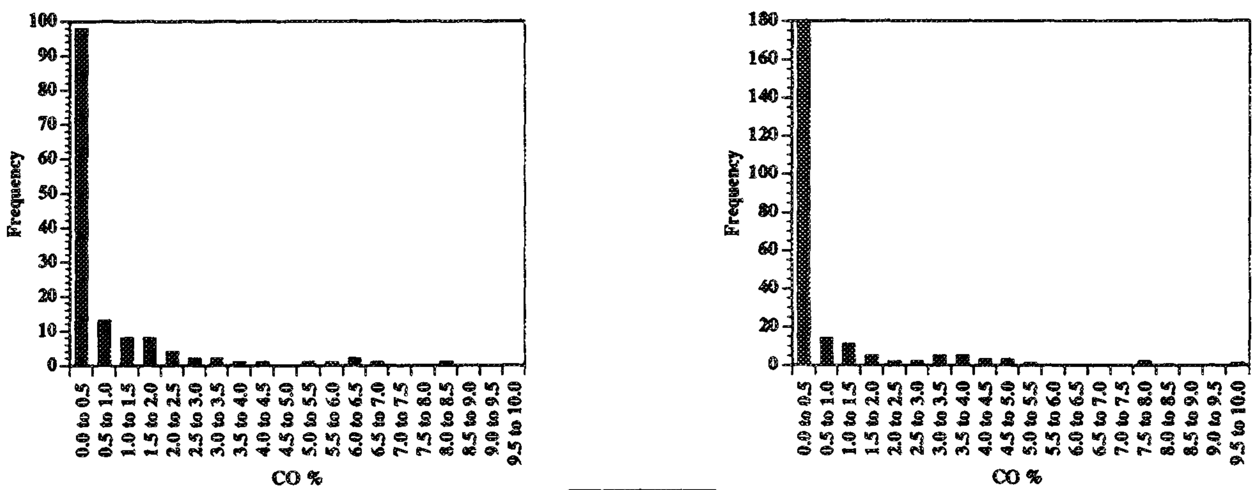
To make an emissions comparison between the Riverside to Los Angeles Metrolink based commute and the Riverside to Los Angeles auto only commute the emissions of a hypothetical 300 commuters using each travel mode were estimated. Based on travel data collected in November, 1994, the total morning commute emissions for 300 drivers using the four Riverside->Los Angeles Metrolink trains was estimated, including driving alone to the Metrolink station. This was compared to the scenario in which the same 300 commuters traveled alone by automobile from home to LA. After a brief discussion of remote sensing emissions data recorded at the Riverside station, the methodology of estimating emissions for both scenarios is given below.

3.1 REMOTE SENSING EMISSIONS DATA

Remote sensing emissions instrumentation was set up for two days coinciding with the Metrolink passenger survey (November 16 - 17, 1994). This remote sensing instrumentation measures CO and HC by using a continuous infrared (IR) beam directly perpendicular to the path of passing vehicles. Instantaneous CO and HC measurements are taken when a vehicle passes through and breaks the IR beam. In addition to these instantaneous emission measurements, license plate information is obtained with a video camera and subsequent image digitization. The remote sensing measurement sites at the Riverside Metrolink station are shown in Figure 1.2.

The remote sensing emissions data are used in this analysis to estimate the percentage of high emitting vehicles (using a 4% CO threshold) and to corroborate cold start percentage data derived from the survey forms. These data were also used to verify the automobile counts entering the Riverside Metrolink parking lot.

The remote sensing data collected on the day of the survey and on the following day (Nov. 16th and 17th, 1994) exhibit highly skewed frequency distributions for CO (Figures 3.1a and 3.1b).



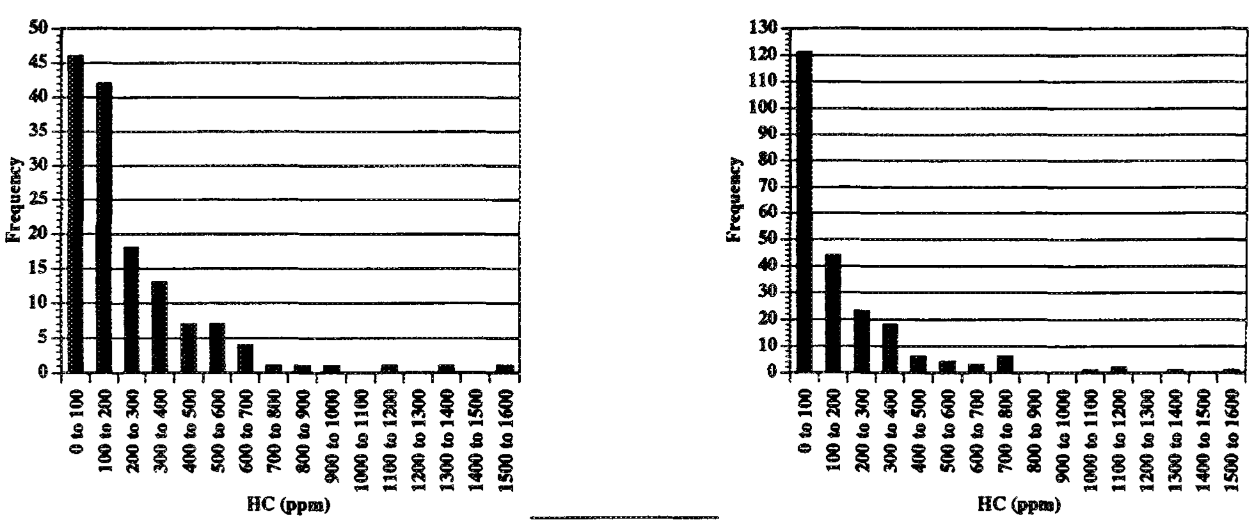
Figures 3.1a and 3.1b Frequency distribution of CO measurements obtained using remote sensing emission instrumentation on November 16th and 17th, 1994.

The location of the remote sensing instrumentation was changed for the second day and a larger number of vehicles was monitored. The total number of observations increased but the distribution of CO readings was quite similar on both days.

3.1.1 Estimating Gross Emitter Vehicles

Determining the number of gross emitter vehicles in the vehicle population is essential for properly estimating the vehicle emissions. Previous remote sensing studies have shown that 5 to 10% of all vehicles are responsible for 50 to 60% of the emissions [Bishop et al., 1993; McAlinden, 1994]. Another study estimated that a single super emitter produces 50 times more CO per mile than a vehicle in good tune producing 0.5% CO [Lawson et al.,1990]. To estimate the number of gross polluting vehicles, a % CO measurement > 4% was used as a cutoff threshold, similar to other remote sensing studies (again, [Bishop et al, 1993; McAlinden, 1994]). Any vehicle with CO emissions greater than 4% was considered a high emitter vehicle. On the first day there were 7 vehicles with CO greater than 4% out of 143 with valid CO data. On the second day there were 10 high emitter vehicles identified out of the 233 total vehicles with valid CO data. Overall there were 17 out of 376 vehicles (4.5%) classified as high emitters by this method. The average emission of the high emitter vehicles for the two days was 5.9% CO.

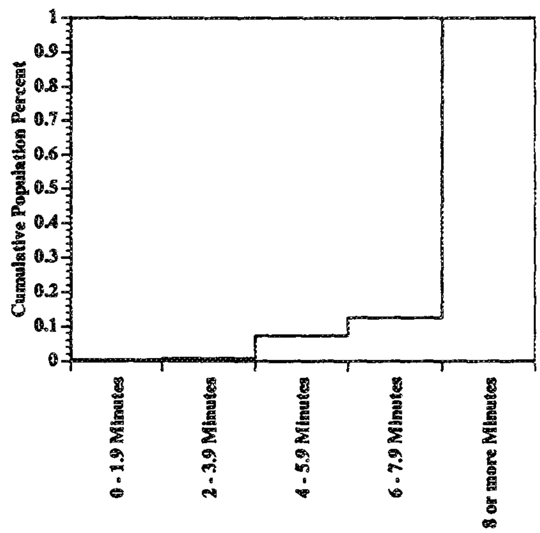
The remote sensing data also exhibit highly skewed frequency distributions for HC (Figures 3.2a and 3.2b). The second location had a much higher proportion of vehicles in the lowest HC emission category. The second location appears to have a higher proportion of non-Riverside residents so this difference in HC proportions may be due to the longer average drive for the riders using the second location, leading to a higher proportion of fully warmed up vehicles.



Figures 3.2a and 3.2b Frequency distribution of HC measurements obtained using the remote sensing instrumentation on November 16th and 17th, 1994.

3.1.2 Estimating the Number of Vehicles in Cold Start Mode

Because modern catalytic converter equipped vehicles have a large drop in emissions after sufficiently warming up, a large percentage of the CO, HC and NOx emissions for a trip are produced in the cold start phase. The first step in identification of cold start vehicles was to remove the high emitter vehicles from consideration. It was assumed that vehicles in good working order would be unlikely to produce CO emissions greater than 4%, even under cold start conditions. For this analysis it was assumed that all vehicles arriving at the Metrolink station were operating at or near hot-stabilized emission rate conditions. The cumulative population percentage plot of surveyed arrival time (Figure 3) shows that 99% of the vehicles have traveled at least 4 minutes prior to arrival.



Figures 3.3 Cumulative Population Percent for Time to Station.

3.2 EMISSIONS ESTIMATES FOR METROLINK-BASED COMMUTES

As described earlier, the Metrolink-based commutes consist of two components: the trip from home to the Riverside Metrolink station, and 2) the Metrolink trip from Riverside to LA Union Station. The emission estimates for both of these cases are described below.

3.2.1 Home to Metrolink Station Component

Based on the passenger survey data, about 315 vehicle trips were made from home to the Riverside station. The emissions associated with these vehicle trips is computed using CARB's EMFAC7F emission model [CARB 1991, 1992]. EMFAC requires a variety of input data, which are taken primarily from the survey results:

- **Vehicle Age Distribution**—This distribution, consisting of the vehicle population by model year, was acquired directly from the survey results (see section 2.4).
- **High Emitting Vehicle Percentage**—This input was derived using the methodology described in section 3.1.1. This value was set to 4.5%.
- **Cold Start Mode**—All trips from home to the Metrolink station were assumed to be cold start trips because the train departure times were all prior to 8:00 AM.
- **Average Trip Distance**—The average distance to the station from the survey results was used for the average trip distance in the model. The average distance to the station calculated from the survey was 13.4 miles with an average trip time to the station of 18.9 minutes.
- **Average Trip Speed**—The average trip speed was determined by simply dividing the average trip distance by the average trip time. Thus the average trip speed used as input into the model was 42.5 mph (13.4 miles in 18.9 minutes) for the Home to Riverside Metrolink trip.

With this set of inputs, EMFAC was run to predict emissions for a fleet of 300 vehicles. The high emitter emissions were estimated using the emissions rate (g/mile) for the cold start portion of the trip, but applied to the entire trip.

3.2.2 Riverside to Los Angeles Metrolink Component

The survey results indicated that 90.3% of the riders boarding in Riverside were heading to the L.A. Union Station. Of the remaining 9.7%, 6.9% embarked before Union Station and 2.8% rode other Metrolink lines beyond Union Station. The emissions from the Metrolink section of the commute were computed using the Riverside to LA Union Station route with data from the SCRRA report [SCRRA, 1992] and the SwRI report [Fritz, 1992]. From Table 7 of the SwRI report, emissions of CO, NOx, HC, and PM in grams per hour (g/hr) for each notch position were obtained for the Metrolink engines. From Appendix C of the SCRRA report the Time at Notch Position in minutes was obtained for the Riverside to LAUS route. The information is summarized in Table 3.1a and 3.1b along with the total emissions estimated for the Riverside to LA Union Station route. The emissions (gm/hour) were calculated using the Time at Notch for the engine settings on the Riverside to LA route by converting the time to fractions of an hour and then multiplying the emissions in grams per hour by the number of hours at that Notch. The trip total was then the sum of the emissions at each Notch. The emissions for the head-in power unit, used to power the air conditioning and other electrical needs of the passenger cars, was estimated as 20% of the locomotive emissions for the trip.

Notch		CO g/bhp-hr	NOx g/bhp-hr	HC g/bhp-hr	PM g/bhp-hr	CO g/hr	NOx g/hr	HC g/hr	PM g/hr
Idle		6.94	114.0	7.02	4.0	59	700	62	14
1		0.83	11.5	0.61	0.22	172	2405	127	45
2		0.62	12.4	0.42	0.21	224	4526	152	78
3		0.28	11.4	0.37	0.29	201	8052	260	208
4		0.27	9.4	0.28	0.25	279	9807	291	263
5		0.38	8.4	0.27	0.24	528	11641	369	331
6		0.34	8.7	0.26	0.23	569	14583	443	395
7		0.48	8.5	0.24	0.21	1199	21513	615	538
8		0.71	7.9	0.25	0.24	2273	25234	802	781

Table 3.1a Passenger Rail Emissions Data [Source: SCRRA 1991, 1992; Fritz 1992]

Notch	Time at Notch (min.)	CO (g)	NOx (g)	HC (g)	PM (g)
Idle	21.4	19.27	249.7	22.11	4.99
1	8.4	24.08	336.7	17.78	6.30
2	6.8	25.39	512.9	17.23	8.84
3	9.4	31.49	1261.5	40.73	32.59
4	12.4	57.66	2026.8	60.14	54.35
5	4.7	41.36	911.9	28.91	25.93
6	6.7	63.54	1628.4	49.47	44.11
7	1.4	27.98	502.0	14.35	12.55
8	24.8	939.51	10430	331.49	322.8
Trip Total		1232.0	17860	582.2	512.5

Table 3.1b Riverside - LA passenger rail trip total emissions data.

3.3 EMISSIONS ESTIMATES FOR AUTOMOBILE COMMUTES

The emissions estimation for the automobile commute has been simplified by treating all trips as trips from downtown Riverside to downtown Los Angeles. While the actual commutes were somewhat different, this makes the auto commute more comparable to the Metrolink commute.

The same EMFAC model was used to calculate total automobile emissions in this scenario. In this case, the following inputs were changed:

- **Average Trip Distance**—The average distance for the automobile-only scenario was set to 65 miles. The actual average commute distance is difficult to calculate because the information on the home location is quite rough (ZIP code area) and many possible routes to the main LA routes are possible.

- **Average Trip Speed**—An average morning commute time of 115 minutes was obtained from the SCAG (Southern California Association of Governments) Regional CTP model and used to calculate an average speed of 33.9 mph using the 65 mile trip distance for downtown Riverside to downtown LA.

Large differences in automobile emissions exist between winter and summer weather conditions so the EMFAC model was run using both typical winter and typical summer temperatures. Winter and summer model runs using 300 vehicles were made for the automobile portion of the commute on Metrolink, and for the Riverside to Los Angeles automobile-only commute as shown in Table 3.2.

	Winter Trip Emissions (kg)				Summer Trip Emissions (kg)			
	CO	NOx	HC	PM	CO	NOx	HC	PM
Home - Los Angeles	109.21	8.88	12.76	.19	55.20	7.18	7.43	.19
Home - Metrolink	41.34	2.77	4.29	.04	19.88	2.25	2.21	.04

Table 3.2. Winter and Summer Total Automobile Emissions.

3.4 EMISSIONS COMPARISONS

The estimated total emissions for the Metrolink-based commute scenario are compared on a pollutant by pollutant basis with the estimated automobile-only scenario emissions. Again, the comparison was based on a hypothetical scenario of 300 individuals driving alone to downtown Los Angeles against an alternative scenario of 300 individuals driving alone to the Metrolink Riverside station and riding the four morning trains into Los Angeles. This simplification was necessary because of the difficulties involved in accounting for the number of passengers who board and disembark at each station along the line. In addition, it was not clear how to estimate the percentage of passengers who might carpool to Los Angeles if they were not taking the Metrolink. All train locomotive emissions given are single engine emissions multiplied by 1.2 to account for the head-in power unit then multiplied by four to account for the four departure times used to move the riders into Los Angeles (Table 3.3). It should be noted that the four in-bound trains to LA have a total ridership of about 1100. The Riverside passengers proportion of the train emissions was calculated as Riverside passenger-miles/total-line passenger-miles. The number of passenger miles for each station was calculated by multiplying the January 1994 average daily boardings (source: Metrolink staff) by the number of miles from the station to LA. This was considered to be more realistic than simply taking the proportion based only on the number of passengers boarding at Riverside since Riverside passengers travel the farthest. By this measure, transporting the Riverside Metrolink passengers accounted for 41% of the emissions from the Riverside line.

	Winter Trip Emissions(kg)				Summer Trip Emissions(kg)			
	CO	NOx	HC	PM	CO	NOx	HC	PM
Automobile Home - Los Angeles	109.21	8.88	12.76	0.19	55.20	7.18	7.43	0.19
Automobile Home - Riverside	41.34	2.77	4.29	0.04	19.88	2.25	2.21	0.04
Metrolink* Riverside - Los Angeles	2.43	35.15	1.15	1.01	2.43	35.15	1.15	1.01
Metrolink Trip Total	43.77	37.82	5.44	1.05	22.31	37.40	3.35	1.05
Automobile Trip Total	109.21	8.88	12.76	0.19	55.20	7.18	7.43	0.19

* Riverside Metrolink train emissions calculated as .41 * Total emissions for 4 locomotives plus an additional 20% for the power units.

Table 3.3. Total trip emissions for automobile-only and Metrolink-based commutes.

These results indicate that at current Riverside Metrolink ridership levels there is a net decrease in CO and hydrocarbon emissions and a net increase in emissions for NOx and particulate matter. The ratios of Metrolink-commute emissions to auto-only-commute emissions are different in the winter from the summer but the overall trend is the same.

The emissions for CO were 2.49 times as high with the automobile-based commute in winter and automobiles were 2.47 times as high in the summer (Figure 3.4).

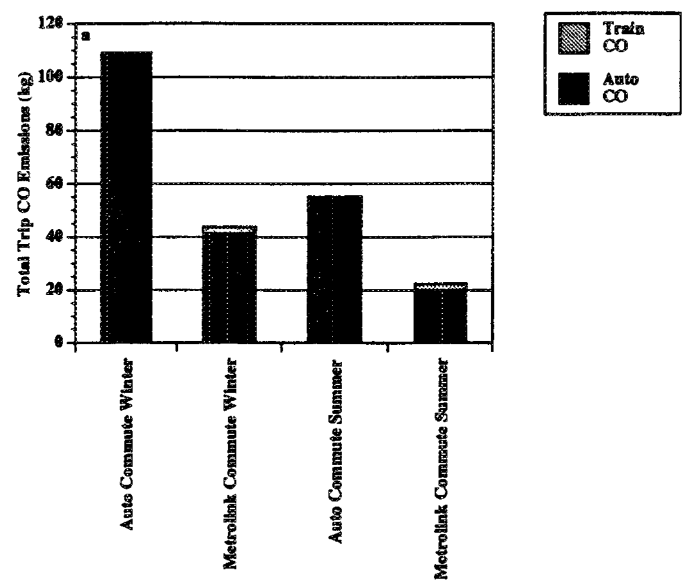


Figure 3.4 Total trip CO emissions for auto- and Metrolink-commutes.

The NOx emissions were 4.26 times higher for the Metrolink commute than driving alone in the winter and the Metrolink emissions were 5.21 times higher in the summer (Figure 3.5).

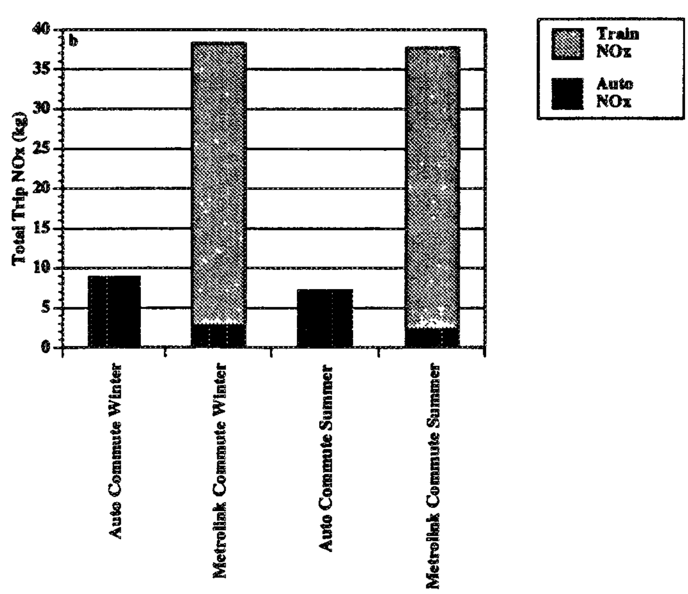


Figure 3.5 Total trip NOx emissions for auto- and Metrolink-commutes.

The hydrocarbon emissions for the auto commute against the Metrolink commute in the winter were 2.34 times higher while the summer ratio had the auto commute 2.21 times higher than the Metrolink. (Figure 3.6).

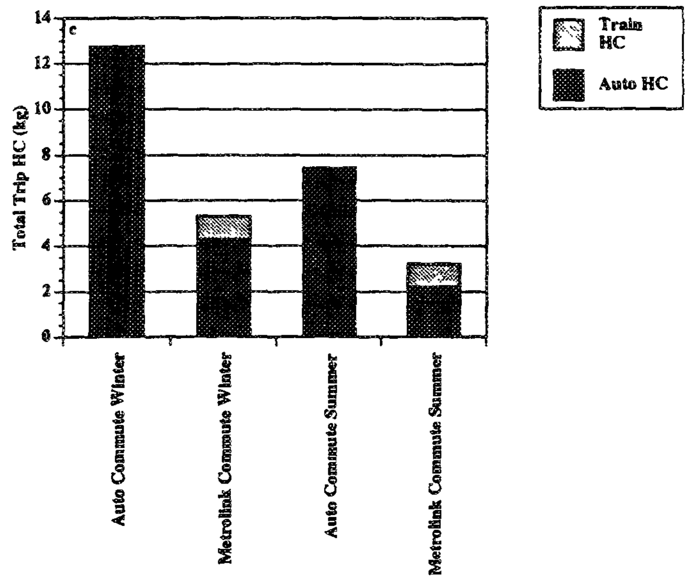


Figure 3.6 Total trip HC emissions for auto- and Metrolink-commutes.

The particulate emissions were 5.53 times higher for the Metrolink-based commutes in both the winter and the summer (Figure 3.7).

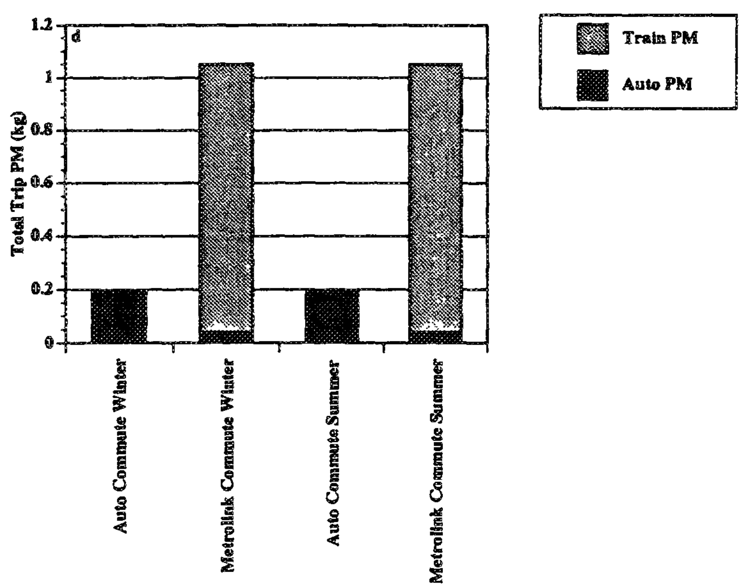


Figure 3.7 Total trip particulate emissions for auto- and Metrolink-commutes.

3.5 ESTIMATED RIDERSHIP FOR A NET AIR QUALITY BENEFIT

The emissions data from section 3.4 can be used to estimate the number of riders necessary for the Metrolink to achieve a net air quality benefit when compared to auto-only commutes. As was noted previously, there is a net reduction in CO and hydrocarbon emissions at the current ridership levels, and the number of additional riders needed to produce a net benefit will vary greatly between the other pollutants. There are two factors influencing the emissions mix: 1) the different emissions profiles for the four pollutants between automobiles and trains; and 2) the differential effect of cold starts on the automobile emissions for the two commutes. For this analysis it is assumed that additional riders will have the same profile on the survey data as those currently riding the Metrolink.

The train emissions are assumed to be the same, regardless of the number of riders on board. The per-vehicle emissions for the auto-only commute provide the slope of a straight line, increasing with the addition of each new vehicle. The per-vehicle emissions were calculated as a weighted average of the high emitter rate and the rate for the regular vehicle population.

*Total Auto Emissions = Number Of Vehicles*Home To LA Per Vehicle Emissions*

The estimated emissions line for the Metrolink commute has a slope equal to the per vehicle emissions for the Home to Riverside auto emissions, with an intercept equal to the total trip emissions for the Metrolink train (Figure 3.8).

*Total Riverside Metrolink Emissions = Riverside Train Emissions + Number Of Vehicles*Home To Riverside Per Vehicle Emissions*

The point at which the lines cross for each pollutant is the estimated number of riders necessary to break even on emissions. This point is equal to the train emissions divided by the difference in the per-vehicle emission rates for Home-to-LA and Home-to-Metrolink. The estimated number of vehicles necessary to break even on emissions are rounded up to the next whole number because the number of vehicles can only be an integer. The calculated number of vehicles for all four pollutants (winter, summer) are: CO (11, 21); NOx (1503, 2138); HC (41, 66); and PM (1941, 1941). These estimates should not be taken as exact because of the uncertainty inherent in the estimation of both the automobile emissions and the train emissions and apply only to the Riverside-to-LA commute.

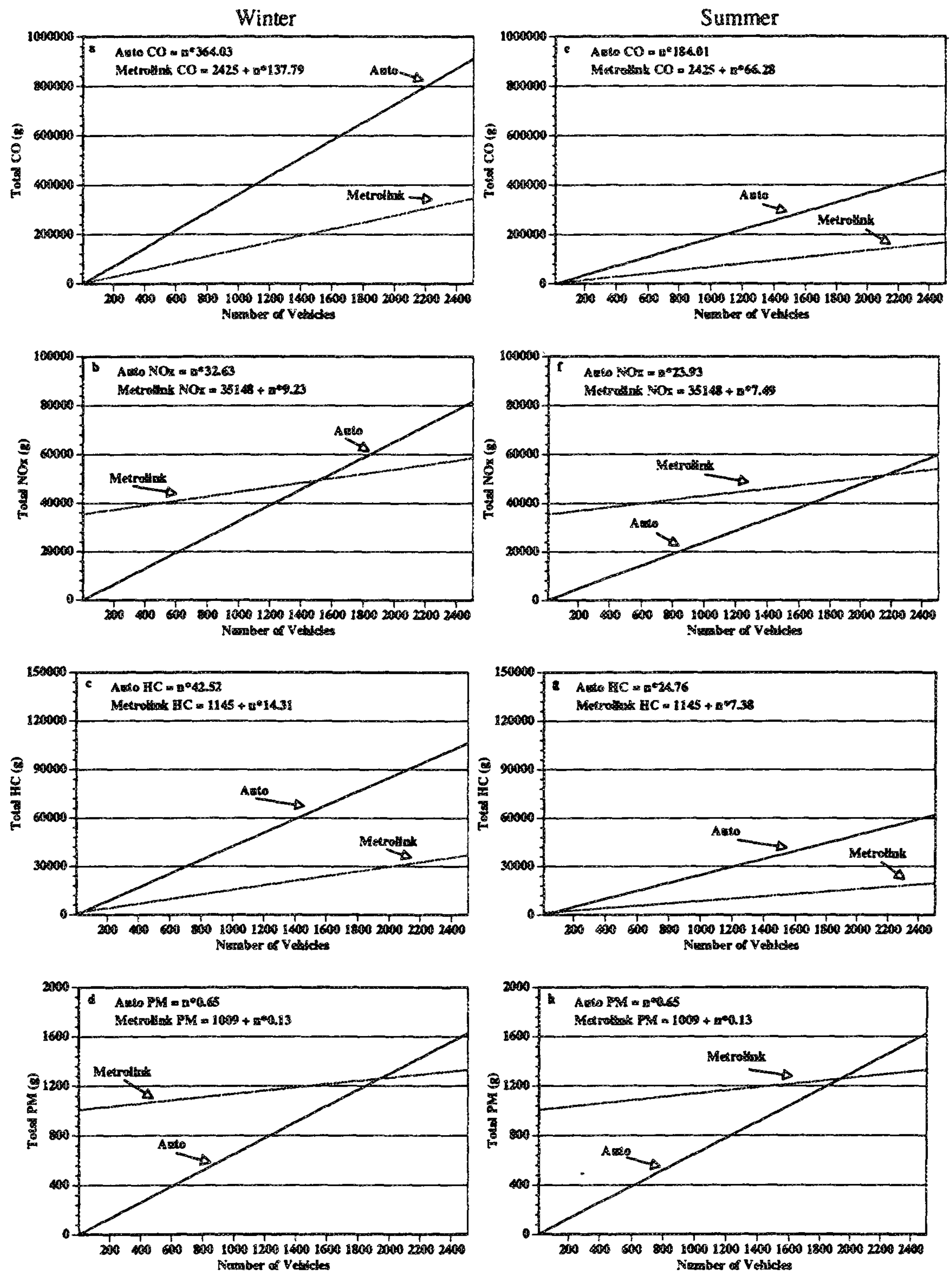


Figure 3.8 a-h Total Estimated Riverside to Los Angeles Trip Emissions of CO, NOx, HC, and PM.

4 Conclusions and Recommendations

While there is considerable room for error in the emissions estimates, at current ridership levels several conclusions applicable only to the Riverside to Los Angeles commute can be drawn as indicated below:

- At current ridership levels, the total amount of CO, NOx, HC, and PM combined for the Metrolink Riverside to LAUS commute is less than that generated by the automobile commute;
- Switching from an automobile commute to a Metrolink-based commute has a differential effect on the four pollutants (i.e., some pollutants increase, others decrease); specifically:
- A Metrolink commute produces less CO and HC emissions than an automobile commute;
- The NOx and particulate emissions from a Metrolink commute are higher than those of an automobile-only commute.

The number of passengers necessary for the Riverside Metrolink commute to break even varies by pollutant and season. Some general conclusions for the current diesel powered Metrolink trains are:

- Fewer than 100 riders are necessary for the Riverside Metrolink commute to break even on CO and HC;
- About 2000 riders are necessary for the Riverside Metrolink commute to break even on particulates;
- Between 1500 and 2200 riders are necessary for the Riverside to LAUS Metrolink commute to break even on NOx.

The survey results give a clear description of the Metrolink Riverside passenger population. The majority of the passengers are coming from Moreno Valley and Riverside and are taking the train to work in Los Angeles. They are driving alone and are typically in newer vehicles. There were significantly fewer 1970 and older vehicles in the survey than in the registered vehicle population in Southern California. This difference in vehicle age distribution means that the pollution estimates for the Metrolink commuters, both to the station and to Los Angeles would be higher if they had a vehicle profile similar to the regional one.

The use of either cleaner diesel engines or alternative fuel/electric engines appears to be the best method of attaining emissions parity on all pollutants. It should also be noted that people do not ride the train strictly out of pollution considerations. The most frequently cited reason in the survey for taking the Metrolink was convenience. Convenience and other intangible benefits of the Metrolink, while not as easy to quantify as emissions, should be considered.

The surveyed vehicle population contained very few old, high emitting vehicles in comparison to the region. If ridership growth brings in more drivers of older vehicles the pollution savings will be greater than predicted here. There was a relatively small percentage of the rider population from the Riverside area.

These facts lead to several recommendations:

- Future marketing of the Metrolink should be targeted on the Riverside area, both because of the smaller ridership and because of the greater emissions reductions;
- Metrolink marketing aimed at commuters using older vehicles and high emitting vehicles would be expected to produce greater emissions reductions;
- Because of the heavy dependence of the emission estimates on the remote sensing and survey work, similar studies on other lines will need to be conducted before drawing general conclusions about the entire Metrolink system;
- Studying the driver population characteristics at other stations along the Metrolink Riverside line will enhance the results.

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COMMUTER TRAVEL SURVEY FORM

University of California at Riverside
College of Engineering
Center for Environmental Research & Technology

We appreciate your assistance in completing this brief questionnaire. The objective of this study is to evaluate and compare total pollutant emissions for different commuting trip scenarios.

DATE: November 16, 1994
Wednesday

LOCATION: Riverside Metrolink Station
Train Departure Time________________ AM

1. What is your home Zip Code? ____________________

2. How did you get to the Metrolink station this morning? Carpool / Drove Alone / Bus / Someone Dropped You / Bike / Walk? (Please circle one)

3. What is the approximate distance & time it takes to travel from your home to the Metrolink Station? ________________ Miles __________________ Minutes

4. If you drove to the Riverside Metrolink station, please indicate YEAR________________ and MAKE _________________________ of your car.

5. Where do you get off the train? Station__________________

6. What is your final Destination? City_____________________ Zip ____________________

7. Mode of travel from the Metro drop-off station to your final destination: Bus / Car / Rail / Walk / Bike / None (Please circle one)

8. What is the approximate distance & time it takes to travel from the drop-off station to your final destination: _____________ Miles____________ Minutes

9. Purpose of this trip: Work / Shopping / Pleasure / Home / Other (Please circle one)

10. What is the primary reason for choosing Metrolink? No Other Choice /Economical / Convenience / Air quality (Please circle one)

11. How did you travel before riding on the Metrolink? Bus / Car / Carpool / Motorcycle / Rail / None (Please circle one)

12. What other types of transportation do you have access to? Bus / Car / Motorcycle / Carpool / None (Please circle one)

13. How often do you ride Metrolink on the average in a week?
    0 1 2 3 4 5 (Please circle one)

PLEASE RETURN THE COMPLETED SURVEY FORM TO THE STUDENT ONBOARD BEFORE REACHING THE ONTARIO STATION OR REQUEST A RETURN ENVELOPE

THANK YOU FOR YOUR COOPERATION