Using Residential Patterns and Transit To Decrease Auto Dependence and Costs

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EXECUTIVE SUMMARY

Introduction

This study is a first attempt to measure reductions in automobile usage and personal transportation costs that result from different characteristics of a neighborhood. Its purpose is to support a proposed enhancement to Energy Efficient Mortgage programs, such as those being encouraged by the California Home Energy Efficiency Rating System, Inc. (CHEERS).

Under energy efficient mortgages, the ability to qualify for a mortgage includes a consideration of utility bill savings as well as the direct costs of a mortgage. Utility savings are subtracted from the usual computation of Principal, Interest, Taxes and Insurance to determine qualification. If the characteristics of a neighborhood allow the reliable calculation of transportation costs savings as well, these too could be subtracted from Principal, Interest, Taxes and Insurance when calculating mortgage qualification.

This study evaluates the effects of neighborhood characteristics on motor vehicle usage per household (autos/HH) and total vehicles miles travelled annually per household (VMT/HH). It first defines four neighborhood descriptors that *a priori* influence personal transportation costs. These are:

- Residential density, or the number of dwelling units per residential land area.
- Transit accessibility. An index of transit accessibility is defined and measured for the neighborhoods under study.
- Neighborhood shopping. An index is developed that defines the ability to perform neighborhood shopping errands with a short walking trip from a home.
- Pedestrian accessibility. Factors that encourage or discourage walking are combined into an index that is quantified for the neighborhoods under study.

In addition, mean household income and household size (people/HH) are evaluated as explanatory variables for transportation costs.

Twenty-eight communities in California, representing a diverse range of variation in the four neighborhood variables being tested, were selected for this analysis. Census data were used to estimate the mean number of autos per household for each community. Analysis of smog check data according to the zip code of auto ownership were used to compute vehicle miles travelled per automobile. Methods described in the text were used to define and evaluate the other neighborhood variables.

Once the characteristics of these neighborhoods were defined, statistical methods were employed to provide the best explanation of the observed values of autos/HH and VMT/HH.

Overview of Results

Using the variables estimated in this study, it is possible to project automobile ownership and usage, and thus average costs, with good reliability. The best statistical correlations we were able to find are based only on density and the transit accessibility index; adding other variables or replacing these variables with others did not explain usage data any better than these two alone. The results obtained were:

$$\text{Autos/HH} = 2.704*(\text{density})^{-.25} \qquad R^2 = 0.85\text{; and}$$

$$\text{VMT/HH} = 34{,}270*(\text{density})^{-.25}*\text{TAI}^{-.076} \qquad R^2 = 0.83.$$

Using these two equations, and estimates for annual fixed costs of car ownership and variable costs of an additional mile of driving, allow the calculation of a matrix of average annual household auto expense as a function of density and the transit accessibility index. These are presented in Table 8 of the text.

Application of the Results to Mortgage Qualification

The results described in the equations and in Table 8 are sufficient to allow at least one method of calculating annual transportation cost savings for an individual house or a particular neighborhood compared to a base case of a typical low density suburb. One recipe for doing so could be as follows:

The predicted average annual household transportation cost savings for a particular dwelling unit could be calculated as follows:

- Calculate the average household density (households per residential acre) for the census tract in which the dwelling unit is located by using the enumerated households for the tract, and the acres of residential land measured by the local planning department or regional planning agency.
- 2) Calculate the transit service by identifying each bus line within 1/4 mile walking distance of the dwelling unit and each passenger rail stop or ferry terminal within 1/2 mile of the dwelling unit. For each line within the prescribed distance, calculate the daily number of buses, rail vehicles or ferries on these lines (in both directions) using transit schedules. "Standardize" these vehicles by multiplying the number of vehicles by (# seats on the average transit vehicle)/(50 seats). Divide this by 24 hours per day to get the transit service.
- 3) Look up the average annual household auto costs in Table 8. Values for units with densities or transit service falling between those shown on Table 8 can be calculated by interpolation. Alternatively, the predicted annual auto costs can be calculated using the above equation.
- 4) Subtract the predicted annual auto costs from those for the typical suburban area used as the loan standard.
- 5) Add up the average annual transit costs for all public transit within the city (average annual transit farebox revenues divided by the city's households). Subtract the corresponding "average annual transit costs" for the "typical suburban area" from this. Subtract this transit cost difference from the annual auto savings to get the annual household transportation cost savings.
- 6) Divide the results by 12 months and add to the standard PITI (principal, interest, taxes and insurance) mortgage qualification formula.

Thus, the primary objective of this study has been achieved: providing a first cut at a formula for quantifying the value of location efficiency that can be used in the context of energy efficient mortgages. Several areas for additional research present themselves as a consequence of the results derived in this study.

Discussion

This study confirms and extends the results of a number of previous studies that have suggested household density as the major explanatory variable for variations in vehicle miles travelled, and annual transportation costs. In all of these studies, a community with double the density will have 25-30% less driving per family when the impacts of all the conditions generally accompanying higher density (including better transit, more local shopping, and a more pedestrian-friendly environment) are included.

This study's results are also significant because previous studies focused only on different neighborhoods in a single metropolitan area, whereas this study's results were derived from four different metropolitan areas and one rural county throughout California.

After density, the only other variable that produced statistically significant explanatory power was the transit accessibility index. While all of the other variables, including household income and household size, were statistically significant predictors of observed driving behavior when considered individually, they failed to be significant when the effects of density and transit were considered first. This result may be due to limitations in the sample size. They may also be due to the correlation between the other neighborhood characteristics and the two with the most explanatory power: density and transit accessibility.

The failure of the income variable to be statistically significant is an important departure from previous studies, and suggests further research. It is well established that higher income families drive more, everything else being equal. But this study finds that when everything else isn't equal -- when the characteristics of the neighborhoods in which people live are taken into account -- income fails to provide statistically significant results. This may be in part because none of the neighborhoods studied was extremely poor: one can hypothesize that the inclusion of extreme poverty neighborhoods in the sample would demonstrate an income effect. But for the range of neighborhoods covered by this study, and to which the results are likely to be applied, income variations do not change the predictions of driving.

This is a valuable result for application to energy efficient mortgages, because it suggests the possibility of evaluating transportation savings without regard to the demographic characteristics of a neighborhood.

Summary

Variations in automobile usage per household and in personal transportation costs between communities can be quantified with a good deal of accuracy using two simple equations. These can provide the basis for calculating a first approximation to average transportation cost savings. It appears to be feasible to use this to develop repeatable estimates of transportation cost savings for use in energy efficient mortgages.

TABLE OF CONTENTS

1. INTRODUCTION

The Costs of Auto Dependence

American families spend a sizable fraction of their income on local transportation, primarily on autos. John Moffet and Peter Miller estimate $775 billion to $930 billion in direct annual auto costs in the United States (Moffet & Miller, 1993). That averages *$8,350 to $10,000, or $700 to $835 per month for each household*. This averages nearly $11 per commute trip, based on 34% of mileage for commuting (Metropolitan Transportation Commission) and an average of 26 monthly commute roundtrips per household (1990 census).

Driving costs vary systematically between neighborhoods within urban areas. Denser, central areas with good transit and nearby employers and shopping require less driving than sprawling bedroom suburbs with little transit and no nearby shopping or jobs. John Holtzclaw estimated an average annual auto cost per household in dense northeast San Francisco of $4,200 (0.6 autos per household) compared to $17,800 (2.3 autos per household) in suburban Danville-San Ramon, for an *annual savings of $13,600, or $1,130 per month*, for San Francisco households (Holtzclaw, 1991). These costs are consistent with the Moffet and Miller national averages when Californians' higher driving rates are considered and central city and suburban costs are averaged.

It makes sense to allow families incurring lower transportation costs to apply those savings to mortgage payments. If a family choosing to buy a house and live in the denser area with good transit could apply a $500 per month auto and transit savings to their mortgage payments, that family should be able to qualify for a $50,000 more expensive house at the same combined monthly housing and transportation payments. Implementing such mortgage criteria requires predicting the variation in average local transportation costs, and how they are affected by such measurable neighborhood variables as density, the availability of nearby transit and neighborhood shopping and the safety and appeal of the neighborhood to pedestrians and bicyclists. The calculation of transportation costs includes private autos and light trucks, and local public transit costs.

The Causes of Auto Dependence

Auto use is encouraged by the auto's versatility, speed (as long as congestion is avoided and parking is ample), privacy, comfort and apparent safety. Auto dependence is fostered by subsidies which decrease the marginal or per mile cost of driving; economic policies and social attitudes which encourage moving from denser, convenient central areas to sprawling suburbs; urban renewal and freeway construction; low density settlement patterns and isolation of residential areas from shopping, services and jobs; poor public transit service; and pedestrian- and bicycle-unfriendly residential and shopping areas.

The marginal cost of driving (additional cost per mile) comprises only 14 percent of total direct automobile costs in the first year of ownership, and averages 38 percent (less than 13 cents per mile) over 12 years of ownership according to the Federal Highway Administration

(1991). The marginal costs include the fuel, some parking, tolls, maintenance and tires; ownership costs include annual registration and taxes, depreciation, finance costs, insurance and some parking fees.

The low marginal costs encourage driving by decreasing the apparent cost of driving, and, in fact, increased mileage, while raising the total costs, decreases the cost *per mile*. Many of the hidden subsidies to driving are dependent on the miles driven and would discourage additional driving if their costs were levied directly on auto use, more than doubling the cost per mile. These subsidies include road repair, policing and motorist protection, parking, accidents, noise, vibration damage, pollution damage, global warming, petroleum subsidies, policing the petroleum supply line, and congestion.

Since before World War II, federal housing policies, including those of the Federal Housing Administration (established by the National Housing Act in 1934), Veterans Home Administration and the Federal National Mortgage Association (FNMA), have driven up single-use suburban sprawl by "redeveloping" urban centers, officially or unofficially redlining urban centers, strongly biasing ownership towards single-family homes, encouraging or mandating low density developments, and prohibiting commercial activities in residential areas (Glazer, 1973; Stone, 1973; and National Commission on Urban Problems, 1968 & 1973). Redlining impedes upkeep and rehabilitation of central areas.

Urban renewal removes more affordable housing, usually from the urban center near jobs, neighborhood shopping and transit. Construction of freeways through urban centers and into rural areas removes block-wide swaths homes and businesses from the urban center and opens up rural areas for development.

Lowering residential densities and separating commercial areas from residential areas increase distances between houses, between friends or fellow commuters, and from home to market or restaurant. Increasing trip distances not only increases the length of the trip driven, but also causes more to be driven rather than walked, biked or taken on public transit.

Many suburban areas have development codes and practices which inhibit walking, bicycling and public transit. These include the absence of sidewalks, bus shelters and inviting street furniture, or where buildings are set back behind parking or landscaping and lack attractive fronts. Winding and dead-end streets, *cul de sacs*, and such pedestrian barriers as freeways, drainage ditches and parking in front of businesses increase trip distances. High traffic speeds and the absence of sidewalks, stop signs and stoplights decrease pedestrian safety and discourage walking or biking. Since most public transit users get to transit by walking or bicycling, conditions which discourage walking or bicycling cut transit patronage.

Purpose of This Study

The purpose of this study is to elaborate the impacts of a community's 1) household density, 2) accessibility to public transit, 3) accessibility to neighborhood shopping, and 4) pedestrian and bicycle accessibility, on the use of private automobiles by the community's residents. This study tests the hypothesis that residents drive fewer miles when they live in communities with higher densities, more transit service, nearby shopping (restaurants, markets, drugstores, etc.) and an attractive, inviting pedestrian environment.

This study tests the proposition that these community characteristics decrease average trip lengths, facilitate transit use and encourage walking and bicycling, thereby decreasing auto use and residents' transportation costs. The neighborhood shopping measure is also a surrogate for job, entertainment, and recreation trips, and visits to relatives and friends.

This study intends to measure the independent impacts of each of these community characteristics on total household driving. If that can be accomplished, the average household auto costs could be calculated for a housing location using these variables.

The calculation might take the following form:

a) Use census tract population density or net household density to look up the average annual household auto expenses in a Density-Auto Expense Table. Census tract density could easily be mapped on a land use map.

b) Calculate the daily average number of standardized buses within 1/4 mile walking distance and the standardized rail cars or ferries within 1/2 mile of the residence. Look up the resulting average annual additional savings or costs in a Transit Access-Auto Expense Table, and subtract from the auto costs derived above.

If the equation relating density and transit to VMT is more complicated than addition, a table of auto costs at each density and transit accessibility could be used.

c) If five restaurants, food stores and drugstores are within 1/4 mile walking distance subtract the shopping accessibility bonus from auto costs derived above.

d) Look up the average annual household auto savings for pedestrian access in the Pedestrian Access-Auto Expense Table and subtract them from the auto costs derived above. These savings or costs are based upon the pedestrian grid completeness, hilliness, sidewalks, building setbacks and traffic controls in the census tract. Census tract pedestrian accessibility could be mapped on a land use map.

e) Add up the average household transit costs for the city and add to the auto costs derived above.

f) Subtract the total annual household transportation cost obtained in a-e from the suburban average to obtain the annual household savings; divide by 12 months; and add to the standard PITI (principal, interest, taxes and insurance) mortgage qualification formula.

The average transportation costs associated with a specific location would be added to the house's mortgage, tax and insurance costs to get the total transportation and mortgage expenses for a house. This provides the basis for allowing a family moving into an area with low auto dependence to qualify for larger housing mortgages based on its transportation cost savings. Further, this study intends to define each of these community characteristics in such a way that it can be used to guide land use and transportation planners in designing urban areas to reduce dependence on cars.

Constraints On The Study

This analysis is complicated by the objective of defining variables which adequately predict the extent of auto dependence, yet are simple to measure and apply to mortgage loan policy and urban development policy, all within urban areas that are complex and uneven.

Consider density. Lower household densities result in fewer households nearby, decreasing the average number of family members and friends within walking, bicycling or transit distance. Lower density neighborhoods are harder to serve by transit and in American cities are usually located farther from job centers. So, residential density is also a surrogate for nearness and for public transit access to concentrations of jobs and shopping. One task is disentangling transit access and local shopping from density. Some high density areas are built right next to low density areas. High density apartments might be surrounded by extensive low density housing, giving a low density average. To accommodate this variability, this study looks at communities of 20,000 people or more in order to reflect the larger community environment. At this scale, density and transit service should reflect accessibility to jobs (comprising one-fifth of total trips and one-third of total auto mileage) and to shopping, services and friends.

However, some architects are designing transit oriented developments (TOD), which are medium density neighborhoods with shopping and pedestrian amenities, outside the developed metropolitan area. How much will the higher density of these areas and perhaps better transit service compensate for the area's isolation from job and perhaps shopping centers? A neighborhood in the San Francisco area and one in the Los Angeles area were selected to test this.

High income may be correlated with more driving, independent of neighborhood characteristics. The influence of household income is corrected for.

This study uses reliable measurements of auto mileage, based on odometer readings taken when automobiles receive biennial California *Smog Checks*. Unlike travel surveys, these data do not depend on the subjects' willingness or ability to remember and report their driving.

There is one important caveat. The high density evaluated here does not fit the media image of monolithic run-down high-rise projects. The highest density area studied, Nob-Russian-Telegraph Hills-Chinatown-North Beach-Fisherman's Wharf in San Francisco, achieved nearly 120 units per net acre primarily with 3 to 6 story apartment houses. The area is popular and well kept up. Its high housing prices show high demand.

Achieving high density need not mean massive redevelopment. It can be achieved by infilling with 3 to 4 story apartments or condos, over restaurants and markets, constructed on lots left empty, on parking lots, and on other underused land along transit corridors and around transit stations. The pedestrian and commercial activities of these higher density areas enhance their neighborliness, excitement and livability. As these core areas grow and densify, new transit corridors between them could provide additional avenues for infill growth. Neighborhoods farther from these transit corridors remain at low density. This is the traditional urban growth pattern.

2. SURVEY OF PREVIOUS STUDIES

No previous studies have analyzed the separate impacts of this study's four independent variables (density, transit, shopping, pedestrian accessibility) on driving. One cluster of studies has focused on the impact on driving of density, with the other variables co-varying. A second cluster has tried to identify the community characteristics which promote walking and transit use. A third cluster has tried to measure how far people are willing to walk.

Density Based Studies

John Holtzclaw evaluated the reduction in driving in the San Francisco region resulting from higher population and household densities (Holtzclaw, 1991). The analysis indicated that neighborhood businesses and improved transit service co-vary with density. It also estimated fuel, pollutant emissions and auto ownership cost savings.

The study used a novel source of vehicle miles traveled (VMT) data: odometer readings taken during California's mandatory biennial auto emissions (smog check) inspections. This data captured all auto travel, including vacation, so should have been an accurate indication of total vehicular use and how much total VMT could be saved by increasing the density of residential areas. And these measurements eliminate concerns about reporting accuracy, trip length estimation accuracy, data completeness, response rate adequacy, response bias and inhomogeneous analytical areas.

Five communities within the San Francisco region were selected to achieve a wide range of density, including one of the densest communities west of Manhattan.

! Nob Hill to Fishermans' Wharf (northeast San Francisco) - somewhat densely settled, richly served by neighborhood business and transit. [Also in this study.]

! San Francisco (all) - moderate to dense settlement, neighborhood business and transit service. [Also in this study.]

! Rockridge (north Oakland - south Berkeley) - moderate settlement density, neighborhood business and transit service. [Part of this community is in this study.]

! Walnut Creek (suburban) - low to moderate settlement density, neighborhood business and bus service, but with two BART stations. [Part of this community is in this study.]

! Danville - San Ramon (suburban) - low settlement density, neighborhood business and little transit service. [San Ramon is in this study.]

Comparing the extremes, the Nob Hill area was found to have 31 times higher net household density, 26 times higher gross population density and 198 times higher local serving job density than Danville-San Ramon, while only about 1/3 the auto ownership per capita and 1/4 the auto ownership per household. The other communities fell within these extremes, except for Walnut Creek's auto ownership per capita, and varied uniformly in the order presented. Comparing communities showed that the higher the population, household or local serving job density, the lower the VMT, as shown in Table 1. VMT measurements for other large counties and the state were included for comparison.

Table 1

1988 Density and Auto Use

	Net HH Density hh / res acr	Gross Pop Den people / tot acr	Gro Loc Ser Job Dens rt&srv job / tot acre	Annual VMT / cap	Annual VMT / hh
Nob-Rus-Chin-N Bea-Tele-Fish Wharf	117	52	83	3,462	7,437
San Francisco	32	23	8.4	5,046	11,848
Rockridge (N. Oak-S. Berkeley	14	10	3.1	7,249	15,707
Walnut Creek	6.8	4.2	1.4	8,434	19,054
Danville-San Ramon	3.8	2.0	0.4	10,248	31,291
Sacramento				8,482	
Los Angeles				7,993	
Orange				9,687	
San Diego				8,486	
California				8,635	

Net household density = households/residential acre
Gross population density = people/total acre
Gross local serving job density = (retail jobs + service jobs)/total acres
VMT/cap = vehicle miles traveled/capita

John Holtzclaw

This study showed that as the household, population and commercial densities and transit service decrease the auto ownership rate and vehicle miles traveled (VMT) per capita and per household increase. These VMT variations primarily reflect auto ownership rates since VMT/auto varied less between neighborhoods. Using the Hertz Corporation's estimates of auto ownership and operating costs per mile, the average Nob Hill area family annually spent nearly $14,000 less on autos than the average Danville-San Ramon family. San Francisco families spent $11,000 less, Rockridge families nearly $9,000 and Walnut Creek families nearly $8,000 less than Danville-San Ramon families.

The study found that doubling residential or population density reduced the annual auto mileage per capita or per household by 20 to 30 percent. The study concluded that if the population of an area doubled wholly by infill its VMT would likely increase only 40 to 60 percent, rather than the 100 percent it would increase if the city grew retaining its present density pattern. In contrast, doubling population at low density, halving the average density, would likely increase average auto mileage by 150 to 186 percent. At 30% reduction in VMT as density doubles, VMT varies as the reciprocal of the square root of the household density:

$$\underline{VMT_2} = \underline{POP_2}\,(0.7)^{1.4 \ln \frac{D2}{D1}}$$

$VMT_1 \quad POP_1$

or alternatively,

$$\frac{VMT_2/POP_2}{VMT_1/POP_1} = \left(\frac{D_1}{D_2}\right)^{.515}$$

$$\frac{VMT}{POP} \; \% \; \frac{1}{\%D}$$

where: VMT = vehicle miles traveled; POP = population of community; D = density of community; VMT/POP = VMT per capita.

The study also evaluated how effectively public transit reduced driving. San Francisco's higher density and better transit service shortened trip lengths sufficiently to allow one mile on transit to replace eight miles of driving compared to trips in Danville - San Ramon. This savings was attributed to the increased convenience of higher density mixed-use areas. Similarly, the suburban areas of Walnut Creek and Danville-San Ramon, which had similar histories prior to Bart opening 13 years before the study data, were compared. In that time Walnut Creek had developed to over twice the density as Danville-San Ramon, with 3 to 4 times the local serving jobs, resulting in 18 percent less auto travel per capita and 39 percent less auto travel per household. The study found that one mile on transit in Walnut Creek replaced four miles of driving compared to trips in Danville - San Ramon, or 13.6 miles of driving per household.

Holtzclaw's general density-VMT relationship was confirmed by Metropolitan Transportation Commission consultant Greig Harvey of DHS, Inc. He analyzed MTC's 1981 San Francisco Bay Area travel survey. MTC compiled 6200 weekday and 900 weekend responses with a mailed questionnaire and followup phoning. The households surveyed were selected randomly from a reverse directory, with corrections for household size and income.

Mr. Harvey aggregated the survey responses into MTC's 34 superdistricts (175,000 average population) with the results showing the same pattern of per capita VMT with residential density (defined as persons per residential acre) as derived by Holtzclaw. A curve of 30 percent decrease in per capita VMT as density doubles tracked the data well.

The NRDC report reviewed the following eight studies in some detail.

A survey of New York State residents' odometer readings, with telephone follow-up to increase the response rate, found that car owning Manhattan households drove 8,000 miles a year, or 46 percent, less than a comparable household on 10 acres in exurbia (Zupan & Cumella, 1981). But only 20 percent of Manhattan households owned cars.

A New York City energy study (New York City, 1980) showed that the average American consumed 4.1 times as much gasoline as residents of the City, implying a VMT ratio of 4.1:1. They could not measure the fuel consumption in Manhattan alone so they included Manhattan with the rest of New York City. Of course this averages the low fuel consumption of denser Manhattan with the higher consumption of the other four boroughs.

A travel survey in the Greater Toronto Area (University of Toronto/York University, 1989) showed that residents of the dense central area with its excellent transit and wealth of jobs drove or rode in an automobile about 40 percent as much as the residents of the lower density cities bordering Metropolitan Toronto. The survey found that doubling the density results in a decrease in per capita VMT of about 25 percent.

A travel survey in the Chicago area (Boyce, *et al*, 1981) analyzed morning commuting by concentric rings centered on the loop. The results show that a doubling of density results in a 30 percent reduction in VMT.

Robert Dunphy and Kimberly Fisher analyzed the trips reported in the 1990 National Personal Transportation Survey (NPTS), assigning each household to a density range based on its ZIP code's density. So households in a 10,000 to 49,000 persons per square mile ZIP code in San Francisco were lumped in with similar households in New York, Chicago, Boston, Los Angeles, and elsewhere. This data shows a strong decrease in VMT (Personal Vehicle Miles in Table 5) with increasing density. It seems to show a break at about 6000-7000 p/sm (10-11 hh/res ac), with a slower decrease in VMT as density increases at lower densities, and a faster decrease at higher densities (maximum was about 200 hh/res ac). At densities above the break, each doubling of density reduced VMT per capita by 40%. Over the urban range of 1500 p/sm (2 hh/res ac) to the maximum, each doubling of density reduced VMT per capita by 28%.

Peter Newman and Jeffrey Kenworthy (1989) surveyed major cities around the world. They found that the residents of the American cities consumed nearly twice as much gasoline per capita as Australians, nearly four times as much as Europeans and ten times that of the three "westernized" Asian cities. The extremely low density urbanized areas of the US and Australia consumed over 6 times as much energy per capita as the very high density areas of Europe and the Far East. The usual concerns about fuel consumption surveys were minimized by including relatively large geographical areas in the analysis.

A travel survey of United Kingdom cities, reported by Newman and Kenworthy (1989), found that as density increases from 8 to 80 persons/hectare the auto travel per person decreases about 64 percent. That is a 25 percent reduction in per capita VMT as density is doubled. They also found that the residents of the low density areas traveled farther at higher speeds, but had to spend more time at it. This striking finding has major implications about the cost-effectiveness of highway programs intended to increase average speeds since most of the assumed benefits consist of saved time.

Newman and Kenworthy (1989) examined fuel consumption in Manhattan and the New York region. Their analysis indicated that Manhattan's residents drive 1/7 as much per capita as the average American. As density increases from 8 to 43 units per acre, VMT is reduced 54 percent, or a 30 percent reduction in VMT as density is doubled. The previous caveat about fuel consumption studies applies.

The U. S. Department of Transportation (McElhaney, 1989) estimated VMT for American urbanized areas. Even at this large scale of aggregation and with much scatter the data suggested a reduction of 30 percent in VMT as density doubles.

Community Characteristics Promoting Transit and Walking

Several analysts have identified the densities necessary to support transit systems. Certainly, transit can be operated at high frequency in low density areas with adequate subsidies or fares. Costs can be cut on low ridership routes by using smaller vehicles or automating the system (automating can backfire and substantially raise the capital and operating costs of complex systems). However, considering the unwillingness of the American public to subsidize "empty buses" in normal operation, these guidelines are useful. These studies provide an indication of patronage changes with density. Other studies have shown the efficacy of mixing uses and locating shopping near housing concentrations on reducing driving.

Two California agencies have guides for developing pedestrian and transit accessible communities: California Air Resources Board (1993 Draft), and Nancy Hanson of the California Energy Commission (1993, with updates).

From their study of 32 major cities around the world, Peter Newman and Jeffrey Kenworthy (1989) report on a United Kingdom study and conclude that below 20 persons/hectare (8 persons/acre, and 8-10 du/res acre (dwelling units/residential acre) at household sizes and land uses common to San Francisco area cities) there is a marked increase in driving, and below 30 persons/hectare (12 persons/acre, 12-16 du/res acre) the bus service becomes poor. They recommend densities above 30-40 persons/hectare (12-16 persons/acre, 12-20 du/res ac) for public transit oriented urban lifestyles.

Boris Pushkarev and Jeffrey Zupan (1982) recommend the following densities (dwelling units per residential acre):

Bus: minimum service, 1/2 mi between routes, 20 buses/day	4 du/res ac
Bus: intermed serv, 1/2 mi between routes, 40 buses/day	7 du/res ac
Bus: freq serv, 1/2 mi between routes, 120 buses/day	15 du/res ac
Light rail: 5 min peak headways	9 du/res ac, 25 - 100 sq mi corridor
Rapid tr: 5 min peak headways	12 du/res ac, 100 - 150 sq mi corridor
Commuter rail: 20 trains/day	1 - 2 du/ res ac, on existing track

The Institute of Transportation Engineers (1989) recommends the following *minimums*:

1 bus/hour	4 to 6 du/res. acre	5 to 8 msf of commercial/office
1 bus/30 min	7 to 8 du/res ac	8 to 20 msf of commercial/office
Lt rail, feeder buses	9 du/res ac	35 to 50 msf of commercial/office

Marcia Lowe recommends at least 7 du/res ac for local bus service and 9 du/res ac for light rail (1992).

Sacramento Rapid Transit recommend at least 10 du/res ac within 1/4 mile and 5 du/res ac outside that for bus service, and 10 du/res ac for light rail service (1987).

Consultants determined that 43 du/res acre within 1/8 mile and 10 du/res acre in the next 1/8 mile would be necessary for rail transit (Barton-Ashman Associates, *1990)*.

Snohomish county planners similarly found 7 to 15 du/residential acre can support frequent local bus service. They found that a large, pedestrian accessible, area at these densities might also support light rail (Snohomish County Transportation Authority, 1989).

Seattle planners have concluded that transit ridership increases significantly when the density of jobs exceeds 50 employees per acre in centers with at least 10,000 jobs (Seattle METRO, 1987).

The rate of auto travel to a central business district shopping area well served by rail and bus transit was found to be 75% lower than that to a comparable suburban shopping area (JHK and Associates, 1993). Compared to the suburban mall, auto use at the urban center dropped from 95% to 38% of shoppers, while transit use increased from 4% to 32%, and walking increased from 1% to 29%.

A survey of five cities found that over 70% would switch from auto to walking or bicycling for shopping and personal business if the trips were only 1/2 mile and pedestrian walkways were provided (Ferrol Robinson, *et al*, 1980). Nancy Hanson calculates that if half of the shopping or personal business trips that are between 1/2 mile and 5 miles could be shortened to 1/2 mile, and half those trips taken by foot, then total vehicle trips would decline by over 5% (1993)

While only 3 to 8% of mid-day lunch or errand trips were found to be by walking in typical single-use office parks, walking increased to 20-30% in pedestrian accessible mixed-use areas (David Unterman, 1984).

A survey of suburban centers found that 27-33% of the employed residents living in the center also worked at the center (Kevin Hooper, 1988).

A study of 400 Portland neighborhoods showed "that households in pedestrian friendly neighborhoods make over three times as many transit trips and nearly four times as many walk and bicycle trips as households located in neighborhoods with poor pedestrian environments" (1000 Friends of Oregon, 1994). Households in the highest pedestrian friendly areas drive half as mulch as those in the least pedestrian friendly areas. "The analysis suggests that vehicle miles traveled per household in pedestrian hostile neighborhoods would be reduced by as much as 10% with a significant improvement in the pedestrian environment." The measures of pedestrian friendliness were density, proximity to employment, grid pattern streets, continuous sidewalks and easy street crossings.

The California Air Resources Board has recommended the following actions to reduce auto use (1993).

	VMT or trip reductions at site	VMT or trip reductions in region
Bike, pedestrian, traffic flow improvements	1 - 10%	1 - 2%
Mixed uses, higher densities	20 - 50%	4 - 11%
Improved transit, ridesharing, traffic flow		5 - 10%

Walking Distances To Transit

How far people are willing to walk to work, shop, visit friends or to transit depends upon many factors which make up pedestrian accessibility, including hilliness, the availability and condition of sidewalks, trees and such street furniture as awnings for protection from sun or rain, seating and other amenities, other pedestrians and interesting stores or vistas along the walk, the amount and speed of the street traffic and the ease and safety of street crossings. Studies should find greater willingness to walk as the pedestrian accessibility of an area increases. As communities improve neighborhood shopping and achieve higher densities with more pedestrians, the distance its residents are willing to walk should increase.

Boris Pushkarev and Jeffrey Zupan report that the median (half are longer and half are shorter) walk to the New York subway is .35 mi, and the median walk to New Jersey commuter rail stations is .5 to .6 mile (1980). They use 1/2 mile walking distance as "rail territory".

The National Personal Transportation Study found that 70% of Americans will walk 500 feet for normal daily trips, 40% are willing to walk 1,000 feet (1/5 mile), and 10% will walk a half mile (David Unterman, 1990). This study shows little willingness to walk in the pedestrian-unfriendly environments of most Americans.

The NPTS also found that 10.3% of those living within 1/4 mile of public transit used it to get to work, while only 3.8% of those living within 1/4 and 2 miles used it, and less than 1% of those living farther away used it (U.S.DOT, 1986). Michael Bernick found that 30 to 40% of apartment residents living within 1/2 mile of Walnut Creek and Pleasant Hill BART stations took BART to work and another 25% used other public transit, compared to 13% using transit regionwide (1990).

Pedestrian analyst Michael Replogle found that Montgomery County, Maryland residents will walk 1/4 mile median distance to a bus and 1/2 mile to a rail stop, and recommends assuming those distances for analyses (1984).

A trip survey in the San Francisco area gave an average time for all walking trips of 12.5 minutes, which is 0.625 mile at 3 mph, a common average walking rate (U.S. DOT, *1988*).

3. THE COMMUNITIES AND THEIR CHARACTERISTICS

The Communities

This study compares eleven communities in the San Francisco area, eight in the Los Angeles area, five in the San Diego area and three in Sacramento. Five of those in the San Francisco area were studied in the 1991 NRDC analysis (although Rockridge and Walnut Creek were each shaved by one ZIP code, and the three Danville-San Ramon ZIPs pared to one San Ramon ZIP in this analysis). Those five communities were selected because they vary uniformly from high density with good transit, neighborhood shopping and pedestrian accessibility at one extreme, to low density with poor transit, shopping separated from residences and poor pedestrian accessibility at the other. These variables co-varied within these communities. The communities were selected to minimize the impacts of variations in income and ethnicity on driving. Those communities are shown in bold on the tables.

The additional San Francisco area communities were selected with the advice of planners at the Association of Bay Area Governments. These communities were selected to diverge from uniform co-variance on one characteristic so the impact of that characteristic could be measured. For instance, Lafayette is similar to San Ramon except for its higher income, and Central Berkeley matches Rockridge but has lower income. Alameda matches Rockridge but has less transit. Daly City matches Rockridge but has less neighborhood shopping. Los Altos-Los Altos Hills matches Lafayette but is more pedestrian friendly. Morgan Hill was selected to match Alameda, except that it is located far from the urban core: a test of the non-centrally located but transit-oriented "traditional village" concept. It will be seen later that the data do not support many of these comparisons. For instance, while Lafayette does have higher income than San Ramon, it also has somewhat better transit service and neighborhood shopping but less pedestrian accessibility--muddying the direct comparison.

The Los Angeles area communities were selected to co-vary from the high-medium density south Long Beach through medium density south Santa Monica and south central Pasadena and low-medium density Alhambra to Moreno Valley at the lowest density. Downey was selected to match Alhambra but with less transit. Beverly Hills matches Alhambra but has higher income. Riverside was selected to match Alhambra, except that it is located far from the urban core: another test of non-centrally located but transit-oriented "traditional village" concept.

The San Diego area communities were selected to co-vary from medium density Uptown through Escondido and Clairemont to lowest density Bostonia-Crest-Flinn Springs-Blossom Valley. La Costa was selected to match Bostonia, *et al.*, but with higher income.

The Sacramento communities were selected to co-vary from medium density Central City through East Sacramento-North Land Park to low density South Sacramento.

These community descriptions were circulated to the city planning departments for review.

TABLE 2
COMMUNITIES STUDIED

Name	Co-Variance Deviation	ZIPs	Census Tracts
		San Francisco Area	
Nob-Rus-NoBea		94108, 94111, 94133	101, 103 - 108, 112 - 119, 121
San Francisco		941xx	all San Francisco
centr Berkeley	$ < Rock	94702, 94703	4218, 4219, 4222, 4223, 4230, 4231, 4233 -4235, 4240
Daly City MU	< Rock	94014, 94015	6004 - 6009, 6011 - 6015, 6016.01 -6016.03
Alameda	Tr < Rock	94501	4271 - 4286
Rockridge		94618, 94705	4001 - 4003, 4042, 4043, 4236 - 4239
Walnut Creek		94596, 94598	3382.01, 3382.02, 3383.01, 3383.02, 3390, 3400.01, 3400.02, 3430.01 - 3430.03, 3461.01, 3553.02
San Ramon		94583	3451.01 - 3451.04, 3451.08, 3451.09, 3452.02
Morgan Hill	"Rural" Ala	95037	5123.03, 5123.04, 5123.98
Lafayette	$ > SR	94549	3470, 3480, 3490, 3500, 3512
LAltos-LAH	Ped > Laf	94022, 94024	5100.01, 5100.02, 5101 - 5105, 5117.01 - 5117.03
		Los Angeles Area	
s Long Beach	Densest	90802	5759, 5760, 5761, 5762, 5765, 5766
		90813	5728, 5729, 5752, 5753, 5754, 5755, 5756, 5758, 5763, 5764
s Santa Mon	Hi/med dens	90401	7015.02, 7017.02, 7019
		90405	7020, 7021, 7022, 7023
sw Bev Hills	$ > Alh	90212	7009.02, 7010
sc Pasadena	Hi/med dens	91101	4622, 4636
		91106	4623, 4627, 4634, 4635, 4640
Alhambra	Med dens	91801	4808.02, 4818, 4819.01. 4819.02
		91803	4803, 4804, 4808.01, 4810, 4815, 4816
c Downey	Tr < Alh	90241	5508, 5509, 5510, 5513, 5514
n Riverside	Rural Alh	92501	301, 302, 303, 423
Moreno Valley	Lo dens	92387	422.04, 424, 425.01, 425.02, 425.03,
		92388	426.01
		San Diego	
Upto-MisH-Hil	Med dens	92103	1, 2, 3, 4, 6, 7, 60, 61
		92116	5, 10, 11, 12, 17, 18, 19, 20.01, 21
Clairemont	Med/lo dens	92117	85.01, 85.02, 85.03, 85.04, 85.05, 85.06, 85.07, 91.01, 91.02
La Costa	$ > Bos	92009	178.05, 178.07, 178.08, 200.11, 200.12
Escondido	Med dens	92025	202.02, 202.98, 204.03, 205, 206.01, 206.98, 207.01
		92027	201.01, 202.04, 202.05, 202.97, 207.03, 207.05, 207.06
Bos-Cr-Fl Sp-BV	Lo dens	92021	155.01, 155.02, 163, 164.01, 164.02, 165.01, 165.02, 167.01, 168.02, 168.06, 168.09
		Sacramento	
Cent City	Med dens	95814	5 - 12, 20, 21, 53
		95816	4, 13, 14, 19
ESac-nLndPk	Med/lo dens	95819	1 - 3, 15 - 17, 52.01
		95818	22 - 24
S Sac	Lo dens	95823	45, 49.03 - 49.06, 96.02

Note: n, e, s, w, c = north, east, south, west, central

John Holtzclaw

Measuring Density, Income, Transit, Shopping and Pedestrian Access
To the Communities

Certain community characteristics are believed to increase or decrease the amount of driving by residents. For this study these variables were measured in each community so their impacts on vehicle miles traveled (VMT) could be evaluated. These "independent" variables are *density, income, transit, neighborhood shopping, and pedestrian accessibility.* The dependent variables are *auto ownership*, and *vehicle miles traveled*, which is described later. The independent variables are operationalized to facilitate use of available data and to give results that can guide planners to design cities that afford residents alternatives to driving. The definition of these variables, their measurement, and sources of data are described below. Many of these measurements come from census enumerations, which have been challenged as being too low. However these measurements are the most accurate, and consistent between cities, that are available. The values of these variables for the communities studied are shown in Tables 3 and 4. These measurements were circulated to the city planning departments for review.

Density

As the density of a community increases many such trip destinations as jobs, markets, restaurants, friends and relatives are nearer, shortening trips. A study of San Francisco Bay Area communities found that if density doubled, per capita VMT fell by 20 to 30 percent, reported in Holtzclaw (1991). That study did not evaluate the independent impacts of transit, shopping or pedestrian accessibility. Each of them increased in parallel with density, a common pattern in American urban areas. This study attempts to tease apart these independent factors.

The *population density* measures the total residents per unit area. This is a useful indicator of the density of drivers, potential transit users, workers, mouths to feed, or bodies to clothe or provide parks for. Streets, parks, recreation, office, manufacturing, commercial and undeveloped areas are included. This explains why higher residential density (which includes only residential land) is often higher than the population density.

! $$\text{population density} = \frac{\text{total population}}{\text{total area}}$$

The U.S. census enumerates the population by census tract (generally 10,000 residents or less) and estimates its land area. These are available at tract or aggregates of tracts from city, county and regional planning departments, and private firms, as well as from the Census Bureau. The California Department of Finance annually updates county and city population estimates, using decennial census enumerations, housing changes, drivers license changes, auto registrations, school enrollments births and voter registrations. Cities, counties and regional planning agencies often independently estimate or disaggregate state estimates to smaller areas.

This study used 1990 census measures of population and area, aggregated to community level by the regional planning agencies (except in Sacramento). Census tracts were aggregated to approximate the ZIP code areas for which estimates of VMT per vehicle were calculated. U.S. Census Bureau reaggregations of census tract data to ZIPs are now

Table 3
1990 Community Demographics and Densities

Community	Population	House-Holds	Acres	Resid Acres	Pop Density Pop/Acre	Net Pop Density Pop/Res Ac	Net HH Density HH/Res Ac	- Res Density - DU/Res Ac	TAI Transit	NSI Shop-ping	PAI Pedes-trian
San Francisco Area											
Nob-Rus-NoBea	48,075	24,213	977	240	49.2	200.3	100.9	110.	90	1.00	.66
San Francisco	723,959	305,984	29,888	6,336	24.2	114.3	48.3	52.	70	.76	.49
central Berkeley	34,320	15,740	2,848	1,008	12.1	34.0	15.6	16.4	49	.16	.58
Daly City	84,486	27,094	5,788	1,815	14.6	46.5	14.9	15.5	13	.17	.10
Alameda	70,157	29,235	6,834	2,404	10.3	29.2	12.2	12.8	6.7	.22	.48
Rockridge	33,619	15,207	4,113	1,578	8.2	21.3	9.6	10.1	27	.24	.13
Walnut Creek	61,036	26,166	13,190	5,576	4.6	10.9	4.7	4.9	21	.10	.07
San Ramon	30,692	11,629	12,747	3,659	2.4	8.4	3.2	3.4	1.0	.00	.08
Morgan Hill	28,429	9,258	17,065	4,048	1.7	7.0	2.3	2.4	3.1	.13	.16
Lafayette	26,004	9,766	14,185	4,416	1.8	5.9	2.2	2.3	11	.09	.02
Los Altos-L A H	36,086	13,293	17,132	7,204	2.1	5.0	1.8	1.9	2.3	.12	.03
Los Angeles Area											
s Long Beach	101,241	35,115	6,382	1,455	15.9	69.6	24.1	25.5	19	.57	.66
s Santa Monica	35,633	19,202	2,374	1,274	15.0	28.0	15.1	15.9	20	.71	.59
sw Beverly Hills	11,418	5,821	589	429	19.4	26.6	13.6	14.3	13	.65	.71
sc Pasadena	43,733	20,497	3,142	1,971	13.9	22.2	10.4	11.0	5.5	.37	.42
Alhambra	81,375	28,362	4,870	3,290	16.7	24.7	8.6	9.1	4.7	.24	.37
c Downey	30,363	11,955	2,682	1,754	11.3	17.3	6.8	7.2	2.1	.16	.21
n Riverside	17,813	5,979	3,458	1,157	5.2	15.4	5.2	5.5	0.6	.07	.13
Moreno Valley	118,779	35,106	31,526	10,134	3.8	11.7	3.5	3.7	0.4	.08	.09
San Diego Area											
Uptown	66,016	34,202	4,719	2,787	14.0	23.7	12.3	13.1	9.0	.50	.39
Clairemont	50,017	19,889	5,666	3,203	8.8	15.6	6.2	6.6	2.4	.08	.07
La Costa	25,423	10,495	10,955	2,626	2.3	9.7	4.0	4.3	0.5	.03	.01
Escondido	82,850	28,204	44,128	7,923	1.9	10.5	3.6	3.8	2.1	.03	.09
Bos-Cr-Fl Sp-BV	62,479	22,423	28,125	8,639	2.2	7.2	2.6	2.8	0.8	.04	.02
Sacramento Area											
Central City	32,406	17,175	4,086	774	7.9	41.9	22.2	23.5	20	.17	.41
E Sac-n Land P	40,655	18,329	5,460	2439	7.4	16.7	7.5	8.0	5.3	.10	.26
S Sac	54,838	18,944	6,330	2873	8.7	19.1	6.6	7.0	1.2	.13	.03
Merced Co.	178,403	55,331	$1.2\ 10^6$		.1						

Population, Households and Acres are from the 1990 U.S. Census.
Residential Acres excludes streets. They were measured by ABAG, SCAG, SANDAG and the Sacramento Planning Department.
Residential Density includes vacant units, based upon 1990 U.S. Census. This is the measure used in planning codes and development plans.

TAI = 3(buses both dir/day)(seats/bus)(%hh to 1/4 mi) + 3(railcars both dir/day)(seats/car)(%hh to 1/2 mi) / (50 seats/std bus)(24 hr/day)

NSI = fraction of hh within 1/4 mi of 5 key local commercial (market, restaurant, drugstore) establishments

PAI = (fraction of through streets)(fraction of roadway below 5% grade).33[(fraction blocks with walks, each side) + (building entry coefficient) + (fraction of streets with traffic controlled)]; Building entry coefficient = [1 if 0 - 3 ft avg. building setback from walk; 0.5 if 4 - 10 ft; 0.3 if 11 - 20 ft; 0.1 if 21 - 40 ft; 0 if > 40 ft]

n, e, s, w, c = north, east, south, west, central

Prepared by John Holtzclaw

Table 4
1990 Community Characteristics

Community	Pop Density Pop/Acre	Net HH Density HH/Res Ac	Income/Capita $	Income/HH $	TAI Transit	NSI Shopping	PAI Pedestrian	Autos/Capita	Autos/HH
San Francisco Area									
Nob-Rus-NoBea	49.2	100.9	21,792	42,044	90	1.00	.66	.28	.56
San Francisco	24.2	48.3	19,695	45,664	70	.76	.49	.45	1.06
central Berkeley	12.1	15.6	15,960	34,567	49	.16	.58	.58	1.28
Daly City	14.6	14.9	14,814	45,892	13	.17	.10	.55	1.73
Alameda	10.3	12.2	20,287	47,887	6.7	.22	.48	.65	1.58
Rockridge	8.2	9.6	26,116	57,208	27	.24	.13	.66	1.46
Walnut Creek	4.6	4.7	26,245	60,647	21	.10	.07	.79	1.83
San Ramon	2.4	3.2	26,493	69,975	1.0	.00	.08	.79	2.10
Morgan Hill	1.7	2.3	20,410	61,957	3.1	.13	.16	.72	2.22
Lafayette	1.8	2.2	33,557	89,101	11	.09	.02	.81	2.18
Los Altos-L A H	2.1	1.8	43,936	118,870	2.3	.12	.03	.87	2.38
Los Angeles Area									
s Long Beach	15.9	24.1	9,712	28,000	19	.57	.66	.45	1.29
s Santa Monica	15.0	15.0	25,153	46,677	20	.71	.59	.78	1.45
sw Beverly Hills	19.4	13.5	25,991	50,981	13	.65	.71	.77	1.51
sc Pasadena	13.9	10.4	20,392	43,510	5.5	.37	.42	.70	1.50
Alhambra	16.7	8.6	14,727	42,197	4.7	.24	.37	.61	1.74
c Downey	11.3	6.8	18,716	47,535	2.1	.16	.21	.71	1.81
n Riverside	5.2	5.2	11,373	33,884	0.6	.07	.13	.58	1.72
Moreno Valley	3.8	3.5	15,095	51,074	0.4	.08	.09	.61	2.07
San Diego Area									
Uptown	14.0	12.3	19,124	36,570	9.0	.50	.39	.70	1.35
Clairemont	8.8	6.2	17,558	44,210	2.4	.08	.07	.78	1.98
La Costa	2.3	4.0	26,082	63,117	.5	.03	.01	.80	1.95
Escondido	1.9	3.6	14,053	40,688	2.1	.03	.09	.60	1.75
Bos-Cr-Fl Sp-BV	2.2	2.6	13,990	38,394	.8	.04	.02	.67	1.88
Sacramento Area									
Central City	7.9	22.2	14,226	24,880	20	.17	.41	.50	.94
E Sac-n Land P	7.4	7.5	18,180	39,835	5.3	.10	.26	.64	1.43
S Sac	8.7	6.6	12,021	34,358	1.2	.13	.03	.57	1.65
Merced Co.	.1		10,606	34,197				.56	1.79

Population, Households, Income, Autos and Acres are from the 1990 U.S. Census. Household density excludes vacant residential units.

Residential Acres excludes streets. They were measured by ABAG, SCAG, SANDAG and the Sacramento Planning Department.

$$TAI = \frac{3(\text{buses both dir/day})(\text{seats/bus})(\text{\%hh to 1/4 mi}) + 3(\text{railcars both dir/day})(\text{seats/car})(\text{\%hh to 1/2 mi})}{(50\ \text{seats/std bus})(24\ \text{hr/day})}$$

NSI = fraction of hh within 1/4 mi of 5 key local commercial (market, restaurant, drugstore) establishments.

PAI = (fraction of through streets)(fraction of roadway below 5% grade).33[(fraction blocks with walks, each side) + (building entry coefficient) + (fraction of streets with traffic controlled)]; Building entry coefficient = [1 if 0 - 3 ft avg. building setback from walk; 0.5 if 4 - 10 ft; 0.3 if 11 - 20 ft; 0.1 if 21 - 40 ft; 0 if > 40 ft]

VMT = Vehicle miles traveled, calculated from the California Bureau of Automotive Repair's odometer readings taken

during smog-checks.
n, e, s, w, c = north, east, south, west, central *Prepared by John Holtzclaw*

available from the Census Bureau or from some regional planning agencies. However, these estimates do not include total or residential land measurements (see discussion below). This study used this Census Bureau reaggregations to ZIPs in Sacramento because SACOG aggregations of census tracts were not available. Since total area was not included in the ZIP tables it was calculated by totaling the areas listed in SACOGs published Census tract table, except in South Sacramento where it was measured from the map because non-city area was absent from the table.

The *net population density* measures the total number of residents per unit *residential* area. Comparing the net population density with the population density indicates the fraction of the land area that is devoted to residential development. Table 1 indicates that the residential land is only 1/4 to 1/5 of the total land in denser central cities. The residential fraction increases to 1/2 in "bedroom" suburbs, and drops again in fringe areas containing agricultural and natural lands.

! net population density = $\frac{\text{total population}}{\text{net residential area}}$

Population measurements are discussed above. Residential land area is not available from census data, and can be very difficult to obtain. Most city planning departments measure residential land, but it may not be readily available to the public. Some regional planning agencies aggregate land use measurements from city and county planning departments, but independent measurements from satellite photos incorporated in geographic information systems (GIS) are becoming more common. Some residential land measurements require substantial judgement, especially in mixed-use areas. A building with first floor markets and ten floors of apartments above can be designated commercial, residential or mixed urban, or can be prorated between categories in proportion to the square feet of different uses. The analyst must be careful in specifying the land use categories to be included in order to get consistency between cities and regions. Except in Sacramento where city planning estimates were used, this study used estimates of residential area by regional planning agencies to achieve consistency within each region and to accommodate communities which combine more than one city or city and county. In Sacramento the planning department's estimates of average single family and multifamily densities were multiplied by the measured single family and multifamily areas to calculate the housing capacity at buildout. The actual built housing, as reported by the Census Bureau, was used to calculate the developed area.

The *net household density* measures the density of households in residential areas, an indication of the number of workers and commuters. The net household density equals the residential density reduced for vacant units and increased for any doubling up of households. This is the basic density measurement used herein. The communities within each metropolitan area are listed by descending net household density.

! net household density = $\frac{\text{total households}}{\text{net residential area}}$

Like population, households are enumerated by the U.S. census, with inter-censal estimates by state, county, city and regional planning agencies. Residentially occupied group quarters, like residential hotels, are included as households. This report used 1990 census estimates of households, as reported by regional planning agencies, except in Sacramento where the Census Bureau's reaggregations to ZIP were used.

The *residential density* measures the density of dwelling units in residential areas. This is the common measure of residential density used by planning departments and developers, and with which the public is most familiar.

! $\text{residential density} = \dfrac{\text{total dwelling units}}{\text{net residential area}}$

Like population and households, dwelling units are enumerated in the U.S. census. This study used the census measurement of households and countywide housing vacancy rate to estimate each community's housing. Measurement of residential area is described above.

Income

Income is an indicator of a household or individual's ability to afford more expensive transportation, or travel farther in that transportation. It was included as a variable to gage its impact on VMT independent of the other variables. The measurement of income used in this report is the 1990 census sample of income, aggregated to community level by the regional planning agencies. Each community's mean income per capita and per household are given in the tables.

TAI: Transit Accessibility Index

The public transit accessibility index measures community's transit service. This analysis assumes that the average public transit passenger will walk 1/4 mile to a bus, or 1/2 mile to a rail transit or ferry station. Pushkarev and Zupan report a 0.35 mile median walking distance to a New York subway, a 0.5 to 0.6 mile median walk to New Jersey commuter rail, and 0.2 miles to a bus stop (1982). Kenworthy and Newman recommend high density development within 800 meters (1/2 mile) of rapid transit stations (1989). Replogle recommends using a 1/4 mile median walking distance to bus stops and 1/2 mile to rail stops (1984).

! TAI = average household's (daily average) hourly access to transit

$$= \frac{\text{'(buses,both dir/day)(seats/bus)(\%hh to 1/4 mi) + '(railcars,both dir/day)(seats/car)(\%hh to 1/2 mi)}}{\text{(50 seats/std bus)(24 hr/day)}}$$

This analysis multiplies the number of hourly buses or railcars by the route's access to the community's residential population. A bus serving a larger fraction of the residents counts more heavily. Buses and railcars are standardized to 50 seat vehicles for comparison. The results are stated in vehicles per hour, on a 24 hour basis.

Simpler measures would be to count only the number of bus routes or buses per day or hour. But that measure would equate a high frequency bus route through the center of town serving a large fraction of residents with an infrequent one through low density peripheral areas. NRDC's 1991 study counted bus and rail routes through each community. A more complex measure would be to weight the above equation for accessibility by such measures of the "usefulness" of the route as jobs or stores within a quarter mile of the route. This would make an already difficult measurement (see below) even more difficult. And unnecessary if we assume that more "useful" routes will pick up more passengers, allowing more frequent service, increasing their weighting in the calculation. The Thousand Friends of Oregon uses the number of jobs within a 30 minute transit ride in their Portland simulation. However, this ignores the

3/4 of trips that are not work related, and also increases calculation difficulty. Another variation would be to discount routes with headways of 1/2 hour or more, since these are less desirable and probably less used. However, some argue that just being connected to the transit network is worth a lot.

Bicycle access to transit, including safe storage at stations and bikes on transit, increases the range of the pedestrian commuter-shed beyond the 1/4 mile for buses and 1/2 mile for rail. The efficacy of such facilities has been demonstrated in Europe, Japan and elsewhere. However, the dearth of attractive bike facilities at stations and the bias against commuter biking in this country frustrates measuring their potential impacts on driving at this time.

The measurement should be straightforward. First, identify the location, acreage and average density of housing on a land use map of the community. Use these to calculate the total housing, for comparison with the census housing count. Since residential densities exclude roads, acreage measurements which include roads will give housing estimates high by about a third. This is not a problem since this analysis depends on the relative location of housing, not the absolute amount. Lacking a land use map, a zoning map can be used by assuming average densities a little below the maximum density allowed in a zone. Areas zoned for development but as yet not developed can often be identified by absence of street infrastructure or subdivision indications on this map or on a roadmap. Lay out each transit route or station on the map, and measure the acreage of housing at each density within 1/4 mile walk of bus routes (1/2 mile of rail or ferry stations). Walking distances are not air distances, but are laid out along actual roads or walks, and do not cross freeways, rivers, drainage ditches or other obstructions. Multiply the measured housing acreages by their densities to calculate the number of dwelling units "accessible" to the transit route, and divide by the previously calculated total housing in the community to get the fraction of total housing accessible to the route. Then multiple this fraction of total housing accessible to the route by the standard buses per hour (from the route schedule) to get the community service level. For instance, a route with 5 buses/hour, daily average, coming within 1/4 mile of 10 percent of the housing would provide 0.5 vehicles/hour (5 x .1) to the average resident. Add these for all transit routes to get the TAI.

The measurements should have been straight forward, but it proved difficult to obtain land use and transit maps. Local planning departments in California are strapped for funding due to Prop. 13 and the state's poor economy. While a few departments responded quickly and completely, notably Long Beach, Downey, Long Beach Transit, Orange County Transit, Riverside Transit, BART, CalTrain and San Francisco Muni, most responded with incomplete information and only after repeated calls. Since some San Diego cities sent nothing, residential densities from a SANDAG regional land use map were transferred onto a road map.

NSI: Neighborhood Shopping Index

The neighborhood shopping index measures the fraction of the community's population which has five critical local commercial establishments within 1/4 mile walking distance. Critical local commerce are defined as food markets, restaurants and drugstores, with supermarkets counting as two establishments. Why five? Five establishments comprise sufficient destinations to provide walking alternatives for a substantial fraction of commercial trips. Before 5 was selected, 2, 3, 4 and 5 establishments were tested in San Francisco. Every residence in northeast San Francisco had 2, 3 and 4 commercial establishments within 1/4 mile, and 99.8 percent had 5 establishments. For all San Francisco, 84 percent of residences were within 1/4 mile of 2 establishments, 81 percent near 3, 78 percent near 4, and 76 percent near 5. Using 5 establishments as the standard gives a range of 1.00 in northeast San Francisco to .00 in San Ramon, the full range. Using fewer would diminish the credibility of the shopping area.

Neighborhood shopping is also a surrogate for other shopping. These five firms (restaurants, markets and drugstores) are probably accompanied by other firms like cleaners, accountants, real estate, video rentals and nail polishers. A little further away may be a larger shopping area. These are also jobs. So the neighborhood shopping index is a measure of retail and other firms, and jobs within walking distance.

! NSI = fraction of hh within 1/4 mi of 5 key local commercial establishments

The measurement begins by identifying and quantifying housing on a land use map, similar to that used to measure TAI. Then locations of markets, restaurants and drugstores are added. If the locations of individual establishments are unknown, commercial zoning can be used. In these areas, I assumed one commercial establishment (market, restaurant or drugstore) per block-side of commercial zoning. So, a block with both sides of the street zoned local commercial is assumed to have two such establishments. Spot checks in San Francisco and Sacramento support this assumption. This assumption was used in most communities since very few planning departments identified individual businesses. However, I had to walk northeast San Francisco to identify each establishment since they were integrated into most residential blocks. Draw the boundary of the area within 1/4 mile of 5 key commercial establishments on the map. As with the TAI analysis, multiply the acreages by the densities of residences within 1/4 mile limit to get the dwelling units. Divide this by the community's total dwelling units to get the NSI. Such standardized guidelines, along with one person making all measurements helps provide consistency between neighborhoods.

PFI: Pedestrian Accessibility Index

The pedestrian accessibility index measures neighborhood qualities which make a community inviting and safe to walk in. These factors include a continuous street grid, sidewalks, convenient building entrances, safe traffic speeds, and gentle street slopes. Street continuity measures the ability to walk or bicycle through an area unhindered by *cul de sacs*, or streets broken by freeways or turning back upon themselves, all of which lengthen or decrease the convenience of trips. Continuous street grids also allow the pedestrian more route choices. Steep grades discourage walking or biking, unless they have great views or other amenities. Both broken street grids and steep grades are physical barriers to pedestrians, and so were used as multipliers. The other three variables relate more to attractiveness to pedestrians, and are additive. The Berkeley Planning Department suggested that making all of these additive would be easier to understand, and perhaps more accurate. Sidewalks and slow or controlled traffic increase the safety and attractiveness to pedestrians. Berkeley also suggested that controlling major streets or arterials is more crucial than local streets. However, some pedestrians are intimidated by uncontrolled neighborhood street intersections. Building entrances set back far from the sidewalk, especially behind parking spaces, lengthen walks and reduce pedestrian appeal. Pedestrians are especially attracted to bustling walks with interesting shop windows and doors at hand. The Berkeley Planning Department suggested that setbacks on residential streets do not have the same deleterious effect on pedestrians that they do on commercial streets, and can even increase pedestrian interest. There are many areas for additional research here.

Bicycles are crucial to "pedestrian" accessibility, especially in less compact areas, but even in Manhattan. However the conditions which maximize bicycle friendliness and safety are seldom achieved in this country. These include separation of bicycles from pedestrians and motorized traffic, direct routing, clear-visibility intersections and minimal grades. Even separated bike paths usually combine bikes with pedestrians, often intersect blindly with sidewalks or streets, with priority given to motorized street traffic at those intersections, or cross over streets on steep pedestrian/bike bridges, and have indirect routing. Many bikers prefer to assert their rights to the streets and seek safer auto speed limits. Of the factors measured in this study, street/path continuity, road grades and controlled traffic are important to bicycle friendliness. The PAI varies from 0 to 1.

! PAI = continuous street grids, gentle street slopes, sidewalks, convenient building entrances, and controlled traffic

= (fraction of through streets)(fraction of roadway below 5% grade)(.33)[(fraction of blocks with walks, each side) + (building entry coefficient) + (fraction of streets with traffic controlled)]

! Building entry coefficient = [1 if 0 - 3 ft avg. building setback from walk; 0.5 if 4 - 10 ft; 0.3 if 11 - 20 ft; 0.1 if 21 - 40 ft; 0 if > 40 ft]

The fraction of through streets is measured as the fraction of the community's area with over 90 percent of streets proceeding (in a near-rectilinear pattern) directly through to the nearest collector or commercial streets, or commercial centers. On a street map measure the fraction of the total community area with curving or dead-end streets which lengthen pedestrian trips to commercial areas. Streets which curve back upon themselves to meet the same or perpendicular streets at each end qualify. Subtract this fraction from one to get the fraction of through streets. Planning departments were asked to identify where paths allowed pedestrians and bikers access between dead-end streets, which would complete the street grids for pedestrians. However, most departments (that responded at all) just sent bike path maps, which seldom show such short paths between streets.

The fraction of roadway below 5 percent grade is measured from USGS topo maps. The linear distance between elevation lines which would comprise a 5 percent slope is calculated. Any street with elevation lines closer together has grades above 5 percent. The variable is calculated by subtracting the fraction of blocks above that grade from one.

The fraction of the total streets with sidewalks on both sides is estimated by the local planning department. Sidewalks on only one side count as half.

Commercial and residential building setbacks from the sidewalk are estimated by local planners or are inferred from the zoning minimums.

Controlled traffic streets have speed limits at 20 mph or less, or have stoplights or stop signs at least every 600 feet (a long block), with pedestrian crosswalks. It is measured as the fraction of intersections in the community which are controlled by stoplights or 4-way stop signs. An intersection with 2-way stop signs counts as half a 4-way intersection. Long blocks are interpreted as having an uncontrolled intersection every 600 feet. Where cities refused to provide this information on maps, the city's rules for locating stoplights and signs were used.

Commonly, intersections of major ("classified") streets are stoplighted or 4-way signed, residential streets are stop signed at intersections with major streets, and residential-residential intersections are unsigned.

Auto Ownership

Auto ownership includes autos and light trucks, as enumerated in the U.S. census. Each community's autos per capita and autos per household are shown in the tables.

Analysis of Auto Mileage

The analysis of annual miles driven in each of the communities studied was assisted by the California Department of Motor Vehicles, and by the California Bureau of Automotive Repair, which conducts auto emissions inspections. Automobiles registered in highly polluted (federal non-attainment) areas are inspected biennially before registration renewal. At that time their odometer reading are recorded, along with emissions data, and forwarded to the BAR. This allows comparison of odometer readings taken approximately two years apart.

The DMV prepared computer files of license plate numbers for all vehicles registered in 1989 in each of the specified zip codes.

Ms. Kari Yoshizuka of BAR matched license plate numbers from the DMV files with BAR's Test Analyzer System (TAS) data files for 1989 and 1991. The BAR matched 1989 and 1991 odometer readings to calculate the two year and annual mileage. Cars with 1991 odometer readings less than 1989 readings were assumed to have passed 100,000 miles (turned over) and added 100,000 to their readings. For comparison, randomly sampled vehicle reports from the inspection stations in the counties of Alameda, Contra Costa, San Mateo, Santa Clara, Los Angeles, Riverside, Sacramento and San Diego, and the state were analyzed.

These files were analyzed by the statistical software package SAS (Statistical Analysis System), obtaining the "sample size", "mean annual VMT/car" and "standard deviation of mean" reported in Table 5.

The previously calculated autos per capita and autos per household were used to calculate the annual VMT per capita and per household reported in Table 5. These results, along with the density analyses for the San Francisco region communities, are reported in Table 6.

Table 5
1990 Annual Vehicle Miles Traveled

Community	N Sample Size	Mean Annual VMT/car	Std Error of mean (mi)	Autos / Capita	Autos / HH	VMT / Capita	VMT / HH
San Francisco Area							
Nob-Rus-NoBea	177	9,855	481	.28	.56	2,759	5,519
San Francisco	3,818	10,619	112	.45	1.06	4,779	11,256
central Berkeley	246	9,737	418	.58	1.28	5,647	12,463
Daly City	667	11,128	260	.55	1.73	6,120	19,251
Alameda	461	10,765	333	.65	1.58	6,997	17,009
Rockridge	252	9,781	376	.66	1.46	6,455	14,280
Walnut Creek	499	12,175	333	.79	1.83	9,618	22,280
San Ramon	321	13,406	424	.79	2.10	10,591	28,153
Morgan Hill	228	12,809	449	.72	2.22	9,222	28,436
Lafayette	225	10,229	416	.81	2.18	8,285	22,299
Los Altos-L A H	280	10,971	378	.87	2.38	9,545	26,111
Los Angeles Area							
s Long Beach	406	11,823	343	.45	1.29	5,320	15,252
s Santa Monica	188	10,155	442	.78	1.45	7,921	14,725
sw Beverly Hills	122	8,591	534	.77	1.51	6,615	12,972
sc Pasadena	200	11,504	462	.70	1.50	8,053	17,256
Alhambra	525	12,447	312	.61	1.74	7,593	21,658
c Downey	207	11,828	486	.71	1.81	8,398	21,409
n Riverside	100	13,773	860	.58	1.72	7,988	23,690
Moreno Valley	141	13,875	716	.61	2.07	8,464	28,721
San Diego Area							
Uptown	386	11,469	361	.70	1.35	8,028	15,483
Clairemont	394	11,455	322	.78	1.98	8,935	22,681
La Costa	120	14,031	671	.80	1.95	11,225	27,360
Escondido	454	12,397	327	.60	1.75	7,438	21,695
Bos-Cr-Fl Sp-BV	378	11,424	334	.67	1.88	7,654	21,477
Sacramento Area							
Central City	172	10,710	483	.50	.94	5,355	10,067
E Sac-n Land P	323	10,082	345	.64	1.43	6,452	14,417
S Sac	402	12,016	339	.57	1.65	6,849	19,826
Merced Co.	450	13,282	558	.56	1.79	7,438	23,775
Alameda Co.	10,911	11,260	64		1.68		18,917
Contra Costa	6,257	11,838	90		1.91		22,611
San Mateo Co.	5,560	10,969	90		1.90		20,841
Santa Clara Co.	12,885	11,185	56		1.99		22,258
Los Angeles Co.	53,686	11,620	31		1.68		19,522
Riverside Co.	6,544	13,165	97		1.83		24,092
San Diego Co.	32,045	11,799	52		1.78		21,002
Sacramento Co.	7,432	11,423	79		1.73		19,762
California	346,918	12,072	17		1.78		21,488

Population, Households, Income, Autos and Acres are from the 1990 U.S. Census. Household density excludes vacant residential units.
Residential Acres excludes streets. They were measured by ABAG, SCAG, SANDAG and the Sacramento Planning Department.

TAI = $\frac{\text{3(buses both dir/day)(seats/bus)(\%hh to 1/4 mi) + 3(railcars both dir/day)(seats/car)(\%hh to 1/2 mi)}}{\text{(50 seats/std bus)(24 hr/day)}}$

NSI = fraction of hh within 1/4 mi of 5 key local commercial (market, restaurant, drugstore) establishments.

PAI = (fraction of through streets)(fraction of roadway below 5% grade).33[(fraction blocks with walks, each side) + (building entry coefficient) + (fraction of streets with traffic controlled)]; Building entry coefficient = [1 if 0 - 3 ft avg. building setback from walk; 0.5 if 4 - 10 ft; 0.3 if 11 - 20 ft; 0.1 if 21 - 40 ft; 0 if > 40 ft]

VMT = Vehicle miles traveled, calculated from the California Bureau of Automotive Repair's odometer readings taken during smog-checks.

n, e, s, w, c = north, east, south, west, central	*Prepared by John Holtzclaw*

Table 6
1990 Community Characteristics And Auto Use

Community	Pop Density Pop/Acre	Net HH Density HH/Res Ac	Income/Capita $	Income/HH $	TAI Transit	NSI Shop-ping	PAI Pedes-trian	Autos/Capita	Autos/HH	VMT/Capita	VMT/HH
San Francisco Area											
Nob-Rus-NoBea	49.2	100.9	21,792	42,044	90	1.00	.66	.28	.56	2,759	5,519
San Francisco	24.2	48.3	19,695	45,664	70	.76	.49	.45	1.06	4,779	11,256
central Berkeley	12.1	15.6	15,960	34,567	49	.16	.58	.58	1.28	5,647	12,463
Daly City	14.6	14.9	14,814	45,892	13	.17	.10	.55	1.73	6,120	19,251
Alameda	10.3	12.2	20,287	47,887	6.7	.22	.48	.65	1.58	6,997	17,009
Rockridge	8.2	9.6	26,116	57,208	27	.24	.13	.66	1.46	6,455	14,280
Walnut Creek	4.6	4.7	26,245	60,647	21	.10	.07	.79	1.83	9,618	22,280
San Ramon	2.4	3.2	26,493	69,975	1.0	.00	.08	.79	2.10	10,591	28,153
Morgan Hill	1.7	2.3	20,410	61,957	3.1	.13	.16	.72	2.22	9,222	28,436
Lafayette	1.8	2.2	33,557	89,101	11	.09	.02	.81	2.18	8,285	22,299
Los Altos-L A H	2.1	1.8	43,936	118,870	2.3	.12	.03	.87	2.38	9,545	26,111
Los Angeles Area											
s Long Beach	15.9	24.1	9,712	28,000	19	.57	.66	.45	1.29	5,320	15,252
s Santa Monica	15.0	15.0	25,153	46,677	20	.71	.59	.78	1.45	7,921	14,725
sw Beverly Hills	19.4	13.5	25,991	50,981	13	.65	.71	.77	1.51	6,615	12,972
sc Pasadena	13.9	10.4	20,392	43,510	5.5	.37	.42	.70	1.50	8,053	17,256
Alhambra	16.7	8.6	14,727	42,197	4.7	.24	.37	.61	1.74	7,593	21,658
c Downey	11.3	6.8	18,716	47,535	2.1	.16	.21	.71	1.81	8,398	21,409
n Riverside	5.2	5.2	11,373	33,884	0.6	.07	.13	.58	1.72	7,988	23,690
Moreno Valley	3.8	3.5	15,095	51,074	0.4	.08	.09	.61	2.07	8,464	28,721
San Diego Area											
Uptown	14.0	12.3	19,124	36,570	9.0	.50	.39	.70	1.35	8,028	15,483
Clairemont	8.8	6.2	17,558	44,210	2.4	.08	.07	.78	1.98	8,935	22,681
La Costa	2.3	4.0	26,082	63,117	.5	.03	.01	.80	1.95	11,225	27,360
Escondido	1.9	3.6	14,053	40,688	2.1	.03	.09	.60	1.75	7,438	21,695
Bos-Cr-Fl Sp-BV	2.2	2.6	13,990	38,394	.8	.04	.02	.67	1.88	7,654	21,477
Sacramento Area											
Central City	7.9	22.2	14,226	24,880	20	.17	.41	.50	.94	5,355	10,067
E Sac-n Land P	7.4	7.5	18,180	39,835	5.3	.10	.26	.64	1.43	6,452	14,417
S Sac	8.7	6.6	12,021	34,358	1.2	.13	.03	.57	1.65	6,849	19,826
Merced Co.	.1		10,606	34,197				.56	1.79	7,438	23,775

Population, Households, Income, Autos and Acres are from the 1990 U.S. Census. Household density excludes vacant residential units.

Residential Acres excludes streets. They were measured by ABAG, SCAG, SANDAG and the Sacramento Planning Department.

$$TAI = \frac{3(\text{buses both dir/day})(\text{seats/bus})(\text{\%hh to 1/4 mi}) + 3(\text{railcars both dir/day})(\text{seats/car})(\text{\%hh to 1/2 mi})}{(50 \text{ seats/std bus})(24 \text{ hr/day})}$$

NSI = fraction of hh within 1/4 mi of 5 key local commercial (market, restaurant, drugstore) establishments.

PAI = (fraction of through streets)(fraction of roadway below 5% grade).33[(fraction blocks with walks, each side) + (building entry coefficient) + fraction of streets with traffic controlled)]; Building entry coefficient = [1 if 0 - 3 ft avg. building setback from walk; 0.5 if 4 - 10 ft; 0.3 if 11 - 20 ft; 0.1 if 21 - 40 ft; 0 if > 40 ft]

VMT = Vehicle miles traveled, calculated from the California Bureau of Automotive Repair's odometer readings taken during smog-checks.

n, e, s, w, c = north, east, south, west, central

Prepared by John Holtzclaw

4. THE RESULTS OF THE ANALYSIS

Density

The communities within each of the four regions are arrayed in order of descending *net household density* in Tables 3 through 6. It is interesting to note that the San Francisco area has the broadest range of densities, including the two highest density areas and the three lowest density areas that were studied. *Population density*, which is the measure people per total acres in the community, also descends with a few interesting exceptions. With more land dedicated to administrative and commercial activities, and shorter blocks resulting in more roadspace, Central Berkeley has lower population density than Daly City. Morgan Hill and Lafayette have lower population densities than Los Altos-Los Altos Hills because they encompass more undeveloped hillsides. In Los Angeles, southwest Beverly Hills and Alhambra have higher population densities than south Long Beach and south Santa Monica because they have longer blocks (lower roadspace) and less park, commercial and industrial area. Bostonia, *et al*, in the San Diego area, includes less undeveloped area than does Escondido. Surprisingly, Central City has lower population density than South Sacramento. This is due to the concentration of offices and commercial activities in Central Sacramento and to its lower family size.

Transit, Shopping and Pedestrian Indices

In general the transit, shopping and pedestrian indices ascend with net household density: increased density correlates with better transit service, more neighborhood shopping and greater pedestrian friendliness, but there are interesting exceptions.

The *transit index* measures the hourly average number of buses within 1/4 mile, or railcars or ferries within 1/2 mile (standardized to 50 seat buses, railcars or ferries), of the average household. It ranges from 90 buses per hour in northeast San Francisco to a low of 0.4 in Moreno Valley. In the San Francisco area, rail, especially BART, dominates. All communities with more than 7 transit vehicles per hour have BART stations. Rockridge, Walnut Creek and Lafayette have much better transit service than their densities would suggest: all have BART stations. Otherwise, higher density areas have better transit except for minor exceptions. Outside the San Francisco area the only rail systems in operation in these communities in 1990 was the Sacramento light rail, operating in Central City and East Sacramento. It seems to be operating at the service levels of the buses it replaces.

The *neighborhood shopping index* measures the fraction of households with five key local commercial establishments (markets, restaurants and drugstores) within a 1/4 mile walk. This ranges from essentially every household in northeast San Francisco to no household in San Ramon. The exceptions to the rule that shopping is better in denser areas include central Berkeley where much shopping is concentrated outside the community, Daly City where shopping is concentrated in shopping centers, Morgan Hill and Los Altos which were developed earlier as towns, south Santa Monica and southwest Beverly Hills which include a larger area's shopping within them, and South Sacramento with housing located nearer to shopping than would be otherwise expected.

The *pedestrian accessibility index* measures the completeness of the pedestrian street grid (dead-end streets lengthen walking distances), hilliness, availability of sidewalks, location of building entrances close to the sidewalk rather than behind parking or lawns, and threats from nearby traffic. This ranges from .71 in southwest Beverly Hills to .01 in La Costa. The biggest surprise was Beverly Hills high measure on this variable. The area of Beverly Hills in this study is the level, denser multifamily area along upscale regional shopping streets, not the sprawling hilly residential area where nighttime pedestrians can be stopped and questioned by police (those who belong there drive, not walk). Northeast San Francisco was brought down by its hills and some intersections without 4-way stopsigns or stoplights. Daly City was lowered by its wandering street grid, lack of sidewalks, long streets with little traffic control, and buildings generally set back from the sidewalk.

Auto Ownership

It is clear from Table 4 that auto ownership decreases as density increases, as theory and previous research predict. In the San Francisco area, which offers the maximum variation in densities, the lowest auto ownership is in the densest community, northeast San Francisco, with 0.56 autos per household. The least dense area, Los Altos-Los Altos Hills, has the highest auto ownership, at 2.38 autos per household, or 4.25 times higher than northeast San Francisco. In the progression from high to low densities, the auto ownership in Daly City and Alameda stand out as higher than expected. Daly City has a BART station, but very low pedestrian accessibility and low shopping accessibility. Alameda lacks BART. All four cities below Walnut Creek in density have auto ownerships above 2 per family. Of the four, only Lafayette has BART, which may account for its slightly lower auto ownership than expected. While all four are very low density, their order changes with different measurements of density.

The range of densities between communities and auto ownerships is much narrower in Los Angeles than in San Francisco. But, again, auto ownership rises as density declines. The densest community, south Long Beach, has the lowest auto ownership at 1.29 autos per household. At the other extreme, Moreno Valley has the highest auto ownership, 2.07. In San Diego, Uptown has the highest density and lowest auto ownership. The next two densest communities, however, have slightly higher auto ownerships than would be expected from the San Francisco progression, while the last two have slightly lower auto ownerships than expected. Consequently, Clairemont and La Costa have higher auto ownerships than Escondido and Bostonia, *et al*. This deviation from expected is slight, however. In Sacramento, the progression is uniformly as predicted, with Central City at the lowest auto ownership and South Sacramento the highest.

The auto ownership for each of the counties in which the above communities are located, and a representative rural county, were calculated from 1990 census data. As with the communities themselves, the denser, more urban counties have the lowest auto ownerships. San Francisco is lowest with 1.06 autos/HH, followed by Alameda and Los Angeles counties at 1.68, Sacramento county at 1.73, and San Diego county at 1.78. Semi-rural Riverside and rural, relatively low-income Merced counties are next at 1.79 and 1.83. The highest auto ownerships are in the suburban counties San Mateo, Contra Costa and Santa Clara, at 1.90, 1.91 and 1.99. The whole state averages 1.78 autos/HH.

Robert Clear of Lawrence Berkeley Labs statistically analyzed auto ownership for the communities. For this statistical analysis, northeast San Francisco data were subtracted from that for the city as a whole ensure statistical independence of the data points. Auto ownership was tested against density, the transit (TAI), pedestrian (PAI) and shopping (NSI) indices, and family income and household size, and various power functions of these independent variables. Density and the transit, shopping and pedestrian indices are strongly correlated with each other, and we found statistically significant fits of auto ownership with them, and with household income and household size. The best simple fit was 2.704 ("0.050) times the fourth root of household density, explaining 85% of the variance:

P $\quad$ Autos/HH = 2.704 * $(\text{Density})^{-.25}$ $\quad R^2 = 0.850$

No combination of variables offered a robust fit that was much better than this simple fit. It is not clear from the limited data available whether we simply don't have enough data to see the smaller effects of the other variables, or whether density is the causative variable for the other variables. Simple fits were made to the equation $y = A + Bx$, where x is one of the independent variables, and A and B are the fitted constants. Using HH Density as x explained 60% of the variance, $(\text{TAI})^{1/2}$ explained 58%, $(\text{PAI})^{2/3}$ explained 57%, PAI explained 56%, TAI explained 55%, $(\text{NSI})^{3/4}$ explained 51%, NSI explained 51%, HH Income explained 42%, and Person/HH explained 40%.

Vehicle Miles Traveled

It is clear from Table 6 that vehicle miles traveled per household (VMT/HH) increases as household density and the transit, shopping and pedestrian indices decrease, as theory and previous research predict. In the San Francisco area, which offers the maximum variation in densities, the lowest VMT/HH is in the densest community, northeast San Francisco, with 5,519 VMT per household. The least dense area, Los Altos-Los Altos Hills, has the third highest mileage, at 26,111 VMT per household. Morgan Hill, the third least dense community has the highest mileage, at 28,436 VMT/HH, or 5.2 times higher than northeast San Francisco. These VMTs include vacation and weekend travel. If residents of all areas take similar vacations, excluding vacation travel would result in even more dramatic differences in VMT at different densities.

In the progression from high to low densities, the VMT/HH in Daly City stands out as higher than expected. Daly City has a BART station, but very low pedestrian accessibility and low shopping accessibility. Rockridge stands out with lower VMT/HH than expected; it has very good transit and pretty good shopping. Lafayette, which is the only one of the four least dense cities with BART, has lower VMT/HH than the other three. While all four are very low density, their order changes with different measurements of density.

Comparisons between similar communities can be suggestive. Daly City is similar to central Berkeley on all variables except for its much lower transit and pedestrian accessibilities.

Perhaps as a consequence, Daly City has 35% higher household auto ownership and 54% higher household VMT. Alameda's slightly lower density and lower transit accessibility ought to drive its auto use higher than Daly City's. Its pedestrian accessibility is nearly five times higher, however, so its household VMT is 12% lower. Rockridge's higher transit accessibility should decrease its relative VMT below Alameda's, but its lower pedestrian accessibility should increase it; Rockridge has 16% lower household VMT. Morgan Hill was selected for its transit oriented development (TOD)-like qualities. Although Morgan Hill has lower density than that usually planned for TODs, its shopping and pedestrian accessibilities are higher than the other three low density communities. Its household VMT is the highest of all communities, however.

The range of densities between communities and auto ownerships is much narrower in Los Angeles than in San Francisco. But, again, VMT/HH rises as density declines. The densest community, south Long Beach, has the third lowest VMT/HH at 15,252. Southwest Beverly Hills, the third densest community, with pretty good transit and shopping and the best pedestrian accessibility measured, has the lowest VMT/HH, 12,972. At the other extreme, Moreno Valley has the highest mileage, 28,712.

In San Diego, Uptown has the highest density and lowest auto mileage. The next two densest communities, however, have higher VMT/HH than would be expected from the San Francisco progression, while the last two have lower auto ownerships than expected. Consequently, Clairemont and La Costa have higher VMT/HH than Escondido and Bostonia, *et al*.

In Sacramento, the progression is uniformly as predicted, with Central City at the lowest auto mileage and South Sacramento the highest.

The auto mileage for each of the counties in which the above communities are located, and a representative rural county, were also included in Table 5. As with the communities themselves, the denser, more urban counties have the lowest auto use, and rural and suburban counties the highest. San Francisco is lowest with 11,256 VMT/HH, followed by Alameda county at 18,917 miles/HH, Los Angeles county at 19,522, Sacramento county at 19,762, San Mateo county at 20,841, San Diego county at 21,002, Santa Clara county at 22,258, and Contra Costa county at 22,611. Rural Merced and semi-rural Riverside counties are highest at 23,775 and 24,092 miles/HH. The whole state averages 21,488 VMT/HH, almost twice that of San Francisco.

The 1991 study of five San Francisco communities showed that as density doubled, VMT/HH decreased by 20 to 30 percent. Presenting the results in that form assists planners and government officials in understanding the power of density to reduce driving, and guiding development toward more efficient, pedestrian oriented communities. In this generalization, density surrogates for the other variables which co-vary with it, transit and shopping. This relationship was tested with this data for these 28 communities, with net household density surrogating for its co-variables, the transit, shopping and pedestrian indices. The data are plotted in Figure 1, along with curves representing 25% and 30% reductions in VMT/HH as density doubles, the curves drawn to intersect the data point for the highest density community, northeast San Francisco. Again, the data are fairly well fit by decreases in VMT/HH of 25 to 30 percent every time density doubles in the range of densities from 1.8 to 101 households per residential acre.

Note that there is no apparent difference between communities in northern and southern California. How do these results compare with those from cities outside California and outside the U.S.? The VMT/household and households/residential acre for 34 principal world cities (metropolitan areas) can be approximated from Newman and Kenworthy's (1989) data. Their extremely low density, low density and medium density groupings of cities fall within our range of (are predicted by our) data. These groupings consist mostly of U.S., Canadian and Australian cities. The high density and very high density groupings (European and Asian cities), however, apparently are 10% and 25% lower in VMT/household (respectively) than we would expect from our California data.

Robert Clear of Lawrence Berkeley Labs statistically analyzed VMT/auto and VMT/HH for our data. For this statistical analysis, northeast San Francisco data was subtracted from that for the whole city to improve the independence between variables. VMT/auto and VMT/HH were tested against density, the transit (TAI), pedestrian (PAI) and shopping (NSI) indices, and family income and household size, and various power functions of these independent variables.

Unlike auto ownership, VMT/auto varies over a fairly narrow range. Miles per car is weakly correlated with six of the test variables. The largest variance (R^2=0.576) correlates with the $TAI^{-0.061}$: auto use per car declines as transit service increases. An additional person in the household adds 2084 miles per car (R^2=0.419). An increase of 1.0 in the PAI decreases miles per car by 3288 (R^2=0.307): auto use per car declines as communities become more pedestrian friendly. An increase of 1.0 in the NSI decreases miles per car by 2742 (R^2=0.269): auto use per car declines as communities add neighborhood shopping. An additional auto in the household increases driving by 1703 miles per car (R^2=0.254). Finally, VMT/auto correlates with $Density^{-.064}$ (R^2=0.245): auto use per car declines as density increases. We found significant correlations against all three indices, household size, auto ownership and density. We surprisingly did not find a fit to household income.

The best fit for VMT/HH is the product of 34,270 ("2690), the fourth root of household density and $TAI^{-0.076}$, explaining 83% of the variance.

P $$VMT/HH = 34{,}270 * (Density)^{-.25} * TAI^{-.076} \quad R^2=0.830$$

With this formulation, as density doubles VMT declines by 16%, and as transit service doubles VMT declines by 5%. The next best fit was the product of the fourth root of household density and $TAI^{-0.06}$, explaining 82% of the variance. With this formulation, as density doubles VMT declines by 16%, and as transit service doubles VMT declines by 4%. Testing density alone, 77% of the variance is explained by the general formulation that doubling density reduces VMT by 20%; this correlation is included in Figure 1. And 72% of the variance is explained by the formulation that doubling density reduces VMT by 25%. These fits are relatively insensitive to whether we assume that the uncertainties for the values of the data points are equal or are proportional to the square-roots of their values.

While neighborhood shopping and pedestrian accessibility were not statistically significant predictors of household VMT, their correlations with auto ownership and VMT per auto suggest that they influence auto use and might prove significant predictors of household VMT when tested against a larger data set.

One startling observation from this analysis is how poorly household income predicts auto ownership or VMT. Some observers have tried to assign most of the variations in driving to income. While income extremes were avoided in selecting these communities, the income variation of $28,000 to $119,000 should have been sufficient to identify such an effect if it were strong. These data did not find one.

5. PREDICTING ANNUAL AUTO COSTS

The information is now available to predict the variation of average annual household auto costs from the neighborhood's density and transit service. The density and transit service correlations,

- Autos/HH = 2.704 * $(\text{Density})^{-.25}$ and
- VMT/HH = 34,270 * $(\text{Density})^{-.25}$ * $\text{TAI}^{-.076}$,

are used to predict the auto ownership and annual vehicle miles traveled (VMT) per household. The variation of predicted VMT/HH is shown in Table 7.

The average costs of owning and operating an automobile, calculated by the Federal Highway Administration *(1991*), are $2,203/auto annually and $0.127/mile. The predicted annual household auto costs are:

- HH auto costs/year = \$2,203 * 2.704 * $(\text{Density})^{-.25}$
  + \$0.127 * 34,270 * $(\text{Density})^{-.25}$ * $\text{TAI}^{-.076}$

The variation in annual auto costs is shown in Table 8.

The annual household auto costs equation provides the basis for predicting transportation savings accruing to a homebuyer. Predicted average annual household transportation cost savings for a particular dwelling unit are calculated as follows:

- 1) Calculate the average household density (households per residential acre) for the census tract in which the dwelling unit is located by using the enumerated households for the tract, and the acres of residential land measured by the local planning department or regional planning agency.
- 2) Calculate the transit service by identifying each bus line within 1/4 mile walking distance of the dwelling unit and each passenger rail stop or ferry terminal within 1/2 mile of the dwelling unit. For each line within the prescribed distance, calculate the daily number of buses, rail vehicles or ferries on these lines (in both directions) using transit schedules. "Standardize" these vehicles by multiplying the number of vehicles by (# seats on the average transit vehicle)/50 seats. Divide this by 24 hours per day to get the transit service.
- 3) Look up the average annual household auto costs in Table 8. Values for units with densities or transit service falling between those shown on Table 8 can be calculated by interpolation (see examples below). Alternatively, the predicted annual auto costs can be calculated using the above equation.
- 4) Subtract the predicted annual auto costs from those for the typical suburban area used as the loan standard.
- 5) Add up the average annual transit costs for all public transit within the city (average annual transit farebox revenues divided by the city's households). Subtract the corresponding "average annual transit costs" for the "typical suburban area" from this. Subtract this transit cost difference from the annual auto savings to get the annual household transportation cost savings.
- 6) Divide the results by 12 months and add to the standard PITI (principal, interest, taxes and insurance) mortgage qualification formula.

Table 7
Predicted Annual Vehicle Miles Traveled/Household

Density Census Tract HH/Res Ac	Public Transit Service 50 Seat Vehicles Per Hour Within 1/4 Mi (1/2 Mi For Rail & Ferries); 24 Hr Avg											
	1000	500	100	50	30	20	10	5	3	2	1	.5
1000	3,605	3,800	4,295	4,527	4,706	4,853	5,116	5,393	5,606	5,781	6,094	6,424
500	4,287	4,519	5,107	5,383	5,596	5,772	6,084	6,413	6,667	6,875	7,247	7,639
100	6,411	6,758	7,637	8,050	8,369	8,630	9,097	9,589	9,969	10,028	10,837	11,423
50	7,624	8,036	9,082	9,573	9,952	10,263	10,819	11,404	11,855	12,226	12,888	13,585
30	8,666	9,131	10,319	10,877	11,308	11,662	12,292	12,957	13,470	13,892	14,643	15,435
20	9,586	10,105	11,420	12,037	12,514	12,906	13,604	14,340	14,907	15,374	16,205	17,082
10	11,400	12,017	13,580	14,315	14,882	15,347	16,178	17,053	17,728	18,283	19,271	20,304
5	13,557	14,291	16,150	17,024	17,697	18,251	19,239	20,279	21,082	21,742	22,918	24,157
3	15,404	16,237	18,350	19,342	20,108	20,737	21,859	23,042	23,954	24,703	26,040	27,448
2	17,047	17,969	20,308	21,406	22,253	22,950	24,191	25,500	26,509	27,339	28,818	30,376

Annual VMT/HH = 34,270 * $(\text{Density})^{-.25}$ * $(\text{TAI})^{-.076}$

Prepared by John Holtzclaw

Table 8
Predicted Annual Household Auto Expenses -- Ownership & VMT
Dollars

Density Census Tract HH/Res Ac	Public Transit Service 50 Seat Vehicles Per Hour Within 1/4 Mi (1/2 Mi For Rail & Ferries); 24 Hr Avg											
	1000	500	100	50	30	20	10	5	3	2	1	.5
1000	1,517	1,542	1,605	1,634	1,657	1,676	1,709	1,744	1,771	1,794	1,833	1,875
500	1,804	1,834	1,908	1,943	1,970	1,993	2,032	2,074	2,106	2,133	2,180	2,230
100	2,698	2,742	2,854	2,906	2,947	2,980	3,039	3,102	3,150	3,157	3,260	3,334
50	3,206	3,261	3,394	3,456	3,504	3,544	3,614	3,688	3,746	3,793	3,877	3,965
30	3,646	3,705	3,856	3,927	3,981	4,026	4,106	4,191	4,256	4,310	4,382	4,506
20	4,034	4,100	4,267	4,346	4,406	4,456	4,545	4,638	4,710	4,769	4,875	4,986
10	4,798	4,876	5,075	5,168	5,240	5,299	5,404	5,516	5,601	5,672	5,797	5,928
5	5,705	5,799	6,035	6,146	6,231	6,302	6,427	6,559	6,661	6,745	6,894	7,052
3	6,483	6,588	6,857	6,983	7,080	7,160	7,302	7,453	7,568	7,664	7,833	8,012
2	7,174	7,291	7,588	7,728	7,835	7,924	8,081	8,248	8,376	8,481	8,669	8,867

Auto Ownership = 2.704 * $(\text{Density})^{-.25}$
Annual VMT/HH = 34,270 * $(\text{Density})^{-.25}$ * $(\text{TAI})^{-.076}$
Average auto costs = $2,203/auto + $0.127/mile, based on keeping new car for 12 years and driving it 128,500 miles, *Cost of Owning and Operating Automobiles, Vans and Light Trucks, 1991*, Federal Highway Administration
The communities studdied fall within the cells blocked off with dotted lines.

Let's apply the methodology to some known communities to calculate their predicted auto savings (steps 1 - 4).

- San Ramon: density of 3.2 hh/res ac, and 1.0 transit vehicles/hr. At 1 veh/hr and a density of 3 HH/res ac, the predicted annual expenditure is $7,833. This is $369 under the $8,202 annual costs calculated from its known auto ownership and VMT/HH (table 6). San Ramon's auto costs are underestimated.

  Holtzclaw (1991) estimated Danville-San Ramon BART ridership at 500 passenger-miles per household. BART estimates fares to average 12 cents per mile. So San Ramon's average household transit costs are $60 per year, or $5 per month.
- northeast San Francisco: density of 101 hh/res acre, and 90 std transit vehicles/hour. With a density of 100, interpolating between transit services of 100 and 50, the annual household auto savings are predicted to be $2,854 + $(2,906 - 2,854)10/50 = $2,864. We measured northeast San Francisco's autos/HH at .56, however, somewhat below the .85 predicted by the equation. Likewise, we measured its VMT/HH at 5,519, somewhat below the 7,720 that the equation predicts (Table 7). Using the measured auto ownership and VMT/HH (table 6), the annual HH auto costs are $1,935. The equation overpredicts the annual costs of these households by $929, and so is quite conservative here.

1989-90, Muni collected $76,700,000 in fares, giving an household average of $251/year (S.F. Muni, 1991). Holtzclaw (1991) found San Francisco households averaging 343 passenger-miles per household, equal to $41/year. Adding Muni to BART costs gives average household costs of $292/year.

If we take San Ramon as our typical suburban area, the predicted annual HH auto cost savings would be $4,969, or $414/mo. Using measured auto ownership and VMT/HH (table 6) for northeast San Francisco and San Ramon, however, the actual annual savings for northeast San Francisco compared to San Ramon is $6,267. So the equation is conservative by $1,298 ($108/mo) in predicting the annual savings accruing to the average homeowner in northeast San Francisco. When we include transit costs, the San Francisco family is predicted to save $4,677/year, or $390/mo.

- San Francisco: density of 48 hh/res ac, and 70 std transit vehicles/hr. Assuming a density of 50, and interpolating between transit services of 100 and 50, the annual household auto costs are predicted to be $3,394 + $(3,456 - 3,394)30/50 = $3,431. We measured San Francisco at 1.06 autos/HH and 11,256 VMT/HH, for annual HH auto costs of $3,765, exceeding the predicted costs by $334.

Again, if we take San Ramon as our typical suburban area, the predicted annual HH auto cost savings would be $4,402, or $367/mo. Using measured auto ownership and VMT/HH for San Francisco and San Ramon, however, the actual annual savings for San Francisco compared to San Ramon is $4,437. So the equation is conservative by $35 in predicting the annual auto savings accruing to the average homeowner in San Francisco. When we include transit costs, the San Francisco family is predicted to save $4,110/year, or $342/mo.

APPENDIX

DETAILED DESCRIPTION OF COMMUNITIES

San Francisco Area Communities

The **northeast San Francisco** Nob, Russian and Telegraph Hills, Chinatown, North Beach and Fisherman's Wharf community is the highest density area within the San Francisco region. It is a primary tourist attraction known for its charm, beauty and activity. It consists primarily of 2 to 4 story apartment/condo buildings with occasional concentrations of mid and high rise buildings. Most of its households are small or single workers, but it also includes larger and extended families. While mostly middle class, its residents range from low income to the wealthy inhabiting some hilltop homes. Local serving businesses are concentrated in centers such as Chinatown, North Beach and Fishermans Wharf, but most blocks have at least one market, restaurant or laundry. The community is crossed by 18 frequent service bus and trolley routes and 3 cable car lines, has one ferry terminal and close access to the transit systems serving downtown, including regional ferries and buses, BART, Muni Metro light rail and the peninsula commuter trains. In short, it has the best transit access in the region, and is within easy walking distance of the downtown business and commercial center. Sidewalks are ubiquitous and most buildings front on them with no setbacks. The streets are developed in a regular grid pattern, but some are steep or discontinuous at hillsides. The only other impediment to pedestrians is traffic at the minority of intersections without stoplights or 4-way stopsigns. This area was included in the 1991 study.

San Francisco is a compact city with high average residential density and neighborhood shopping for an American city, while only medium to low density compared to major European and Asian cities. It contains a rich mixture of residential densities. All family sizes from single workers to large families are well represented. It is one of the most ethnically and racially diverse cities in the country, with a slight majority of whites, and strong minorities of Asians, Hispanics and blacks. It is middle class, but its residents range from poor to wealthy. Corner markets, restaurants and shopping streets are common in the older neighborhoods. Most commercial buildings front onto the sidewalk, rather than be set back behind parking, and older residential areas have no building setback, while most newer residences are set back 5 to 20 feet. The regular street grid is broken only by curving streets on newly developed hills, and by 15 miles of freeways. Sidewalks are nearly ubiquitous, but steep roads on hillsides, and intersections lacking stoplights or 4-way stopsigns to increase pedestrian safety, are impediments to walking. Most of San Francisco is well served by transit, with 5 Muni Metro light rail lines; 58 local bus and trolley lines; 3 cable car lines; BART to Alameda and Contra Costa counties to the east and southwest to San Mateo county; the Caltrain peninsula commuter service to San Mateo and Santa Clara counties to the southeast; long haul intercity buses southeast to San Mateo and Santa Clara counties, to Alameda and Contra Costa counties across the bay to the east and to Marin and Sonoma counties across the Golden Gate to the north; ferries to Alameda, Contra Costa and Marin counties and Amtrak connections to the rest of the state and beyond. This high density and excellent transit service results partially from San

Francisco's small geographical size for a major American city and location at the center of the country's fourth most populous region. Consequently it is included here, and was included in the 1991 study, for comparison with the smaller communities studied.

Central Berkeley, across the bay from San Francisco in Alameda county, is in the flatlands west of the University of California. It includes part of the north, west and south Berkeley, and westbrae neighborhoods. It is a racially diverse, middle class community, about half white, with large black and smaller Asian and Hispanic minorities. A large student population brings the average income down somewhat. The housing is primarily pre-WW2, much of it pre-WW1, and is a medium density mix of single family units and apartments throughout, with over half the households renting. Most neighborhood shopping lies along major arterials. The road grid is not broken by dead-end streets or *cul de sacs* hindering pedestrians and bicycles, although many intersections in residential areas have auto barriers or diverters to prevent through auto traffic. With sidewalks throughout, the only measured pedestrian impediments are the buildings set back from the sidewalk and the majority of intersections that are not controlled by stoplights or 4-way stopsigns. The area has two BART stations and is two blocks from a third, and is crossed by 16 AC Transit bus routes.

Daly City borders San Francisco to the south, along the ocean. It is a close-in suburban middle class community. It is primarily white and Asian (mostly Filipino), but also containing substantial Hispanic and black populations. Most housing is post-WW2 single family, almost row housing, with many secondary or in-law units, along curvy rolling hill roads, but with pockets of apartments especially near freeway exits and shopping centers, to bring the average up to medium density. Neighborhood shopping is concentrated in shopping centers near freeway exits or the intersections of major roads. Pedestrian impediments include areas isolated behind 3 freeways, the mostly curvy and dead-end streets and buildings set back from the sidewalk, all increasing trip lengths, and the hills. The many intersections not controlled by stoplights or 4-way stopsigns, and the long, often steep and curvy, blocks encourage high auto speeds, threatening pedestrian safety. The community is served by a BART station, which dominates transit service, 15 SamTrans bus routes, and one San Francisco Muni bus route.

Alameda is an island nestled against the Oakland waterfront south of the Bay Bridge, and includes the northern tip of the peninsula containing the Oakland Airport. Alameda Naval Air Station occupies the northern third of the island. The city's population is predominantly middle-class and white, but has sizeable Asian and smaller black populations. Most of the housing on the island is pre-WW2, with much of it pre-WW1. Most of the housing on the peninsula, one-fifth of the city's total housing, was developed recently. The housing is of medium density, higher on the island than on the peninsula. Neighborhood shopping is concentrated along two major cross streets on the island and in a center on the peninsula. Pedestrian impediments include a curvy road pattern and many dead-end streets on the peninsula and some on the island and buildings generally set back from the sidewalk, all of which lengthen pedestrian trips, and only a minority of intersections with stoplights or 4-way stopsigns to slow auto traffic and increase pedestrian safety. The city is served by 7 AC Transit bus routes.

The **Rockridge** area of north Oakland and south Berkeley, between Central Berkeley and Alameda, is of low to medium residential density. It covers the lowlands south of the University of California, extending into the residential hills, and consists primarily of single family dwellings, with apartment houses and neighborhood shopping along major streets, primarily in the lowlands. Many single workers and students live among the families. It is primarily middle class, but with some low income in the lowlands and some wealthy on the hillsides. It is primarily white, with minority Asians, blacks and Hispanics. The regular street grid pattern is broken in the hills and adjacent to freeways, lengthening walking distances. Other impediments to pedestrians include steep grades and missing sidewalks in the hills, residential buildings set back from the sidewalk, and pedestrian hazards from the high traffic speeds at the many uncontrolled intersections. It is crossed by BART, with a station at its center, and 11 AC Transit bus routes, including the major routes between the Berkeley and Oakland downtowns. A larger Rockridge area was included in the 1991 study.

Walnut Creek is a low density suburban Contra Costa county community 10 miles east of Oakland-Berkeley, across the Berkeley Hills. It has grown rapidly since the completion of the Caldecot Tunnel through the Berkeley Hills and the Route 24 freeway in 1959. Since the completion of BART in 1975, industrial park style industry, a shopping center and a two story or higher residential area have developed around the large BART parking lot. Its residents consist primarily of nuclear families and single workers. While its older areas retain some low income residents, its newer areas house the middle and upper income. Largely white, it has small Asian and Hispanic minorities. Most neighborhood shopping is clustered in the central area near BART, and at the intersections of major roads. Pedestrian impediments include an irregular street pattern and buildings set back from the sidewalks which lengthen walking distances, missing sidewalks and the high traffic speed at the many intersections without stoplights or 4-way stops. It has 8 bus routes serving the BART station and the city. A larger section of Walnut Creek was in the 1991 study.

San Ramon lies 10 miles south of Walnut Creek, covering the valley and hills in southern Contra Costa County, just north of Pleasanton, in Alameda county. The area has grown rapidly since the completion of the Route 680 freeway in 1967. It is a classical sprawling suburban bedroom community, consisting mostly of single family housing, with neighborhood shopping located primarily along the old main road, Route 21, paralleling the freeway. While some low income remain in older housing, the area is primarily middle income with some wealthy housing enclaves. Largely white, it has a small Asian and Hispanic minorities. One County Connection and one BART Express bus route along this road serves the Walnut Creek BART station and connects to Dublin in Alameda county. Neighborhood shopping is clustered away from residential areas. Pedestrian impediments include an irregular and broken street grid and buildings set back from the sidewalks, which increase walking distances. The many missing sidewalks and the high traffic speeds at the many intersections lacking stoplights or 4-way stops increase pedestrian hazards. It was aggregated with Danville in the 1991 study.

Morgan Hill is an older low density California farming town 20 miles south of downtown San Jose on Highway 101 that has experienced substantial growth as a middle to upper-middle class bedroom community in recent years. This predominantly white community contains a substantial Hispanic minority. Residences are low to medium density, extending across the valley and into the low hills on both sides. Neighborhood shopping is concentrated along the old highway and in two shopping centers. Impediments to pedestrians include curving and dead-end streets, especially in the newly developed areas, and buildings set back from the sidewalk, all of which increase pedestrian trip lengths. The streets without sidewalks and the majority of intersections which have no stoplights or 4-way stopsigns to moderate traffic speeds lower pedestrian safety. Five Santa Clara County Transit bus routes serve the city.

Lafayette is a suburban community adjacent to and just west of Walnut Creek in Contra Costa County. Lying primarily in rolling wooded hills, Lafayette is split by the Route 24 freeway from Oakland to Walnut Creek and beyond, and has a BART station adjacent to the freeway. Largely white, it has small Asian and Hispanic minorities. This middle to upper middle class neighborhood is low density single family except for a few apartments near the freeway and the BART station. Almost all neighborhood shopping lies along the south side of the freeway near BART. Pedestrian impediments include a winding road pattern and buildings set back from the sidewalks, substantially lengthening walking distances, and hills. The area's paucity of sidewalks, combined with high auto speeds resulting from a paucity of stoplights or 4-way stopsigns and long residential blocks, threaten pedestrian safety. The area has 3 County Connection bus routes, but public transit service is dominated by BART, which provides 96 percent of transit accessibility. While BART provides excellent transit to the nearby area, public transit in the rest of Lafayette is almost non-existent.

Los Altos-Los Altos Hills is a very low density upper middle class community southeast of Palo Alto and ten miles west of San Jose, in western Santa Clara Valley (Los Altos) and into the foothills (Los Altos Hills). Largely white, it has an Asian minority. Most housing is post-WW2, and single-family except for some multi-family near downtown Los Altos and near El Camino Real. Neighborhood shopping is concentrated in downtown Los Altos and along El Camino Real and Foothill Expressway. Los Altos Hills allows no multi-family housing or local commerce: the ultimate bedroom suburb. Pedestrian impediments include the lack of a regular street grid in much of Los Altos and all of Los Altos Hills, with resulting curvy dead-end streets that increase pedestrian trip lengths. The predominant large set back of residential buildings from sidewalks further increases pedestrian distances. The hills discourage walking. The lack of sidewalks, especially in Los Altos Hills, and the minority of intersections with stoplights or 4-way stopsigns to slow traffic decrease pedestrian safety. Only six bus routes serve the community.

Los Angeles Area Communities

The southern portion of **Long Beach** is about 20 miles south of downtown Los Angeles, along the ocean. This older, medium to high density, area is one of the densest, most pedestrian oriented communities in the Los Angeles area. It is an ethnically and racially diverse lower-middle income urban community with many apartment houses. Hispanics, whites, Asian and blacks are well represented. Medium to high density housing is widespread throughout the community, with high-rises along Ocean Boulevard and Alamitos Ave. Neighborhood shopping is well distributed along major streets. Pedestrians are encouraged by the regular and complete street grid, with little area cut off from commerce by freeways, minimal hills and ubiquitous sidewalks. Pedestrian impediments include buildings set back from sidewalks, increasing walking distances, and high traffic speeds encouraged by the minority of intersections without stoplights or 4-way stopsigns. The community is served by 32 Long Beach Transit bus routes, 3 Rapid Transit District bus routes and an Orange County bus line.

Southern Santa Monica is a traditional, medium density middle class area 15 miles west of downtown Los Angeles along the ocean. The predominantly white population contains Hispanic, Asian and black minorities. Most of the higher density housing, including a few high-rises fronts the ocean. Neighborhood shopping is concentrated in downtown and along seven arterials. The community is split by the Santa Monica Freeway, although the area one long block each side of the freeway northeast of Lincoln Boulevard is not within the study area. Pedestrians are encouraged by the regular street grid and ubiquitous sidewalks. Pedestrian impediments include some steep streets, increased walking distances from buildings set back from the sidewalk, and high traffic speeds encouraged by the majority of intersections without stoplights or 4-way stopsigns. The community is served by 8 Santa Monica Transit bus routes and 5 Rapid Transit District bus routes.

Southwestern Beverly Hills is a low to medium density, middle class community 6 miles west of downtown Los Angeles. It is predominately white, with small Asian and Hispanic minorities. Neighborhood businesses are located along Santa Monica and Wilshire Boulevards and Beverly Drive, with some along Olympic Boulevard. Adjacent to the commerce are three- and four-story apartments, transitioning through two-story apartments to single-family housing. Most of its housing was build between the world wars. Pedestrians are encouraged by the regular street grid, lack of hills and ubiquitous sidewalks. Pedestrian impediments include buildings moderately set back from the sidewalks, increasing walking distances, and high traffic speeds encouraged by long north-south blocks and the minority of intersections without stoplights or 4-way stopsigns. Overall, this area had the best pedestrian accessibility of any community studied. It is served by 3 Santa Monica Transit bus routes and 5 Rapid Transit District bus routes.

South central Pasadena is 9 miles northeast of downtown Los Angeles. It is a low to medium density area of pre-WW2 houses and apartment houses, with some newer apartment houses. The higher density housing is located along Colorado Boulevard and Foothill Freeway, with a lesser concentration along Marengo Ave. This middle-class majority white area has substantial minorities of Hispanics, blacks and Asian. Neighborhood shopping is spread along Colorado Boulevard and Walnut Street, with a smaller concentration along Lake Avenue. Pedestrians are encouraged by the lack of hills and sidewalks throughout. Pedestrian impediments include some curvy roads and dead-end roads at the freeway and buildings set back from the sidewalk, all of which lengthen walking trips. Walking is further discouraged by the high traffic speeds accompanying the lack of stoplights and 4-way stopsigns at most intersections. The community is served by 11 Rapid Transit District routes and 1 Los Angeles County Transit route.

Alhambra is 6 miles east of downtown Los Angeles. This ethnically and racially diverse, low to medium density, middle class area is predominantly Asian and Hispanic, with a large white minority and a smaller black minority. Most multi-family housing is in the northern half of the city. The southern area is cut by the San Bernardino Freeway. Neighborhood shopping is concentrated in the older downtown and a regional shopping center, and along North Main Street and Valley Boulevard. Pedestrian impediments include areas with curvy and dead-end streets, including streets cut by the freeway and Mission Road, and buildings set well back from the sidewalks, all of which increase walking distances. Walking is further discouraged by the minority of streets without sidewalks and high traffic speeds accompanying the long blocks and the lack of stoplights and 4-way stopsigns at many intersections. The community is served by 13 Rapid Transit District bus routes.

Central Downey is 10 miles southeast of downtown Los Angeles. This low density, middle class, integrated community has a majority white population with sizeable Hispanic and smaller Asian populations. Much of the housing predates WW2, with the medium density areas nearer town center and lower density toward the east and west. Neighborhood shopping occurs along Firestone and Paramount Boulevards, Florence Avenue and in Stonewood Shopping Center. Pedestrian impediments include a broken street grid with many dead-end streets, and buildings set well back from sidewalks, all of which increase walking distances. The majority of blocks without sidewalks and high traffic speeds accompanying the long blocks and the lack of stoplights and 4-way stopsigns at most intersections are pedestrian hazards. The community is served by 6 Rapid Transit District bus routes.

Northern Riverside is in a desert valley 50 miles east of downtown Los Angeles. This racially and ethnically diverse, lower-middle income community has a slight majority of whites, with a large minority of Hispanics, many blacks and some Asians. Averaging low density with medium density areas nearer downtown, it has recently experienced low density growth around its edges. Neighborhood shopping is concentrated downtown, with some along North Main Street and off of Interstate 215. Pedestrian impediments include a broken street grid with many dead-end streets, especially adjacent to the two freeways bisecting the community, and buildings set back from sidewalks, all of which increase walking distances. The minority of blocks without sidewalks and high traffic speeds accompanying both the long blocks and the absence of stoplights and 4-way stopsigns at most intersections hazard pedestrian safety. The community is served by 9 Riverside Transit Agency bus routes.

Moreno Valley is a sprawling, rapidly growing, middle income desert valley community just east of Riverside. It is racially and ethnically diverse, with a slight majority of whites, but with a large Hispanic minority, and sizeable minorities of blacks and Asians. Neighborhood commerce is concentrated along Sunnymead Boulevard, just south of Freeway 60 which splits the community, and on Alessandro and Perris Boulevards and Heathcock Street. Pedestrian impediments include a broken and curvy street grid with many dead-end streets, especially adjacent to the freeway, and buildings set back from sidewalks, all of which increase walking distances. The minority of blocks without sidewalks and high traffic speeds accompanying both the long blocks and the absence of stoplights and 4-way stopsigns at most intersections hazard pedestrian safety. The community is served by 3 Riverside Transit Agency bus routes.

San Diego Area Communities

Uptown, which includes the neighborhoods of Mission Hills and Hillcrest, is a medium density community within the City of San Diego. The community is centrally located just north of downtown and northwest of Balboa Park. It is one of the oldest areas in San Diego, with many houses built between the World Wars. The housing is mostly a mix of older single family units, including some mansions and California-style bungalows, and newer multifamily units. The area is known for its character and sense of urban style. The residents include families and young singles, as well as many senior citizens. It is a middle class, predominantly white community, with minorities of Hispanics, blacks and Asians. Neighborhood shopping is spread along major arterials, especially Fifth, University, El Cajon and Adams Avenues, Park Boulevard, and Washington and India Streets. Pedestrian impediments include breaks in the regular street grid at freeways, dead-end streets and canyons, and buildings set back from the sidewalk, both of which lengthen walking distances. The high traffic speeds accompanying the absence of stoplights and 4-way stopsigns at most intersections hazard pedestrian safety. The community is served by 14 San Diego Transit bus routes.

Clairemont is on a mesa cut with canyons 5 miles north of Uptown, in San Diego. This middle income community is predominantly white with Hispanic and Asian minorities. This low density post-WW2 suburban community is mostly single family. Most neighborhood shopping is concentrated in two shopping centers and along Clairemont Drive and Clairemont Mesa Boulevard. Pedestrian impediments include a broken and curvy street grid with many dead-end streets, especially adjacent to canyons and freeways, and buildings set back from sidewalks, both of which substantially increase walking distances. The high traffic speeds accompanying the long blocks and the lack of stoplights and 4-way stopsigns at most intersections compromises pedestrian safety. The community is served by 6 San Diego Transit bus routes.

La Costa is a growing, low density bedroom community in the southeast corner of the City of Carlsbad, about 2 miles inland and 27 miles north of downtown San Diego. This upper-middle income community is predominantly white, with small Hispanic and Asian minorities. The community surrounds the La Costa Resort. Residential construction began in the 1970s, with a mix of upscale tract homes, condominiums and custom homes on large lots. Neighborhood shopping is concentrated in shopping centers along Interstate 5 and El Camino Real. Pedestrian impediments include a curvy streets with many dead-end streets, especially adjacent to canyons and the freeway, and buildings set well back from sidewalks, all of which substantially increase walking distances. The streets without sidewalks and high traffic speeds accompanying both the long blocks and the absence of stoplights and 4-way stopsigns at most intersections compromises pedestrian safety. The community is served by 5 North County Transit District and 1 San Diego County Transit bus routes.

Escondido, a low density, middle class community 25 miles north of downtown San Diego is located in an inland valley surrounded by hills. Incorporated in 1888, Escondido first developed as an agricultural community, but since the 1960's has experienced rapid industrial development and suburban sprawl. It has a large Hispanic minority and smaller Asian minority. The pre-WW1 town homes and farm houses have been joined by post-WW2 ranch-style homes and newer housing tracts and downtown multifamily housing. Neighborhood shopping is concentrated along Valley and Centre City Parkways, downtown and just off Interstate 15. Pedestrian impediments include an incomplete street grid with many dead-end streets, especially adjacent to the freeway and in the hillsides, and buildings set back from sidewalks, all of which substantially increase walking distances. The hilly streets discourage walking. The streets without sidewalks and high traffic speeds accompanying both the long blocks and the absence of stoplights and 4-way stopsigns at most intersections compromise pedestrian safety. The community is served by 7 North County Transit District, 3 San Diego County Transit and 1 San Diego Transit bus routes.

Bostonia, Crest, Flinn Springs and Blossom Valley is a sprawling middle class suburban/rural area 15 miles northeast of downtown San Diego in the desert and desert hills. The area is predominantly white, with a substantial Hispanic minority and smaller Asian and black minorities. The only multifamily housing is in Bostonia, just northeast of El Cajon, and along the Olde Highway. Neighborhood shopping is in shopping centers outside the area and along Broadway, Second and Main Streets and the Olde Highway. The area is bordered by or split by two freeways, Highway 67 and Interstate 8. Pedestrian impediments include curvy streets, an incomplete street grid with many dead-end streets, especially adjacent to the freeways and in the hills, and buildings set back from sidewalks, all of which substantially increase walking distances. The hilly streets discourage walking. The streets without sidewalks and high traffic speeds accompanying both the long blocks and the absence of stoplights and 4-way stopsigns at most intersections threaten pedestrian safety. The community is served by 7 San Diego County Transit and 2 San Diego Transit bus routes.

Sacramento Communities

The **Central City** area of Sacramento is the most densely developed community in the Sacramento area. This older, essentially built out, middle class area contains the city's central business district and state government offices on the west side, a large industrial area on the north along the American River, and a majority of residences in the eastern half. It is cut by three freeways near its west, south and east borders. Its lower-middle class population is primarily white with substantial Hispanic and black and smaller Asian minorities. Neighborhood shopping is concentrated along J, K, L, 12, 21 and 30 Streets, Alhambra Boulevard and Broadway. Much of the housing predates WW1, while many apartment houses are post-WW2. Pedestrians benefit from few steep streets, ubiquitous sidewalks and a complete street grid, except where the freeways isolate areas from shopping. Pedestrian impediments include buildings set back from the sidewalk, and the danger represented by the high traffic speeds accompanying the lack of stoplights or 4-way stopsigns on many intersections. The community is served by 28 Sacramento Regional Transit bus routes and a light rail route.

East Sacramento and north Land Park are two similar nearby but not contiguous areas which were aggregated in order to expand the pool of vehicle data. East Sacramento is just east of Central City, extending to California State University. North Land Park is just south of Central City, extending to William Land Park. Their middle class population is primarily white with substantial Asian and smaller Hispanic and black minorities. Housing is primarily single family built between the wars and right after WW2. The area is essentially built out. Neighborhood shopping is located primarily along H and J Streets, Elvas Avenue, and Alhambra and Folsom Boulevards in East Sacramento, and along Riverside Boulevard in north Land Park.

The area is flat and most streets have sidewalks. Pedestrian impediments include a street grid interrupted by curvy streets and railroad tracks, with many dead-end streets, and buildings set well back from sidewalks, all of which substantially increase walking distances. The high traffic speeds accompanying the lack of stoplights and 4-way stopsigns at most intersections threaten pedestrian safety. The community is served by 15 Sacramento Regional Transit bus routes and a light rail route through East Sacramento.

South Sacramento is a rapidly developing low density middle class bedroom community between the Union Pacific Tracks and Highway 99. Its population is majority white with large black and substantial Hispanic and Asian minorities. Neighborhood shopping is concentrated along Florin and Mack Roads, and just off Highway 99. Pedestrian impediments include curvy streets, an incomplete street grid with many dead-end streets, especially adjacent to the freeway, railroad tracks and Morrison and Elder Creeks, and buildings set well back from sidewalks, all of which substantially increase walking distances. The streets without sidewalks and high traffic speeds accompanying both the long blocks and the lack of stoplights and 4-way stopsigns at most intersections threaten pedestrian safety. The area is served by 10 Sacramento Regional Transit bus routes.

The rural San Joaquin Valley county of **Merced** was included for comparison to the urban and suburban areas analyzed. Its largest town is Merced, and second largest is Los Banos. Its population is primarily white with a large Hispanic minority and much smaller Asian and black minorities. It is a middle class farming area with some giant corporate farms and farmworkers.

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