Smart Growth -- As Seen From the Air

Convenient Neighborhood, Skip the Car

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ABSTRACT

The design of our urban areas and their transportation systems strongly influences emissions of urban air pollutants. Smart Growth can increase neighborhood convenience, consequently reducing driving to one-fourth or less, by:

- increasing neighborhood density to raise the number of nearby destinations,
- including markets, restaurants and other commerce and services in residential neighborhoods (mixed-use),
- locating neighborhoods close to job centers,
- providing safe, attractive and convenient pedestrian and bicycle conditions,
- limiting parking, and
- providing frequent, convenient, affordable and safe public transit.

Such neighborhoods encourage walking, bicycling and use of transit for most trips. Equations developed from research using all these variables except parking in the Chicago, Los Angeles and San Francisco regions predicts 79 to 96% of the variance in auto ownership and 80 to 94% of the variance in driving (vehicle miles traveled -- VMT) for neighborhoods within those regions. Residential density is the most effective urban variable in predicting auto ownership and driving. The next most effective variable is the amount of nearby public transit. Finally comes pedestrian and bicycle friendliness, including the fineness of the street grid, provision of public sidewalks and weather protection, location of buildings close to the sidewalk rather than behind parking lots, and traffic safety. Center proximity slightly improved the prediction of VMT in the San Francisco area, the only area where data was available. We had no measure of the amount of private and public parking by neighborhood. The success of these neighborhoods in attracting and retaining residents also depends upon:

- nearby parks, creeks, recreation areas, and other open spaces and wildlife habitat,
- attractive, quality architecture of the neighborhood and buildings,
- quality construction, built to last much longer than housing or shopping centers located in sprawl.

INTRODUCTION

Motor Vehicle Pollution

Motor vehicles are the single largest source of urban air pollution and a major source of water pollution. In the San Francisco Bay Area, for instance, on-road vehicles emit 49% of the reactive organic gases[1], 52% of the nitrogen oxides[1] and 69% of carbon monoxide [2]. In Los Angeles, motor vehicles and their fuels account for about 90% of the cancer risk[3]. These toxins, along with dumped motor oils, wash into our streams and bays, becoming major water pollutants.

Nevertheless, U.S. vehicle miles traveled (VMT) grew at well over 3 percent per year during the 1980s, and is forecast to increase another 25 percent per capita between 1990 and 2010.[4, 5] What drove this growth and what can be done to rein it in? These questions have stimulated vigorous discussions in the transportation community.

Research on How Urban Design Impacts VMT

How does sprawl drive up VMT? Low density areas are designed to force residents to drive for most trips. Their zoning requires front and side yard setbacks, wide streets and two or more off-street parking places, reducing densities and separating destinations. Many suburbs prohibit sidewalks and convenient nearby markets, restaurants and other commerce. These government mandates force destinations farther apart, lengthening trips to where non-automotive modes become less viable.

Contrast this with traditional cities which grew up around pedestrians, allowing residents to walk, bicycle or take transit to jobs, corner markets and other nearby commerce. They have relatively high densities: ranging from row houses on narrow lots through 3 to 4 story walk-ups to high-rise elevator apartments, condos and co-ops--at 20 to 200 households/residential acre. They are proximate to major job and shopping centers, but have their own local shopping and services, and sidewalks and other amenities to encourage walking. They have excellent access to transit. They were so complete that many residents seldom left them. These areas are now the central and adjacent areas of our older cities and some of the older suburbs. Smart growth replicates traditional city form.

But can we measure the reductions in driving sufficient to provide reproducible emission credits to smart growth? Some progress is evident.

In a survey of 32 major cities around the world, Peter Newman and Jeffrey Kenworthy found that the residents of American cities consumed nearly twice as much gasoline per capita as Australians, nearly four times as much as the more compact European cities and ten times that of three compact westernized Asian cities, Hong Kong, Singapore and Tokyo.[6] However, they lacked measurements of VMT, or data for neighborhoods rather than whole metropolitan areas, split into central cities and suburbs. Their data suggest that driving is reduced 30 percent every time density doubles. If so, sprawling suburban areas would benefit from modest increases in density. A few 3 to 5 story limited-parking condos or apartment houses replacing parking lots or other underused land along major streets could double their density, cutting household mileage 30 percent. If this relationship, a reduction in driving of 30% every time density doubles, holds up to the density of Manhattan, its families would drive only 8%, or 1/12, as much as nearby suburbanites.

Travel surveys, where household residents log each trip, give more direct estimates of VMT. Newman and Kenworthy reported results of a travel survey of United Kingdom cities, which give a 25 percent reduction in per capita VMT as density is doubled.[6] Similarly, a travel survey in the Greater Toronto Area suggested that doubling density results in a decrease in per capita VMT of about 25 percent.[7] A comparison of cities in Washington state found housing density, population density, jobs-housing balance and retail-housing balance to co-vary and to be associated with reduced driving.[8]

But the cost of such surveys limits them to too few households to provide a statistical analysis of all the important variables at neighborhood level. The above studies were for much larger areas than neighborhoods, limiting their ability to measure the effects of neighborhood characteristics like density, transit service and pedestrian and bicycle friendliness. A 1990 study of five communities, ranging from traditional to suburban, in the San Francisco region used actual odometer readings.[9] The study found that high residential density, nearby shopping, good transit and a good walking environment go together, while low density zones lacked all these. The co-variance of these variables increases the difficulty of disentangling their effects, but does allow density to capture much of the effects of the others. The residents of higher density communities drove 20 to 30 percent per household less every time neighborhood density doubled. Nob Hill, at 32 times higher household density as San Ramon, had 1/4 its household auto ownership and VMT. However, the limited number of communities studied prevented disentangling the effects of residential density, nearby shopping, transit and the walking environment.

Using a household travel survey in the Seattle area, Frank and Pivo found that employment density, population density, land-use mix and jobs-housing balance are associated with less auto use.[10] These relationships held up even when household demographics, car ownership and transit are controlled.

A study of 27 neighborhoods in San Francisco, Los Angeles, San Diego and Sacramento, using odometer readings, found that doubling residential density cut auto ownership 16%, while doubling public transit service reduced VMT an additional 5%.[11] With density as a surrogate for all the variables, doubling residential density cut VMT 20%.

Kara Kockelman, in a study of over 1000 travel analysis zones and 1,200 census tracts in the San Francisco Bay Area, found that the following influence household VMT: household size, auto ownership, income, weighted jobs within 30 minutes, dissimilarity of the zone's major land use from its neighbors, and the balance of land uses within each zone within a half mile.[12]

Robert Dunphy and Kimberly Fisher calculated the average VMT from the 1990 National Personal Transportation Survey (NPTS) for households whose ZIP codes had the same population density.[13] For the five density ranges above 4000 persons/square mile (about 5 households/residential acre), their Table 4 shows a decrease of 38% in daily driving as density doubles.

These studies have shown a strong relationship between urban form and driving. Of course it makes intuitive sense that people living in neighborhoods originally built for the convenience of residents without private automobiles would have lower auto ownership and driving. But which of the mix of variables that comprise these neighborhoods are the most crucial? If we can identify which of the variables is most effective, and measure their effects, then architects and developers can incorporate them into smart growth, and air quality analysts can credit such design with emissions reductions.

Our location efficiency study explores the hypothesis that the average household's auto ownership and driving decrease measurably as likely trip destinations become more convenient, especially by non-automotive modes. Further, it tests the assumptions that residential density, center proximity, local shopping, public transit accessibility and the pedestrian and bicycle friendliness of the neighborhood are good measures of that convenience.

Which variables do we test?

- Density - a measure of the number of nearby destinations. Residential density, the number of households per residential acre, seems to be the best measure, probably because it focuses on the developed area and is not diluted by farmland or parks within the zone but outside the everyday neighborhood. But other measures of density are also tested.
- Center proximity - a measure of the neighborhood's access to concentrations of jobs and shopping.
- Local shopping - a measure of the amount of restaurants, markets, retail stores, insurance agents, and of course video rental stores, nearby.
- Public transit - important as an alternative to driving.
- Pedestrian and bicycle friendliness - how attractive are areas to these alternatives to driving.

We would also have liked to test the impacts of parking supply, but were barred by the lack of detailed zonal data on parking. Traditional dense areas have narrow streets and limited parking. In addition, the land required by on-site parking itself reduces the density. In the Bay Area, a 3-story apartment house's density could range from 28 units/acre to 64 due only to differences in parking requirements of existing zoning laws.[14] Consequently, to some extent density captures parking tightness.

This study also sought to quantify the statistical relationship of such locational variables to auto ownership and driving to facilitate the Location Efficient Mortgage[CM] (LEM). The LEM allows a household to buy a more expensive home in a location efficient area by committing its auto savings to repaying the mortgage, interest, taxes and insurance. I reported preliminary results of this study in the 1997 AWMA meetings.[15]

THIS LOCATION EFFICIENCY STUDY

This study, sponsored by the Natural Resources Defense Council (NRDC), the Center for Neighborhood Technology (CNT) in Chicago, and the Surface Transportation Policy Project in Washington, DC, includes every neighborhood in the San Francisco, LA and Chicago areas.

The zones analyzed are the Chicago Area Transportation Study's 316 Dram-Empal zones covering the Chicago metropolitan area, the Southern California Association of Governments' 1700 Travel Analysis Zones covering the Los Angeles metropolitan area and the Metropolitan Transportation Commission's 1099 Travel Analysis Zones in the San Francisco metropolitan area.

Zones comprised primarily or wholly of parks, military bases, prisons, airports or industrial facilities are outside the scope of this analysis and were eliminated from the data base.

The Variables

The dependent variables are **vehicles available per household** and **vehicle miles traveled** (VMT). Average vehicle availability for each zone is from the 1990 U.S. Census. VMT per vehicle is derived from odometer readings recorded when owners take their vehicles in for emission systems inspections (smog checks) in California and Illinois. Average VMT per household is calculated as the VMT per vehicle times the number of vehicles per household for each zone.

The dependent variables were tested against a wide range of potential explanatory variables, including the most important socio-economic factors of household income and household size. Locational variables tested were: density, transit service and access to jobs by transit, availability of local shopping, pedestrian and bicycle friendliness, and proximity to jobs.

The **density** measures tested were households/residential acre, population/acre and population/residential acre. Households/residential acre (Hh/RA) had the strongest correlation to vehicle ownership, while households/total acre (Hh/TA) had the strongest correlation to VMT/vehicle. Total acreage includes residential, commercial, industrial, agricultural, parks and open space, and any other categories reported. The data were compiled from the census and regional planning organizations.

Household and per capita **income** ($/Hh, $/P) and **household size** (P/Hh) were derived from 1990 census data.

The measure of **transit** accessibility is zonal transit density (Tr), which is the daily average number of buses or trains per hour times the fraction of the zone within 1/4 mi of each bus stop (or ½mi of each rail or ferry stop or station), summed for all transit routes in or near the zone. There is some double counting where stops are less than 1/4 mile apart, but correcting for this would not substantially alter the order of the TAZs nor the relative differences between zones. Therefore this measure provides a robust assessment of transit service. An alternative measure, the zonal transit density times the number of jobs reached within 30 minutes by transit (TrJ), provided no better correlation with auto ownership or driving than the zonal transit density alone. So the simpler zonal transit density is reported. Routes, schedules and stop locations are from the transit agencies or the metropolitan planning organizations, who also calculated the number of jobs accessible by transit.

The measure of **center proximity** (CP) is the number of jobs within a 30 minute drive, calculated by the Metropolitan Transportation Commission for the San Francisco region. An alternative measure is the number of jobs within a 15 minute drive divided by the number of jobs within a 30 minute drive (E15/E30). This provides a measure of the relative availability of jobs locally. Including CP in the VMT/vehicle analysis provided a marginally higher R^2, but was available only in San Francisco and therefore not included in the general analysis. E15/E30 did not improve R^2 as much as CP did.

Local shopping (Sh) is the number of service and retail jobs per developed area within the zone, from the U.S. Census. Zones with centroids less than 1/4 mi apart were combined for this calculation. Local shopping is strongly correlated with density and transit, and did not add to the R^2 after they were taken into account.

The measure of **pedestrian/bicycle friendliness** (Ped) is the number of census blocks per hectare (scale of the street grid), plus an adder based upon the mean year the housing was built, both from the U.S. Census, with bonuses for traffic calming, good pedestrian conditions, bike lanes, paths, and bike parking, whether as part of the initial design or added later. Had direct measurements of the continuity, width and quality of sidewalks, nearness of buildings to the sidewalk, and traffic safety been available, we would have preferred using them to using the mean year the housing was built. A fine street grid shortens routes and offers more alternatives, and the frequent intersections slow traffic. The measure works because older neighborhoods tend to have a fine street grid, sidewalks, narrow streets, slower traffic and buildings closer to the sidewalk.

We also tested socioeconomic variables available at the zonal level: average **household size**, average **household income** and average **per capita income**. These were derived from the U.S. Census. However, we were not able to explore any independent impact of neighborhood **parking supply** or **cost**.

Analysis of vehicles available and driving

The correlation of each individual independent variable (locational and socio-economic) with auto ownership and VMT was tested. In the San Francisco area, for instance, Hh/RA explained 63% of the variance in Veh/Hh, followed by transit-job access at 55%, Hh/TA at 52%, transit service at 49%, income/household at 43%, shopping at 35% and household size at 28%. In each of the three metropolitan areas, Hh/RA explained the most variance in Veh/Hh and VMT/Hh, see Figure 1. These correlations show a very strong relationship of residential density to auto ownership and driving in all three regions studied, even before evaluating the other variables--income, household size, transit service, pedestrian/bicycle friendliness, etc. When tested against each other, density, transit, local shopping, center proximity and pedestrian/bicycle friendliness prove to be highly correlated. While this makes it harder to pick apart the separate influences, it means that density to some extent captures the effects of local shopping, transit and pedestrian and bicycle friendliness.

As much as possible, we based the forms of our fits on simple modeling of the physical situations. For instance, since doubling density doubles the number of nearby destinations, and doubling transit service doubles the number of destinations you can easily reach, it is reasonable to expect that for both each doubling would decrease auto ownership and VMT by a similar percentage--a log-log or power fit. However, there are limitations on how many cars a household can own, and how many miles even the most auto-entranced folk can drive, therefore we modified the power fit form to be bounded as the density goes to zero. Similarly, since more people in the household increase the number of drivers and people to be driven around, we expected a linear relationship of household size with autos and VMT. However, we had less reason to anticipate a particular mathematical form (linear, power, bounded power, root, polynomial, exponential, etc.) for the relationship between income or pedestrian/bicycle friendliness and auto ownership or VMT. So we tested various mathematically simple forms that had appropriate behavior over the ranges of the independent variables. We derived the forms of the equations using the San Francisco data and then used these forms to derive the equations for the other two regions.

Using the data available in all three geographical regions and the same equation forms, the variables which consistently explain the most variance in vehicles/household (Veh/Hh) are net residential density (Hh/RA), per capita income ($/P), household size (P/H) and transit accessibility (Tr), see Table 1. For vehicle miles traveled/vehicle (VMT/Veh) the best variables are total residential density (Hh/TA), P/H, pedestrian/bicycle friendliness (Ped) and $/P. These are the equations which when applied in the same form in all three regions give the highest R^2.

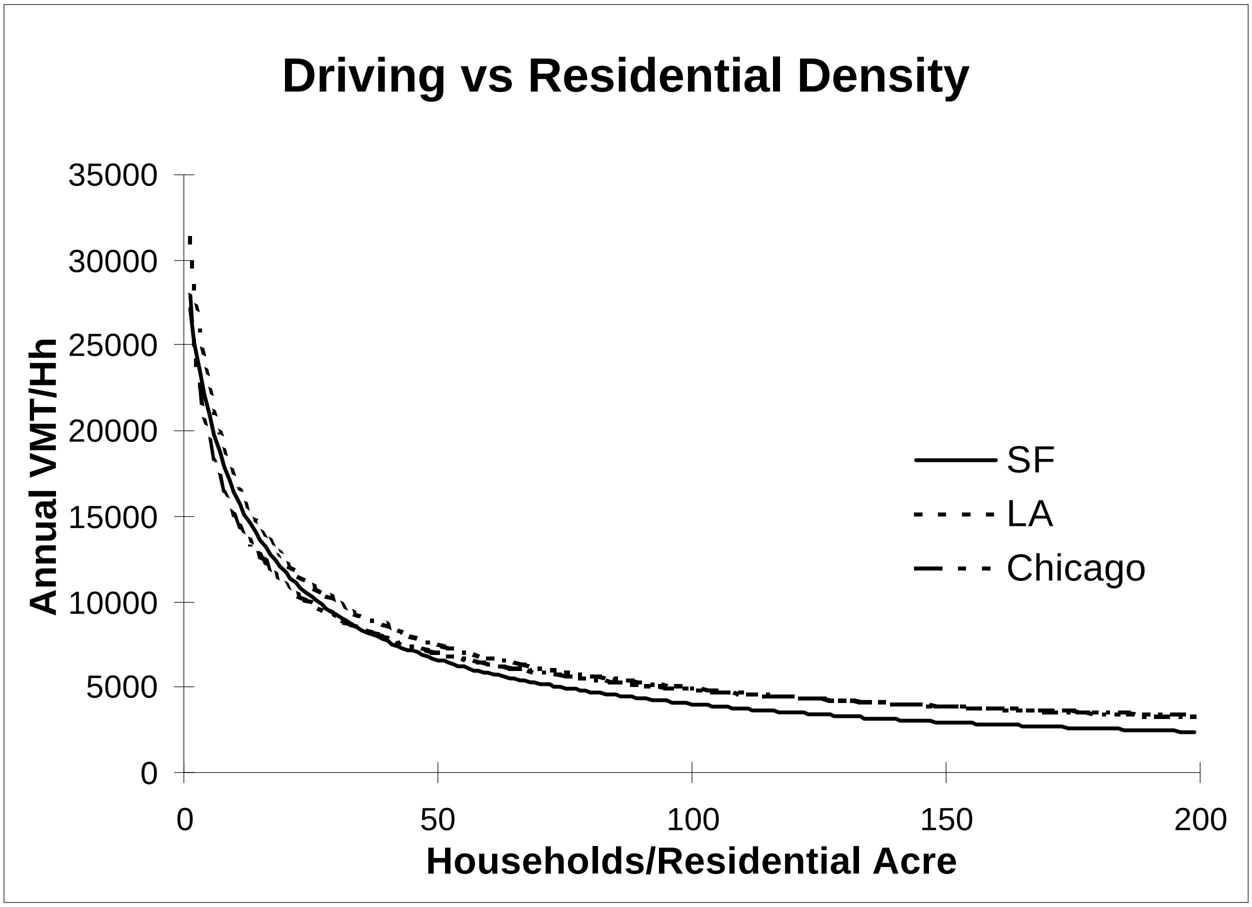
In both the Veh/Hh and VMT/Veh models, density is raised to a negative power, so doubling density causes a fixed decrease in Veh or VMT. In the Veh/Hh model, transit service is raised to a negative power, so doubling Tr causes a fixed decrease in Veh. Household size acts as expected, each additional person adds a fixed increase in Veh or VMT. Improvements in pedestrian and bicycle friendliness reduce VMT/Veh, but with the square root of Ped. The impact of per capita income is a little less straight-forward. It increases with ownership by declining increments as income increases. But VMT/Veh decreases as income increases. The result is that up to an annual income of $25,000 to 30,000, VMT/Hh increases with income as expected, but levels off and falls slightly at higher incomes up to $100,000 per person.

The best San Francisco model for VMT/Veh using variables available in all three regions is the same as in Table 1, but with a function for Zonal Transit Density in place of that for Households/Total Acre. Tr gives an R^2 of 44.1%, which is slightly better than the 43.8% in the above table. But in the other two regions, Tr in place of H/RA reduced the R^2 to 40.0% for Chicago and 37.6% for LA, substantially poorer than the Hh/Tot Acre fit. So the recommended equations use Hh/Tot Acre.

In all three cities, the R^2 for VMT/Veh is much lower than the R^2 for Veh/Hh, indicating that neighborhood conditions more strongly impact the decisions on how many vehicles to have available than they do each decision to use the vehicles on hand. However, since Veh/Hh varies much more from zone to zone (1 s.d. equals ±25% for San Francisco) than does VMT/Hh (±9%), Veh/Hh is more important, and the R^2 for the resulting VMT/Hh is almost the same as for Veh/Hh.

Data for center proximity was only available for the San Francisco region, so none of the fits in Table 1 are based on it. The Veh/Hh fit in Table 3 is already highly significant, and center

Figure 1. The reduction in vehicle miles traveled per household as residential density increases.



proximity added no significance. However, for vehicle use, center proximity added about 5% to the total variation explained, giving a total R^2 of 53.9% for the San Francisco region. This suggests that the impacts of CP, while not measured in Chicago and Los Angeles, should be further explored. The equations in Table 2 provide a high explanation of variation.

Figure 2 shows the impact of residential density and transit on VMT/Hh using the equation for the San Francisco area. This shows that a household with regional average income and family size living in a 2 Hh/RA neighborhood with zero transit service, for instance, would average over 23,000 miles annually. Raising the density to 150 Hh/RA would reduce the mileage to 10,300. But it also shows that more modest increases in density reduce driving. It also shows that at each level of transit service increases of density reduce driving. Similarly, it shows that an increase in Tr to 300 would reduce annual driving to under 15,400. And it shows that more modest increases in transit service reduce driving. At the highest density and transit service in this example, annual mileage is 3,700.

Extending These Analyses

These equations allow the use of available neighborhood locational and demographic

Table 1. The best equations (1 - 9) to predict Veh/Hh, VMT/Veh and VMT/Hh in all three regions.

	R^2

Chicago

$$\frac{Veh}{Hh}=1.902\left(9.955+\frac{H}{RA}\right)^{-0.2797}\left(1-e^{-\left(0.000142\frac{\$}{P}\right)^{1.2915}}\right)\left(1+0.4893\frac{P}{H}\right)(Tr+2.960)^{-0.0685}$$ 96.3%

$$\frac{VMT}{Veh}=11620\left(0.1662+\frac{H}{TA}\right)^{-0.0547}\left(1+0.00653\frac{P}{H}\right)\left(1-0.0249\sqrt{Ped}\right)-0.0818\left(\frac{\$}{P}-22136\right)$$ 46.8%

$$\frac{VMT}{Hh}=\frac{Veh}{Hh}\times\frac{VMT}{Veh}$$ 93.5%

Los Angeles

$$\frac{Veh}{Hh}=1.732\left(6.155+\frac{H}{RA}\right)^{-0.0925}\left(1-e^{-\left(0.000131\frac{\$}{P}\right)^{0.8278}}\right)\left(1+0.7936\frac{P}{H}\right)(Tr+30.796)^{-0.1865}$$ 78.6%

$$\frac{VMT}{Veh}=11624\left(0.3432+\frac{H}{TA}\right)^{-0.0681}\left(1+0.01555\frac{P}{H}\right)\left(1-0.1078\sqrt{Ped}\right)-0.04095\left(\frac{\$}{P}-22136\right)$$ 42.0%

$$\frac{VMT}{Hh}=\frac{Veh}{Hh}\times\frac{VMT}{Veh}$$ 80.0%

San Francisco

$$\frac{Veh}{Hh}=4.722\left(22.520+\frac{H}{RA}\right)^{-0.3471}\left(1-e^{-\left(0.000112\frac{\$}{P}\right)^{1.2386}}\right)\left(1+1.0519\frac{P}{H}\right)(Tr+60.312)^{-0.2336}$$ 90.2%

$$\frac{VMT}{Veh}=10386\left(0.5041+\frac{H}{TA}\right)^{-0.0419}\left(1+0.02759\frac{P}{H}\right)\left(1-0.0704\sqrt{Ped}\right)-0.01743\left(\frac{\$}{P}-22136\right)$$ 43.8%

$$\frac{VMT}{Hh}=\frac{Veh}{Hh}\times\frac{VMT}{Veh}$$ 87.1%

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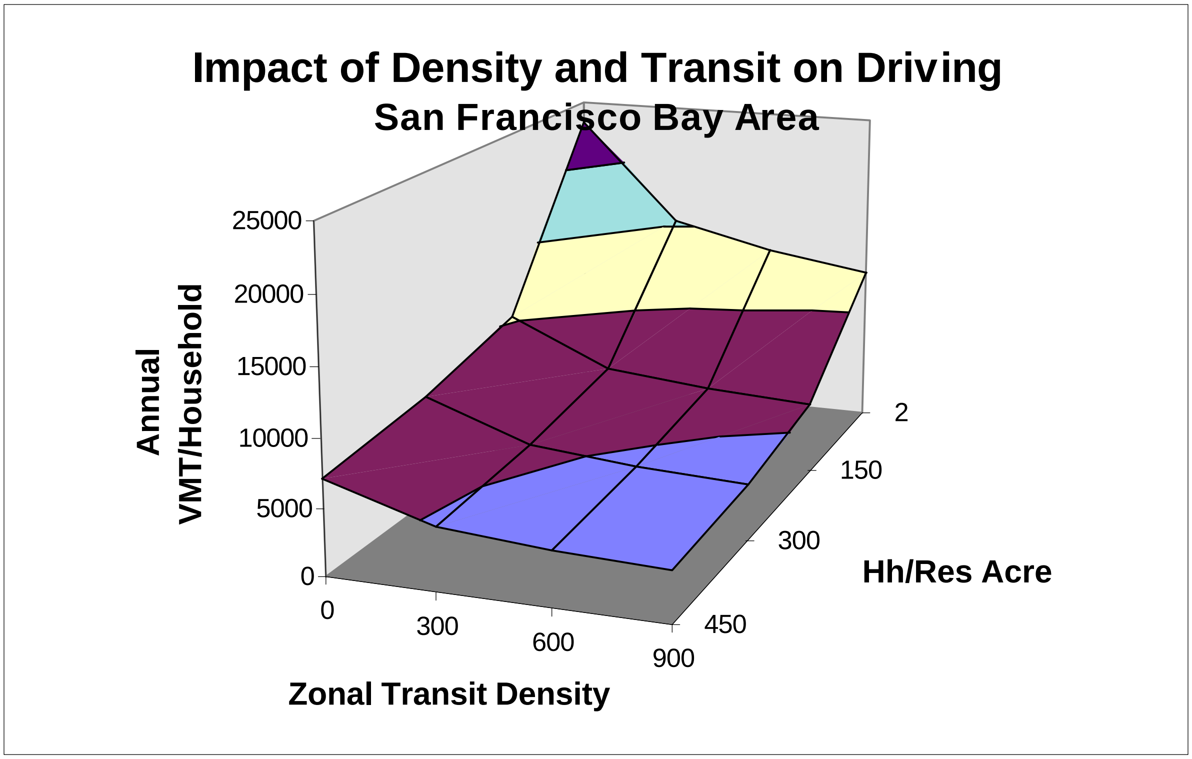
* H/RA is Households/Residential Acres, H/TA is Households/Total Acre, $/P is Income/Capita, P/H is Persons/Hh, Tr is Zonal Transit Density and Ped is Ped/Bicycle Friendliness.

characteristics to predict average auto ownership and mileage by neighborhood in three of major U.S. regions. Extending the analyses to other metropolitan areas is a first step. Extending the analysis from vehicles and VMT to vehicle trips and vehicle starts would increase its applicability to air quality analysis. Expanding the analysis from just the characteristics of residential neighborhoods to the concentration or dispersal of jobs or commerce would extend its utility to air quality analysis.

This study was made in order to quantify the transportation savings of average families living in convenient location efficient neighborhoods, allowing them to qualify for Location Efficient Mortgages[SM]. LEMs allow families to apply these transportation savings to qualifying for a higher

Figure 2. How residential density and transit impact VMT/Hh using the San Francisco area equation.



mortgage. Location Efficiency analysis is already being extended to allow LEMs in Seattle, Washington and Portland, Oregon. In neither of these are mileage readings for vehicles available. The dominance of Veh/Hh in the calculations of VMT/Hh facilitated these extensions. Veh/Hh, available from the U.S. Census in all cities, along with densities, income, household size, transit service and pedestrian and bicycle friendliness, allow the Veh/Hh equation to be calibrated. Average VMT/Veh is calculated by state departments of transportation based upon fuel use, screenline monitoring and other gross measures. This allows the VMT/Veh equation to be calibrated to the regional average VMT/Veh.

Extending the analysis to other important dependent variables - vehicle trips and vehicle starts - would require localized measures of these. The closest available measures are household travel surveys, but as with VMT analysis these contain insufficient data. For instance, in the San Francisco region there average less than ten households per zone. The scarce data problem is aggravated by the lack of any households in many zones, especially the denser zones, which are scarcer to begin with. Since fewer trips commence in denser zones, and are consequently less critical to transportation planning, planners have tended to slight them. But aggregating zones by residential density provides more respectable household numbers, allowing derivation of a gross relationship of trips to VMT by residential density. This relationship could be used to extend the predictions of VMT/Hh to trips/household. Similarly, the time between trips, if reported in the household travel survey, could be used to extend the predictions to cold starts.

Similarly, the impacts on trips and VMT of job and commerce concentrations could be estimated by use of household travel surveys. Jobs and local shopping employees are known by zone. Grouping the zones by local shopping density or job ranges would allow shopping trips terminating in these zones to be measured. A crude relationship of shopping or job density with trips would allow evaluation of their impacts on air quality. Similarly, the analysis could be extended to cold starts and trip lengths.

SO WHAT IS SMART GROWTH, AS SEEN FROM THE AIR?

Smart growth, defined as that which minimizes the emissions of air pollutants per capita or per household, looks quite similar to that defined by smart growth advocates. It creates convenient neighborhoods, new or traditional, and using auto ownership and VMT as its measures, its characteristics are:

- increasing neighborhood density to raise the number of nearby destinations,
- including markets, restaurants and other commerce and services in residential neighborhoods (mixed-use),
- locating neighborhoods close to job centers,
- providing safe, attractive and convenient pedestrian and bicycle conditions,
- limiting parking, and
- providing frequent, convenient, affordable and safe public transit.

While not discussed in the foregoing analysis, the success of these areas in attracting and retaining residents depends upon their satisfaction with these neighborhoods. Since these neighborhoods encourage walking and meeting neighbors on the sidewalk, at the market or at recreation, a sense of community and neighborhood satisfaction is built up. But attention to other factors is also necessary to these neighborhoods ultimate success:

- nearby parks, creeks, recreation areas, and other open spaces and wildlife habitat,
- attractive, quality architecture of the neighborhood and buildings, and
- quality construction, built to last much longer than housing or shopping centers located in sprawl.

This study suggests the following actions to reduce our dependence on the automobile, afford us more transportation options, reduce congestion buildup and reduce air pollution:

1. reform our restrictive (big government) zoning policies in residential and commercial areas to allow higher residential densities, eliminate front- and side-yard setbacks and off-street parking requirements, narrow roadways, and promote neighborhood commerce.
2. design our residential, commercial, office and industrial areas to promote walking, bicycling and public transit, including traffic calming.
3. improve public transit service, convenience, safety, attractiveness and affordability.
4. prohibit highway expansion.
5. prohibit residential growth outside developed neighborhoods.
6. implement the LEM.

While not analyzed in this study, VMT reductions would also be facilitated by elimination of such subsidies to driving as free parking (subsidized by higher property taxes, rents, goods and service prices), pollution and noise damages, global warming, wars in the Mid-East, police/fire/ambulance to motorists, road construction and maintenance (property taxes) and congestion.

Some resources to help you achieve Smart Growth can be found at:
Sierra Club www.sierraclub.org/sprawl
Victoria Transport Policy Institute http://www.vtpi.org
Center for Neighborhood Technology http://www.cnt.org/
Surface Transportation Policy Project http://www.transact.org/stpp.htm
Congress for New Urbanism http://www.cnu.org/
American Planning Organization http://www.planning.org/index.html
American Farmland Trust http://www.farmland.org/

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REFERENCES

1. *Proposed Final San Francisco Bay Area Ozone Attainment Plan for the 1-Hour National Ozone Standard;* Bay Area Air Quality Management District: San Francisco, June 9, 1999; Table 7.
2. *Proposed Final Bay Area '94 Clean Air Plan;* Bay Area Air Quality Management District: San Francisco, Nov. 1994; Table 1.
3. *Multiple Air Toxics Exposure Study in the South Coast Air Basin: MATES - II*; South Coast Air Quality Management District: Diamond Bar CA, Nov. 1999.
4. *Saving Energy in U.S. Transportation*; Office of Technology Assessment, U.S. Congress, July 1994, OTA-ETI-589; p9.
5. *Energy and Transportation, Task Force Report*; The President's Council on Sustainable

Development, 1996, U.S. G.P.O.: 1996-404-680:20028; p35.
6. Newman, P.; Kenworthy. J. *Cities and Automobile Dependence: An International Sourcebook*, Gower Publishing: Aldershot, England, 1989.
7. University of Toronto/York University. *The Transportation Tomorrow Survey: Travel Survey Summary for the Greater Toronto Area*, June 1989.
8. Pivo, G., Hess, P., Thatte, A. *Land Use Trends Affecting Auto Dependence in Washington's Metropolitan Areas, 1970 - 1990*, Washington state DOT, WA-RD 380.1, 1995.
9. Holtzclaw, J. *Explaining Urban Density and Transit Impacts on Auto Use*. Natural Resources Defense Council: San Francisco, 15 January 1991, in California Energy Commission, Docket No. 89-CR-90.
10. Frank, L., Pivo, G. *Relationships Between Land Use and Travel Behavior in the Puget Sound Region,* Washington state DOT, WA-RD 351.1, 1994.
11. Holtzclaw, J. *Using Residential Patterns and Transit To Decrease Auto Dependence and Costs*. Natural Resources Defense Council: San Francisco, and California Home Energy Efficiency Rating Systems: Costa Mesa, California, 1994.
12. Kockelman, K. M. *Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area*, Thesis for Masters of City Planning, UC Berkeley, 1996. Cervero, R., Kockelman, K. *Travel Demand and the Three Ds: Density, Diversity and Design*; University of California at Berkeley, July 1996.
13. Dunphy, R., Fisher, K. "Transportation, Congestion, and Density: New Insights," *Transportation Research Record No. 1552*, Washington DC: Transportation Research Board, November 1996, pp89-96.
14. J. Cook, R. Diaz, L. Klieman, T. Rood and J. Wu. *Parking Policies in Bay Area Jurisdictions: A Survey of Parking Requirements, Their Methodological Origins, and an Exploration of Their Land Use Impacts,* U. California, Department of City and Regional Planning, Spring 1997.
15. Holtzclaw, J.; *Designing Cities to Reduce Driving and Pollution: New Studies in Chicago, LA and San Francisco*; Air & Waste Management Association: Pittsburgh, June 8-13, 1997. www.sierraclub.org/sprawl.

KEY WORDS

auto emissions
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pedestrians
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