

The Urban Structure and Personal Travel: An Analysis of Portland, or Data and Some National and International Data

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Urban form in the US (and now elsewhere) has tended to be “market driven” with little or no policy input and very little forethought. The advent of new, faster transportation has changed the relative accessibility of vacant land, and both the value to the owner and developers. With improvements in accessibility, more newly developable land becomes available, increasing its value to the owner and decreasing the cost of vacant developable land. Making it more possible to live at lower density at an affordable cost. This has occurred with the advent of commuter rail (in a limited band along the corridors), and to a much larger degree, with the advent of the car, ubiquitous highways, and later, high-speed freeways. Lewis Mumford^{2, 3} has most aptly and intuitively described this response of urban form to the change in transport supply.

When people in Portland were surveyed on their residential choices, they clearly favored living on acreage in the country, with close access to urban amenities, somewhat paradoxical and not possible for the majority. This is the picture that has been sold to sell suburbia, with the belief that it would be possible with enough freeway construction.

This classic trade-off between travel cost (mostly time) and the price of land (and hence the ability to afford larger pieces of it), paradoxically, is at the root of traffic congestion and an increase in road costs. To get a larger home on a larger lot than would be possible otherwise a people accept more distance between home and work (Edwin Mills⁴). If the full cost were assigned to the new suburban dwellers – both in time, and in the cost of highway construction, a rational economic decision could be made. However estimates of the portion of highways built with

¹Note that the contents present the views of their authors, not necessarily those of the Department of Energy, RAND, or any other organization with which the authors may be affiliated.

²Lewis Mumford (1961), “The City in History,” Secker & Warburg.

³Lewis Mumford (1964), “The Highway and the City,” Secker and Warburg.

⁴Edwin S. Mills (1972), “Studies in the Structure of the Urban Economy,” Johns Hopkins Press.

user funds (gas tax and registrations) ranges from 60% to 65%. Given that residents of the inner city and suburbs pay for a large portion of this, the new marginal suburban dweller is initially highly subsidized. This is later rectified as new fringe dwellers continue to arrive at this “cheap” low-density land until the roads are congested and the time costs are no longer attractive. This leads in turn to an outcry against congestion and a plea for further road improvements, restarting the cycle.

As highways congest, there is a perception that there is a cost of congestion – the time lost when traveling in congestion as compared to uncongested travel time. This is indeed the argument made by economists in justifying investment in highways. This presumes that travel needs of each individual are fixed and immutable in terms of frequency and origin-destination patterns. In fact data show that the use of time for travel is fairly constant, and that travelers modify their travel demand (choose different destinations, different times of day, or forgo some travel – sometimes with e-substitution or in-home activities). They also chain activities, rather than leaving home for a single activity, this is more time-efficient.

In Portland, Oregon, there has been a desire to understand the mechanisms leading to travel demand, and the part played by urban design and the configuration of land uses in the urban region. Portland data show that residents in denser, inner-city, mixed use areas consume significantly fewer miles of car travel, substituting slow modes, such as walking, bicycling and transit. Primarily lower-order (slow) streets serve these inner city dwellers. These have some congestion, so that car mobility, expressed as speed, is sharply reduced. Yet the data suggest that these people spend much the same time traveling, and have as many out of home activities as their suburban cousins.

The conclusions that can be drawn from these data lead to a different point of view from those urban planners and traffic engineers who favor building their way out of the problem with more freeways and more mass transit. Their focus is in the reduction of traffic congestion, creating more mobility (speed). The point of view in this presentation is that the real issue is accessibility. In other words, how many activity locations can you get to in a given amount of time? This argument contends that activity opportunities per hour of travel are more important than miles per hour. One could go further, and suggest that the quality of life is improved when the number of activities per hour by different travel modes is improved – accessibility on foot, bike and transit, as well as the car. This becomes important when including those too young to drive (and their harried parents), and those becoming too old to drive (a rapidly growing sector of the population). Two things, the speed of travel *and the density of activity opportunities*

affect activity opportunities per hour. The development of a slightly denser environment, and the change of zoning policies to promote more mixed use (shops, schools, restaurants, close to houses) can reduce car use, and cold starts. This is a shift in focus that saves energy and promotes a healthier environment. The substitution of walking time for riding time is an additional health benefit.

This issue becomes, however, one of policy. In Oregon the policies that affect development decisions are twofold: the desire to minimize the loss of valuable farmland in the Willamette Valley to urban development and the desire to minimize pollution and energy consumption. Given these policies, there has been an attempt to include the effects of urban form (juxtaposition of households and activity locations on a macro scale) and urban design (mix of uses on a micro scale, such as mixed use zoning) in planning for the Portland region. Most of this plan evaluation in Portland is carried out using transportation models developed from a household activity and travel survey carried out in the Portland metropolitan area in 1994 and 1995.

The data from this household activity and travel survey are the source for much of the following discussion.

Measures of Urban Density and Land Use Mix

The study of the interaction of urban form or urban design and transportation demand has a long history. (See Buch⁵, Cervero⁶, Cambridge Systematics Inc.⁷,

⁵M. Buch and M. Hickman (1999), "The Link Between Land Use and Transit: Recent Experience in Dallas," paper presented at the 78th. Annual Meeting, Transportation Research Board, Washington, D.C.

⁶R. Cervero (1991) "Land Use and Travel at Suburban Activity Centers," *Transportation Quarterly*, Vol. 45, pp. 479-491; R. Cervero (1996) , "Mixed Land-Uses and Commuting: Evidence from the American Housing Survey," *Transportation Research A*, Vol. 30, pp. 361-377; R. Cervero and R. Gorham (1995), "Commuting in Transit Versus Automobile Neighborhoods," *Journal of the American Planning Association*, Vol. 61, pp. 210-225; R. Cervero and K. Kockelman (1997), "Travel Demand and the 3Ds: Density, Diversity, and Design," *Transportation Research D*, Vol. 2, pp. 199-219; R. Cervero and C. Radisch (1996) "Travel Choices in Pedestrian Versus Automobile Oriented Neighborhoods," *Transport Policy*, Vol. 3, pp. 127-141.

⁷Cambridge Systematics, Inc. (1994), "The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior," Technology Sharing Program, U.S. Department of Transportation, Washington, D.C., pp. 3-1- 3-25.

Dunphy⁸, Ewing⁹, Sun¹⁰, Frank¹¹, Handy¹², Hess¹³, Holtzclaw¹⁴, Kockelman¹⁵, McNally¹⁶, Noland¹⁷, Parsons Brinckerhoff, Quade and Douglas¹⁸, Rutherford¹⁹ and Schimek²⁰). The results have been mixed and inconclusive. This may have been due to data limitations, and the use of density measures based on arbitrary polygons, such as census geography (tracts), or a regular grid (cells). These are unrelated to destinations available within walking distance, and have serious boundary effect problems when using disaggregate data. (A traveler may reside inside and near the boundary of a polygon that is of low density, and yet be next to a high density of activity opportunities in the next-door polygon). At least one researcher (Kockelman) has sought to compensate for this by including effects of neighbor polygons (in this case, cells).

⁸R. T. Dunphy and K. Fisher (1996), "Transportation, Congestion, and Density: New Insights," *Transportation Research Record* 1552, pp. 89-96.

⁹R. Ewing (1995) "Beyond Density, Mode Choice, and Single-Purpose Trips," *Transportation Quarterly*, Vol. 49, pp. 15-24; R. Ewing, M. DeAnna, and S. Li (1996) "Land Use Impacts on Trip Generation Rates," *Transportation Research Record* 1518, pp. 1-7. (Data reanalyzed by Fehr & Peers.)

¹⁰X. Sun, C. G. Wilmot, and T. Kasturi (1998), "Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Travel Survey," paper presented at the 77th Annual Meeting, Transportation Research Board, Washington, D.C.

¹¹L.D. Frank and G. Pivo (1994b), *Relationships Between Land Use and Travel Behavior in the Puget Sound Region*, Washington State Department of Transportation, Seattle, pp. 9-37.

¹²S. Handy, (1993), "Regional Versus Local Accessibility: Implications for Non-Work Travel," *Transportation Research Record* 1400, pp. 58-66; S. Handy (1996), "Urban Form and Pedestrian Choices: Study of Austin Neighborhoods," *Transportation Research Record* 1552, pp. 135-144.

¹³P. M. Hess et al. (1999), "Neighborhood Site Design and Pedestrian Travel," paper presented at the Annual Meeting of the Association of Collegiate Schools of Planning, American Planning Association, Chicago.

¹⁴J. Holtzclaw (1994), *Using Residential Patterns and Transit to Decrease Auto Dependence and Costs*, Natural Resources Defense Council, San Francisco, pp. 16-23.

¹⁵K. M. Kockelman (1997), "Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area," paper presented at the 76th Annual Meeting, Transportation Research Board, Washington, D.C.

¹⁶M. G. McNally and A. Kulkarni (1997), "An Assessment of the Land Use-Transportation System and Travel Behavior," paper presented at the 76th Annual Meeting, Transportation Research Board, Washington, D.C. (Fehr & Peers conducted expanded analysis of database, 1999)

¹⁷R. B. Noland and W. A. Cowart (1999), "Analysis of Metropolitan Highway Capacity and the Growth in Vehicle Miles of Travel," paper submitted for presentation at the 79th Annual Meeting, Transportation Research Board, Washington, D.C.

¹⁸Parsons Brinckerhoff Quade Douglas (1993), "The Pedestrian Environment," 1000 Friends of Oregon, Portland, pp. 29-34; Parsons Brinckerhoff Quade Douglas (1994), "Building Orientation: A Supplement to "The Pedestrian Environment," 1000 Friends of Oregon, Portland, pp. 9-14.

¹⁹G. S. Rutherford, E. McCormack, and M. Wilkinson (1996), "Travel Impacts of Urban Form: Implications From an Analysis of Two Seattle Area Travel Diaries," TMIP Conference on Urban Design, Telecommuting, and Travel Behavior, Federal Highway Administration, Washington, D.C.

²⁰P. Schimek (1996), "Household Motor Vehicle Ownership and Use: How Much Does Residential Density Matter?" *Transportation Research Record* 1552, pp. 120-125.

Portland Data: A Microanalysis

The Portland data have been organized differently from most of that in the previous research. It uses a continuous measure of density, or mix, that does not utilize polygons. This has been made possible because use has been made of a household activity and travel diary designed for the development of an urban travel model. The data is discrete (disaggregate), with all household and traveler activity locations geocoded to coordinates accurate to within a few feet. The availability of land use data organized within a Geographic Information System (GIS) and available at the parcel level has made the continuous density measures possible. The data comprises all the travel to activities, by all modes, over a two-day period for over 6000 households in the Portland region. The data includes activities that did not include the need to travel.

Density measures were made using the GIS, by capturing the number of jobs, retail jobs, acres of park, number of minor intersections, households, (any objective measure that might be useful) by distance band (1/4 mile, 1/2 mile, 3/4 mile, 1 mile, etc.) from the household, or the activity location. With the assumption that these are distances consistent with a 5-minute walk, 10-minute walk and so on. The hypothesis was that the density a household's travelers are interested in is the density of activity locations (places to do things – work, shop, and play, do business and so on). The availability of other households is of relatively minor importance. Other studies have posited that housing density is important, while it is true that sometimes housing density is correlated with the availability of other activity density (a surrogate), it often is not, in truth this is a highly variable circumstance – so leads to inconclusive conclusions.

Some Density Measures in the Portland Study

For the purposes of this presentation, the strongest variables in the Portland study that show distinct land-use effects emerging from the development of travel models have been summarized and put into a descriptive form. The travel models used multivariate and multinomial regressions, both linear and non-linear, but primarily of the logit (logistic regression) form.

For the purposes of developing descriptive tables and graphs, all of the measures have been assigned to each of the surveyed households. They have then been grouped in 10 quantiles (deciles) for each measure, so that means for each decile can be computed and shown. To give some sense of real values, the range of values for the measure for each decile are also shown here. *The deciles are always*

numbered 1 through 10, 1 is the least “urban” (ex-urban), 10 is the most “urban”, usually in the inner Westside, the inner Eastside and surrounding the downtown.

Mix. “Mix” is a number used to define the balance and intensity of jobs and households. This is the product of households and workers within a _ mile radius of the point of interest, divided by the sum of households and workers in the _ mile radius. The households are normalized to employment by multiplying the household in _ mile by the ratio of regional employment to regional households. Where $HH_{1/2m_N} = HH_{1/2m} * (EMP_{Reg.} / HH_{Reg.})$. (Subscript Reg. is total

Table 1
Mix Decile Rangels

Deciles Mix	Range	
	Lower	Upper
1	0	0
2	0	2
3	2	18
4	18	41
5	41	71
6	71	109
7	109	161
8	162	245
9	245	426
10	426	2335

regional, HH=households, EMP = employment, subscript N denotes normalized, subscript 1/2m denotes _ mile radius)

$$MIX = (HH_{1/2m_N} * EMP_{1/2m}) / (HH_{1/2m_N} + EMP_{1/2m})$$

Workers—1 mile. Another measure is the total number of workers within 1 mile of the household, or activity location. The range in Portland ran from 0 to 116,000.

Retail—1 mile. A similar measure is the number of retail workers within 1 mile of the household or activity location. This measure is very useful, as retail density also serves, to some extent as a surrogate for other services, and turns out to be the most important measure of the degree of urbanization in our models.

A mile represents about 20 minutes walking.

Local Intersections—Miles. Yet another measure is the number of local intersections within _ mi. radius. This is a surrogate for continuity of the walking environment. For a future or policy analysis it could be replaced with the number

of path intersections/local intersections in a design that has few local streets with but an overlay of pedestrian paths. The range in Portland is from 1 to 310 local intersections in a $\frac{1}{2}$ mile, with the top 3 deciles (most urban) ranging from 160 to 310.

Urban Index. An urban design index chosen for this paper (Urban Index) is a combination index using the number of retail jobs within a mile of the household combined with the number of local street intersections within a $\frac{1}{2}$ mile. These were the strongest urban design variables in multivariate regression analyses.

Table 2
Deciles Retail Jobs 1 mi

Deciles Retail 1 mi.	Range	
	Lower	Upper
1	0	7
2	8	70
3	70	206
4	207	382
5	382	597
6	598	889
7	890	1317
8	1319	1933
9	1941	3395
10	3434	12759

Table 3
Deciles Urban Index—Combination

Deciles Urb_Index	Range LocInt_1/2 Mi		Range Retail_1 Mi	
	Lower	Upper	Lower	Upper
1	1	104	0	188
2	6	217	0	4974
3	61	217	8	6433
4	87	159	70	1316
5	87	229	71	4256
6	105	297	207	5671
7	120	288	384	5449
8	132	309	621	10576
9	146	300	892	12522
10	175	288	1950	12759

Note that here, the combined ranges for the values are shown. Thus decile 10 has more than 175 local intersections within $\frac{1}{2}$ mile and more than 1950 retail jobs within 1 mile.

Travel Characteristics Associated with Urban Design/Density

Traditionally, predictive models developed in US practice have their roots in the 1960s and were primarily designed to predict auto travel demand on an uncongested network of streets. As such, surveys did not collect information on “slow modes” – walk and bicycle, or on short trips of less than $\frac{1}{2}$ mile. For most

models it was assumed that car ownership was exogenous, or at most related to the variables of household size and income alone. It was also assumed that the quantity of travel to activities was related to car ownership, and household size. These models were developed primarily to guide highway investment. They were later slightly modified to predict transit ridership more completely. Transit ridership models were primarily driven by transit service characteristic (compared to the car for the same journey), and car ownership (assumed exogenous, or at best income driven).

As a part of building predictive models for the Portland Metro area, it was noticed, many years ago, that the traditional predictors of travel quantity used in US practice were not accurate when tested on sub-sets of the households that had significantly different urban characteristics from the mean. It was also noticed that the transit service available to the household, measured as jobs accessible by transit in 30 minutes, the pedestrian environment, measured as retail jobs accessible by walking in 20 minutes and the continuity of the street network, measured as local intersection density, indeed have an effect on cars owned.

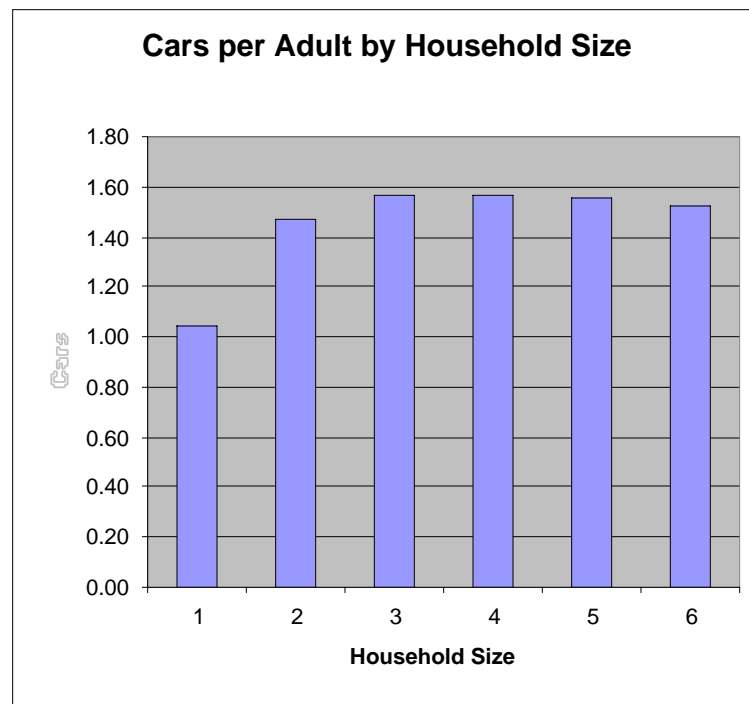
The following sections will give an example of an effective car ownership model, estimated using logit regression; a descriptive display of differences within different urban environments; and a series of descriptive displays for other travel metrics. Models for all of these elements will not be shown, as they are complex and interactive.

Car Ownership

Car ownership has been traditionally regarded as dependent on household size and income. The Portland data show that these are certainly variables of interest, however, these days, when there are more cars than drivers, it is of interest to look at cars per adult (here 18+), per household.

Table 4
Cars per Adult by HH Size

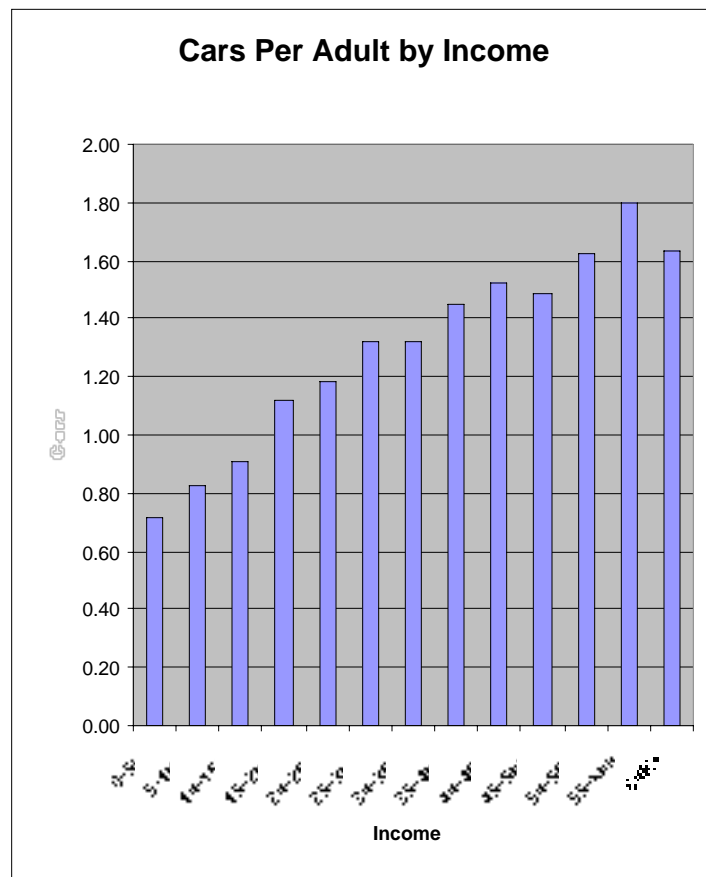
HHsize	Mean	Std. Dev.	Freq.
1	1.04	0.65	1851
2	1.47	0.79	2797
3	1.56	0.84	1119
4	1.57	0.87	948
5	1.56	0.86	347
6	1.53	0.90	154
Total	1.39	0.81	7216



We can also look at cars by income group for the whole region.

Table 5
Cars Per Adult by Income

Income	Mean	Std. Dev.	Freq.
0-5K	0.71	0.63	52
5-10K	0.83	0.78	200
10-15K	0.91	0.75	337
15-20K	1.12	0.71	396
20-25K	1.18	0.73	457
25-30K	1.32	0.64	482
30-35K	1.33	0.69	571
35-40K	1.45	0.88	496
40-45K	1.52	0.79	542
45-50K	1.49	0.71	366
50-55K	1.63	0.82	457
55-60K	1.80	1.07	160
60K+	1.63	0.82	1247
Total	1.39	0.81	5763



We can now move on to look at the car ownership by MIX and Urban Index.

Table 6
Cars Per Adult by MIX Variable

Deciles MIX	Mean	Std. Dev.	Freq.
1	1.66	0.96	1055
2	1.56	0.78	156
3	1.52	0.81	728
4	1.53	0.80	733
5	1.43	0.78	709
6	1.37	0.71	691
7	1.31	0.71	679
8	1.28	0.72	690
9	1.17	0.68	698
10	0.98	0.72	731
Total	1.38	0.80	6870

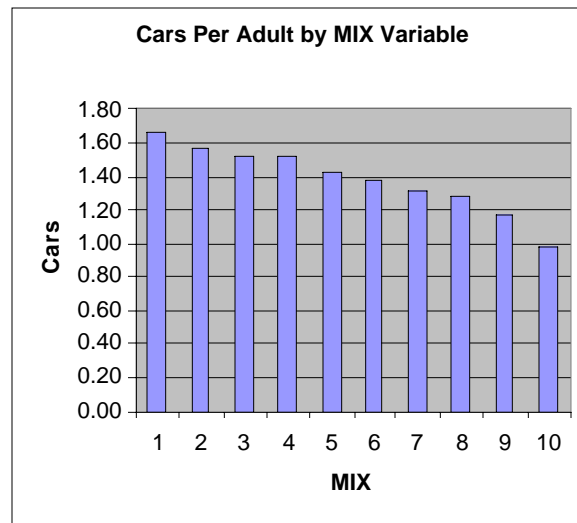
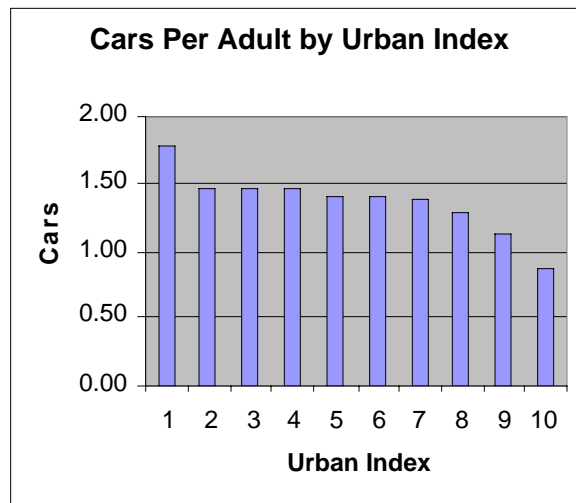


Table 7
Cars per Adult by HH Size

Deciles Urban Index	Mean	Std. Dev.	Freq.
1	1.78	0.92	727
2	1.45	0.74	833
3	1.47	0.85	705
4	1.47	0.76	638
5	1.40	0.79	595
6	1.39	0.77	683
7	1.37	0.73	768
8	1.28	0.71	605
9	1.13	0.71	707
10	0.85	0.65	516
Total	1.38	0.80	6777



Car Ownership Model—An Example

This car ownership model is intended as an example to give the reader some sense of the variables of importance and also to show the statistical fit. The rest of the metrics will be shown descriptively only. Although the models used in Portland account for all of the described effects, they do so in more complex interactive ways, too complex for a paper of this scope.

Table 8
Variables and Coefficients- Car Ownership Model

Cars in HH	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
1-Car						
In HH Income	0.9843373	0.1006453	9.78	0	0.7870762	1.181598
Persons in HH	0.2736137	0.1223973	2.235	0.025	0.0337195	0.513508
Workers in HH	0.3385346	0.1287423	2.63	0.009	0.0862044	0.5908648
Adults in HH	0.484109	0.2616866	1.85	0.064	-0.0287874	0.9970053
Retail jobs in 1mi	-0.0001325	0.0000311	-4.264	0	-0.0001934	-0.0000716
Local Int. in 1/2 mi	-0.0020657	0.0019545	-1.057	0.291	-0.0058965	0.0017651
Jobs by Transit 30min	-4.04E-06	1.32E-06	-3.06	0.002	-6.62E-06	-1.45E-06
Constant 1	-8.068329	1.040728	-7.753	0	-10.10812	-6.02854
2-Cars						
In HH Income	2.115116	0.1191553	17.751	0	1.881576	2.348656
Persons in HH	0.8497877	0.1249471	6.801	0	0.6048959	1.09468
Workers in HH	0.6987862	0.1354029	5.161	0	0.4334013	0.964171
Adults in HH	1.1623	0.265057	4.385	0	0.6427981	1.681802
Retail jobs in 1mi	-0.0002374	0.0000397	-5.976	0	-0.0003153	-0.0001596
Local Int. in 1/2 mi	-0.0031639	0.0020735	-1.526	0.127	-0.0072279	0.0009001
Jobs by Transit 30min	-7.89E-06	1.47E-06	-5.369	0	-0.0000108	-5.01E-06
Constant 2	-21.66061	1.240426	-17.462	0	-24.0918	-19.22942
3-Cars						
In HH Income	2.252273	0.1408918	15.986	0	1.97613	2.528415
Persons in HH	0.9113492	0.129191	7.054	0	0.6581394	1.164559
Workers in HH	1.160385	0.1471366	7.886	0	0.872003	1.448768
Adults in HH	1.247499	0.2723545	4.58	0	0.7136936	1.781304
Retail jobs in 1mi	-0.0004069	0.0000668	-6.09	0	-0.0005379	-0.000276
Local Int. in 1/2 mi	-0.0052738	0.0022611	-2.332	0.02	-0.0097055	-0.0008422
Jobs by Transit 30min	-8.68E-06	1.79E-06	-4.859	0	-0.0000122	-5.18E-06
Constant 3	-25.01953	1.483462	-16.866	0	-27.92707	-22.112
4+Cars						
In HH Income	2.222513	0.1840548	12.075	0	1.861772	2.583253
Persons in HH	1.000593	0.1385841	7.22	0	0.728973	1.272212
Workers in HH	1.613175	0.1707538	9.447	0	1.278504	1.947846
Adults in HH	1.516216	0.2836213	5.346	0	0.9603284	2.072104
Retail jobs in 1mi	-0.0002596	0.0000895	-2.9	0.004	-0.0004351	-0.0000842
Local Int. in 1/2 mi	-0.0073351	0.0026612	-2.756	0.006	-0.0125509	-0.0021193
Jobs by Transit 30min	-0.0000104	2.40E-06	-4.349	0	-0.0000151	-5.74E-06
Constant 4	-27.23391	1.976477	-13.779	0	-31.10774	-23.36009

Cars=0 is the comparison choice.

The following logit regression explicitly estimates the probability of owning an discrete number of vehicles:

Multinomial regression	Number of obs = 4953
	chi2(28) =2980.88
	Prob > chi2 = 0.0000
Log Likelihood = -4896.6853	Pseudo R2 = 0.2334

Below is shown the result of model application to disparate urban environments.

Table 9
Region-Wide Application

Cars in HH	Survey%	Model %
0-Cars	4.94	5.79
1-Car	31.15	32.59
2-Cars	44.53	44.54
3-Cars	14.25	12.72
4+Cars	5.12	4.36
Total	100	100

Table 10
Most Urban (Decile 10)

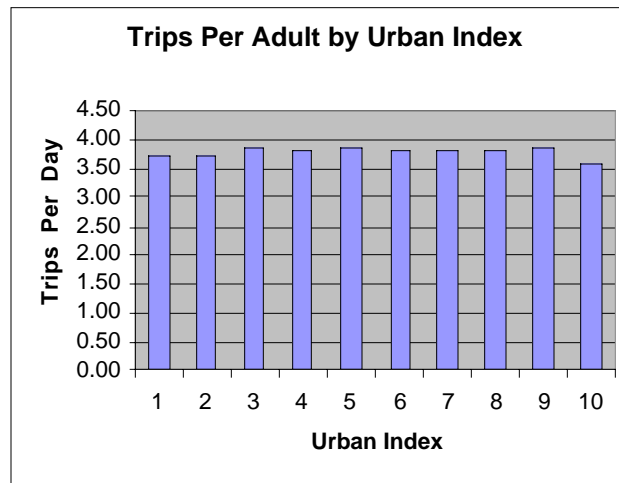
HH-Cars	Survey%	Model%
0-Cars	24.13	25.41
1-Car	51.16	49.37
2-Cars	20.27	21.54
3-Cars	3.86	2.68
4+Cars	0.58	1
Total	100	100

Trips to Activities

In considering the travel behavior exhibited by individual adults, the Portland study indicates that in areas with a high urban index there is a lower car ownership. It therefore might be expected that out of home activities and hence trip-making might be lower. But this is not the case as we can see below. The trip rates are almost constant. A look at trips made to activities reveals little variation across differences in the urban environment.

Table 11
DailyTrips Per Adult by Urban Index

Urban Index	Mean	Std. Dev.	Freq.
1	3.74	2.09	1731
2	3.74	2.06	1865
3	3.88	2.19	1569
4	3.84	2.14	1432
5	3.89	2.23	1255
6	3.81	2.09	1462
7	3.81	2.08	1651
8	3.83	2.18	1202
9	3.89	2.28	1257
10	3.55	2.11	763
Total	3.80	2.14	14187

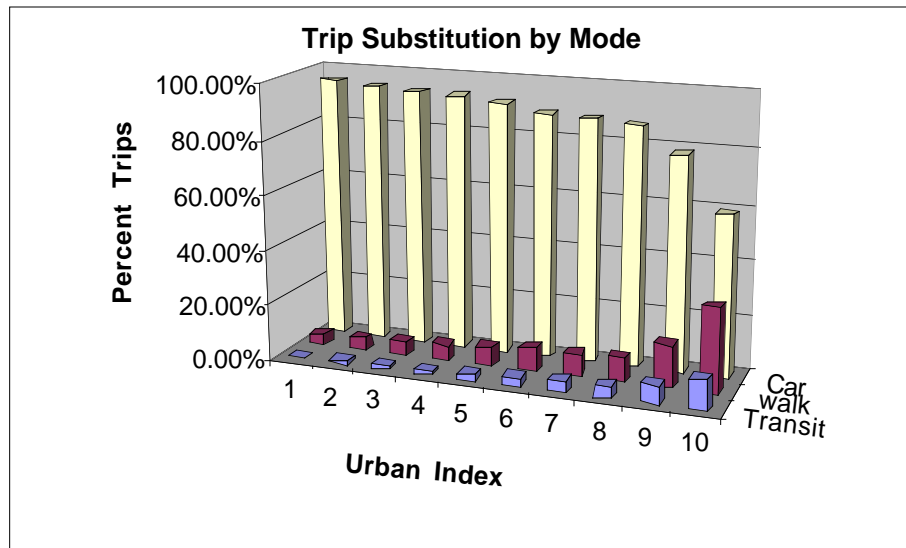


Mode of Travel to Activities—Substitution

Of much more interest is the substitution of modes of travel used, with increasing use of slower modes of walking and transit in the denser parts of the region. Similar behaviors are demonstrated for MIX and various other density variables.

Table 12
Mode Substitution by Urban Index

Urban Index	By Car	Transit	Walk	Total	% Car	% Transit	% Walk
1	3.58	0.02	0.14	3.74	95.68%	0.53%	3.79%
2	3.54	0.04	0.16	3.74	94.51%	1.15%	4.34%
3	3.62	0.05	0.20	3.88	93.33%	1.40%	5.27%
4	3.57	0.06	0.21	3.84	92.99%	1.56%	5.45%
5	3.55	0.08	0.26	3.89	91.25%	2.09%	6.65%
6	3.38	0.11	0.32	3.81	88.66%	3.00%	8.34%
7	3.35	0.15	0.31	3.81	87.89%	3.97%	8.14%
8	3.33	0.16	0.34	3.83	86.90%	4.22%	8.88%
9	3.03	0.26	0.60	3.89	77.85%	6.73%	15.42%
10	2.08	0.39	1.09	3.55	58.53%	10.87%	30.60%
Total	3.36	0.12	0.33	3.80	88.28%	3.14%	8.58%



Vehicle Miles of Travel per Person per Day

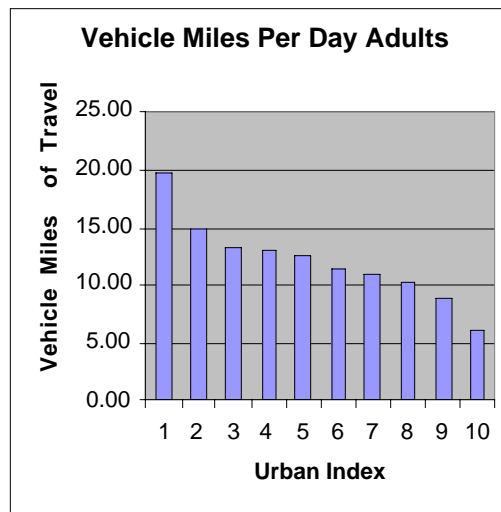
Of most interest for the purpose of gauging energy consumption is vehicle miles of travel. This, along with trips (cold starts for cars), is of importance in vehicular emissions, which affect air quality. The Portland study clearly reveals that the areas with the best density of activity opportunities, and the most continuous street network, have significantly lower vehicle miles of travel per person, compared with lower density locations.

Note that there is a danger of reading too much into the graphic. The areas of high urban index are mainly within the central city. A variable that is not

Table 13
Vehicle Miles Per Adult by Urban Index

Urban Index	Mean	Std. Dev.	Freq.
1	19.82	22.47	1725
2	14.82	17.43	1860
3	13.22	15.69	1565
4	13.11	15.48	1432
5	12.59	15.04	1254
6	11.40	13.75	1457
7	10.80	13.43	1651
8	10.19	13.09	1200
9	9.00	12.51	1253
10	6.28	10.16	763
Total	12.69	16.08	14160

NOTE: Portland data.



discussed in this paper is that of accessibility by car. This could be simply expressed as the number of activity locations accessible by car within 10, 20 or 30 minutes. Put simply, household locations with a high Urban Index in these data are, by nature of their location, also going to have a high value of accessibility by car, even though they are located in areas with very slow car travel. This means that they have many nearby choices by car, which contributes to a reduction in the vehicle miles of travel.²¹

Notional Data—a Macroanalysis

In a more general sense the gross densities and road supply for regions can be looked at to get some sense of the implied relationships between density, road supply and daily vehicle miles of travel per person. The following data were culled from Highway Statistics 1998, Office of Highway Policy Information, Federal Highway Administration.

These data are developed from FHWA's Highway Performance Measurement system (HPMS). The States collect these data individually, with some differences in quality, in other words, some measurement error. These data are developed from traffic counts, which cannot discern the difference between personal travel, commercial and truck travel and travel by non-residents of the region. As such these will show higher values of daily vehicle miles of travel (DVMT) per person than will data from household surveys. Cities are highly idiosyncratic, with various amounts of unbuildable area (bodies of water etc.). Even so the data suggests some relationships on a gross scale. The clear standout is New York, the biggest and also the least homogeneous in structure and density. It has areas of extremely high and extremely low density, with enough high density and mixed use to see significant pedestrian and transit travel, hence the very low DVMT. It is always a surprise to see Los Angeles as the densest urban area in the US, however it is fairly homogeneous, and was developed (as was Portland) in the streetcar era, and so has large areas of regular street pattern, and small single family lots, mixed with multifamily. New York and Boston were shaped in the railroad and streetcar era. The three highest auto-use cities are also the ones that have seen most of their development during the auto-dominant era (Houston,

²¹This raises the issue of macro, rather than micro effects. This has to do with another issue in urban planning, the relative location of households and jobs. Urban transport models are ideally suited to measure response to alternative land-use scenarios that use different ways of locating major employment areas relative to new housing. This exercise is not often undertaken, but can be very useful in determining a policy direction for preferred land-use arrangements. Work done in Portland, in particular the 1000 Friends of Oregon Land Use, Transportation and Air Quality study (LUTRAQ) and the development of Metro's 2040 plan has demonstrated that the combination of micro and macro design policies can reduce car-based travel demand.

Atlanta and Dallas-Ft. Worth.) these are also cities that have been the most aggressive in attempting to serve the demand for auto travel, building freeways in an attempt to avoid congested conditions. They have the lowest density, the largest amount of road space per capita and the highest DVMT per capita. Phoenix is unusual in that initial development followed a no-freeway policy, with a very extensive high-level regular arterial street system, slower than freeways, but with large capacity. The no-freeway policy has been dropped with significant recent freeway building.

All of these cities were chosen for this display because they are freestanding cities with little interaction with others. The data are shown in the following tables (Tables 14 & 15).

The relationships shown by the Portland data are, in a general sense borne out by the national data. However, the national data also suggest that an increased road supply is strongly related to lower overall density and increased vehicle miles of travel. This is probably a circular relationship – initial traffic demand increase (from car availability) leads to more and faster roads, in turn making more lower cost rural land accessible, in turn leading to more fringe development at a lower density, in turn generating more traffic demand, in turn leading to more road construction, and so on.

Acronyms in the tables are DVMT—Daily Vehicle Miles of Travel, ADT—Average Daily Traffic, mi.—miles, Fwy – freeway.

Table 14
DVMT per Capita by Density—US 1998

City/Region (Urbanized Area)	Persons/ Sq. mi.	DVMT/ Cap
Los Angeles	5650	21.7
New York	4140	15.7
San Diego	3660	21.5
Sacramento	3530	20.5
San-Fran-Oak.	3340	21.2
Portland-Vancouver	3140	21.1
Boston	2550	20.5
Denver	2540	22.5
Phoenix	2360	21.5
Seattle	2350	25.5
Dallas-Ft. Worth	2170	29.2
Minneapolis-St Paul	1950	24.2
Atlanta	1600	35.8
Houston	1560	38.4

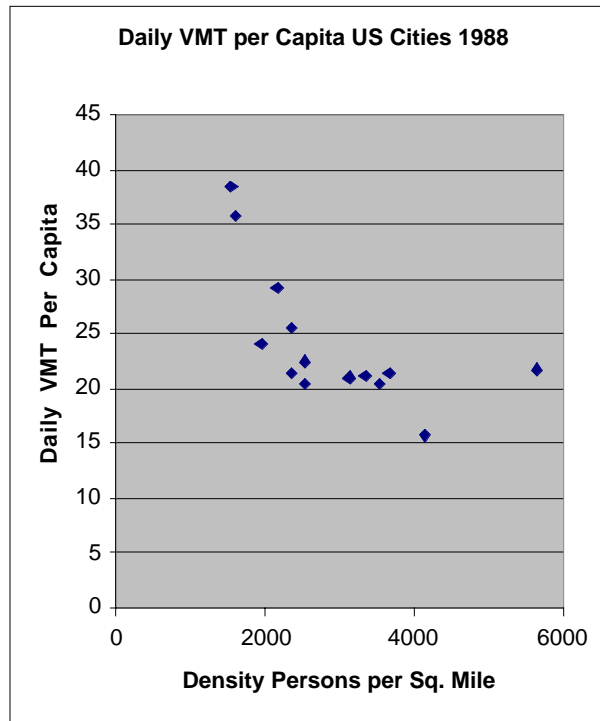
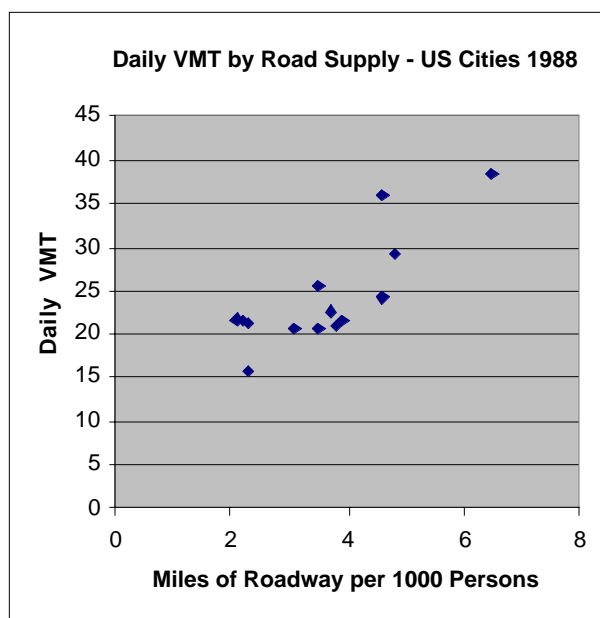


Table 15
DVMT per Capita by Mi. Road/1000 persons US 1998

City/Region	Mi. Rd/ 1000	DVMT/ Cap
Los Angeles	2.1	21.7
San Diego	2.2	21.5
New York	2.3	15.7
San-Fran-Oak.	2.3	21.2
Sacramento	3.1	20.5
Boston	3.5	20.5
Seattle	3.5	25.5
Denver	3.7	22.5
Portland-Vancouver	3.8	21.1
Phoenix	3.9	21.5
Atlanta	4.6	35.8
Minneapolis-St Paul	4.6	24.2
Dallas-Ft. Worth	4.8	29.2
Houston	6.5	38.4



The Use of Time for Travel

Wherever they live and however they travel, people spend about the same amount of time traveling. This was the result of research in the late 1970s and 1980 by Yacov Zahavi, and others²² into time used in travel as reported in several transportation studies of vastly disparate cities.

Looking at Table 16, it can be seen that whether a person lives in Bogotá, Columbia, Washington DC, Calgary, Santiago, Chile, or Portland, OR, the mean number of minutes spent traveling is similar. What differs is the use of modes of travel and travel system speed. This is not to say that everyone travels for this time, there is a distribution of time in each city, but the means are similar. The same is true for different parts of Portland and for different income groups.

As has been seen, there is significant substitution of slow modes for fast in areas of Portland that have more density and mixed land use. The assumption was that people would go to fewer activities or spend more time traveling. As it happens, they did neither.

Table 16
Daily Mean Time of Travel per Traveler. Hours

REGION	Year	Class 1	Class 2	Total
By Income		Hi Inc.	Lo Inc.	
Bogotá, Columbia	N/A	1.05	1.78	
Santiago, Chile	N/A	1.09	1.52	
Singapore	N/A	1.14	1.36	
By Mode Used		Car	Transit	
Washington, DC	1955	1.09	1.27	
	1968	1.11	1.42	
Minneapolis-St. Paul	1958	1.14	1.05	
	1970	1.13	1.15	
All USA	1970	1.06	0.99	
By Car Availability		0- Cars	1+ Cars	
St. Louis	1976	1.06	1.04	1.04
Nuremberg	1975	1.40	1.26	
Total - No Classification				
Toronto	1964			1.09
Calgary	1971			1.11
Montreal	1971			1.18
Portland, OR*	1994			1.09

Source: Zahavi et al, and Metro

*Portland travel includes pedestrian and bicycle travel – the others only motorized modes.

²²Y. Zahavi, M. J. Beckman, and Thomas F. Golob, (1981), The 'UMOT'/Urban Interactions. Prepared for the U.S. Department of Transportation, Report No. DOT/RSPA/DPB-10/7.

The following work focuses on the use of time as a way to raise the issue of what are rational and reasonable measures of performance for the evaluation of the transportation system.

Table 17
Time Spent Traveling—Adults by Urban Index

Urban Index	Mean	Std. Dev.	Freq.
1	77.53	69.36	1725
2	60.66	46.38	1860
3	60.19	47.11	1565
4	58.80	41.70	1432
5	59.31	44.41	1254
6	60.93	44.84	1457
7	60.78	46.78	1651
8	61.05	46.41	1200
9	62.81	48.16	1253
10	65.85	50.23	763
Total	62.90	49.81	14160

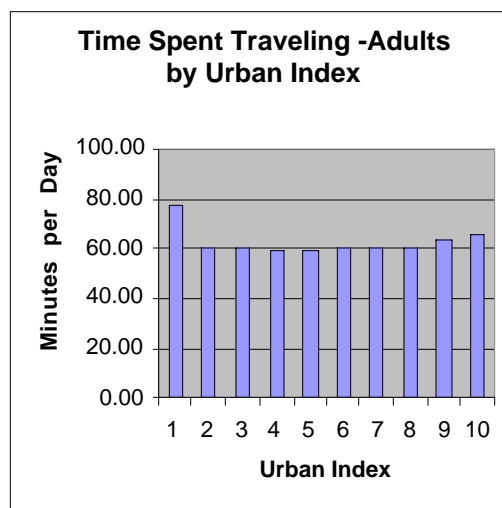
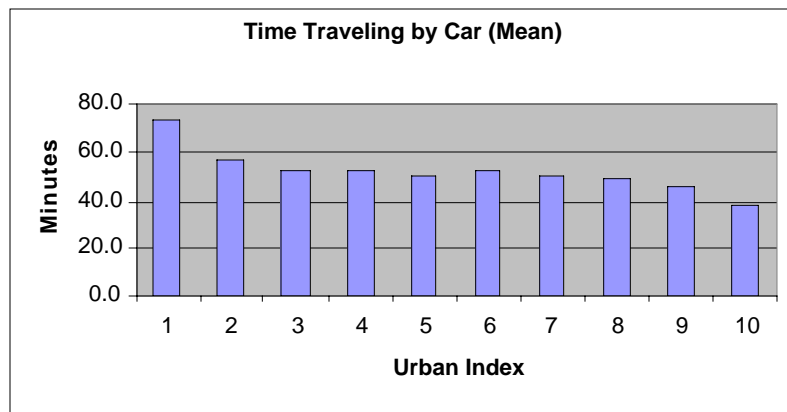
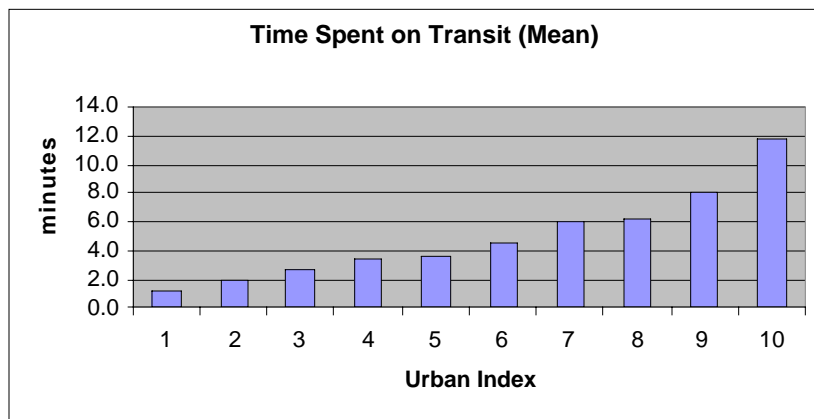
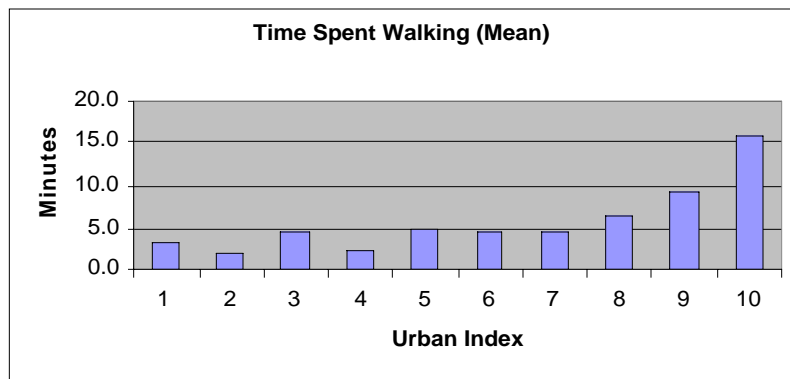


Table 18 and the following graphs show that there is substitution in the use of time among modes, but the total time in travel is similar. It is interesting to note that the third highest urban index shows time spent walking at twice, that of the second highest at three times and the highest at five times that of the suburbs. Remembering that the number of out of home activities did not change among these groups, it is clear that those in the denser areas can accomplish their activity needs, and do so in a healthier way, with no extra use of time.

Table 18
Mean Time of Travel by Mode by Urban Index (Minutes)

Urban Index	Time Car	Time Walk	Time Transit	Total	Freq.
1	73.2	3.3	1.1	77.5	1725
2	56.7	2.0	2.0	60.7	1860
3	52.9	4.5	2.8	60.2	1565
4	52.9	2.4	3.5	58.8	1432
5	50.7	5.0	3.6	59.3	1254
6	51.9	4.4	4.6	60.9	1457
7	50.2	4.6	6.0	60.8	1651
8	48.4	6.4	6.3	61.0	1200
9	45.6	9.1	8.1	62.8	1253
10	38.3	15.7	11.8	65.9	763

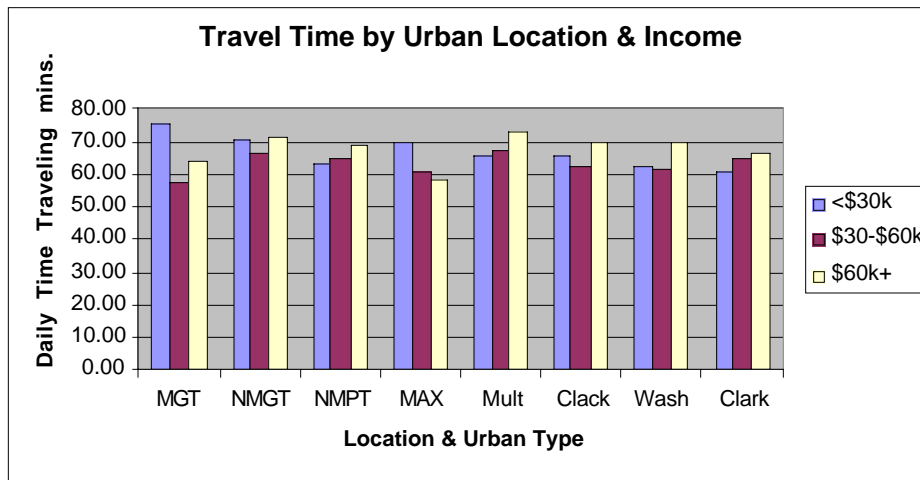




Moving away from the analysis by Urban Index, to an analysis by the household initial survey strata, within which random samples were taken. The first four are in the City of Portland, going from good transit and mixed land-use to no mix and an average level of transit service, with MAX being households within the light rail corridor. The last four are suburban in nature, with Clark County, Washington having some urban mix. Table 19 shows that there is little difference in time used by both urban structure and income.

Table 19
Daily Travel Time by Urban Location & Income

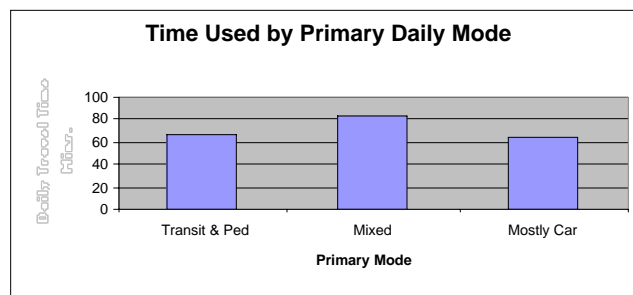
Survey Strata	Label	<\$30k	\$30-\$60k	\$60k+	Total
Mixed+GoodTransit	MGT	75.13	57.78	64.35	66.47
NoMix+GoodTransit	NMGT	70.57	66.52	71.87	69.58
NoMixPoorTransit	NMPT	63.36	65.12	68.69	65.36
MAXCorridor	MAX	69.85	60.94	58.13	62.87
SuburbanMultnomah	Mult	66.14	66.88	73.08	67.92
SuburbanClackamas	Clack	66.10	62.46	69.57	65.74
SuburbanWashington	Wash	62.08	61.77	69.51	64.35
Clark County, WA	Clark	60.39	65.35	66.42	64.51
Total		64.70	64.49	68.45	65.60



Finally we can look at travel time segmented by travelers that use different modes (Table 20). When we look at all-day travel, very few travelers use only one mode. So the following table is set into three groups – those that do not use a car (“Transit and Pedestrian”), those that mix their modes (more than 25% of their time on walk or transit and less than 75% of their time in a car), and those that are primarily car travelers (more than 75% of their travel time by car).

Table 20
Travel Time by Mode Most Used

Primary Mode	Mean	Std. Dev.	Freq.	Modes
Transit & Ped	64.63401	45.20859	347	All Slow
Mixed	82.14394	43.66445	396	>25% slow
Mostly Car	63.58168	37.80112	3722	>75% car
Total	65.30974	39.31762	4465	



Measures of Performance for Transportation

This section addresses the traditional measures of performance of the transport system (congestion, mobility and time lost to congestion), and suggests other measures that might be more appropriate. The traditional measures always lead to warrants for new road building, leading to higher speeds, leading to more low density suburban development, leading to more congestion and lower speeds, leading to more new roads ----and so on.

Percent Congested

Here congestion is measured as defined in the Highway Capacity Manual, by levels of service A through E, with failure at level "F" (below E). This measure is a one hour peak measure (am or pm), although many cities now recognize that they may have to accept more than one hour congested. This measure is an arbitrary, ad-hoc definition developed by traffic engineers around 1960, during the heyday of highway construction.

These levels of congestion are linked to hourly traffic flows, and can thus be defined from traffic counts (present day) and model forecasts (future). Usually expressed as the percent of roads congested for 1 hour, two hours and so on.

Mobility and Value of Time Lost to Congestion

The next concept is that of mobility, defined as the average speed of the network, or types of highway, often linked to congestion by calculating the free (uncongested) speed and the congested speed and using the ratio as a measure of mobility. This is usually expressed as travel time at free speed over travel time under congestion. The next step is to sum all the excess time for all travelers, calculated by this method, assign a value of time (usually \$10 to \$20 per hour, or 16 to 32 cents per minute, and calculate the cost of congestion by multiplying the excess time by the value of time.

This approach assumes that the demand for travel is fixed spatially, and not by time. In reality travelers take actions to conserve time – change destination, travel at a different time, chain activities into a single trip, and in the longer time frame, land develops differently, with more density of both housing and activity locations.

Activities Accessible by Time Increment

This is, perhaps the most tempting. It is simply a measure of activity locations accessible within 10, 20, 30, 40 minutes etc. These could be jobs accessible, retail establishments accessible, retail jobs accessible and so on. This could be by fastest mode, or by each mode separately.

As an example, in a system of a given size in terms of people and jobs, a system with $\frac{1}{2}$ the speed and twice the density of another system would have exactly the same accessibility measure in terms of activities reachable in a fixed time. If average time used remained constant and the same modes were used, the vehicle miles traveled would be halved. The increased densities, however, also make transit more efficient and usable, and increase the probability of walking.

Energy Use per Capita? Per activity Visited?

These are other ways of thinking, we could look at different land use arrangements, with different transport investments, and calculate energy demand from the system, relatively easy to do with current travel demand models, and very easy to do accurately with Los Alamos' new transport model – Transims.

Conclusions & Recommendations

It has been demonstrated that density, mix and urban design all have an effect on travel demand. It is also strongly suggested that mean travel time consumed by travelers per day is relatively constant, suggesting that the amount of travel (miles) is affected by the travel speed in the network. There is a need to consider changes to both single-use land use zoning and the layout of urban and suburban streets. Different future designs can give different travel, car use can be reduced, and walking and transit use increased – leading to less energy consumed, cleaner air, more exercise in traveling and better health. These elements are already a part of urban planning in Portland. While the private market carries out land development, government can take actions to steer or guide development towards a preferred policy land-use scenario.

When looking at the amount of travel in US cities, it is clear that those cities with lower densities, and a larger road supply consume significantly more vehicle miles of travel.

The three cities that have been mainly formed in the last 50 years, under a policy of plentiful supply of roads and freeways, Houston, Atlanta and Dallas-Ft. Worth

clearly have the best road supply, the lowest densities **and the most vehicle use** – Houston and Atlanta in the order of 50% more vehicle miles of travel per capita than comparable sized cities. It is of note that Houston and Atlanta are two of the cities in the US with the most air pollution (along with Los Angeles – a very large city). Urban economic theory and urban land-use forecasting models both suggest that developing land use is strongly affected by the speed of the network. The faster the travel speeds and the more ubiquitous the network, the lower the density developed under free market conditions.

While it is very difficult, politically, to introduce the concept of land use design and control as a part of the solution, and highway over-development as part of the problem, it is a dialog that needs engaging.

There is the need to go much further in developing forecasts that consider the interaction of land-use and transport investment. Currently land-use forecasts are made administratively, or with very little transport supply input, and then are considered fixed while transport solutions are sought. The truth is that different transport investments create different land use futures. There is a real need to carry out forecasts with integrated transport and land-use models. This is a discipline that is very under-developed and in much need of more research.