STATISTICAL ANALYSIS OF URBAN DESIGN VARIABLES AND THEIR USE IN TRAVEL DEMAND MODELS

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EXECUTIVE SUMMARY

Many travel demand models do not account for land use mixing and urban design effects. The purpose of this study is to further the understanding of how aspects of urban design influence transportation choices. This research identifies where it is important for models to account for urban design issues and where there would be minimal or no effect. It is intended to show how much land use change is necessary to significantly affect travel behavior.

An extensive review was conducted of numerous recent studies that investigated the relationships between travel and the mixed-use and pedestrian-oriented design elements of urban areas. Simple statistical correlations have suggested that these elements can encourage shorter trips and trips by non-auto modes but the more rigorous studies have been largely inconclusive.

The research identified eight specific urban design variables for further investigation. These generally fell into one of two categories: those related to accessibility (quantitative) and those related to other characteristics of the urban environment (qualitative). The accessibility variables affect the accessibility of destinations by various modes of travel or increase accessibility to other activities. These included: Census block density, dissimilarity index, entropy index, less auto-dependent urban form, residential parking permit districts and proximity to retail business establishments. The environmental variables included skinny streets and building coverage ratio.[1]

Each variable was studied to determine feasibility for data development and testing. The environmental variables proved to be too difficult to quantify using currently available Geographic Information System (GIS) data and software but should be considered in the future as necessary data and software become available. Several of the accessibility variables were also technically complex and difficult to forecast. Model estimation data was prepared for the Census block, business establishment and residential parking permit variables.

These variables were tested using 1994/1995 Oregon Household Survey Data, along with three other accessibility-related variables currently used in the Portland Metro models. These include local street intersections, household density and employment density. The accessibility variables proved to be closely correlated with one another. It was surmised that they are also closely related to, and therefore would be co-linear with, the other accessibility and environmental variables. For example, increasing the variety of uses in close proximity produces a more attractive pedestrian environment.

[1] Some variables are not clearly quantitative or qualitative and judgment was required to categorize the variable.

Each of the correlated variables showed significance when tested alone. When tested together, some variables failed statistical tests for significance. Based on this evaluation, the focus of the remainder of the study was directed at developing a measure that captured multiple aspects of an accessible mixed-use development pattern. This measure includes:

- The density of local street intersections - where intersections are more prevalent, walk and bike distances tend to be shorter.
- The density of households - with higher densities the average distance between households is shorter, making walking and bicycling easier and more cost-effective to serve with transit.
- The density of retail businesses - higher densities mean shorter travel distances, making it easier for people to shop without using a car and to chain shopping trips together by walking, biking and/or public transit.

A test data set was prepared by compiling the number of local intersections, households and retail business establishments within a half-mile of each household included in the Household Survey Data. Three methods to combine these variables into a composite urban design measure were tested: fuzzy logic, factor analysis and harmonic mean. The results for the three methods were not significantly different and the latter method proved to be easiest to implement. An examination of the results for various neighborhood prototypes indicated that the relative significance of each component was preserved in the composite urban design measure.

The composite urban design measure was tested to determine its effect on both auto ownership and mode choice. In the case of auto ownership, the composite measure did not improve overall explanatory power of the existing model of auto ownership choices which depends on household size, number of workers and income. In the case of mode choice, the composite urban design measure was found to be important in predicting mode choices.

Sensitivity tests were conducted to see how changes in the composite urban design measure would affect the predicted use of non-automobile travel modes. To do this, all areas of the Portland region were stratified into four neighborhood types representing different levels of the composite urban design measure. Type 1 is characterized by discontinuous streets, low-density housing and no retail goods and services, such as the East Portland/Johnson Creek area. Type 2 has somewhat better street connectivity, higher residential density and/or access to retail businesses, such as parts of Lake Oswego. Type 3 has even more of the characteristics of a mixed-use urban neighborhood, such as Garden Home. Type 4 is characterized by a regular street grid, medium- to high-density residential neighborhoods and integral retail businesses, such as the NW 21st/23rd Avenue neighborhood. A summary of neighborhood-type characteristics is included in the following table.

Characteristic	Type 1	Type 2	Type 3	Type 4
Portion of Portland Metropolitan Area	40%	30%	20%	10%
Non-Automobile Mode Share	4.69%	8.96%	12.66%	32.33%
Average Number of Households within ½ mile of TAZ*	976	1779	2869	4567
Average Number of Retail Businesses within ½ mile of TAZ*	3	19	35	121
Average Number of Local Intersections within ½ mile of TAZ*	65	103	168	232
Value of Urban Design Variable	**19**	**128**	**399**	**1496**
Average Number of Retail Employees within ½ mile of TAZ*	125	570	762	2447
Employees/Retail Business	36	30	22	20

*The Metro area was divided into about 1300 Transportation Analysis Zones for analytical purposes.

Average Value by Neighborhood Type

For the initial testing, the value of the composite urban design measure was increased by 10 percent, 20 percent and 30 percent in each of the area prototypes. This corresponded to changes in one or more of the component variables ranging from modest to fairly substantial. Since the values of the composite urban design measure for nearly three-quarters of the Portland area were less than 10 percent of the average values for neighborhoods of Type 4, these marginal increases proved to be ineffective at reducing predicted automobile use. Even the 30 percent across-the-board increase in the composite urban design measure resulted in only half of a percent reduction in predicted auto use.[2]

An additional sensitivity test was performed to see what would happen if all the neighborhoods classified as Type 3 were changed so that their composite urban design values matched the average for neighborhoods classified as Type 4. To do this the values of the composite urban design measures for these neighborhoods was increased an average of 275 percent. Major land use and street system changes would need to occur to achieve this increase. Such a change is estimated to result in a 44 percent increase in predicted non-auto mode trips and a 6.5 percent reduction in auto use in the area affected. The regional effects would be smaller. However, the benefits may be underestimated for reasons noted above.

[2] This reduction may be somewhat underestimated, since the kind of urban design changes necessary to achieve the 30 percent increase would also be likely to affect trip distances and transit accessibility. These were not varied in the sensitivity testing.

Conclusions

This study tested the relationship between mixed land use patterns and travel behavior. Conclusions of this research include:

- A simple mixed-use variable that incorporates measures of residential density, employment density and local street intersection density is useful for predicting travel mode choice.
- There is a strong statistical association between this mixed-use variable and mode choice.
- A statistical model which incorporates this variable explains mode choice behavior better than a model which includes the elements of this measure separately, confirming the concept that land use mixing is useful and probably has some real effect on mode choice behavior.
- This mixed-use variable did not have a significant effect on auto ownership decisions.
- Across the board increases in land use mixing of up to 30 percent has minimal effects on regional auto travel (less than one percent) because most of the region has low mixing values and the effects of mixing are small until values are relatively large.

In summary, while land use mixing does influence mode choice behavior and this influence can be captured in urban travel models, the amount of influence is relatively small. Very large increases in residential, employment and street densities are necessary to achieve even modest decreases in automobile use.

STATISTICAL ANALYSIS OF URBAN DESIGN VARIABLES AND THEIR USE IN TRAVEL DEMAND MODELS

INTRODUCTION

Many planners and policy makers are concerned with the effects of urban design and mixed-use development on transportation choices. Several statistical surveys suggest that mixed-use development patterns are influential in encouraging shorter trip lengths and the use of non-single occupancy vehicle (SOV) travel modes. However, the conclusions derived from researchers are mixed.

Numerous urban design characteristics potentially affect travel behavior. A number of these affect the accessibility of destinations by various modes of travel. For example, if more stores are located within walking distance of a residential neighborhood, then it will be easier for residents to walk to a store to shop. Similarly, if buses run more frequently thus reducing wait time to catch a bus, then people can go more places in the time they have available. This increases accessibility to other activities. A number of other urban design characteristics do not affect accessibility, but may make walking, bicycling or using public transportation more desirable. These could include skinny streets, street trees, building orientation and the amount of parking lots.

Portland Metro's travel demand model uses several urban design variables including mixed land use, retail employment within one mile, total employment within 30 minutes by transit, and number of intersections of local streets. These urban design variables are accessibility-related measures and are correlated with each other. This and the lack of detailed data make it difficult to understand the impacts of individual urban design elements on travel.

The purpose of this research is to better understand the effects of urban design variables so that they can be incorporated into urban travel demand models. This will allow the transportation impacts of urban design policies to be estimated. This research focuses on the accessibility characteristics of urban design variables and their impact on travel behavior. Refining and testing these types of variables leads to a better understanding of urban design variables in transportation models. The study did not address other urban design characteristics. Data to objectively describe these are relatively difficult to obtain and to forecast and are an area for future research.

This report is organized into the following elements:

- Introduction
- Research into the most recent studies of urban design variables
- Selection of the final urban design variables to test
- Preparing the data to calculate the final urban design variables
- Performing statistical analyses and estimating the auto-ownership model with the final urban design variables
- Analyzing urban design variables in the mode choice model

- Carrying out a mixed land-use sensitivity test
- Developing a representative sample area
- Conclusions

This research project is sponsored by the Oregon Modeling Steering Committee (OMSC). The OMSC Performance Measurements Subcommittee provided research and project oversight. Lane Council of Governments (LCOG), Portland Metro (Metro), and the Oregon Department of Transportation (ODOT) staff were responsible for data preparation, model estimation, and analysis of the model results and data.

RECENT STUDIES

Metro and LCOG staff summarized current urban design research conducted in the United States and other countries. This included papers from the Transportation Research Board (TRB), the Federal Transportation Model Improvement Program (TMIP), and research by the consulting firm Parsons Brinckerhoff Quade and Douglas. Studies reviewed, definitions, sources, required data to calculate the value, and an assessment regarding the degree of difficulty to prepare the variables are included in the references in Appendix 1. The categories of urban design variables considered include:

Accessibility	Diversity
Balance	Neighborhood Design
Connectivity	Pedestrian-oriented
Crime	Transit-oriented
Density	

SELECTED VARIABLES

The many variables were categorized into one of two types: quantitative and qualitative. Quantitative variables are more objective and can be easily measured. They deal with land use variety, circulation efficiency and proximity. Qualitative variables are more subjective and deal with the human interaction aspects of urban design that are more difficult to measure, such as building orientation, pedestrian safety and streetscape. It is recognized that the distinction between quantitative and qualitative measures is not always clear and some judgment was required to define these measures. Appendix 2 lists these variables.

After studying the most current research, eight variables were chosen for further analysis based primarily upon their potential for producing significant results. These included skinny streets, Census blocks, dissimilarity index, building coverage, residential parking permit, less auto-dependent urban form (LADUF), entropy index and business establishments. Each variable was analyzed for the feasibility and implementation of use.

Following is a summary of the analyses of each urban design variable. They are defined and discussed in more detail in Appendix 3.

Skinny streets - This typically refers to local streets having a paved width less than 30 feet and a corner turning radius of less than 10 feet. The purpose of skinny streets is to slow traffic and make a friendlier environment for pedestrians. Collecting and forecasting this data is difficult.

Census blocks - The number of Census blocks is correlated to the number of local intersections and other measures of population density. This variable is difficult to forecast for large, currently undeveloped tracts.

Dissimilarity index - The dissimilarity index is a measure of land use mixing. It is a measure of the degree to which differing land uses come into contact with one another. It is calculated by dividing areas into grids, characterizing each grid cell by the predominant land use, and then evaluating the similarity between each grid cell and its neighbors. The results of this measure depend on the choice of grid cell size and the number of land use categories. For example, if the grid cells are small and the number of land use categories is few, the result is a fairly low level of dissimilarity. The complexity of this measure makes it difficult to compute and forecast.

Mean entropy - Entropy is an indicator of land use balance and is like the dissimilarity index. It measures the uniformity in dispersion of various development types. The analysis of this variable is fairly complex and presents some technical challenges to implement. Entropy is not an easy variable to explain to non-technical public and elected officials.

Building coverage index - Building coverage is the proportional land area occupied by buildings. It is associated with a number of urban design attributes, including building orientation, parking supply and orientation, setback, streetscape and density. This variable will likely require aerial photography interpretation software in order to be efficiently produced for an entire urban area. It is not clear how parking structures should be handled.

Less auto-dependent urban form (LAUDF) -This is a composite urban design variable. The value combines measures for density, land use mix and circulation using 150 meter grid cells as the geographic unit of analysis. Although current data is readily available to compute the values, the analysis required to calculate a measure that maximizes its explanatory power is complex and difficult. It is also difficult to forecast this measure.

Residential parking permit areas - The residential parking permit areas are neighborhoods in which long-term weekday on-street parking is available only to area residents with parking permits. These areas tend to be centrally located near major attractors such as retail, service and employment centers. This variable is similar to other accessibility variables because areas where residential parking permits are required tend to be older neighborhoods where there is good street connectivity, bus service, sidewalks and proximity to downtown areas. This variable was found not to be a strong predictor of auto ownership.

Business establishments -Retail and service activities are typically represented in models by employment. However, they can also be represented by retail and service business establishments. While employment is an appropriate indicator of the number of primary trips made to an activity location, it is not particularly useful for predicting the choice of travel mode. Business establishments may be a more useful measure for predicting mode choice.

Each variable was studied to determine feasibility for data development and testing. The environmental variables proved to be too difficult to quantify using currently available GIS data and software but should be considered in the future as necessary data and software become available. Several of the accessibility variables were also technically complex and difficult to forecast. Model estimation data was prepared for the Census block, business establishment and residential parking permit variables.

The variables were tested using 1994/1995 Oregon Household Survey Data and three other accessibility-related variables that are currently used in the Portland Metro models. These include local street intersections, household density and employment density. The accessibility variables proved to be closely correlated with one another. It was surmised that they are also closely related to, and therefore would be co-linear with, the other accessibility and environmental variables. For example, increasing the variety of uses in close proximity produces a more attractive pedestrian environment.

Each of the correlated variables showed significance when tested alone. When tested together, some variables failed statistical tests for significance. Based on this evaluation, the focus of the rest of the study was directed at developing a measure that captured multiple aspects of an accessible mixed-use development pattern. This measure includes:

- The density of local street intersections - where intersections are more prevalent, walk and bicycle distances tend to be shorter.
- The density of households - at higher densities, the average distance between households is shorter, making walking and bicycling easier and more cost effective to serve with transit.
- The density of retail businesses - higher densities mean shorter travel distances, making it easier for people to shop without using a car and to chain shopping trips together by walking, biking and/or public transit.

DATA-SET PREPARATION

There are many ways to calculate mixed use and there is a question as to which calculation provides the most accurate representation of mixed land use patterns. The Portland Metro transportation model is calculated as a harmonic mean - the product of employment and population divided by the sum of employment and population. This formulation appears to work well but it is hard to understand intuitively.

The Portland Metro mixed-use variable involves calculating the mean values of variables being combined and normalizing one of the variables to this mean (Table 1). The data consists of three value levels for each variable - low (L), medium (M) and high (H). The variables are retail businesses within a half mile (RetB), number of households within a half mile (Hhold), and number of local intersections within a half mile (Localint). Each variable is calculated within a half-mile radius of the activity location.

	RetB	Hhold	Localint
L	6	1012	68
M	21	1814	112
H	71	3825	215
Mean	32	2217	132
Normalize factor to RetB		**69.3 (2217/32)**	**4.13 (132/32)**

L-low; M-medium; H-high; RetB-retail businesses within a half mile; Hhold-households within a half mile; Localint-local intersections within a half mile

Table 1. Example of Normalization Procedure

Four tests of composite urban design measures were conducted using a harmonic mean to produce the composite measures.

Composite Urban Design Measures Test I

- Calculate a new-scaled household variable that is normalized to the smaller mean, which is a retail business.
- Calculate harmonic mean. This variable is called the mixed-use variable.

Mixed I = (RetB * (hhold/69.3)) / (RetB + (hhold/69.3))

The mixed I measure is an abstract one and is not easy to understand. Table 2 expresses the calculation in terms of three sample gradations. The RetB and Normhh variable values were chosen for illustrative purposes.

Combine	Rank	RetB	Normhh	Mixretbhh
L-L	9	6	15	4
L-M	8	6	26	5
L-H	7	6	55	5.5
M-L	6	21	15	8.6
M-M	5	21	26	11.6
M-H	3	21	55	15.2
H-L	4	71	15	12.1
H-M	2	71	26	19.1
H-H	1	71	55	31.0

L-low; M-medium; H-high; RetB-retail businesses within a half mile; Normhh-normalized value for households within a half mile; Mixretbhh-mixed value with retail business and households

Table 2. Mixed I Calculation Result Summary

The first column indicates the combined relationship between number of retail businesses (**H**igh, **M**edium, **L**ow) and number of households (**H**igh, **M**edium, **L**ow). The rank column represents the order of the mixed value result. A lower rank suggests a higher mixed land use value. For example, a transportation analysis zone (TAZ) with a medium number of retail businesses and a high number of households has a higher mixed value compared to a TAZ with a high number of retail businesses and a low number of households.

Composite Urban Design Measures Test II

- Calculate a retail business variable, normalized to highest mean, which is number of households.
- Calculate Mixed II.

$$\text{Mixed II} = ((\text{RetB} * 69.3) * (\text{hhold})) / ((\text{RetB} * 69.3) + (\text{hhold}))$$

Test II was done to determine the effect of normalizing to household. The same illustrative variable values as in Table 2 are used in the calculation. Table 3 shows that the two tests result in the same ranking scheme.

Combine	Rank	Nor_retb	Hhold	Mixretbhh
L-L	9	416	1012	295
L-M	8	416	1814	338
L-H	7	416	3825	375
M-L	6	1455	1012	597
M-M	5	1455	1814	807
M-H	3	1455	3825	1054
H-L	4	4919	1012	839
H-M	2	4919	1814	1325
H-H	1	4919	3825	2152

L-low; M-medium; H-high; Nor_retb-normalized value for retail businesses within a half mile; Hhold-households within a half mile; Mixretbhh-mixed value with retail business and households

Table 3. Mixed II Calculation Result Summary

Composite Urban Design Measures Test III

- Test III was executed to quantify the impact of omitting the normalization process.
- Calculate Composite III without normalization.

$$\text{Mixed III} = (\text{RetB} * \text{hhold}) / (\text{RetB} + \text{hhold})$$

The larger number in this mixed-use formula usually influences this calculation. In this case, number of households has more influence than the number of retail businesses (Table 4). The most effective mixed-use design is one that is “big” and the household and employment are in balance.

Combine	Rank	Retb	Hhold	Mixretbhh
L-L	9	6	1012	5.96
L-M	8	6	1814	5.98
L-H	7	6	3825	5.99
M-L	6	21	1012	20.57
M-M	5	21	1814	20.76
M-H	4	21	3825	20.89
H-L	3	71	1012	66.35
H-M	2	71	1814	68.33
H-H	1	71	3825	69.71

L-low; M-medium; H-high; RetB-retail businesses within a half mile; Hhold-households within a half mile; Mixretbhh-mixed value with retail business and households

Table 4. Mixed III Calculation Result Summary

These three tests showed how the mixed ***harmonic mean*** value is calculated. Test I or Test II is preferred since variables are normalized before calculating the mixed values. This normalization effect accounts for the problem when the average value of one variable is much larger and influences the value of the mixed calculation.

Composite Urban Design Measures Test IV

Harmonic means can also be tested with three variables - number of retail businesses (RetB), number of households (hhold) and number of local intersections (locint).

- Calculate new-scaled household and local intersection variables that are normalized to the smaller mean, which is a retail business.
- Calculate harmonic mean with three variables. This variable is called the mixed-use variable.

The following formula shows how a three dimensional harmonic mean value is calculated.

Mixed IV (ret,hh,locint) =
(RetB * (hhold/69.3) * (locint/4.13)) / (RetB + (hhold/69.3)+ (locint/4.13))

Table 5 suggests that the ranking is due to the well-balanced combination of the three variables. The highest mixed value in this table is the consequence of a well-balanced value of H-H-H for retail, households and intersections. Intuitively, the result is reasonable. If any low category is among the combination, the mix value has a lower rank than another combination near its category. For example, the M-M-L combination has a rank of 17 while M-M-M has a rank of 13 and M-L-H has a rank of 14. Furthermore, the combination with the first rank has the best mixed-use while the combination with the last rank of 27 has the worst mixed use.

Combine	Rank	RetB	Normhh	Norlint	Mixretbhhlint
L-L-L	27	6	15	16.48	38.95
L-L-M	26	6	15	27.15	49.83
L-L-H	24	6	15	52.12	62.81
L-M-L	25	6	26	16.48	53.21
L-M-M	22	6	26	27.15	71.89
L-M-H	20	6	26	52.12	97.13
L-H-L	23	6	55	16.48	70.29
L-H-M	19	6	55	27.15	101.79
L-H-H	16	6	55	52.12	152.35
M-L-L	21	21	15	16.48	97.07
M-L-M	18	21	15	27.15	132.71
M-L-H	14	21	15	52.12	182.25
M-M-L	17	21	26	16.48	142.37
M-M-M	13	21	26	27.15	200.84
M-M-H	9	21	26	52.12	288.60
M-H-L	12	21	55	16.48	206.19
M-H-M	8	21	55	27.15	304.56
M-H-H	4	21	55	52.12	470.89
H-L-L	15	71	15	16.48	167.46
H-L-M	11	71	15	27.15	249.73
H-L-H	7	71	15	52.12	392.48
H-M-L	10	71	26	16.48	269.61
H-M-M	6	71	26	27.15	405.96
H-M-H	3	71	26	52.12	648.98
H-H-L	5	71	55	16.485	452.85
H-H-M	2	71	55	27.152	694.00
H-H-H	1	71	55	52.121	1145.69

L-low; M-medium; H-high; RetB-retail businesses within a half mile; Normhh-normalized value for households within a half mile; Norlint-normalized value for number of local intersections; Mixretbhhlint-mixed value with retail business, households and local intersections

Table 5. Mixed IV Calculation Result Summary

STATISTICAL ANALYSIS IN THE AUTO-OWNERSHIP MODEL

Numerous statistical analyses were tested comparing the different urban design variables in the auto ownership model. The auto ownership model used the 1994/1995 Household Survey Data in the analysis. Multiple variables were used in the estimation, including several combined design variables such as the multi-modal-accessibility-logsum value, and a mixed land use variable (retb, hhold, locint). In addition, Brian Gregor from the Oregon Department of Transportation created a model that used "fuzzy logic"[3] to combine the accessibility variables. This fuzzy logic model combined number of households and workplace proximity to produce a fuzzy logic mixed-use variable. A factor value combining retail, household and local intersection was also developed and used in estimating the auto-ownership model.

Following is a list of the variables with definitions:

- HHhm: number of household by half mile
- Rethm: number of retail employment by half mile
- RetBhm: number of retail business by half mile
- ServBhm: number of service business by half mile
- RetB1m: number of retail business by one mile
- MutAcc: logsum of multi accessibility value from mode choice model (value includes eleven mode constants, impedance, cost, accessibility)
- Totemphm: total employment by half mile
- TotBhm: total business by half mile
- Totemp30T: total employment within 30 minutes by transit
- Locinthm: local intersection by half mile
- Ret.ratio hm/1m: retail employment by half mile/ retail employment by 1 mile
- Ret.ratio hm/Max: retail employ by half mile/maximum retail employ by half mile
- Fuzzmixhm: fuzzy mixed value of household, retail, and intersection by half mile
- Mixrethhhm: mixed, retail and household by half mile
- MixretBhhhm: mixed, retail business and household by half mile
- Mixtotemphhhm: mixed, total employment and household by half mile
- FactretBhhlinthm: factor, retail business, household, local intersection by half mile
- MixretBhhlinthm: mixed, retail business, household, local intersection by half mile
- Dwelling: single dwelling vs. multi dwelling
- Hhsize: household size
- Income: household income
- Work4: number of workers (0,1,2,3)

When tested individually, the accessibility-related variables showed strong statistical significance and explanatory power. The T-statistics and R-square of each accessibility variable in the auto-ownership regression model was similar (Table 6). Thus any one of these variables will not change the model conclusions. Each of these variables explains the same statistical property. Moreover the variables are highly correlated to each other.

[3] Documented in a spreadsheet "FuzzyMixed_v1a.xls". June 18, 2001. brian.j.gregor@odot.state.or.us

Model	Variable Name	T-Stat	R-Square
1. Single Accessibility Variable Test			
1	**HHhm**	-26.27	0.090
2	**Rethm**	-25.00	0.082
3	**RetBhm**	-25.46	0.087
4	**ServBhm**	-22.23	0.068
5	**RetB1m**	-25.29	0.087
6	**MutAcc.**	-21.90	0.082
7	**Totemphm**	-22.80	0.069
8	**TotBhm**	-23.86	0.078
9	**Totemp30T**	-26.79	0.093
10	**Locinthm**	-24.91	0.082
11	**Ret.ratio hm/1m**	-10.45	0.016
12	**Ret.ratio hm/max**	-25.46	0.087
2. Combined Accessibility Variable Test			
13	**Fuzzmixhm**	-25.46	0.108
14	**Mixrethhhm**	-28.62	0.105
15	**MixretBhhhm**	-27.48	0.101
16	**Mixtotemphhhm**	-29.06	0.108
17	**Factretbhhlinthm**	-28.13	0.104
18	**MixretBhhlinthm**	-30.18	0.115
3. Test with Household & Combined			
19	**Hhhm**	-5.21	
	Rethm	-12.00	
	Locinthm	-7.76	0.116
20	**Mixretbhhhm**	-16.84	
	Locinthm	-9.92	0.117
21	**hhsize**	24.73	
	Income	2.76	
	work4	26.00	
	Dwelling	6.20	
	Hhhm	-3.38	
	RetBhm	-8.37	
	Locinthm	-8.42	0.328
22	**hhsize**	24.36	
	Income	2.89	
	Work4	25.17	
	Dwelling	6.41	
	MixretBhhlinthm	-23.16	0.331

Table 6. Auto Ownership Model with Urban Accessibility Variable Test

Models 1 through 12 showed the auto-ownership results with a single accessibility variable. The models show similar results in terms of their T-statistics and R-squares. Models 13 through 18 present auto-ownership results when combined variables such as the various mixed variables and the factor variable are used. The composite mixed variable, MixretBhhlinthm, combines number of retail businesses, number of households, and number of local intersections within a half-mile. It has the highest R-square among the other composite variables.

Models 19 through 22 test whether a composite mixed use variable adds more explanatory value than its components when used separately. Auto ownership was tested with each of the accessibility variables alone and then with a composite mixed value. Models 19 and 20, which include no household and demographic variables, show no benefit in using the mixed variable. The test statistics for model 19, which uses the variables separately, are about the same as for model 20 which uses a composite variable. Moreover, the total variation explained with these models (R-square value) is about the same as for model 18. When the household and demographic variables are added in models 21 and 22, the amount of variation explained increases but there is still no significant improvement in using the composite variable.

The above tests show no evidence of an advantage of using the mixed-use variable. Moreover, using individual accessibility variables or mixed land use variables produce auto-ownership models with similar results.

STATISTICAL ANALYSIS IN THE MODE CHOICE MODEL

The following analysis continues the understanding of mixed use variables in the model choice models. Home-based-other trips were used for the mode choice model test. Table 7 shows the correlation between number of retail businesses within a half-mile (prethbhm), number of households within a half-mile (phhhm), number of local intersections within a half-mile (plinthm), mixed land use within a half-mile (pmxrbhli), a factor variable composed of the first three variables within a half-mile, and a non-auto mode dummy variable (wlkbikbus).

. cor retbhm hhhm linthm mxrbhli factor wlkbikbus (obs=26480)

	retbhm	hhhm	linthm	mxrbhli	factor	wlkbikbus
retbhm	1.0000					
hhhm	0.5807	1.0000				
linthm	0.5007	0.7961	1.0000			
mxrbhli	0.8654	0.7981	0.6824	1.0000		
factor	0.6761	0.9611	0.9139	0.8478	1.0000	
wlkbikbus	0.5489	0.4234	0.3965	0.5445	0.4772	1.0000

prethbhm-number of retail businesses within a half-mile; phhhm-number of households within a half-mile; plinthm-number of local intersections within a half-mile; pmxrbhli-mixed land use within a half-mile; factor-variable composed of the first three variables within a half-mile; wlkbikbus-a non-auto mode dummy variable

Table 7. Correlation Matrix

All variables are based on the production location which is home. According to the correlation table, retail businesses (prethbhm) and mixed land-use (pmxrbhli) have the highest correlation to the non-auto mode (wlkbikbus).

The following two simple regression models tested which accessibility variable has more explanatory power in choosing the non-auto mode. Model 1 shows how the mixed land-use composite value of number of retail businesses, number of households, and number of local intersections are related to choosing the non-auto mode. Model 2 tested the factor value from the same land use combination. Model 1 has a stronger R-squared and T-statistic value compared to Model 2.

Simple Regression Model 1

```
. reg wkbkbs pmxrbhli

  Source |       SS       df       MS          Number of obs =   26480
---------+------------------------------       F(  1, 26478) =11158.14
   Model |  210.200173     1  210.200173       Prob > F      =  0.0000
Residual |  498.799853 26478  .018838275       R-squared     =  0.2965
---------+------------------------------       Adj R-squared =  0.2964
   Total |  709.000026 26479  .026775937       Root MSE      =  .13725

-----------------------------------------------------------------------
wlkbikbus|      Coef.   Std. Err.       t     P>|t|       [95% Conf.
Interval]
---------+-------------------------------------------------------------
pmxrbhli |   .0001799   1.70e-06    105.632   0.000       .0001766
.0001833
   _cons |   .0536982   .0009641     55.697   0.000       .0518085
.0555879
-----------------------------------------------------------------------
```

Simple Regression Model 2

```
. reg wlkbikbus factor

  Source |       SS       df       MS           Number of obs =   26480
---------+------------------------------        F(  1, 26478) = 7806.44
   Model |   161.43664     1   161.43664        Prob > F      =  0.0000
Residual |  547.563386 26478  .020679938        R-squared     =  0.2277
---------+------------------------------        Adj R-squared =  0.2277
   Total |  709.000026 26479  .026775937        Root MSE      =  .14381

-----------------------------------------------------------------------
wlkbikbus|      Coef.   Std. Err.       t     P>|t|       [95% Conf.
Interval]
-----------------------------------------------------------------------
  factor |   .0856047   .0009689     88.354   0.000       .0837056
.0875037
   _cons |   .1030294   .0008837    116.586   0.000       .1012973
.1047615
-----------------------------------------------------------------------
```

An analysis similar to that done in the auto ownership model was performed with the home-based-other mode choice model. First, individual accessibility variables were tested. Then various mixed land-use variables were added to the models. The following four home-based-other (HBO) mode choice tests were conducted.

Home-Based-Other Mode Choice Model 1

This model tested each urban accessibility variable separately - number of retail businesses, number of households and number of local intersections. Not all modes revealed a strong statistical relationship to each urban accessibility variable due to the strong co-linearity problem as shown in Table 8. Dropping several insignificant accessibility variables due to small t-statistics should improve this model.

Home-Based-Other Model I				Home-Based-Other_Model 2			
R-sq	**.27***	**coef.**	**t-stat.**	**R-sq**	**.269***	**coef.**	**t-stat.**
10	Walk	-0.82	-10.70	10	Walk	-0.72	-9.50
20	Bike	-3.99	-23.70	20	Bike	-3.99	-24.00
30	Transit	-4.78	-21.90	30	Transit	-4.70	-22.20
34	TranImp	-0.03	-6.10	34	TranImp	-0.03	-6.20
51	Cost	-0.55	-11.90	51	Cost	-0.53	-11.60
100	AutoIvtt	-0.10	-6.60	100	AutoIvtt	-0.10	-6.70
107	Biketime	-0.12	-13.10	107	Biketime	-0.12	-13.10
108	Walktime	-0.09	-33.00	108	Walktime	-0.09	-33.00
361	Walkcv0	2.73	21.10	361	Walkcv0	2.65	20.80
362	Bkcv0	2.43	10.80	362	Bkcv0	2.40	10.90
364	Buscv0	4.15	28.00	364	Buscv0	4.09	28.20
371	Walkcv1	0.68	7.50	371	Walkcv1	0.66	7.30
372	Bkcv1	0.54	2.70	372	Bkcv1	0.53	2.70
374	Buscv1	1.01	6.10	374	Buscv1	1.01	6.00
401	Wkhhhm	0.0002	7.90	421	Wklinshm	0.0009	1.80
402	Bkhhhm	0.0000	-0.10	422	Bklinshm	0.0037	3.30
403	bushhhm	0.0001	2.10	423	Buslinshm	0.0052	5.00
411	wkrtbhm	0.0007	1.30	431	Wkmixrtbhm	0.0213	8.50
412	bkrtbhm	-0.0004	-0.30	432	Bkmixrtbhm	0.0039	0.70
413	busrtbhm	-0.0003	-0.40	433	Busmixrtbh	0.0082	1.80
421	wklinshm	-0.0001	-0.20				
422	bklinshm	0.0042	3.50				
423	buslinshm	0.0048	4.20				

*R-square value

Table 8. Home-Based-Other Mode Choice Model with Urban Accessibility Variable Test

Home-Based-Other Mode Choice Model 2

Individual accessibility variables were not successful in Model 1. Therefore, a model including number of local intersections and a mixed land-use combination of number of households and number of retail businesses was tested. This model showed better statistics compared to Model 1 as shown in Table 8. However, some variables still need to be dropped because of low t-statistics.

Home-Based-Other Mode Choice Model 3

From Model 1, the number of local intersections seemed to be correlated to the number of retail businesses. This model tested two accessibility variables - households and retail businesses. The result shows that the number of retail businesses is a weak indicator of accessibility while the number of households dominates that relationship (Table 9).

Home-Based-Other Model 3				Home-Based-Other Model 4			
R-sq	**.268***	**coef.**	**t-stat.**	**R-sq**	**.267***	**coef.**	**t-stat.**
10	Walk	-0.84	-12.30	10	Walk	-0.49	-9.10
20	Bike	-3.75	-25.20	20	Bike	-3.61	-31.40
30	Transit	-4.37	-23.20	30	Transit	-3.92	-26.60
34	TranImp	-0.04	-6.80	34	TranImp	-0.04	-7.40
51	cost	-0.54	-11.80	51	Cost	-0.53	-11.50
100	autoIvtt	-0.11	-7.10	100	AutoIvtt	-0.11	-7.60
107	Biketime	-0.13	-13.60	107	Biketime	-0.13	-13.80
108	Walktime	-0.09	-33.40	108	Walktime	-0.09	-34.00
361	Walkcv0	2.72	21.20	361	Walkcv0	2.65	20.80
362	Bkcv0	2.48	11.10	362	Bkcv0	2.38	10.80
364	Buscv0	4.20	28.60	364	Buscv0	4.10	28.50
371	Walkcv1	0.67	7.50	371	Walkcv1	0.68	7.50
372	Bkcv1	0.60	3.10	372	Bkcv1	0.57	2.90
374	Buscv1	1.07	6.40	374	Buscv1	1.06	6.40
401	wkhhhm	0.0002	10.20	431	Wkmixrtbhm	0.00053	12.50
402	bkhhhm	0.0001	2.80	442	BKmixrtbhm	0.00042	4.90
403	bushhhm	0.0002	5.70	443	Busmixrtbhm	0.00048	6.70
411	wkrtbhm	0.0007	1.30				
412	bkrtbhm	0.0001	0.10				
413	busrtbhm	0.0003	0.30				

*R-square value

Table 9. Home-Based-Other Mode Choice Model with Urban Accessibility Variable Test

Home-Based-Other Mode Choice Model 4

One combined mixed land-use variable, consisting of the number of retail businesses, the number of households and the number of local intersections, improved the model and produced strong t-statistics for all modes as shown in Table 9.

These models are very similar to each other in terms of the R-squared values. To understand the impacts of number of households, number of businesses, number of local intersections or other urban design issues, composite mixed values should be implemented. This composite value provides a solution to the co-linearity problem between urban design variables and allows planners and engineers to measure how design types affect travel behavior.

MIXED LAND USE SENSITIVITY TEST

It is important to understand the sensitivity of an urban accessibility variable when used in modeling. Table 10 summarizes the average values of urban accessibility variables and non-auto travel for the four Portland neighborhood prototypes described earlier. These partitions group TAZs that have similar values of non-auto travel for home-based-other trip purposes. The table shows that the proportions of the Portland metropolitan area are not evenly distributed among these areas. Only 10 percent of the metropolitan area averages 32.33 percent of non-auto mode share, while 70 percent of the metropolitan area has below 10 percent of non-auto mode share.

The relationship between land use mixing and non-auto travel is not linear. The effect of density increase is greater when density is higher than when density is lower. This can be seen by comparing the differences between Types 1 and 2 with the differences between Types 3 and 4. It is also interesting to note that retail employment per business declines as the non-auto mode increases. This supports the hypothesis that large retailers cater more towards serving auto travel.

	Type 1	Pct of region	Type 2	Pct of region	Type 3	Pct of region	Type 4	Pct of region
		40%		**30%**		**20%**		**10%**
Nonauto Mode	4.69%		8.96%		12.66%		32.33%	
HH_hm	976		1779		2869		4567	
Retb_hm	3		19		35		121	
Locint_hm	65		103		168		232	
Mxretbhhli_hm	19		128		399		1496	
Ret_hm	125		570		762		2447	
Ret_emp/business	36		30		22		20	

HH_hm-number of household by half mile; RetB_hm-number of retail business by half mile; Locint_hm-local intersection by half mile; MixretBhhli_hm-mixed, retail business, household, local intersection by half mile; Ret_hm-number of retail employment by half mile; Ret_emp/business-average number of retail employees/establishment.

Table 10. Non-Auto Mode and Land use Data Summary by Four Area Types

Table 11 hypothetically depicts the impact of mixed land use. A sensitivity test was done to the variable mxretbhhli_hm. The variable combined three attributes - number of retail businesses, number of households and number of local intersections by half mile. There are three tests for all regions and four tests for Type 3.

All Type Mixed Use Increases			Type 3 Mixed Use Increases		
Mode	Mode Share (%)	Change (%)	Mode	Mode Share (%)	Change (%)
Walk			**Walk**		
walk base	7.57		walk base	8.99	
walk 10%	7.68	1.51	walk 10%	9.13	1.54
walk 20%	7.80	3.02	walk 20%	9.27	3.09
walk 30%	7.91	4.54	walk 30%	9.41	4.67
			Walk 3 to 4	13.16	46.34
Bike			**Bike**		
Bike base	1.08		Bike base	1.35	
Bike 10%	1.09	1.07	Bike 10%	1.37	1.28
Bike 20%	1.10	2.14	Bike 20%	1.38	2.58
Bike 30%	1.11	3.22	Bike 30%	1.40	3.89
			Bike 3 to 4	1.86	37.69
Bus			**Bus**		
Bus base	1.66		Bus base	2.32	
Bus 10%	1.68	1.52	Bus 10%	2.35	1.33
Bus 20%	1.71	3.07	Bus 20%	2.38	2.68
Bus 30%	1.73	4.63	Bus 30%	2.42	4.05
			Bus 3 to 4	3.27	40.86
Auto			**Auto**		
Auto base	89.70		Auto base	87.34	
Auto 10%	89.55	-0.17	Auto 10%	87.15	-0.21
Auto 20%	89.39	-0.34	Auto 20%	86.96	-0.43
Auto 30%	89.24	-0.51	Auto 30%	86.77	-0.65
			Auto 3 to 4	81.71	-6.44
Total Non-auto			**Total Non-auto**		
Nonauto base	10.30		Nonauto base	12.66	
Nonauto 10%	10.45	1.47	Nonauto10%	12.85	1.47
Nonauto 20%	10.61	2.94	Nonauto20%	13.04	2.96
Nonauto 30%	10.76	4.41	Nonauto30%	13.23	4.47
			Nonauto 3 to 4	18.29	44.41

Table 11. Hypothetical Impacts of Mixed Land Use

Three tests were done to evaluate the potential region-wide effects of increasing mixed use. Mixed use values were increased in all area types and the region-wide effects on mode choice were calculated using HBO Model 4 evaluated in the previous section. The first test increased mixed use by 10 percent, the second by 20 percent and the third by 30 percent. The results of these tests are shown in the left side of Table 11. It can be seen that even a 30 percent across the board increase in the mixed use value only decreases the auto mode share by 0.51 percent (from 89.7 percent to 89.24 percent). A limited effect should be expected because most of the Portland region has low mixed-use values and correspondingly high auto mode shares. This is shown in Table 11.

A fourth test was done to see what would happen if the mixed value of all of Type 3 were raised to the level of Type 4, an increase of approximately 275 percent. The results of this test and the other three tests on Type 3 alone are shown in the right side of Table 11. The 275 percent increase in mixed use increased the non-auto mode share by 44 percent in the area type and decreased the auto mode share by 6.5 percent. This test illustrates how difficult it is to influence mode shares by urban accessibility alone. Note that the changes in region-wide averages would be smaller. As the mixed use value increases, so does density. This can result in shorter trips which will also influence mode share.

REPRESENTATIVE SAMPLE LOCATIONS

The map following Appendix 3 shows locations of the four prototypical neighborhoods described earlier, plus the Jantzen Beach retail mall. It is difficult to translate from quantitative analysis to the real world. The aerial photography map showing the actual location of businesses, households and local streets might help the analyst to understand the concept of mixed land use as it appears in reality.

Three elements are shown: retail business location, household location and local streets. Five locations were chosen to demonstrate the combination of these three variables. Northwest 21st/22nd, Garden Home, Lake Oswego, and East Portland/Johnson Creek illustrate neighborhood prototypes 4 through 1, respectively. Jantzen Beach represents the special case of a suburban regional mall characterized by concentrations of retail and service businesses in low density neighborhoods and with poor local street connectivity. As depicted on the map, there are clear differences between the land use types. Non-auto mode shares are also different among these land use types. The variance is shown in Table 12.

Location	Mixed Type (Retail Business, Household, Local Intersection)	Non-Auto Mode Share (Percent)
Northwest 21st/22nd	HHH	32
Jantzen Beach Mall	HLL	6
Garden Home	MMM	15
Lake Oswego	LHM	9
Johnson Creek	LLL	5

H-high; M-medium; L-low

Table 12. Sample Location Summary

CONCLUSIONS

This study tested the relationship between mixed land use patterns and travel behavior. It evaluated a number of potential measures and found that most are not practical to use for forecasting policy effects. The study found that the practical forecasting measures are ones that measure the accessibility effects of mixed land use patterns. That is, they measure how land use patterns and the street layout affect the ease of getting to urban activities by walking, bicycling and using public transportation. They do not measure the aesthetic qualities of the urban landscape that might have some bearing on travel choices.

Several formulations of mixed use variables were tested to determine their effects on travel behavior. It was found that a simple mixed-use variable that incorporates measures of residential density, employment density and local street intersection density is useful for predicting travel mode choice. There is a strong statistical association between this variable and mode choice. Moreover, a statistical model which incorporates this variable explains mode choice behavior better than a model which includes the elements of this measure separately. This confirms that the concept of land use mixing is useful and probably has some real effect on mode choice behavior. However, it was also found that this variable did not have a significant effect on auto ownership decisions.

Sensitivity tests were performed using the model that incorporated the mixed use variable to determine the potential effects of strengthening mixed land use patterns in the Portland metropolitan region. Transportation analysis zones were grouped into four areas based on having similar averages for non-auto travel. The average land use mixing values in these areas corresponded to the non-auto mode share averages (more mixing = less auto use). It was found that across the board increases in land use mixing of up to 30 percent has minimal effects on regional auto travel (less than one percent) because most of the region has low mixing values and the effects of mixing are small until values are relatively large.

To evaluate the potential effects of a large policy intervention, the land use mixing value of the next to the highest area was increased to be the same as that of the highest area. This was a 275 percent increase. With this change, the estimated non-auto mode share increased by 44 percent while the auto mode share decreased by 6.5 percent in the area. The region wide effects would be smaller. However, this does not account for the potential for shorter trips in the much denser area.

It appears that while land use mixing does influence mode choice behavior and that this influence can be captured in urban travel models, the amount of influence is relatively small. Very large increases in residential, employment and street densities are necessary to achieve even modest decreases in automobile use.

APPENDIX 1
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APPENDIX 2
URBAN DESIGN VARIABLES CONSIDERED

Potential Micro-Scale Design Variables for Travel Demand Models

CATEGORY		DESCRIPTION
1	**Accessibility**	"DIST" - straight-line distance from the regional CBD to the cluster
2	**Accessibility**	"Number of Jobs w/ Walk Access"
3	**Accessibility**	"Number of Residents w/ Walk Access"
4	**Accessibility**	# of access points / perimeter length
5	**Accessibility**	# Retail / Service Employees within x minutes by mode y
6	**Accessibility**	**# Retail / Service Establishments within x minutes by mode y**
7	**Accessibility**	Average # of a Specific Commercial Establishments within a Time Limit
8	**Accessibility**	Average Transit Accessibility Index
9	**Accessibility**	Car Dependency Workers Percentage
10	**Accessibility**	Directness of Non-Motorized Network
11	**Accessibility**	Household to Job Accessibility
12	**Accessibility**	Job to Household Accessibility
13	**Accessibility**	Neighborhood Shopping Index
14	**Accessibility**	Number of Stations Within the 30-Minute Range
15	**Accessibility**	Pedestrian Accessibility Index
16	**Accessibility**	Percentage of Neighborhood Within 1/4 Miles of Convenience Store
17	**Accessibility**	Transit Accessibility Index
18	**Balance**	"Employment/Population" - # of jobs within a 5 km radius of the zone centroid divided by the population within this same 5 km radius.
19	**Balance**	"Entropy Index" {Sum[p*ln(p)]}/ln(k)
20	**Balance**	"Job Balance" - ratio of jobs to dwelling units
21	**Balance**	"Jobs - Housing Ratio" - jobs /dwellings
22	**Balance**	**"Mean Entropy"**
23	**Balance**	"Mix of Land Use (Land Balance)" - Entropy index of land-use mixture within one mile radius of downtown stations and two mile radius of all other stations.
24	**Balance**	"Normalized Employment / Population" - Number of jobs within a 5 km radius of the zone centroid, normalized on the range 0 to 1 by dividing by the largest observed value for jobs within a 5 km radius.
25	**Balance**	"Ratio of Jobs to Housing Units" - jobs / dwelling units
26	**Balance**	Balance of Census Tract Where Work Trip Ends (job to household ratio)
27	**Balance**	Entropy
28	**Bicycle**	Bicycle Path Width

CATEGORY		DESCRIPTION
29	**Bicycle**	"Bicycle Network Connectivity" - % of site ingress / egress rights-of-way that have bike route continuity.
30	**Bicycle**	Percent of potential bike trip on a bike path
31	**Bicycle**	"Curb Lane Width" - Curb lane width excluding gutter section
32	**Connectivity**	"Block Texture" - average blocks per acre
33	**Connectivity**	"Number of Intersections per Acre"- # of intersections / acre
34	**Connectivity**	"Parcel Texture" - average parcel size
35	**Connectivity**	Arterial-Collector Intersections per Road Mile
36	**Connectivity**	Blocks per Square Mile
37	**Connectivity**	**Census Blocks**
38	**Connectivity**	Cul-de-sacs
39	**Connectivity**	Cul-de-Sacs per Road Mile
40	**Connectivity**	Intersections
41	**Connectivity**	Intersections
42	**Connectivity**	Intersections
43	**Connectivity**	Intersections
44	**Connectivity**	Intersections
45	**Connectivity**	Intersections
46	**Connectivity**	Intersections
47	**Connectivity**	Intersections per Road Mile
48	**Connectivity**	Miles of streets
49	**Connectivity**	Network Structure
50	**Connectivity**	Percentage Cul-de-sacs
51	**Connectivity**	Percentage of Four-Way Intersections
52	**Crime**	Perception of Safety
53	**Diversity**	"EMPENT" - reflects the amount of employment mix in each cluster
54	**Diversity**	"Land-Use Diversity" - proportion of dissimilar land uses among 1-acre grid cells
55	**Diversity**	"MIXA" - degree of land-use mixing in the tract where trips began and end.
56	**Diversity**	"MIXEDUSE" -used to show the degree of use mixing.
57	**Diversity**	"MIXHI "/ "MIXMED" - variables indicating the land use diversity within the station area.
58	**Diversity**	"MIXHI"
59	**Diversity**	"MIXMED"
60	**Diversity**	"OFFICE"
61	**Diversity**	"RETAIL"

CATEGORY		DESCRIPTION
62	**Diversity**	"TENANCY"-type of tenant
63	**Diversity**	% total floorspace in office; % total floorspace in retail
64	**Diversity**	Availability of services within 1/4 mile of a site
65	**Diversity**	Commercial Establishments per 10,000 Population
66	**Diversity**	Commercial Uses within 300 feet of residential
67	**Diversity**	**Dissimilarity Index**
68	**Diversity**	Household distance to nearest grocery, gas station, or park
69	**Diversity**	Jobs / Population Ratio
70	**Diversity**	Landscape ecology “patch” metrics
71	**Diversity**	Mix of uses within 1/4 mile of a site
72	**Diversity**	Non-residential activities in the immediate vicinity
73	**Diversity**	Presence of food/drug store
74	**Diversity**	Proportion of commercial parcels w/vertical mixed use
75	**Diversity**	Proportion of Single-Family Homes
76	**Diversity**	Retail / Service Accessibility
77	**Diversity**	Retail / Service Accessibility
78	**Diversity**	Retail / Service Accessibility
79	**Diversity**	Retail / Service Accessibility
80	**Diversity**	Retail / Service Accessibility
81	**Diversity**	Retail / Service Accessibility
82	**Nbhd Design**	"Convenience Shopping Proximity" - % of dwellings within 1/4 mi. of a grocery store
83	**Nbhd Design**	"Neighborhood Completeness" - % of key uses present or adjacent
84	**Nbhd Design**	% Commercial Bldgs built prior to 1951
85	**Nbhd Design**	% Driveways / block face
86	**Nbhd Design**	% garages setback from house or served by alley
87	**Nbhd Design**	% houses with front porches
88	**Nbhd Design**	% no garage / single-car garage
89	**Nbhd Design**	% of blocks with Service alleys
90	**Nbhd Design**	% right-of-way
91	**Nbhd Design**	Average Age of Development
92	**Nbhd Design**	Block length+Width
93	**Nbhd Design**	Multiple use parcels
94	**Nbhd Design**	On-Street Parking Meters
95	**Nbhd Design**	Preponderance of Convenient Services
96	**Nbhd Design**	**Residential parking permit required for daytime on-street parking**
97	**Nbhd Design**	Retail / Service at street level

CATEGORY		DESCRIPTION
98	**Nbhd Design**	Setbacks / Bldg Orientation
99	**Nbhd Design**	"Neighborhood Classification"
100	**Nbhd Design**	**Building Coverage**
101	**Nbhd Design**	**"LADUF" Less Auto-Dependent Urban Form**
102	**Ped**	% of right-of-way for roadway
103	**Ped**	Avg Distance between street lights
104	**Ped**	Factor: design dimension
105	**Ped**	Pedestrian and Bicycle Friendliness
106	**Ped**	Pedestrian Environment Factor
107	**Ped**	Provision of sidewalks
108	**Ped**	Right-of-way Design
109	**Ped**	Traffic volumes
110	**Ped**	Urban Vitality Index
111	**Ped**	Retail Customers / SF (measure of economic vitality)
114	**Ped**	Mean age of development
115	**Ped**	"ARTLEN" - Measures the total length of all arterial streets wider than 2 travel lanes, within a 1/2-mile radius of each BART station.
116	**Ped**	"ARTLEN" - Total length of arterials wider than two lanes.
117	**Ped**	"Average Pedestrian Factor"
118	**Ped**	"FWYPRX" - indicates whether a freeway traverses the station area.
119	**Ped**	"GRID" - indicates whether the station area street pattern resembles a grid pattern.
120	**Ped**	"Pedestrian Environmental Factor" - building setback
121	**Ped**	"Pedestrian Environmental Factor" - ease of street crossings
122	**Ped**	"Pedestrian Environmental Factor" - existence of topological barriers
123	**Ped**	"Pedestrian Environmental Factor" - measure of walk/bike factor.
124	**Ped**	"Pedestrian Environmental Factor" - street connectivity
125	**Ped**	"Pedestrian Network Connectivity" - % of site ingress / egress rights-of-way that have sidewalk continuity.
126	**Ped**	"Sidewalk Availability" (PEF)
127	**Ped**	"Sidewalk Ratio"
128	**Ped**	"Sidewalk" or "Trail Continuity" - A factor that is correlated with the distance pedestrians will travel
129	**Ped**	"Street Connectivity" - ratio of intersections to intersections and cul-de-sacs
130	**Ped**	Driveway Density
131	**Ped**	Length of Roads per Person

CATEGORY		DESCRIPTION
132	**Ped**	Neighborhood Environment
133	**Ped**	Presence of Sidewalk
134	**Ped**	Type of Roadside Development (AREA)
135	**Ped**	Distance From the Urban Center
136	**TOD**	"Ease With Which Employees and Residents Can Use Transit" -miles of transit routes through the sites * number of transit vehicles traveling those routes each day / total site acres
137	**TOD**	"FWYINT" - number of freeway interchanges within a 0.8-km (0.5-mi.) radius of a BART station.
138	**TOD**	"N" - number of parking spaces associated with each space type (i) and garage (j).
139	**TOD**	"PARKING" - the number of parking spaces at each station.
140	**TOD**	"Transit Friendliness Factor" - A function of the characteristics of the area surrounding a transit stop.
141	**TOD**	"Transit Serviceability Index" A subjective variable that describes the ease of service by transit
142	**TOD**	Activity near transit stops
143	**TOD**	Aesthetic Urban Setting
144	**TOD**	PARK/EMP
145	**TOD**	Parking Ratio
146	**TOD**	Parking Spaces per 1000 Commercial Building Density Jobs
147	**TOD**	Parking Stall Ratio
148	**TOD**	Percent Vacant Parking
149	**TOD**	**"Skinny Streets" Attributes**
***Highlighted indicates selected variable for further study**		

URBAN DENSITY VARIABLES CONSIDERED

Potential Variables Describing Size or Intensity of Use

CATEGORY		DESCRIPTION
1	**Density**	"Commercial Building Density" - avg. non-residential building FAR: ratio of floor area to total parcel area.
2	**Density**	Intensity of land uses
3	**Density**	Commercial Building Density - Employment Density
4	**Density**	Commercial Building Density- Employees per Acre
5	**Density**	Commercial Building Density - Job Density (per acre)
6	**Density**	Households per Residential Acres
7	**Density**	Households per Total Acres
8	**Density**	Population per Residential Acres
9	**Density**	Population per Total Acres
10	**Density**	"Residential Density"- number of homes per acre of residential area
11	**Density**	Log of Household Density
12	**Density**	" Commercial Building Density Population Density" - Commercial Building Density population / geographic area
13	**Density**	% of jobs located in the Commercial Building Density
14	**Density**	Average Retail Density
15	**Density**	"EMPDENA" - average gross employment density at origin and destination of trips ending in the tract.
16	**Density**	land use / total area
17	**Density**	"Gross Employment Density" - # of employees within a designated geographic area / size of the geographic area
18	**Density**	"Gross Population Density" - Entire population within a designated geographic area / size of the designated area
19	**Density**	Overall Zoning Density
20	**Density**	% of multifamily dwellings / geographic area.
21	**Density**	"Population Density" - total population / acre or mile
22	**Density**	"Population in Households" - total population / total number of households
23	**Density**	"BLGHEIGHT" - # of stories of office buildings.
24	**Density**	"Residential Density" - units / net residential acre
25	**Density**	Commercial Floor to Area Ratio
26	**Density**	dwelling units / net residential acre
27	**Density**	Retail Floor Area to Area Ratio
28	**Density**	Gross Population Density (DEN)
29	**Density**	"Area Type" - defined in terms of intensity

CATEGORY		DESCRIPTION
30	**Density**	"DENSITY" - gross density of office space in a cluster
31	**Density**	Inhabitants in a Station's Catchment Area
32	**Density**	Inhabitants in the Service Area
33	**Density**	"Floor Space Per Worker (FSW)" - floor space / # of workers
34	**Density**	"SPACE / 25" - office space / a constant 25 square meters per worker for all years
35	**Density**	"Local Serving" Employment Density
36	**Density**	Gross Population Density
37	**Density**	Net Household Density
38	**Density**	Net Residential Density
39	**Density**	Gross Density Households per Acre
40	**Density**	"Change in Employment Density" - change in employment density from base to future year.
41	**Density**	"Change in Population Density" - change in population density from base to future year.
42	**Density**	Square Feet Per Employee
43	**Density**	"Average Residential Density" - dwelling units / net acre of all residential land
44	**Density**	Employees per Net Acre of All Employment Land
45	**Density**	"POPDENA" - avg. of the pop. density at origin and destination of all trips.
46	**Density**	Household Density- households / acre
47	**Density**	Residential Density Gradient
48	**Density**	dwelling units / acre
49	**Density**	average population / square mile
50	**Density**	"Floor-Area Ratio" - total building area / total land area.
51	**Density**	(Population + Employment) / Land Area
52	**Density**	Building Height
52	**Size**	Commercial Building Density Employment Size
53	**Size**	Commercial Building Density jobs
53	**Size**	"Commercial Coverage" - % of commercial area within 1/4 mile of destination.
54	**Size**	"Proportion of Population in Commercial Building Density " - % of population in Commercial Building Density
54	**Size**	"Build-Out Potential" - max. potential floor area that is allowable under current zoning
55	**Size**	Total Number of Households Within a Geographic Area
55	**Size**	Total Zonal Employment

CATEGORY		DESCRIPTION
56	**Size**	Total Zonal Retail Employment
56	**Size**	Total Zonal University Enrollment
57	**Size**	"TOTALSQFT" - total gross square feet of floorspace
57	**Size**	Retail Floor Area
58	**Size**	"SIZE" - square feet of office space in an office cluster
58	**Size**	"SPACE" - occupied mid-year office space within the cordon
59	**Size**	Number of Dwelling Units
59	**Size**	"SPACE / FSW"- occupied mid-year office space within the cordon / measured space per worker
60	**Size**	Building Area
60	**Size**	Gross leasable Area - total amount of leasable space.
61	**Size**	Land Area
61	**Size**	Commercial Floor Area
62	**TOD**	Proportion of Station Area Jobs in a Specific Transit Area
62	**TOD**	Proportion of Station Area Land in a Specific Transit Area
63	**TOD**	"Log of Population Density" - natural log of population per square mile within station catchment area.
63	**TOD**	"DWLDEN" - station area housing density
64	**TOD**	"POPDEN" - station area population density
64	**TOD**	Employees per Acre Within 1/2 Mile of a Subway Station
65	**TOD**	"Population Density" - population per square mile within station catchment area.
65	**TOD**	"Population Density" - population density within 1/2 and 2 miles of a transit station
66	**TOD**	"Log of Employment Density" - Natural log of employees per acre within one mile radius of downtown stations and two mile radius of all other stations.
66	**TOD**	"Employment Density" - employees per acre within one mile radius of downtown stations and two mile radius of all other stations.

APPENDIX 3
URBAN DESIGN VARIABLES EVALUATED

SKINNY STREETS

Description

Skinny Streets typically refers to local streets having a paved width less than 30 feet and corner turning radius of less than 10 feet. Such streets were typical of pre-World War II residential development and have seen a resurgence in recent years. Numerous jurisdictions within Oregon metropolitan areas have adopted skinny street standards for new residential development.

The narrower paved width of skinny streets has been correlated with slower traffic speeds, and the smaller corner radii reduce the width of pedestrian crossings. Both of these features have been associated with improved perceptions of safety among cyclists and pedestrians.

Possible Implementation of the Variable for Model Estimation

Skinny street standards may specify several paved widths, depending on whether the street is one-way or two-way and depending on whether there is no on-street parking, parking on one side only, or parking on both sides. Paved width is a road attribute that is typically carried in municipal engineering databases. Allowable on-street parking is not always carried in the GIS data or may not be as accurate or current as pavement data.

The simplest implementation uses the proportion of TAZ street miles having paved widths of less than some standard width. A standard street width of 28 or 30 feet might be the logical choice. An alternative is to use TAZ local street miles in the calculations, since most streets having less than 30 feet paved width will be local.

A more complex implementation is to narrow the paved width criteria in places where on-street parking is prohibited or limited to one side of the street. However, the elimination of a few street segments from the numerator may not provide enough additional explanatory power to be worth the extra effort.

Possible Implementation of the Variable for Forecasting

The variable would be assumed in new development areas (primarily residential) that are subject to the skinny street standards. Some rules of thumb have to be applied to predict the miles of local skinny streets that occur on greenfield sites (e.g., miles per gross acre).

CENSUS BLOCKS

Description

Census blocks (CB) are the smallest geographic units for which basic demographics are available from the U.S. Census Bureau. They are defined by physical features such as streets, shorelines and railroads.

CB densities (number of blocks per gross unit area) are correlated with urban street pattern and intersection densities. An urban grid typically has a higher CB density than a suburban cul-de-sac pattern. A small-block grid typical of central Portland has a higher CB density than is typical of other Oregon cities.

Possible Implementation of the Variable for Model Estimation

The Chicago Area Transportation Study (CATS) model uses CB density as a surrogate pedestrian environment factor. CATS defines it as the number of CBs per quarter-section (1/4 mile square or 160 acres). It is compiled at the quarter-section grid cell level, and then applied as a TAZ variable presumably using weighted grid cell averages.

A simpler implementation counts the number of CBs in the TAZ and divides by the gross TAZ area.

Possible Implementation of the Variable for Forecasting

Forecasting the CB variable entails some rules of thumb for applying CB densities to varying development patterns. This is similar to forecasting the number of local street intersections currently.

Potential Problems

- This variable is almost certainly collinear with intersection density and choosing one or the other might be necessary.
- Inconsistent results may occur in areas where there are large parcels, despite high pedestrian and bicycle usage. Examples are Portland State University, the Salem Capitol Mall, or the University of Oregon.

DISSIMILARITY INDEX

Description

The dissimilarity index is a measure of land use mixing. Specifically, it is a measure of the degree to which differing land uses come into contact with one another. It is implemented using a grid cell structure, whereby each cell is evaluated in terms of the number of adjacent cells having different land uses.

Possible Implementation of the Variable for Model Estimation

A 1991 paper prepared by Kara Kockelman describes dissimilarity indices based upon a one hectare (approximately 2-1/2 acre) grid structure applied over developed lands. Each cell within the grid is assigned a predominant land use. Kockelman uses a general land use scheme with four major uses - commercial (including office and industrial), residential, educational and recreational. Each cell is assigned a value between 0/8 and 8/8 according to the number of adjacent cells having a different predominant land use. The average of these point accumulations for all developed land within the TAZ is then calculated.

The general mix dissimilarity measure was used for predicting vehicle miles traveled (VMT) and auto ownership, although it was not statistically significant in the latter.

Possible Implementation of the Variable for Forecasting

The index has to be computed for numerous development prototypes and then applied to development areas on the basis of land use policy direction.

Potential Problems

- The challenge is to find the proper fit between grid cell density and number of predominant uses. For example, a cell size of 30 meters generally corresponds to a single parcel. If a relatively small number of land use categories were assigned, the results would be a fairly low level of dissimilarity. For larger grids, the assignment of a predominant use within each grid cell might be problematic. A one hectare cell may contain a dozen or more parcels and there may be a fair amount of dissimilarity even within the cell.
- The use of four general land use categories was somewhat arbitrary. Kockelman also used a more detailed eleven-category land use scheme, but it performed poorly at the one hectare grid level. It might be more appropriate to try at a one acre grid level.

BUILDING COVERAGE INDEX

Description

Building coverage is the proportional land area occupied by buildings. It is associated with a number of urban design attributes, including building orientation, parking supply and orientation, setbacks, streetscape and density. No studies were found in which this variable has been tested.

Possible Implementation of the Variable for Model Estimation

This variable would be captured as a TAZ-wide proportion of building to total land area or building to tax lot land area.

Non-residential building square footage is seldom included in Assessor's data or it may be noted on records not available to the public. Even residential Assessor records, which typically include both square footage and number of stories, may not be useful for accurately estimating the ground floor building footprint. The best source of building coverage data appears to be aerial photographs. Area-wide development of the data would presuppose an automated method for computing building coverage. There are active software developments underway to accomplish this. There are also opportunities to use NASA land satellite data for this purpose.

A pilot project would estimate approximate building coverage for several prototypical areas by manual interpretation of aerial photographs. An ordinal ranking of 5 or 6 prototype quarter-section maps could be used for initial testing.

Possible Implementation of the Variable for Forecasting

The building coverage index would be computed for several prototypical areas and applied to future forecasts for currently undeveloped tracts on the basis of plan and policy direction.

Potential Problems

It is not clear how parking structures should be handled. In downtown Portland, Salem and Eugene, parking structures typically have ground-floor retail uses and help to define the streetscape and pedestrian environment in a beneficial way. In downtown Bellevue, they typically provide plentiful parking for poorly-oriented high-rise buildings that contribute nothing positive to the streetscape.

RESIDENTIAL PARKING PERMIT AREAS

Description

The residential parking permit (RPP) areas are neighborhoods in which long-term weekday on-street parking is available only to area residents who have acquired parking permits. In Portland, Salem and Eugene, these areas tend to be centrally located near major attractors such as retail, service and employment centers. They are also often located adjacent to paid parking areas.

RPP areas are typically characterized by limited parking supply and by high non-auto accessibility to jobs, goods and services. This may be a significant explanatory variable for auto ownership models and for home-based work mode choice models. Being on the fringe of paid-parking areas, the RPP variable may prove to be a useful supplement to parking costs in the mode choice model.

No models were identified that currently use this variable.

Possible Implementation of the Variable for Model Estimation

RPP can be implemented as a continuous TAZ variable with the percent of TAZ area that is subject to RPP restrictions. The data are readily available in GIS polygons.

Possible Implementation of the Variable for Forecasting

Forecasting this variable requires interpretation of local land use and parking policies. It is similar to the problem of forecasting parking costs, since both are closely related to anticipated parking availability.

Potential Problems

- The RPP may cover areas already assigned a parking cost in the mode choice model if the paid parking area is large enough.
- Permit costs, rules and regulations covering RPP areas may differ among cities.

MEAN ENTROPY

Description

Entropy is an indicator of land use balance. It measures the uniformity in dispersion of various development types.

Possible Implementation of the Variable for Model Estimation

Kara Kockelman tested two forms of entropy. The first looked at dispersion of uses among developed hectares within the TAZ or Census tract. The study included six use types for work (residential, commercial, public, office/research, industrial, park/recreation) and four for non-work (excluding office/research and industrial). It may not be an appropriate measure for smaller TAZs, such as typically used for representing central business district areas, where there are not enough developed hectares to accommodate a full spectrum of uses.

The second form considers all developed area within one-half mile. Kockelman called this *mean entropy*:

$$\text{Mean Entropy} = \sum_k \frac{\sum_j \frac{(P_{jk} \times \ln(P_{jk}))}{\ln(J)}}{K}$$

where K = number of developed hectares in the zone and P_{jk} *= Proportion of Use Type j within ½ mile radius of the developed area surrounding the* k^{th} *hectare.*

Mean Entropy proved to be a more useful variable than TAZ-bounded entropy. Kockelman also suggests a weighting scheme whereby the maximum entropy is achieved when the TAZ land use proportions mirror those of the region. In this form, the entropy variable is normalized with respect to the natural log of the number of uses and thus varies between 0 and 1, with 1 representing ***perfect uniformity*** of the uses considered.

This type of analysis can probably be achieved with Arc/View Spatial Analyst software, although some front-end programming work is required.

Possible Implementation of the Variable for Forecasting

Forecasting this variable requires interpretation of local land use policies and an assessment of how the local development community may respond to incentives for building multiple-use developments. It is probably useful to conduct a base-year assessment of selected TAZs representing a range from relatively homogenous to relatively heterogeneous land use patterns, and then categorize future development in terms of one of those prototypes.

Potential Problems

- The analysis is fairly complex and might present some technical challenges.
- Entropy is not an easy variable to explain to non-technical public or elected officials.
- It is like the dissimilarity index, in that a fair amount of trial-and-error must be done to determine the optimal combination of grid cell size and number of land uses.

BUSINESS ESTABLISHMENTS

Description

Retail and service activities are typically represented in models by employment. However, they can also be represented by retail and service business establishments. While employment is an appropriate indicator of the number of primary trips made to an activity location, it is not particularly useful for predicting the choice of travel mode.

A big-box retail outlet may employ a comparable number of persons and generate a comparable number of trips to several block faces of small business, such as those along NW 23rd Avenue in Portland. The latter, however, may also generate a number of secondary trips between the businesses, a high proportion of which are by non-motorized modes. In that case the number of business establishments may be a better indicator than the number of employees.

Possible Implementation of the Variable for Model Estimation

Business establishments (BE) can be implemented in most of the forms that employment is used. Typical examples are number of BE (by type) per square mile, number of BE within a half mile or mile from the TAZ of interest, or number of BE within x minutes by mode y.

Employment records obtained from the state ES202 files typically include address and industrial classification of the firm. These data can also be supplemented with business data from private sources.

Possible Implementation of the Variable for Forecasting

Growth allocation models typically forecast the number of TAZ employees by type. Forecasting the number of business establishments may require some additional input data. Parcel sizes, number of employees at nearby businesses of similar type, and development regulations may give some indication of the number of employees per business establishment that may reasonably be anticipated.

Potential Problems

The use of this variable depends heavily on how respondents in the Household Activity Survey report their activities. For example, if a visit to NW 23rd Avenue is recorded as a single trip to and from the area (perhaps by car) with no trips between stores, the number of BE will not be useful for predicting secondary non-home-based trips or non-motorized travel. It is also likely that visitors to the Washington Square Mall in Beaverton will report a single shopping trip by car (or perhaps a couple of trips if also accessing a smaller, non-contiguous shopping center nearby) and not report trips between business establishments within the centers. Therefore, the separate business establishments within Washington Square probably need to be aggregated for model estimation purposes.

LESS AUTO-DEPENDENT URBAN FORM

Description

Less Auto-Dependent Urban Form (LAUDF) is a composite urban design variable that is discussed in a draft paper by University of Washington PhD candidate Kevin Krizek.

The author combines measures for density, land use mix and circulation using 150 meter cells as the geographic unit of analysis. Parcel data are used for estimating housing density. Employment data with two-digit SIC codes are used to derive retail employment density. Census TIGER files provide the basis for estimating block size and intersection density.

The author found the three continuous variables to be highly co-linear, so factor analysis was used to combine them into a single variable.

Possible Implementation of the Variable for Model Estimation

The data sources are uniform and available in all the metropolitan planning organization (MPO) areas. There is a great deal of latitude in how these or similar variables can be combined into single continuous variables that maintain or that eliminate the co-linearity problems without sacrificing explanatory power.   Principal factor analysis can be used. Scaling to harmonic means is another method. Much of the work in implementing composite variables such as LAUDF would be in exploring optimal methods for combining the components.

Possible Implementation of the Variable for Forecasting

Each component of the composite variable must be forecasted for the future. The density and land use mix components are essentially dealt with in the Portland area regional growth allocation models and processes. The block density or local intersection density component is policy-based. One approach is to develop a handful of prototype areas representing the range of existing intersection densities, then associate future local urban development policies with one of the prototypes.

Potential Problems

- While the base year data are readily available, the analysis required for combining them into a composite that maximizes explanatory power may be very complex and difficult.
- It may be difficult to associate future local urban development policies with a base year intersection density prototype.

REPRESENTATIVE SAMPLE LOCATIONS