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HIGHWAY INTERCHANGES, TRANSPORTATION AND LAND USE

AN EXPLORATION OF CHANGES IN TRANSPORTATION VOLUMES
AND LAND USE FACTORS WITHIN INTERCHANGE CATCHMENTS

Submitted by Matthew Hampton for partial completion of a
Masters of Science Degree in Geography at Portland State University

July 4th, 2005

Highway Interchanges, Transportation and Land Use

An exploration of changes in transportation volumes
and land use factors within interchange catchments

ABSTRACT

Highway interchanges provide the interface for and moderate access to the surface street system and help control congestion. Understanding the relationship between land use and transportation near highway interchanges can help to direct resources where they are most needed to maintain the integrity of the adjacent road system. This paper characterizes and ranks highway interchange areas in the Portland, OR Metropolitan Planning Organization (MPO) area with respect to changes in traffic volume and determines what factors are associated with these impacts. This study compares the transportation, population and land use patterns around 78 highways and freeway interchanges over two time periods. The main outcome measures in this analysis include interchange catchments results for changes in: average daily transportation volumes (ADT), population, developed land, and upzoning. The results show a high correlation between changes in ADT and population indicating interchange area management plans could be one effective solution to help control mobility, accessibility, safety, and preserve the functionality of highway interchanges.

Submitted by Matthew Hampton for partial completion of a
Masters of Science Degree in Geography at Portland State University

June 18th, 2005

Dedication

This paper is dedicated to my dear Stella (July 16th, 1993-June 28th, 2005). She has been by my side on numerous descents of different class IV rivers, has skied off the top of Mt Hood with me and has been the best dog ever (although her predilection for chickens has caused brief consternation at times).

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INTRODUCTION

The State of Oregon has a unique history when it comes to land use and transportation planning. Governor Tom McCall (1967-1975) is credited with helping draft some of the most progressive planning legislation in the nation. He promoted Senate Bill 10 (1969), the mandatory requirement for every city in the state to have a comprehensive land-use plan that included urban growth boundaries (UGB's), and Senate Bill 100 (1973) that created the Land Conservation and Development Commission (LCDC) and the Department of Land Conservation and Development (DLCD). This legislation has profoundly affected the way Oregonians interact with the landscape. It has created land use policies that are directed toward reducing sprawl and it has led to transportation policies that are meant to increase multi-modal travel, support intelligent development patterns, and reduce traffic congestion. The relationship between land use and transportation is codified by these policies and forms the basis of the following research.

In 1991 LCDC created the Transportation Planning Rule (TPR), which requires all cities to develop and adopt Transportation System Plans (TSPs). These system plans incorporate roadway, transit, bicycle, pedestrian, air, rail, water, and pipeline facilities. Larger jurisdictions must also address transportation system management, demand management, parking, and finance. Recently the Oregon Department of Transportation (ODOT) proposed amendments to the TPR with respect to interchanges causing an increased interest in interchange management. One of the amendments under consideration involves restricting zoning near interchanges.

Zoning restrictions near interchanges in the Portland metropolitan area will have a significant impact on the region's future growth plans. The 2040 Growth Plan (the region's blueprint for the future) identifies areas in the region where high intensity mixed-use development should occur. These areas include the Central City, Regional Centers, Town Centers and Station Communities. Inside the UGB there are 24,450 acres of land that could be impacted by the amendment and 8,650 acres lie within the areas planned for high intensity development. 1,230 acres of the parcels planned for the highest level of development are currently vacant (Figure 1). Understanding the relationship between interchange areas, land use and transportation can help inform policy-makers to wisely choose the most cost effective solutions to improve the transportation system. Directing resources where they are most needed are also important to sustain the function of highway interchanges and adjacent interstate highway segments.

Much research has been done on the causal relationships between land use and transportation. Ewing and Cervero (2001) explore over 50 studies that look into the potential for the built environment to moderate travel demand. The nature of

Figure 1. Potential impacts of proposed TPR amendment within 0.5 mile of highway interchanges.

their observations is to show causality between land use and transportation behavior. Giuliano (2004) and Polzin (1999) investigate the opposite and try to illustrate how transportation influences the urban structure. Both dynamics exist and reciprocity between them occurs at different scales due to direct and indirect relationships.

Highway interchanges provide an important interface to the transportation system by increasing connectivity to the surface street system (AASHTO, 2005). Interchanges have also been found to affect land use, land values, development, employment opportunities, travel patterns and taxes (Land, 2000). It has also been shown that highway interchanges can directly impact the development intensity in the nearby land by providing economic resources that in turn can cause congestion and safety hazards (Land, 2002). The potential for interchanges to moderate the street networks that add traffic to highways has led to various management strategies and plans. Interchange area management plans (IAMP's) are important tools for decreasing the investment needed to improve and develop programs that protect the function of highway interchanges and adjacent interstate highway segments (Layton, 2000). The current research on interchange areas illustrate the importance these transportation features have on the landscape. The potential impact of the proposed TPR amendment suggests there is a need for an understanding of the relationships between interchanges, transportation and land use factors.

This paper analyzes changes in traffic volumes on state highways between 1996 and 2001 with respect to changes in three variables; population, developed land, and zoning. The zoning variable is investigated for its impact to moder-

ate traffic volumes, and is derived from changes to local zoning ordinances. A matrix determining zoning intensity change is created and tested for correlation with respect to changes in transportation volumes. The population variable serves as a quantifiable aspect of community growth and the ratio of change in population is tested for correlation with respect to changes in transportation volumes. The development variable targets land that is changing from an undeveloped state to a built-up environment. This is intended to capture recently impacted land to expose areas of new development. The percentage change of land that has developed is tested for correlation with traffic volumes. Based on these variables the following three hypotheses are tested:

- Local government zoning decisions that intensify the use of land are associated/correlated with changes in transportation volumes on the state highway system.
- The rate of population growth is associated/correlated with changes in transportation volumes on the state highway system.
- The rate of land development is associated/correlated with changes in transportation volumes on the state highway system.

DATA

Interchange catchments

The concept of an interchange catchment is similar to the natural resource concept of a watershed except instead of water, the catchment boundaries delineate street networks that “flow” into highway interchanges. For every street in the region there is a highway interchange that is closest and provides

service. Interchange catchments are created for the 78 major freeway/highway interchanges in the study area (Figure 2) by the following method. Centroids from land cover that are classified as ‘developed’ (Figure 3) are snapped to the nearest street segment (Figure 4) and the shortest network distance to the interchanges is calculated. The cost function in this process is distance, which is used as a proxy for the actual network routes to interchanges. Once the interchange id’s are matched to the associated developed land centroids, tri-county block group polygons are used to define the interchange catchment areas. This is accomplished by intersecting the block group polygons with

Figure 2. Highway interchanges within study area.

Figure 3. Centroids of developed land.

Figure 4. Centroids snapped to the nearest roads.

the developed land centroids that have unique interchange ID's. These polygons (Figure 5) become the units of analysis for the exploration of regression and correlation. The 78 regional interchange catchments vary in size and larger catchment areas are

Figure 5. Interchange catchment areas.

found in more rural areas. The tendency for block group size to increase with respect to rurality indicates a general decrease in population density. In a subsequent analysis, interchange catchments are categorized based on population density to derive three classes of urbanization; urban, sub-urban and rural (Figure 6).

Figure 6. Interchange catchments classified by urbanization.

Traffic Counts

The traffic count data are collected by ODOT and consists of average daily traffic counts (ADT) for the years 1996 and 2001. The traffic counts are attributed to a state highway GIS coverage that has been linear referenced by milepost. The highway segments vary across the state with shorter segments

occurring in more urban areas. The average road segment is 1.6 miles. To ensure similar road segments are used for the comparison between dates, the ODOT highway number is concatenated to the beginning milepost number. The resulting 8-digit string is then used as the unique ID for joining the 1996 and 2001 counts into one spatial data set. In areas where the beginning milepost is different, the highway segments are thrown out in order to maintain a direct match between the street segments. Of the 2985 highway segments in the study area, only 16 are thrown out and none of those are near the interchanges in this study.

Traffic volumes for each interchange are calculated by using the average volume of the highway links on either side of the interchange. A percentage

change is calculated and the ratio data becomes the dependent variable in the regression analysis. The data are then converted into three ordinal classes by quantiles (low, medium, and high) to calculate the bivariate frequencies, Chi-square and Kendall's tau correlations (see

Figure 7. Change in traffic volumes.

Figure 7).

Development

Using satellite based land cover for urban analysis is a relatively nascent process, however Yang (2003) has shown the efficacy of using land cover change

for analyzing urban areas. Land cover data is obtained from NOAA's Coastal Change Analysis Program (C-CAP). NOAA completed a 1995 era and 2000 era land cover for the coastal area of the Pacific Northwest that extends into and just beyond the Cascade Range. This 30-meter data set is built to the national standards of the National Land Cover Database (NLCD). Land cover that changed from every cover type to either High Intensity Developed or Low Intensity Developed is collapsed into one group. This isolates land that changed from an undeveloped to a developed condition. The percentage change by area of "developed" land cover is calculated for each interchange catchment area. The ratio-level data is used in the regression analysis and further classified into three

Figure 8. Change in developed land cover.

ordinal classes (low, medium, and high) by quantiles to calculate the bivariate frequencies, Chi-square and Kendall's tau correlations (see Figure 8).

Zoning

Two dates of zoning data (1996 and 2001) are obtained from Metro's Regional Land Information System (RLIS) database. It is comprised of zoning designation boundaries from local zoning ordinances and includes commercial, industrial, multi-family residential, single family residential, rural residential, and parks and open spaces. The change in zoning is calculated between these

Interchanges	High uses				Low uses			
	COM	IND	MFR	total	SFR	RUR	POS	total
300000	-0.42%	-5.10%	-3.90%	-9.41%	-5.00%	16.27%	-1.85%	9.41%
300001	1.00%	-0.42%	-0.11%	0.47%	0.73%	-1.11%	-0.08%	-0.47%
300002	-0.20%	-0.11%	0.97%	0.66%	1.26%	-1.92%	0.00%	-0.66%
300003	0.07%	0.00%	-0.72%	-0.65%	1.26%	-0.61%	0.00%	0.65%
300004	0.01%	-0.01%	-1.51%	-1.51%	1.73%	-0.39%	0.16%	1.51%
300005	0.25%	0.18%	-5.43%	-5.00%	5.36%	-0.36%	0.00%	5.00%
300006	3.77%	-1.73%	-5.15%	-3.11%	6.03%	0.00%	-2.92%	3.11%
300007	4.36%	-2.24%	1.15%	3.27%	-3.26%	-0.01%	0.00%	-3.27%
300008	-0.20%	0.03%	-1.76%	-1.94%	1.93%	0.01%	0.00%	1.94%
300009	1.39%	-0.73%	-0.95%	-0.30%	0.14%	0.00%	0.16%	0.30%
300010	-2.17%	3.49%	-1.09%	0.23%	-0.42%	0.02%	0.18%	-0.23%
300011	0.09%	-0.81%	-0.33%	-1.05%	-0.74%	1.79%	0.00%	1.05%
300012	-0.78%	0.04%	-3.29%	-4.03%	2.62%	-0.08%	1.49%	4.03%
300013	-1.57%	-1.11%	-1.06%	-3.75%	-16.45%	20.23%	-0.03%	3.75%
300014	4.79%	-1.21%	-4.28%	-0.70%	1.67%	-2.92%	1.95%	0.70%
300015	3.03%	-0.31%	-2.62%	0.10%	2.87%	0.00%	-2.97%	-0.10%
300016	-0.01%	0.00%	-0.79%	-0.79%	-2.71%	3.21%	0.29%	0.79%
300017	-0.18%	0.00%	0.31%	0.13%	-2.09%	0.00%	1.96%	-0.13%
300018	0.06%	0.25%	3.68%	4.00%	-8.27%	-0.08%	4.35%	-4.00%

Table 1. Matrix of upzoning by percentage of change in area.

years and a matrix (Table 1) is developed to determine whether a property is upzoned or not. Upzoning is considered to occur when a property is re-zoned to a higher use. A higher use includes allowing greater housing density, commercial properties, or industrial uses. The higher use zoning designations from local zoning ordinances include commercial, industrial, and multi-family while the lower use zoning consist of single family, rural residential, and parks and open spaces. The percentage of upzoning by area is calculated for each interchange catchment between the two time periods. The ratio-level data is used in the regression analysis and further converted by quantiles into three ordinal classes (low, medium, and high) to calculate the bivariate frequencies, Chi-square and Kendall's tau correlations (see Figure 9).

Figure 9. Change in zoning.

Population

US census population are used at the blockgroup level for 1990 and 2000 for each interchange catchment. In a few areas, the blockgroup boundaries between 1990 census and 2000 census changed slightly. To correct this problem, finer grained block level data is converted to centroids for 1990 and unioned to the 2000 blockgroups. This enabled a more accurate comparison between the censuses. The ratio-level data is used in the regression analysis and further converted by quantiles into three ordinal classes (low, medium, and high)

Figure 10. Change in population.

to calculate the bivariate frequencies, Chi-square and Kendall's tau correlation (see Figure 10). Using blockgroup boundaries as a basis to form the interchange catchments prevents the introduction of a potential bias by keeping the geography of the blockgroups intact.

METHODS

All of the collected data is analyzed to determine the changes in values over the two time periods. The change in traffic volumes is then used to assess and rank the interchange catchments with respect to the percent increase. This data becomes the dependent variable for all the subsequent analyses. A linear regression is calculated with the change/time ratio data for the independent

variables (population, development, upzoning). The ratio data are then converted to ordinal values using quantiles for class breaks for all the variables (1=low, 2=medium, 3=high). This permits the calculation of bivariate frequencies, Chi-square and Kendall's tau correlations. Bivariate frequency tables are constructed to analyze the associations between the change in traffic volume and changes in population, development and upzoning. Pearson's Chi-square tests are performed on the ordinal values to test the significance of the relationship between the dependent and independent variables. Finally a bivariate correlation and Kendall's tau are constructed to test the relationships between changes in population, development and zoning.

The author recognizes there are variations in how land is utilized between urban, sub-urban or rural areas. The traffic volume change in interchange catchments that are located in urbanized areas might respond differently to changes in the three independent variables when compared to sub-urban and rural areas. To further investigate the relationships between urbanization, interchange catchments and the independent variables a second set of Chi-square tests are performed. These tests involve analyzing interchange catchments in urban areas and catchments in rural and sub-urban areas.

ANALYSIS

The regression to test the relationship between the traffic volumes and the changes in population, development and zoning is not significant (Table 2). The R Square value shows that only 6.2% of the change in traffic volumes is

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.250(a)	.062	.024	9.421	.062	1.638	3	74	.188
a Predictors: (Constant), PCTPOP, PCTZONE, PCTDEV									

Table 2. Regression of changes in population, development and zoning against traffic volumes.

accounted for by the combined changes in population, development and zoning. The bivariate frequencies generally show the relationships between the change in traffic volumes and the independent variables are such that low changes in volume have higher frequencies across all variables. The frequency of higher levels of change in the population, development and zoning variables are moderate with respect to traffic volume change (Table 3). Pearson's Chi-square

		Zoning			Total
		1	2	3	
Traffic volumes	1	12	10	9	31
	2	4	13	9	26
	3	4	8	9	21
Total		20	31	27	78

		Developed Land			Total
		1	2	3	
Traffic volumes	1	13	9	9	31
	2	4	11	11	26
	3	4	10	7	21
Total		21	30	27	78

		Population			Total
		1	2	3	
Traffic volumes	1	13	12	6	31
	2	12	6	8	26
	3	3	5	13	21
Total		28	23	27	78

Table 3. Bivariate frequencies of quantile-classed variables.

tests for the validity of the relationship between changes in traffic volumes and changes in development and upzoning are not statistically significant. The Chi-

value for changes in development is 6.373 (Table 4) and for zoning the Chi value equals 5.315 (Table 5). Changes in population show a statistically significant relationship to changes in traffic volume as the Chi value is 12.010 with a 98% level of confidence (Table 6). Kendall's tau-b correlation showed that the changes in population are statistically significant to transportation volumes at a 99% level of confidence. Changes in population are also significantly correlated to changes in development. The correlations between change in transportation

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.373(a)	4	.173
Likelihood Ratio	6.303	4	.178
Linear-by-Linear Association	1.928	1	.165
N of Valid Cases	78		
a 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.65.			

Table 4. Chi-square test results from development variable.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.318(a)	4	.256
Likelihood Ratio	5.217	4	.266
Linear-by-Linear Association	2.592	1	.107
N of Valid Cases	78		
a 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.38.			

Table 5. Chi-square test results from zoning variable.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.010(a)	4	.017
Likelihood Ratio	12.249	4	.016
Linear-by-Linear Association	7.859	1	.005
N of Valid Cases	78		
a 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.19.			

Table 6. Chi-square test results from population variable.

volume, and changes in zoning and development are not statistically significant (Table 7).

Correlations						
			PCTZONE	PCTDEV	PCTPOP	PCTADT
Kendall's tau_b	PCTZONE	Correlation Coefficient	1.000	-.003	.014	.073
		Sig. (2-tailed)	.	.965	.853	.357
		N	78	78	78	78
	PCTDEV	Correlation Coefficient	-.003	1.000	.465(**)	.164(*)
		Sig. (2-tailed)	.965	.	.000	.042
		N	78	78	78	78
	PCTPOP	Correlation Coefficient	.014	.465(**)	1.000	.283(**)
		Sig. (2-tailed)	.853	.000	.	.000
		N	78	78	78	78
	PCTADT	Correlation Coefficient	.073	.164(*)	.283(**)	1.000
		Sig. (2-tailed)	.357	.042	.000	.
		N	78	78	78	78

Table 7. Correlation analysis using Kendall's tau-b.

When the level of urbanization is factored into the relationship between interchange catchments and the independent variables a slightly different pattern emerges. The results show that in urban interchange catchments, population is the only factor that produces a statistically significant relationship with changes in transportation volumes. Both the zoning and development variables show weak relationships (Table 8). Interchange catchments in sub-urban and rural areas showed a statistically significant relationship with

Zoning	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.798 ^a	4	.434
Likelihood Ratio	3.911	4	.418
Linear-by-Linear Association	2.738	1	.098
N of Valid Cases	32		

Development	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.914 ^a	4	.418
Likelihood Ratio	3.873	4	.423
Linear-by-Linear Association	1.734	1	.188
N of Valid Cases	32		

Population	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.614 ^a	4	.013
Likelihood Ratio	7.381	4	.025
Linear-by-Linear Association	6.170	1	.013
N of Valid Cases	32		

Table 8. Chi-square test for Urban catchments.

both the population and development variables. The Chi-square test for sub-urban and rural catchments using the zoning variable failed to show a significant relationship (Table 9).

Zoning	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.800 ^a	4	.938
Likelihood Ratio	.817	4	.936
Linear-by-Linear Association	.572	1	.450
N of Valid Cases	46		

Development	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.527 ^a	4	.049
Likelihood Ratio	12.400	4	.015
Linear-by-Linear Association	.002	1	.966
N of Valid Cases	46		

Population	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.025 ^a	4	.091
Likelihood Ratio	7.095	4	.131
Linear-by-Linear Association	2.837	1	.092
N of Valid Cases	46		

Table 9. Chi-square test for sub-urban and rural catchments.

DISCUSSION and CONCLUSION

Evidence linking changes in traffic volumes (1996 and 2001) to changes in variables associated with population, zoning and development suggest that changes in population size have the most significant impact. This result illustrates that as population increases, transportation volumes do as well suggesting a that any improvements to interchange catchment areas should directly address this factor. The lack of statistical significance relating to the changes in development and upzoning with respect to transportation volumes region-wide suggests that while restricting the zoning intensity and buildable lands does modify the land use, it may not have the intended reduction in transportation volumes. These two factors may have been moderated by the overall low percentage of change, however their significance is still statistically less than that of population change. The development variable only shows a significant relationship to interchange catchments in the sub-urban and rural areas. This may be due to the fact that most urbanized areas already have a high percentage of

developed land. To fully comprehend the complexities between land use, transportation and highway interchanges further research is required. However, the differences in the Chi values between urbanized areas and sub-urban/rural areas suggest there is variability between interchange catchments within the region. A variety of strategies should be developed and tailored to specific interchange types.

If the proposed amendment to change the TPR is directed towards limiting the increase in traffic volume, this data suggests zoning restrictions may not be the most effective solution. Further research pertaining to transportation demand management (TDM) strategies focusing on interchange dynamics is suggested. The interchange catchments that ranked the highest with respect to traffic volume increases are primarily situated along Highway 26 west of Portland. This area has seen considerable increases in growth and development over the time period analyzed, primarily from increased employment opportunities in the high technology sector. Employment is a major factor of transportation trips and further research on interchange dynamics should also consider this variable as another source of potential increases in transportation volumes.

IAMP's are recommended on the 16 interchanges that had high levels of transportation volume change (>20%). Some types of interchange management plans include limiting access, controlling spacing (lane cueing) and implementing TDM strategies. TDM strategies include congestion pricing (market or demand based), ride-matching, transit, teleworking, car sharing and other alternative

modes of travel. This additional research implies strategies for limiting the increase in traffic volumes that include direct relationships to the population variable will have a higher likelihood of success than those primarily targeting zoning restrictions.

The complex nature of transportation, land use and highway interchanges suggests that relying on a single solution for solving problems on all interchanges is unwise. A systematic characterization and classification of the interchanges in the region is suggested as a precursor to applying a widespread solution to problems. Individual IAMP's can then be tailored and applied to provide a cost-effective benefit for interchange management.

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