Oregon Department of Transportation

STATEWIDE CONGESTION OVERVIEW FOR OREGON

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1: INTRODUCTION AND SUMMARY

1.1 Introduction

The Statewide Congestion Overview is one of the products of the state congestion management system (CMS). The CMS provides information on transportation system performance related to traffic congestion. This information is intended to help decision-makers identify, select and implement cost-effective ways to manage transportation facilities that alleviate traffic congestion and enhance mobility.

Development of the CMS began after passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). States were required by ISTEA to develop a CMS and five other management systems. In transportation management areas (TMAs), like the Portland metropolitan area, ISTEA established additional planning requirements that tied CMSs into the metropolitan transportation planning process. In these areas, the CMSs have become part of the regulatory planning structure.

In 1996, Congress made the CMS and other management systems optional for the states with the passage of the National Highway System (NHS) Act. However, Congress did not eliminate the CMS-related planning requirements for the TMAs. Although the management systems are no longer required for states, ODOT decided to continue with their development and deployment to provide information that will help the department to make better policy, planning, and project selection decisions.

Responsibility for developing a congestion management system is split between ODOT and Metro. Metro, as the lead transportation-planning agency for the Portland metropolitan area, is developing a CMS for that area which meets the regulatory requirements of ISTEA. ODOT is developing an informational CMS for the state to provide information about congestion on the state highway system.

The purpose of this report is to provide background information on statewide congestion trends and the major factors influencing those trends. Information is drawn from published data sources and existing ODOT databases. Because the information presented in the report is of a general nature, it is most applicable to the development of statewide policy. This report should not be used for identifying site specific congestion problems or solutions to those problems. Those topics will be the subject of other reports to be developed as part of the statewide CMS.

1.2 Executive Summary

This report describes traffic congestion and vehicle travel trends in Oregon. It also describes the various factors that have affected the growth of vehicle travel. It then explores the implications of these trends. Following are the some of the most significant findings.

Congestion on Oregon's main roadways has increased considerably over the past 15 years because vehicle travel grew rapidly while roadway capacity changed little. For example:

- From 1982 to 1995, vehicle miles traveled (VMT) on arterials and collectors increased by 59% while the number of miles of arterial and collector lanes (lane-miles) increased by only 6%.
- Over that same period of time, VMT on urban freeways and expressways increased by 114% while the number of lane-miles of these roads increased by 19%.
- Travel growth was not limited to the use of personal vehicles. Public transit ridership increased by 51% from 1985 to 1996.

About a quarter of adult Oregonians believe that auto traffic congestion is a very serious problem. The proportion is higher in the Portland metropolitan area (35%) and Central Oregon (38%) than elsewhere in the state.

Traffic congestion, notably severe congestion, is growing more rapidly on urban freeways than on other arterials. The average daily traffic volume per lane on urban interstates almost doubled and the severely congested mileage increased more than five-fold between 1982 and 1995.

Congestion in the Portland metropolitan area has increased greatly and is much higher than elsewhere in the state. Daily travel delay in the Portland metropolitan area increased by about 140% between 1982 and 1994. Over 95% of congested freeway mileage and freeway delay in Oregon's metropolitan areas (Portland, Salem, Eugene, and Medford) are in the Portland metropolitan area.

A number of social, economic and demographic factors have pushed demand for travel up at rates substantially exceeding population growth over the past several decades. These factors include employment growth, rising household incomes, increasing automobile ownership, and movement of population and employment to the suburbs. Of these factors, employment growth has had the greatest effect on travel demand and congestion. Employment grew due to the baby boom and increased entry of women into the work force. This resulted in higher household incomes, more automobile purchases, greater purchases of household services, more linking of trips, less use of public transportation and carpooling, and more travel during peak periods. Recovery from the state's economic recession in the early 1980s caused high rates of growth in personal travel.

Suburban development and highway construction contributed to rising VMT but were not the primary causes of rising congestion. While demographic and economic factors establish the fundamental demand for increased motor vehicle travel, public policies and programs influence the amount of vehicle travel that occurs. Policies in Oregon and the U.S. in general have accommodated demand by planning for relatively low-density suburban growth and by building roads to accommodate the additional vehicle travel. While road building may "induce" additional VMT growth, it has had much less effect on VMT growth than have population, employment and income increases. Roadway projects in general have had a net effect of reducing congestion.

Per capita VMT growth is now moderating as employment growth is moderating and automobile ownership is approaching saturation. Motor vehicle use has increased as a result of increasing motor vehicle ownership. The average number of miles driven per registered vehicle has remained fairly constant at about 11,000 miles per year. Vehicle ownership has increased as a result of rising incomes, driven in large part by rising employment. Employment growth is moderating because the proportion of the population that is of working age will decline as the baby-boomers retire and the rate of women entering the work force levels off. Automobile ownership is now approaching saturation levels, with more than one registered vehicle per licensed driver in Oregon. Motor vehicle ownership will increase by about 6% over 20 years if long-term trends continue.

VMT will still grow substantially over the next 20 years because of population growth. Because of this, there will be no inexpensive or painless ways of avoiding significant congestion increases. Oregon's population is projected to grow by about 30% over the next 20 years. Total VMT might increase by about 38% over that time period, assuming that motor vehicle ownership grows by 6%. Even if the state's metropolitan areas are successful in reducing automobile VMT per capita by 10% in accordance with the Transportation Planning Rule, VMT will still grow substantially as a result of population growth. Large increases in highway capacity will be needed to avoid growing congestion unless Oregonians agree to substantially reduce their personal mobility.

1.3 Summary

This report examines several different indicators of traffic congestion in Oregon including public perceptions, vehicle miles traveled, traffic flow density, volume to capacity ratio, commute travel time and peak hour spreading.

Public perceptions of congestion often have more influence on public decisions than do more objective measures of congestion. About a quarter of adult Oregonians believe that auto traffic congestion is a very serious problem. (See Table 1) The proportion is higher in the Portland metropolitan area (35%) and Central Oregon (38%) than elsewhere in the state.

Table 1
How Serious a Problem is Auto Traffic Congestion in Your Community?

	West[1]	Portland[2]	Central[3]	East[4]	Statewide
Critical	4.5%	9.3%	13.4%	2.1%	6.8%
Very serious	13.5%	26.1%	24.2%	5.4%	18.7%
Moderate	37.2%	40.8%	32.2%	22.1%	37.3%
Small problem	17.9%	10.7%	13.9%	20.0%	14.7%
Not a problem	26.9%	13.1%	16.3%	50.5%	22.5%
Total	100%	100%	100%	100%	100%

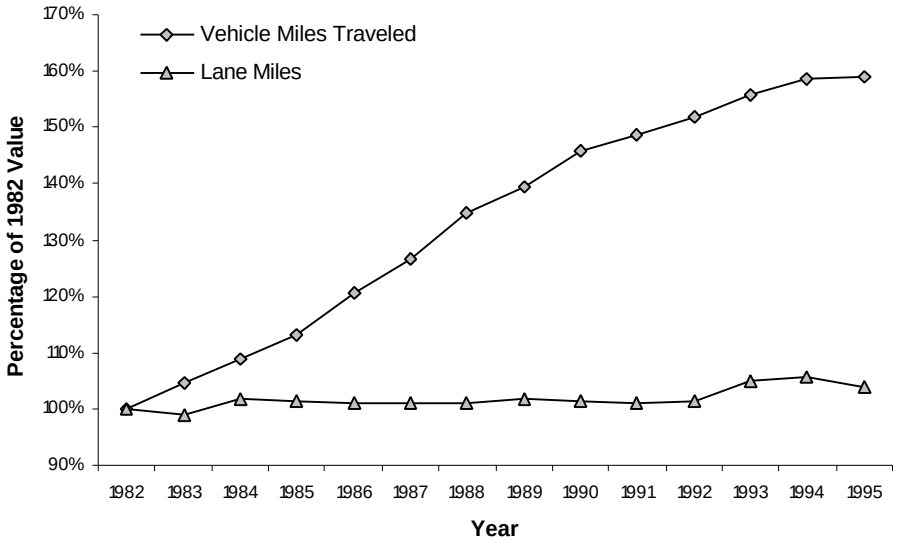
Source: Oregon Population Survey, 1996

Notes:
1 Clatsop, Columbia, Lincoln, Tillamook, Benton, Lane, Linn, Marion, Polk, Coos, Curry, Douglas, Jackson and Josephine counties
2 Clackamas, Multnomah, Washington and Yamhill counties
3 Crook, Deschutes and Jefferson counties
4 Gilliam, Hood River, Morrow, Sherman, Umatilla, Wasco, Wheeler, Grant, Harney, Klamath, Lake, Baker, Malheur, Union and Wallowa counties

This data helps to illustrate that perceptions of congestion are relative to public expectations about transportation performance. A larger proportion of Central Oregon residents than Portland area residents perceive that congestion is serious, and yet by objective measures, the Portland area is the most congested in the state.

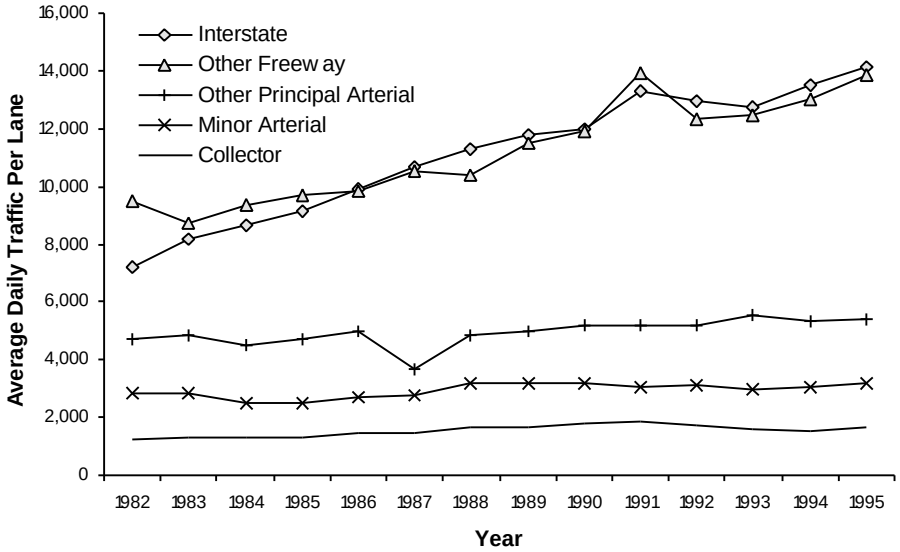
Over the past several decades, roadway traffic has increased greatly while capacity has increased little in comparison. (See Figure 1) As a consequence, the density of traffic on arterials and collectors has increased dramatically in urban areas. (See Figure 2) Travel is becoming increasingly concentrated on freeways and expressways.

Figure 1
Changes in Vehicle Miles Traveled and Lane Miles on Arterials and Collectors in Oregon, 1982 to 1995



Source: ODOT Transportation Planning & Data Sections

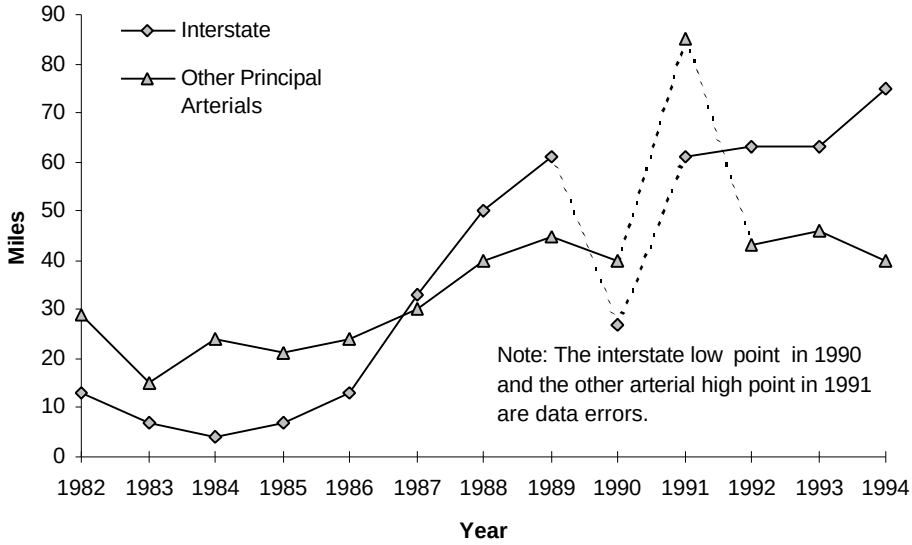
Figure 2
Density of Traffic on Urban Arterials and Collectors in Oregon, 1982 to 1995



Source: ODOT Transportation Planning & Data Sections

Congestion, particularly severe congestion is growing more rapidly on urban freeways than on other arterials. (See Figure 3)

Figure 3
Miles of Severely Congested Urban Roadways in Oregon
Volume to Capacity Ratio > 0.95, 1982 to 1994



Source: ODOT Transportation Planning & Data Sections

Levels of freeway congestion are particularly high in the Portland metropolitan area where a much larger population and higher levels of freeway use on a per capita basis produce high levels of congestion. (See Table 2)

Table 2
Freeway Statistics for Oregon's Primary Metropolitan Areas, 1995

Metropolitan Area	Freeway[1] Daily VMT	Freeway[1] Lane-Miles	ADT per Freeway Lane	Lane-Miles Exceeding 15,000 ADT/lane
Portland	9,159,661	482	18,999	420
Salem	1,002,647	79[2]	12,614	20
Eugene	654,851	65	10,075	0
Medford	221,126	27	8,251	0

Source: ODOT Transportation Planning and Data Sections
Notes: 1 – Freeways include all fully access controlled divided highways
2 - Does not include the freeway lanes that were recently added or are under construction

Congestion in the Portland metropolitan area is important because of the number of people it affects, the dominant position of Portland in the economy of the state, and the strategic location of Portland as a hub of the statewide transportation system. There is a much higher use of the freeway system on a per capita basis in Portland than elsewhere in the state. This is a consequence of:

- Greater integration of the freeway system into land use and travel patterns.
- Having a large market area that attracts substantial amounts of travel from the surrounding area and that uses freeways as the primary access routes.
- The passage of most interstate travel to and from Western Oregon and destinations to the north and east through the Portland metropolitan area on the freeway system.

The number of people and size of the region affected make freeway congestion in the Portland metropolitan area a very important statewide issue.

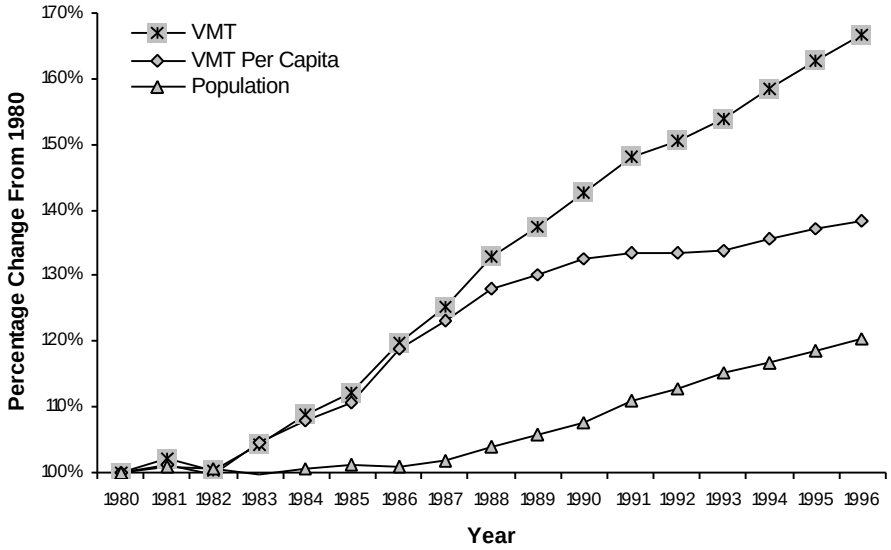
A number of social, economic and demographic factors have pushed travel demand up at rates substantially exceeding population growth over the past several decades. These include employment growth, rising household incomes, increasing automobile ownership, and movement of population and employment to the suburbs. Of these factors, employment growth and rising household incomes have had the greatest effect on increasing demand and congestion.

Employment increased significantly in Oregon over the past several decades because the baby boom generation was entering the labor force, the labor force participation rate of women increased, and Oregon grew out of a major recession. Rising employment affected travel and congestion in several ways. First, it increased commuting travel so it put more vehicles on the road system during peak times. Second, it increased household incomes, which in turn drove up automobile ownership and the ability to travel. Third, it contributed to a shifting of production from the household economy to the market economy. With more workers per household, households had less discretionary time, traveled more to purchase services to substitute for lost time, and increased their use of automobiles to link trips and economize on rising family travel demands.

Increasing employment had large effects on congestion because it increased the proportion of travel occurring during peak times. Commuting travel demand is less responsive to congestion than travel for other purposes such as shopping. Other travel also increased during peak hours because households linked more auxiliary trips to their work trips. This had the effect of shifting more travel into the peak periods, particularly the afternoon peak.

Much of the VMT growth occurring in the 1980s resulted from the state's recovery from a severe economic recession. Per capita VMT rose rapidly as Oregonians went back to work, purchased more automobiles and had more income for discretionary purchases and travel. After the recovery, the rate of per capita VMT growth declined sharply. Long term trends of saturation of automobile ownership, reduction of the rate of women's entry into the labor market, and aging of the baby boomer population are also contributing to a reduction in the rate of per capita VMT growth. However, total VMT continues to grow at a rapid pace because Oregon's population is growing rapidly. (See Figure 4)

Figure 4
Growth of Population, VMT and Per Capita VMT in Oregon, 1980 to 1995



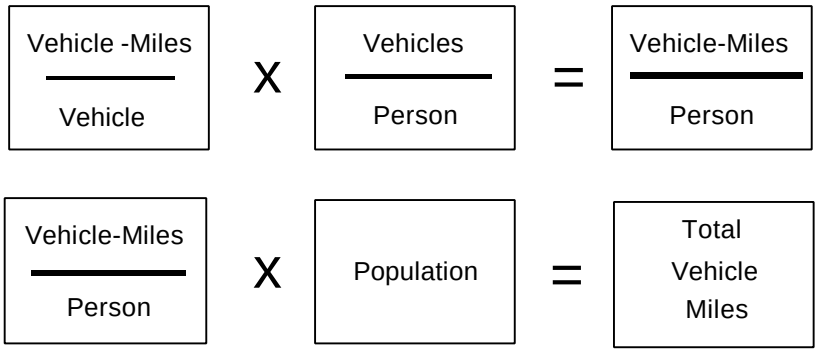
Source: ODOT Transportation Planning & Data Sections, Census, Portland State University

The development of housing and businesses in the suburbs has also had an impact on travel growth in Oregon. Major shifts in the distribution of population and employment between urban centers and suburbs contributed to increased trip lengths and rising VMT. In the Portland-Vancouver metropolitan area, population and employment in suburban counties (Clackamas, Clark, Washington) went from being a minor portion of total metropolitan area population and employment to being the major portion.

As with the other economic and social trends, the effect of continued suburban growth on average metropolitan travel rates is diminishing. Most of the major shifting in the balance of housing and employment in urban and suburban areas has already occurred. Further increases in suburban housing and employment will have proportionally less effect on average per capita vehicle miles traveled. Market forces and urban growth boundaries are bringing suburban land uses more into balance and increasing suburban densities. As a result, the rate of further increases in per capita VMT resulting from suburban growth will diminish.

The future of VMT growth can be projected from the model illustrated in Figure 5. VMT is the product of the number of miles driven per vehicle, the vehicle ownership rate and population. The growth of VMT depends on how each factor grows. Of these factors, vehicle ownership and population have been the most significant.

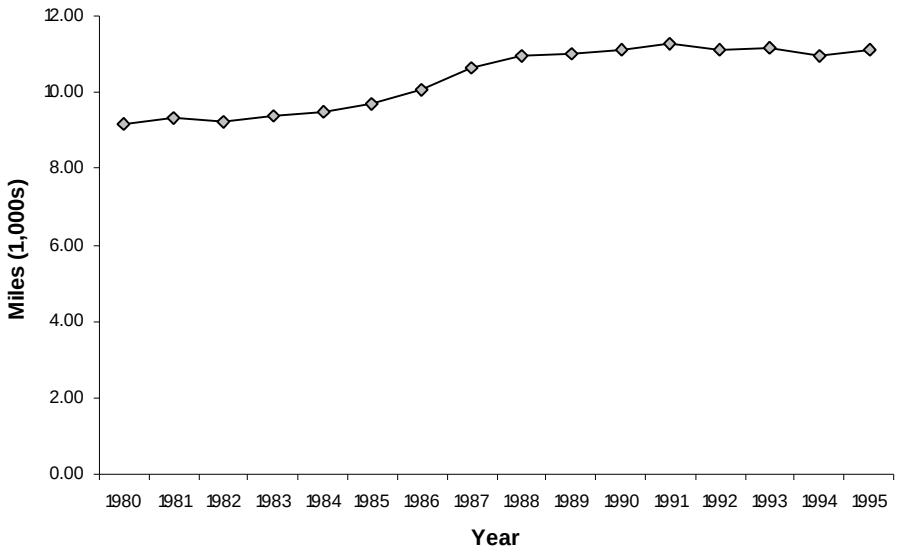
Figure 5
Forecasting VMT Growth



National statistics show that the average number of miles driven per vehicle has remained almost unchanged for decades. Oregon data confirm there has been little change since the late 1980s, when the state had recovered from the recession of the early 1980s. (See Figure 6)

The effect of rising levels of vehicle ownership is diminishing over time. Now there is on average more than one passenger vehicle per person of driving age. The overall trend in vehicle ownership of all classes is showing that we are approaching market saturation. Extrapolating the long-term trend, per capita vehicle ownership should increase by about 6% over the next 20 years. (See Figure 7)

Figure 6
Total Vehicle Miles Traveled per Registered Motor Vehicle
In Oregon, 1980 to 1995

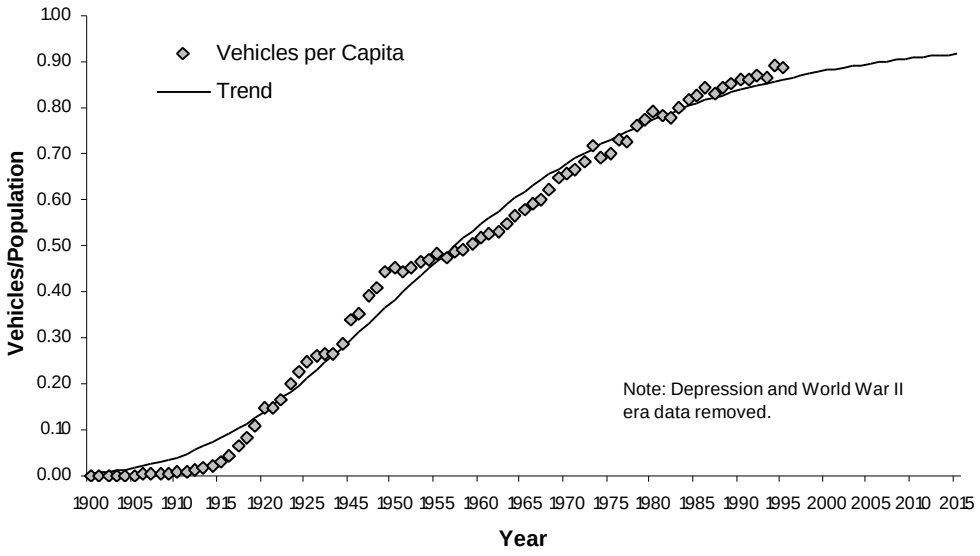


Source: ODOT; FHWA, " Highway Statistics" Table MV-2

Population growth will be the dominant factor driving the growth of travel in the future. Oregon's population has grown steadily over the course of the century except for the period of economic recession in the early 80s. The State Office of Economic Analysis projects over the next 20 years Oregon's population will grow by about 30%. If vehicles per capita increases by 6% total VMT, therefore, might increase by about 38% over the next 20 years. Population growth will be responsible for the bulk this growth.

The fact that VMT growth will be driven primarily by population growth has positive and negative consequences. On the positive side, it means that there will be increasing numbers of people to pay for infrastructure improvements to cope with congestion. If per capita VMT and not population were the driving factor, then the cost burden per person would increase by a greater amount over time. On the negative side, the driving force of population growth makes it less likely that simple or low pain demand management solutions can be found to avoid growing congestion. If VMT were growing mostly because people were driving more, then conceivably congestion could be avoided without reducing present levels of mobility.

Figure 7
Long Term Trend in the Ratio of Motor Vehicles to Population
In Oregon, 1900 to 1995; Projection to 2015



Census; FHWA " Highway Statistics" Tables MV-202, MV-2

The challenges that population growth poses for congestion management are well illustrated by the example of congestion on the Portland metropolitan areas freeways. In 1995, the average daily traffic (ADT) per freeway lane was about 18,800. Freeways in the

Los Angeles urbanized area, in comparison, had an average daily traffic per freeway lane in 1995 of about 22,100. Over the next 20 years population in the Portland area is projected to grow by about 30%. Even if per capita miles traveled by automobiles decreases by 10% within the Metro urban growth boundary and if all other motor vehicle travel remains constant on a per-capita basis, ADT per lane would grow to about 23,200. Automobile travel within the Metro urban growth boundary would have to fall by 40%, or 115 freeway lane-miles would have to be added to the highway system to maintain the 1995 congestion levels.

Oregon's increasing population will cause major increases in congestion unless highway capacity is increased significantly, mobility is reduced significantly below present levels, or costs increase greatly.

2: CONGESTION TRENDS

2.1 Introduction

This chapter presents an overview of various indicators of congestion in Oregon based on information drawn from published sources and ODOT's Highway Performance Monitoring System (HPMS) database. Data sources and analysis methods are described in the appendix.

This chapter looks at several measures of traffic congestion:

- Public Perceptions (Section 2.2)
- Vehicle Miles Traveled (Section 2.3)
- Traffic Flow Density (Section 2.4)
- Volume to Capacity Ratio (Section 2.5)
- Commute Travel Time (Section 2.6)
- Peak Hour Spreading (Section 2.7)

2.2 Public Perceptions of Congestion

Public perceptions of congestion often have more influence on public decisions than do more objective measures, but the subjective nature of public opinion makes comparisons across geography and time difficult. For example, Table 3 shows that people living in Central Oregon perceive congestion to be worse than people living in the Portland metropolitan area do. By several objective measures congestion in the Portland metropolitan area is much more pervasive than it is in Central Oregon. However, Central Oregon has grown very rapidly over the past several decades, so perceptions of high congestion are likely a consequence of the very rapid rate of growth in that area. Moreover, high levels of congestion are present on US 97 in Bend.

Table 3
How Serious a Problem is Auto Traffic Congestion in Your Community?

	West	Portland	Central	East	Statewide
Critical	4.5%	9.3%	13.4%	2.1%	6.8%
Very serious	13.5%	26.1%	24.2%	5.4%	18.7%
Moderate	37.2%	40.8%	32.2%	22.1%	37.3%
Small problem	17.9%	10.7%	13.9%	20.0%	14.7%
Not a problem	26.9%	13.1%	16.3%	50.5%	22.5%
Total	100%	100%	100%	100%	100%

Source: Oregon Population Survey, 1996

Notes: West, Portland, Central and East refer to the geographic areas identified in Table 1.

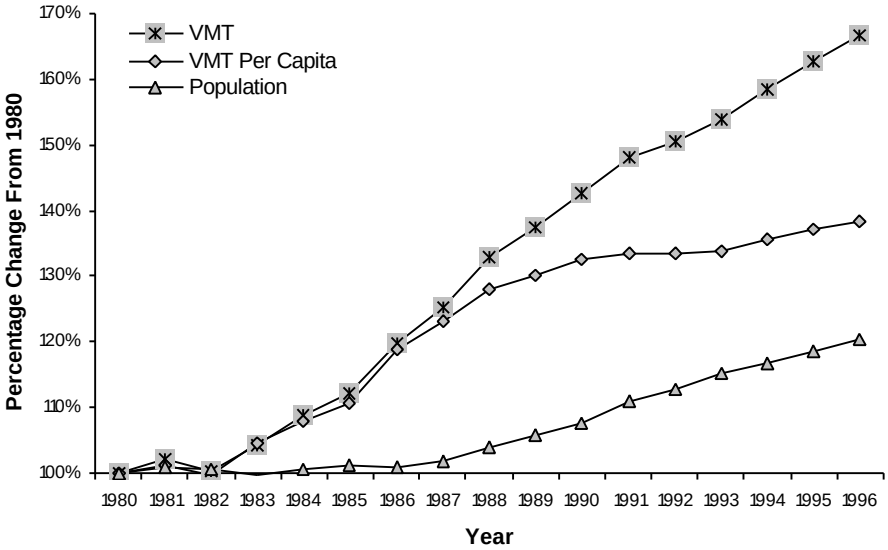
2.3 Vehicle Miles Traveled

Vehicle miles traveled (VMT) is a common measure of total travel demand by motor vehicles. For a given area (e.g., Oregon) VMT is typically defined as the total number of miles traveled by all vehicles on roadways during a given period (e.g., per year). VMT is estimated by several means but the most common is to multiply the annual average daily traffic volume (AADT) on roadway segments by the length of the segments and sum them over the entire roadway system. VMT is commonly reported on an annual or daily basis. Daily vehicle miles traveled are commonly referred to as DVMT.

VMT is often presented in terms of the average number of vehicle miles traveled per person (VMT per capita). This is calculated by dividing total VMT by population. The reader should note that VMT per capita figured in this way does not measure how much the average individual drives because all travel, including travel by trucks and other commercial vehicles, is included in the estimate. Rural counties tend to have higher rates of VMT per capita in part because of the effect of through traffic on total VMT.

Figure 8 shows how VMT and VMT per capita in Oregon have changed from 1980 to 1995. VMT has grown steadily since 1982 when Oregon's economy began improving. From 1982 to 1986, VMT and VMT per capita grew at a rate of about 5% per year. During this period, there was little growth in population, so the increase in VMT was due almost entirely to growth in VMT per capita. After 1986, Oregon's population began to grow at a much higher rate while VMT growth remained fairly constant. VMT per capita grew at a rate of about 3% per year during this period. The rate of growth of VMT per capita declined further after 1990 to less than 1% per year.

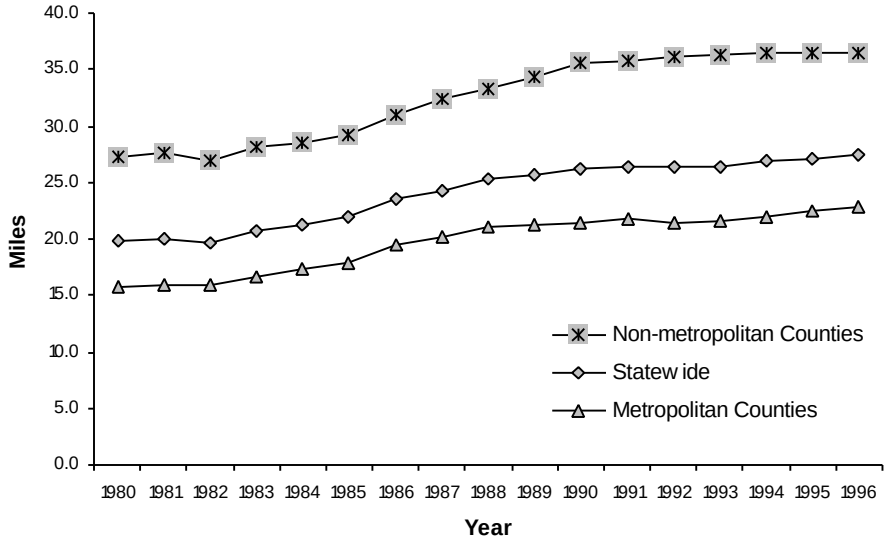
Figure 8
Growth of Population, VMT and VMT Per Capita in Oregon, 1980 to 1995



Source: ODOT Transportation Planning & Data Sections, Census, Portland State University

Figure 9 shows the leveling off of VMT per capita in both metropolitan and non-metropolitan areas of the state.

Figure 9
Average Daily VMT per Capita in Oregon, 1980 – 1995



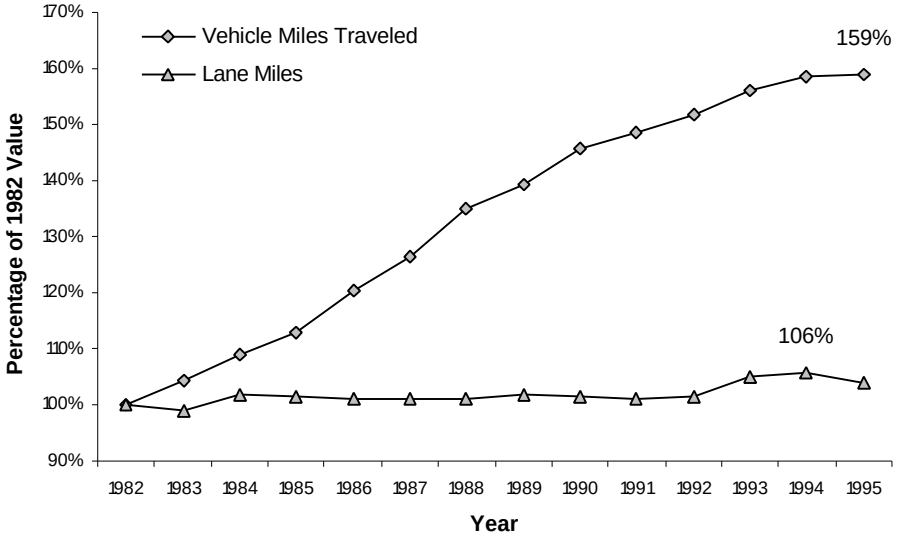
Source: ODOT Transportation Planning & Data Sections, Census, Portland State University

2.4 Traffic Flow Density

Growth of VMT is a simple indicator of growing congestion, but a better indicator is a comparison of VMT with roadway lane-miles. Figure 10 makes this comparison for arterial and collector roads.[1] In 13 years, VMT increased by almost 60% while lane-miles increased by only 6%. With much more vehicle travel and little increase in road supply, congestion had to increase.

VMT and lane-miles can be combined into a measure of congestion. Roadway travel can be measured in daily vehicle miles traveled (DVMT) while roadway supply can be measured in lane-miles. For example, summing the DVMT traveled over the freeway system and dividing by the total number of freeway lane-miles provides a measure of the average daily traffic flow per lane mile on the freeway system. The Texas Transportation Institute (TTI) uses this approach to monitor congestion trends in 50 large metropolitan areas across the country, including the Portland/Vancouver metropolitan area.

Figure 10
Changes in Vehicle Miles Traveled and Lane Miles on Arterials and Collectors in Oregon, 1982 to 1995



Source: ODOT Transportation Planning & Data Sections

TTI has been tracking congestion levels on freeways and other principal arterial roads in metropolitan areas since 1982. TTI computes average daily traffic flow rates separately for freeways and for other principal arterials. It calculates a congestion index representing the degree to which flow rates on those roads exceed threshold values that indicate roads are approaching a congested state. Researchers at TTI have determined that traffic flow rates of 15,000 DVMT per lane mile (i.e., 15,000 ADT per lane) represent the onset of traffic congestion[2] and that traffic flow rates of 13,000 DVMT per lane mile represent conditions approaching a congested state.[3] They determined that for other arterials, congested conditions are approached when traffic flows exceed 5,000 DVMT per lane-mile.

In 1982, the TTI found that the Portland metropolitan area had a congestion index of 0.87 and was the 20th most congested metropolitan area. By 1994, this index had increased 27% to 1.11 and Portland was the 15th most congested metropolitan area. (See Table 4 on following page.)

Table 4
Congestion Index for 30 Metropolitan Areas, 1982 and 1994

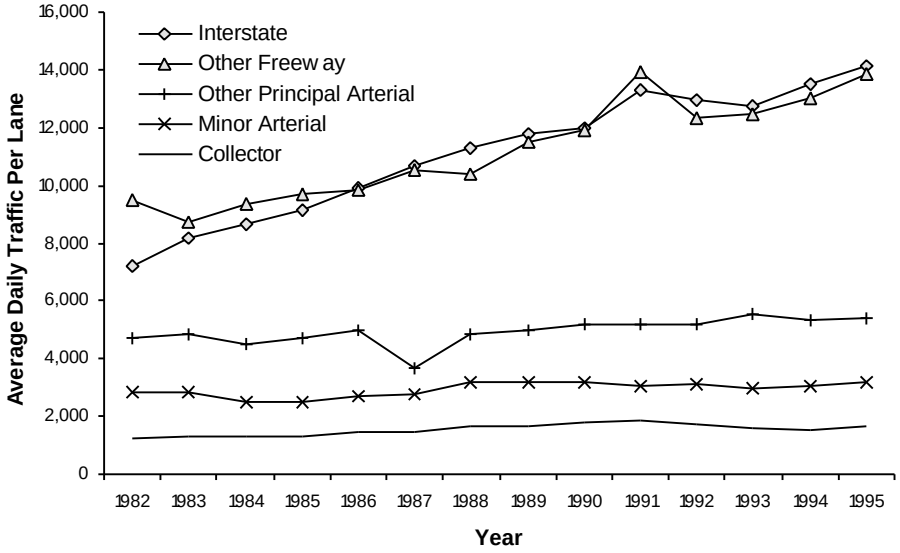
Metropolitan Area	1994 Index	1982 Index	% Change
1. Los Angeles	1.52	1.22	24.6
2. Washington DC	1.43	1.12	27.7
3. San Francisco - Oakland	1.33	1.01	31.7
4. Miami	1.32	1.05	25.7
5. Chicago	1.28	1.02	25.5
6. Seattle - Everett	1.25	0.95	31.6
7. Detroit	1.24	1.06	17.0
8. San Diego	1.21	0.78	55.1
9. San Bernardino - Riverside	1.20	1.11	8.1
10. Atlanta	1.18	0.91	29.7
11. New York	1.15	1.01	13.9
12. Honolulu	1.13	0.92	22.8
13. Houston	1.12	1.17	-4.3
14. New Orleans	1.11	0.98	13.3
15. Portland	1.11	0.87	27.6
16. Dallas	1.09	0.84	29.8
17. Phoenix	1.09	1.15	-5.2
18. Boston	1.08	0.90	20.0
19. Denver	1.07	0.88	21.6
20. Tampa	1.07	0.94	13.8
21. Baltimore	1.06	0.84	26.2
22. Sacramento	1.06	0.80	32.5
23. San Jose	1.06	0.86	23.3
24. Cincinnati	1.05	0.86	22.1
25. Philadelphia	1.05	1.00	5.0
26. Minneapolis – St. Paul	1.04	0.76	36.8
27. Cleveland	1.00	0.80	25.0
28. Milwaukie	1.00	0.83	20.5
29. Ft. Lauderdale	0.99	0.87	13.8
30. Albuquerque	0.98	0.94	4.3

Source: Texas Transportation Institute. Research Reports 1131-8, 1131-9.

Traffic flow densities for Oregon roadways can easily be computed from HPMS data. Figures 11 and 12 show traffic flow rate trends for different roadway functional classes in urban and rural areas of Oregon. The most striking trend is the dramatic increase in traffic flow rates on urban and rural freeways.

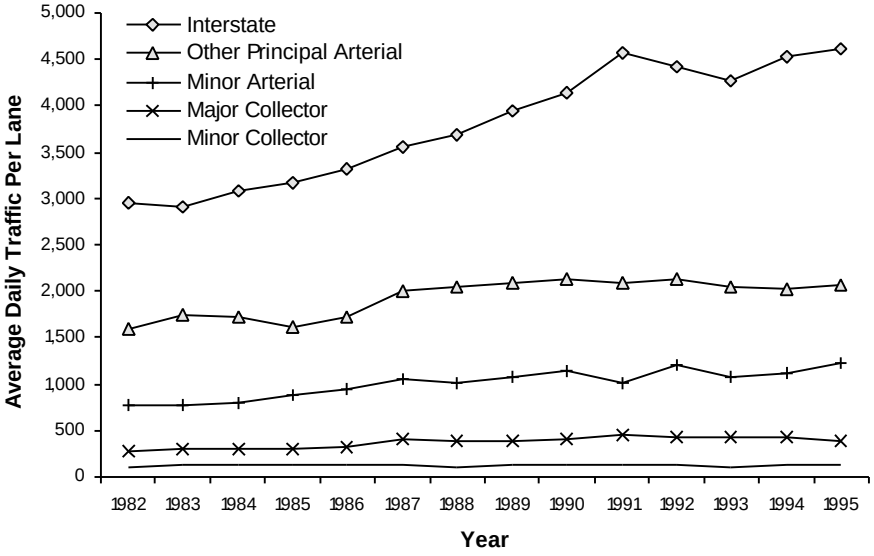
By 1994 the average traffic flow rate for urban freeways and other arterials exceeded the TTI thresholds for the approach of congestion conditions (13,000 DVMT per lane mile for freeways and 5000 DVMT per lane mile for other principal arterials).

Figure 11
Density of Traffic on Urban Arterials and Collectors in Oregon, 1982 to 1995



Source: ODOT Transportation Planning & Data Sections

Figure 12
Density of Traffic on Rural Arterials and Collectors in Oregon, 1982 to 1995



Source: ODOT Transportation Planning & Data Sections

The high average traffic flow rates for urban freeways in Oregon are largely due to the high traffic flows in the Portland metropolitan area. Portland area freeway traffic flows are several times those in other urban areas of the state, including the other three major metropolitan areas (Salem-Keizer, Eugene-Springfield, and Medford-Central Point). This can be seen in Table 5. About 85% of the freeway system in the Portland metropolitan area urban growth boundary had traffic flows indicating congestion.

Table 5
Freeway Statistics for Oregon's Primary Metropolitan Areas, 1995

Metropolitan Area	Freeway[1] Daily VMT	Freeway[1] Lane-Miles	ADT per Freeway Lane	Lane-Miles Exceeding 15,000 ADT/lane
Portland	9,159,661	482	18,999	420
Salem	1,002,647	79[2]	12,614	20
Eugene	654,851	65	10,075	0
Medford	221,126	27	8,251	0

Source: ODOT Transportation Planning and Data Sections
Notes: 1 – Freeways include all fully access controlled divided highways
2 - Does not include the freeway lanes that were recently added or are under construction

2.5 Volume-to-Capacity Ratio

The peak-hour volume-to-capacity ratio (V/C) is a standard measure of roadway congestion. The ratio is computed by dividing the number of vehicles passing through a section of highway during the peak hour by the capacity of the section. Capacity is the maximum volume of traffic that the roadway section is able to carry on a sustained basis. For short intervals and under optimum conditions traffic volumes can exceed capacity, but over longer intervals, traffic flow becomes chaotic and unpredictable when capacity is exceeded.

Volume-to-capacity ratios are typically reported for the weekday peak hour volume or the 30th highest hourly volume of the year. In urban areas, where the highest average hourly volumes occur during the afternoon peak commute times, the peak hour volume and the 30th hour volume are about the same and are typically about eight to ten percent of the average daily traffic volume. In most rural areas, peak (30th hour) volumes occur on the weekends (including Friday evenings) and are typically about 15 percent of the average daily traffic volume.

V/C has a couple of advantages over traffic flow density (DVMT/lane-mile or ADT/lane) as a measure of congestion. V/C is easier to comprehend because capacity provides a clear reference point: the threshold between smooth traffic flow and chaotic (stop-and-go) traffic flow. V/C also can be easily related to other congestion-related performance

characteristics, notably traffic speeds and delay. As the V/C increases, average traffic speeds decrease, although the rate of decrease is not directly proportional to the increase in the V/C. At ratios of less than about 0.7, speeds decline only slightly as V/C increases. At ratios over about 0.7, speeds decrease at an increasing rate as V/C increases. When traffic volumes approach capacity, speeds drop to about eighty percent of free-flow speeds on freeways and to about two-thirds of free-flow speeds on other arterials. When demand exceeds capacity, speeds drop rapidly and change unpredictably, as flow conditions become chaotic.

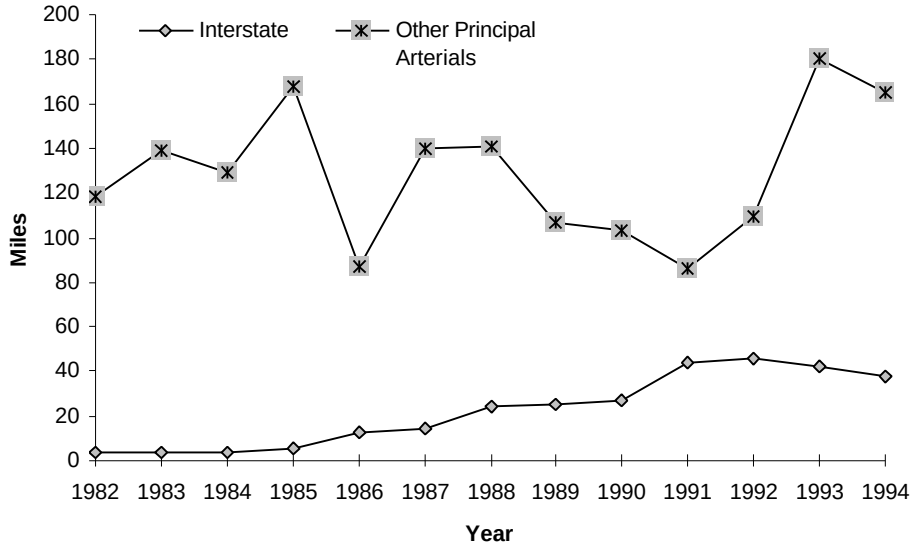
The Highway Performance Monitoring System (HPMS) estimates the total mileage operating at various volume-to-capacity ratios for each roadway functional class. This is done by computing V/C from measurements of sample sections of the roadway system and expanding the results to represent the entire system. The highest rate of sampling is done on freeways and expressways; volumes and capacities are measured and computed for all portions of these roadways. For other functionally classed roadways, only about 5% to 6% of the mileage are sampled. This low level of sampling results in considerable fluctuation of the data.

HPMS-derived V/C data are reported as miles of roadways of each functional class that fall within several defined categories of V/C[4]. For the purpose of this report, data are presented for the number of highway miles at V/C above 0.70 and the number of miles at V/C above 0.95. These are the upper two categories that have been reported for the entire period covered by this report. The 0.70 ratio generally corresponds to the point where travel speeds begin to drop noticeably below free flow speeds. The 0.95 ratio identifies roadway sections that are approaching capacity.

Figure 13 shows miles of rural arterials with peak hour V/C greater than 0.70. (Information is not presented for V/C greater than 0.95 because there are very few miles of rural arterials operating at this level.) The graphs show a steady rise in congested rural freeway miles, although the number of miles is still fairly low. It is much more difficult to discern a trend for other principal arterials given the wide degree of fluctuation in the data over the period. Figure 14 shows the increase in freeway and expressway congestion is more pronounced for urban areas.

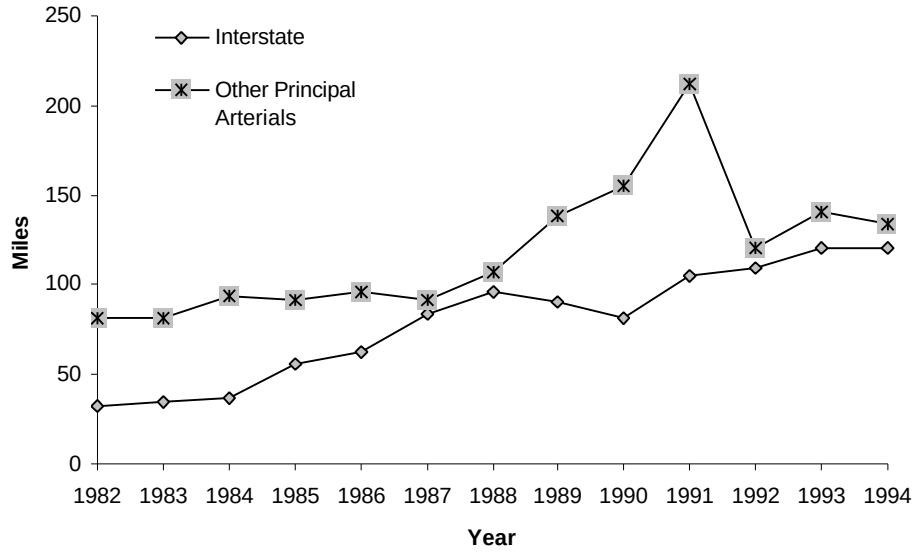
The figures show a fairly consistent trend of rising congestion on other principal arterials in urban areas. The rapid rise in congestion in 1991 and subsequent fall is not consistent with the trend and is most likely the result of a computation or reporting error. Congestion on freeways and expressways grew at a significantly higher rate than on other principal arterials. It can be seen that the miles of congested freeways and expressways (v/c > 0.70) increased from being about half that of other principal arterials to almost equaling the congested mileage of other principal arterials.

Figure 13
Miles of Moderately to Severely Congested Rural Arterials in Oregon
V/C > 0.70, 1982 - 1994



Source: ODOT Transportation Planning & Data Sections

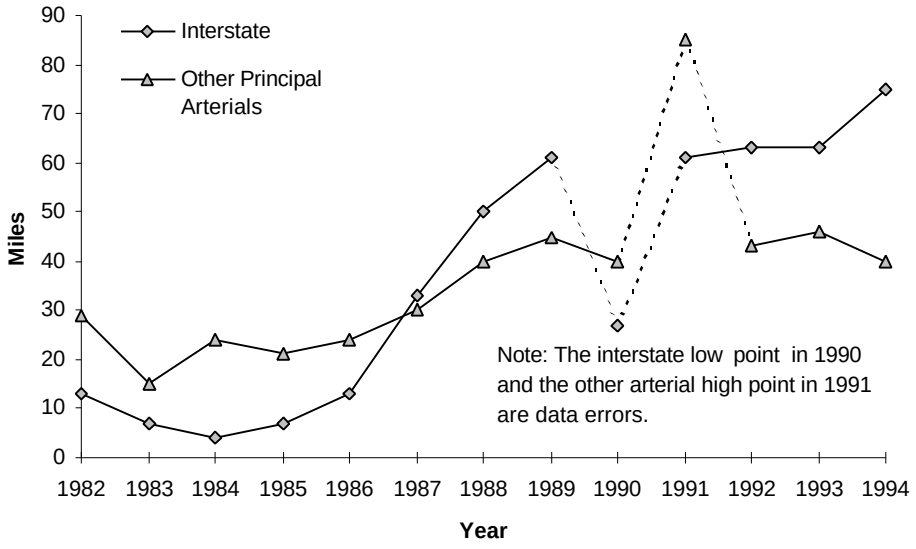
Figure 14
Miles of Moderately to Severely Congested Urban Arterials in Oregon
V/C > 0.70, 1982 - 1994



Source: ODOT Transportation Planning & Data Sections

Figure 15 shows that serious congestion on urban roadways (v/c > 0.95) has grown most rapidly on urban freeways. Serious congestion has also grown on other principal arterials, but not as rapidly. The anomalies in the trends in 1990, for freeways and expressways, and in 1991, for other principal arterials, are most likely the result of computational or reporting errors.

Figure 15
Miles of Severely Congested Urban Arterials in Oregon
V/C > 0.95. 1982 - 1994



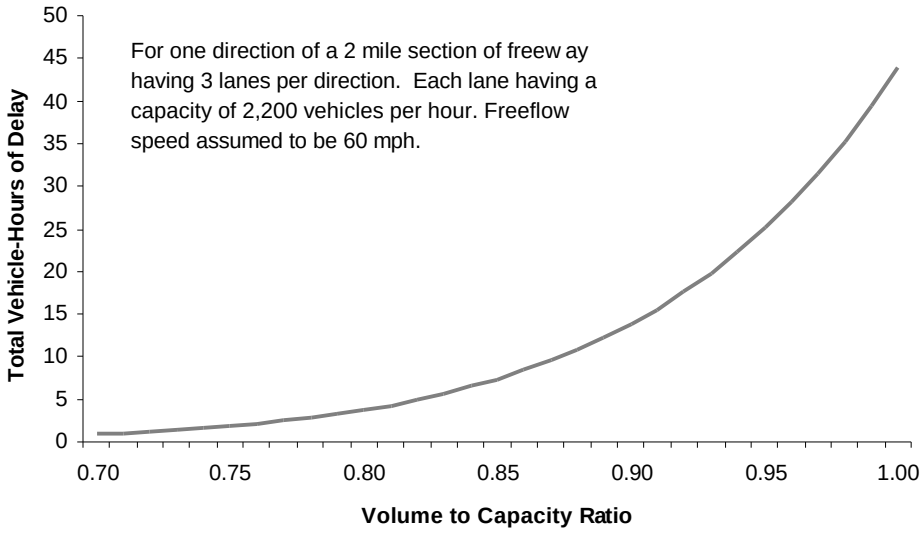
Source: ODOT Transportation Planning & Data Sections

The mileage of seriously congested freeways and expressways (v/c > 0.95) grew to significantly exceed the mileage of seriously congested other principal arterials. The relative increase in congestion on the freeways is particularly noteworthy because the lane-mileage of other principal arterials is almost three times that of the freeway and expressway system. In other words, congestion is becoming increasingly concentrated on freeways and expressways.

2.6 Travel Time and Delay

Travel time and delay are the best measures of congestion. As people drive along a road, they are not aware of the average traffic volume per lane or volume to capacity ratio. They are, however, acutely aware of how much time their trips are taking and how much they are being delayed by congestion. Measures of traffic flow and capacity can give false impressions about travel delay because delay increases exponentially as traffic volumes approach capacity. This is illustrated by Figure 16. Delay is increased ten times more when the volume to capacity ratio increases from 0.9 to 0.95 than when it increases from 0.7 to 0.75. In the example shown in Figure 16, the addition of 100 more vehicles to a two-mile three-lane freeway section (one direction) carrying 5000 vehicles per hour would increase total vehicle delay by about 30 minutes. Adding 100 more vehicles to the same freeway section carrying 6000 vehicles per hour would increase total vehicle delay by over three hours. Even greater increases in delay occur when demand exceeds capacity because traffic speeds drop precipitously, road capacity drops, traffic queues form, and congestion spreads over longer time periods.

Figure 16
Relationship of V/C to Delay



Source: ODOT Planning Section, based on Transportation Research Board. *NCHRP Report 387*. 1997. p 70.

Unfortunately, travel time and delay data are very difficult to collect. These data can be collected by test driving roads at prevailing speeds many times during various hours of the day or by monitoring traffic speeds through an extensive system of speed sensors.

Because of the expense, these data are collected only for limited areas and for specific purposes. A statewide record is not available.

Absent direct measures, travel time can be estimated from traffic volume and capacity data or from household surveys of travel behavior. Each of these means of evaluating travel times has their own limitations. Estimates of travel speeds from V/C are based on average relationships and vary from actual speeds. Estimates based on travel surveys reflect the effects of a number of factors in addition to congestion. Each, however, is worth considering because it adds to the picture of transportation system performance.

Travel time and delay are estimated from volume and capacity information based on generalized observed relationships between average traffic speeds and volumes. Average traffic speeds are easily converted into average travel times. Recurring congestion delay is the difference between congested and uncongested travel times. (Figure 16 is based on the generalized relationship between average speeds and V/C.)

Accidents or other incidents that temporarily reduce capacity and slow traffic cause additional delay that can exceed recurring congestion delay. Incident delay tends to increase as recurring delay increases because:

1. The likelihood of an accident of other incident increases as traffic volumes increase; and
2. Incidents have a greater effect when a road is operating near capacity. (For example, a disabled vehicle on a highway shoulder will have little effect on traffic flow at low V/C, but may cause stop and go traffic to occur when traffic volumes are almost at capacity.

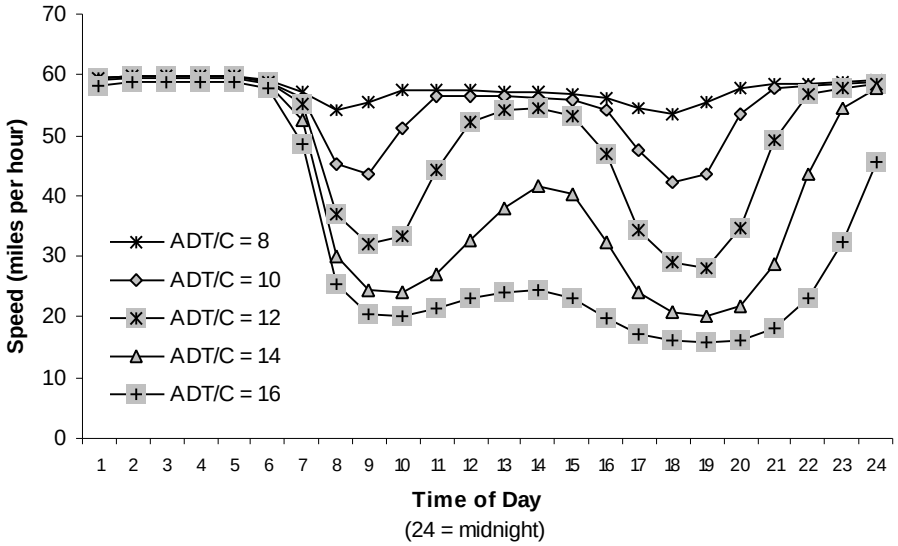
The Texas Transportation Institute has estimated recurring and incident delay on freeways and other principal arterials as part of its ongoing studies on metropolitan congestion. TTI has reported in its most recent study that daily delay in the Portland metropolitan area totaled 123,000 person hours in 1994. This was a 141% increase from the 1982 estimate of 51,000 person hours[5]. Incident delay accounted for 62% of the total delay in 1994.

Daily and peak period delay can be estimated from relationships between highway speeds and the ratio of average daily traffic to hourly highway capacity (ADT/C). Researchers have developed these relationships based on data from hundreds of automatic traffic recorders (ATRs) in urban areas around the country and modeling of the formation and dissipation of traffic queues.[6]

Figure 17 shows generalized relationship between freeway speeds and ADT/C. At ADT/C of 8 or less, traffic speeds decline little over the course of a day. As the ratio increases, speeds decline during the peaks and the peaks broaden. Still, when the ADT/C ratio is 12 or less, speeds during the inter-peak period remain close to the free-flow speed. As ADT/C increases above 12, the morning and afternoon peaks begin merging into one daylong period when speeds are greatly reduced.

Table 6 compares the state's metropolitan areas on the basis of the number of lane-miles of freeway at various ADT/C levels and total daily delay. The difference between Portland and the other areas is clear. Traffic on the freeways in Eugene and Medford are not high enough to cause a significant reduction in traffic speeds. Although ADT/C ratios in Salem are higher, they will be similar to those in Eugene once the current freeway construction is complete. In the Portland metropolitan area, about two-thirds of the freeway system operates at ADT/C levels relating to significant speed reductions during peak hours (>8) and about 10% operates at levels relating to significant speed reductions during the inter-peak period. Freeway delay in the Portland metropolitan area accounts for 98% of all daily freeway delay in Oregon's metropolitan areas.

Figure 17
Relationship of the Average Daily Traffic to Peak Hour Capacity Ratio (ADT/C) and Freeway Speeds by Hour



Source: USDOT. *Estimating The Impacts of Urban Transportation Alternatives* . NHI Course No. 15257

Table 6
Lane-Miles of Freeway by Average Daily Traffic to Capacity Ratio (ADT/C)
And Daily Freeway Delay For Major Metropolitan areas in Oregon, 1995

Metro Area	ADT/C Range						Total Lane-Mi.	Daily Delay (vehicle-hr.)
	<= 8	**8.1 - 10**	**10.1 - 12**	**12.1 - 14**	**14.1 - 16**	**>16**		
Portland	162	179	95	43	0	3	482	31,597
Salem	57	20	2	0	0	0	79	528
Eugene	65	0	0	0	0	0	65	98
Medford	27	0	0	0	0	0	27	5
Total	311	199	97	43	0	3	653	32,227

Source: ODOT Planning and Transportation Data Sections
Note: Assumes 60 mph free flow traffic speeds

Household surveys can provide information on average trip times for various trip purposes such as commuting. The decennial census and the biennial state household survey collect information on commute travel times in Oregon. The US Census Bureau reports the number of workers by ranges of travel time to work. This is shown in Table 7, which compares 1980 and 1990 travel times for Oregon's four urbanized areas.

Table 7
Reported Average Travel Time to Work by Residents
In Oregon's Four Major Urbanized Areas[1], 1980 & 1990

	Portland-Vancouver[2]		Salem-Keizer		Eugene-Springfield		Medford-Central Point	
Minutes	1980	1990	1980	1990	1980	1990	1980	1990
Less than 10	14.7%	13.6%	20.4%	18.4%	21.1%	19.8%	28.1%	28.5%
10 to 19	34.8%	34.7%	47.9%	47.5%	49.8%	51.6%	53.8%	50.1%
20 to 29	24.9%	25.8%	17.2%	17.1%	17.7%	17.0%	11.0%	12.6%
30 to 44	18.4%	18.2%	8.4%	9.0%	6.8%	6.7%	4.2%	5.5%
45 or greater	7.2%	7.7%	6.1%	8.0%	4.6%	4.9%	2.8%	3.4%
Average (min.)	20.6	21.1	17.2	18.4	16.3	16.6	13.5	14.3

Source: 1980 & 1990 Census
Notes: 1. Urbanized areas are portions of metropolitan areas with population densities greater than 1000 per square mile.
2. Data reported in this table is for the Portland-Vancouver urbanized area while Table 6 reports data for Clackamas, Multnomah and Washington counties.

Table 8 compares 1990 and 1996 travel times in different regions of the state gathered from the biennial state household survey.

Table 8
Reported Average Travel Time to Work by Residents
Of Various Regions of Oregon, 1990 & 1996

	Portland		West		Central		East	
Minutes	**1990**	**1996**	**1990**	**1996**	**1990**	**1996**	**1990**	**1996**
10 or Less	29.2%	31.0%	50.5%	43.8%	62.6%	46.6%	64.7%	56.5%
11 to 20	35.1%	31.2%	28.7%	33.0%	20.4%	29.3%	23.0%	24.9%
21 to 30	19.1%	22.0%	12.2%	10.4%	10.5%	12.6%	6.8%	8.7%
31 to 45	13.6%	9.4%	4.1%	6.6%	4.6%	6.5%	3.3%	5.1%
46 to 60	2.6%	4.1%	1.4%	4.2%	0.9%	2.4%	1.1%	2.7%
61 or greater	0.4%	2.4%	3.0%	2.0%	1.0%	2.6%	1.2%	2.0%
Average (min.)	20.9	21.6	16.9	18.3	13.7	17.6	12.5	15.5

Source: 1990 & 1996 Oregon Population Survey
Notes: Portland Metro, West, Central and East refer to the areas identified in Table 1.

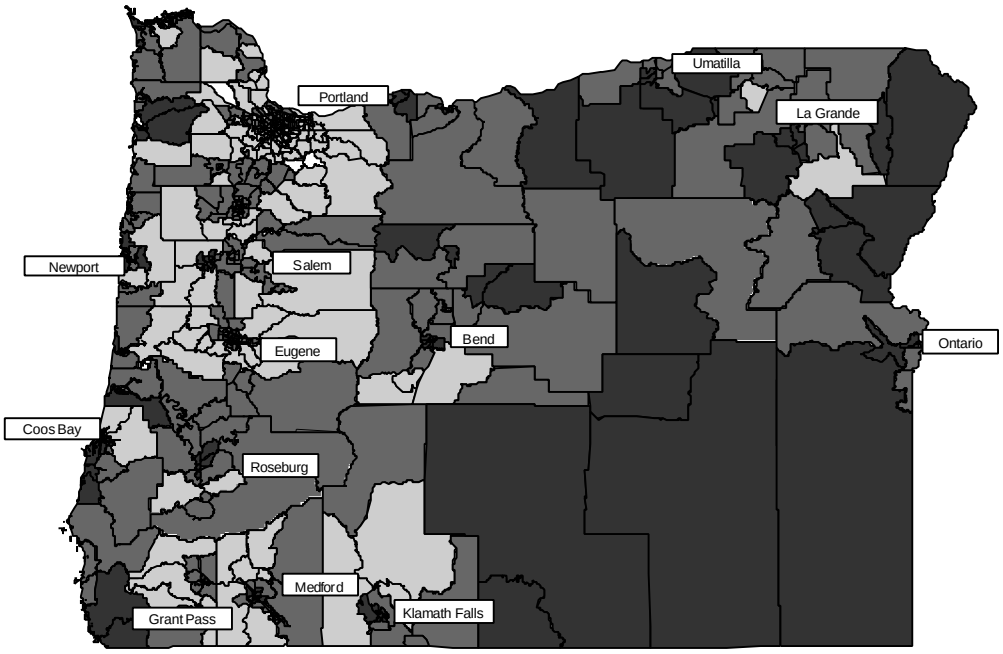
These tables show several interesting patterns. The first is that average travel times to work changed little in the state's major metropolitan areas between 1980 and 1990. The second is that the average commute travel time in Central Oregon increased considerably (28%) between 1990 and 1996 and grew markedly in other areas outside of the Portland metropolitan areas as well. The sizable drops in the percentage of commutes less than ten minutes in length are particularly noteworthy. It is unlikely that this change is solely a consequence of rising congestion. The percentage of short commutes is bound to drop as urban areas grow and people have more choices about where they live and work.

It is also notable that travel time in the Portland Metropolitan Area changed so little despite marked increases in highway congestion. Researchers have noted that commute travel times have been fairly resistant to change in metropolitan areas around the U.S.[7] This observation is consistent with the theory that people have budgets for the amount of time they are willing to travel. They change household and job locations to maintain acceptable travel times.[8]

Figure 18 shows the percentage of workers within each census tract in the state who have commute times that are less than 20 minutes. It can be seen that people with longer commutes live primarily in the fringes of the larger cities in Western and Central Oregon.

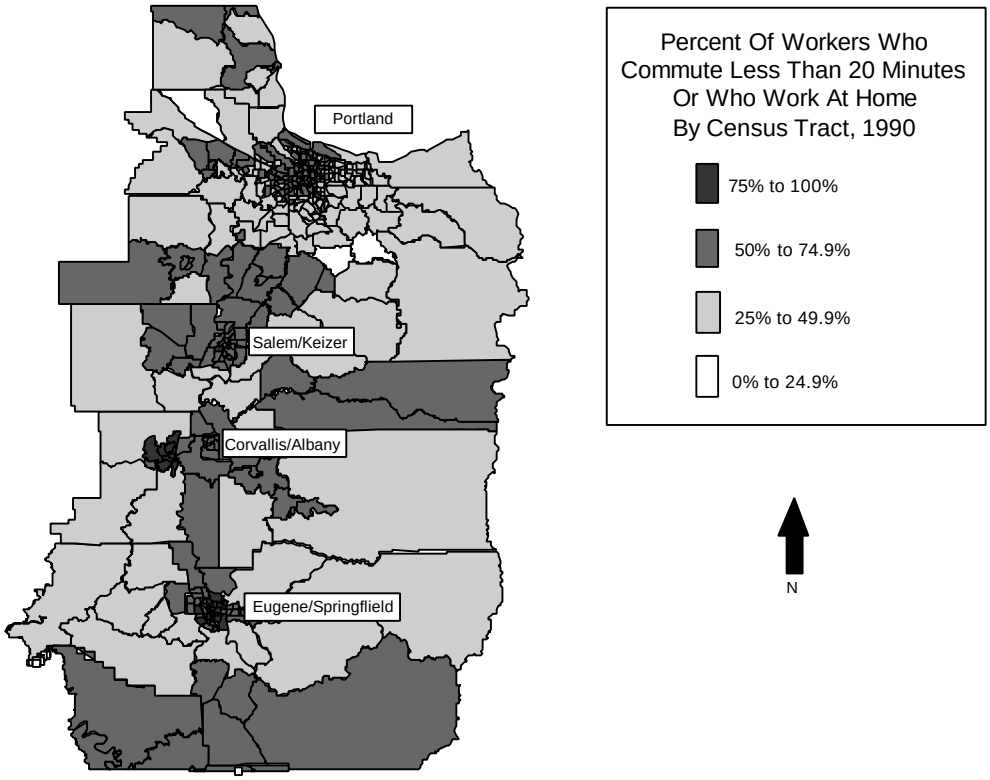
The view of the Willamette Valley shows the relationship of long commutes with urban area size and proximity to the Portland metropolitan area. For most of the Eugene and Corvallis areas, over 75% of people live within 20 minutes of work. The situation is opposite in the Portland metropolitan area where a small proportion of workers have commutes this short. Commute times for Salem residents, while not as short as those of Eugene residents, are significantly shorter than for Portland area residents. Most residents of Salem and its fringes have commutes that are less than 20 minutes.

Figure 18
20-Minute Commutes in Oregon and the Willamette Valley



Not to Scale

Source: US Census STF3A

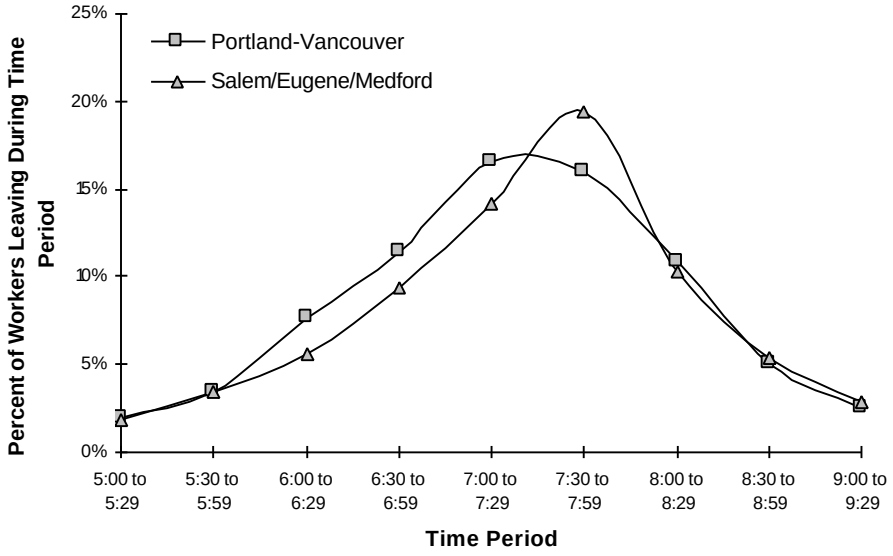


2.7 Peak-Period Spreading

As urban areas grow and become more congested, peak periods of congestion last longer. This peak period spreading occurs because traffic queues form, which take time to dissipate and because people adjust their departure times to avoid the worst of the congestion.

Census data on when people leave for work provides some insight into peak-period spreading. Figure 19 compares departure times for people who live in Portland with the departure times of people who live in the other three metropolitan areas. The morning peak is noticeably broader in Portland.

Figure 19
When People Leave for Work in Portland and Oregon's Other Major Metropolitan Areas, 1990



Source: 1990 Census

Peak period spreading can also be gauged from traffic count data. One simple measure of peak period spreading is the percentage of average daily traffic occurring in the 30th highest hour. This will typically vary from about 8 to 10 percent of the average annual daily traffic. Lower percentages mean greater peak spreading. ODOT maintains over one hundred automatic traffic recorders (ATRs) around the state, which provide these data. Nine of these are located on the freeway system in Portland and there is one apiece on freeways in Salem, Eugene and Medford. Table 9 shows the percentages of average daily traffic occurring in the peak at each of these 12 sites for the last 10 years.

Table 9
Percentage of Average Daily Traffic Occurring at the Peak Hour[1]

Year	Portland									Salem	Eugene	Medford
	26-002	**26-004**	**26-005**	**26-013**	**26-016**	**26-019**	**26-024**	**26-026**	**26-027**	**24-004**	**20-008**	**15-019**
1987	9.1	9.0	9.7	7.6	-	8.4	10.8	-	9.8	10.4	10.3	9.5
1988	-	-	9.4	7.2	-	8.2	10.2	8.7	10.1	10.4	10.2	9.4
1989	-	9.4	-	7.1	9.1	8.4	12.0	-	-	10.4	10.3	9.5
1990	8.7	8.9	9.3	7.0	-	-	10.7	8.9	10.5	10.9	10.3	9.6
1991	8.7	8.8	9.3	-	8.8	8.5	10.5	8.5	9.5	10.9	10.2	9.5
1992	-	9.0	9.1	-	8.4	8.3	10.0	8.3	-	10.6	10.1	9.3
1993	8.5	8.7	9.1	8.0	9.1	8.4	10.5	8.5	9.5	10.7	10.3	9.5
1994	8.4	8.6	8.9	8.0	9.0	8.1	10.6	8.2	9.4	10.5	10.0	9.4
1995	8.4	8.5	-	7.9	9.5	8.0	-	-	9.7	-	10.1	9.3
1996	8.4	8.5	8.5	7.7	8.9	8.0	-	8.4	9.2	10.6	10.2	9.2
'96 Peak Hr. Vol.	10,814	9,608	7,844	13,088	12,154	10,164	11,472[2]	10,763	9,374	2,227	5,744	3,616

Source: ODOT 1996 Traffic Volume Tables
Notes: 1. Peak hour volume is the 30th highest hourly traffic volume
2. Computation of peak hour volume based on 1994 percentage

26-002 - US-26 at Vista Ridge Tunnels (Portland)
26-004 - I-5 on Interstate Bridge (Portland)
26-005 - I-405 at southerly junction on I-5 (Portland)
26-013 - I-84, 0.12 mile east of N.E. Holladay St. ramp (Portland)
26-016 - I-5, 1.1 miles north of S.W. Terwilliger Blvd. (Portland)
26-019 - I-5, 0.03 mile south of N. Ainsworth St. (Portland)
26-024 - I-205 on Government Island
26-026 - I-5 on Marquam Bridge (Portland)
26-027 - I-405 near West Freemont Bridge Intchg. (Portland)
24-004 - OR-22 (N. Santiam Hwy.), 0.9 mile east of Salem
20-008 - I-105, 0.7 mile west of I-5 (Eugene)
15-019 - I-5 south approach of Medford viaduct

Greater peak period spreading in the Portland Metropolitan Area is indicated by lower percentages of traffic occurring during the peak hour. The lowest percentages occur in the most capacity restricted corridors in Portland: the Vista Ridge Tunnels, the Banfield Freeway, I-5 in North Portland, and the Marquam Bridge.

3: DISCUSSION OF CONGESTION TRENDS

3.1 Introduction

Congestion has been increasing because vehicle miles traveled have been increasing at a much faster rate than highway lane-miles. Table 10 shows the changes that occurred over the thirteen-year period between 1982 and 1995. Meanwhile, transit ridership increased by 51% from 1985 to 1996.[9]

Table 10
Changes in VMT and Lane-Miles on Arterials and Collectors
In Oregon, 1982 to 1995

Functional Classification	VMT (percent)	Lane-Miles (percent)
All Arterials and Collectors	59%	6%
Urban Freeways & Expressways	114%	19%
All Urban Arterials and Collectors	67%	30%
Rural Interstate Freeways	55%	4%
All Rural Arterials and Collectors	40%	1%

Source: ODOT Planning and Transportation Data Sections

Three factors explain the rise in vehicle miles traveled in Oregon:

1. The population of drivers has increased. This is due to the growth of population, increase in the percentage of people of driving age, and increase in the percentage of people who drive.
2. Employment growth has increased the number of commuters and the average number of workers per household. This increased household income and auto ownership. It also increased trip linking, which decreased use of alternative travel modes.
3. Government policies and programs have accommodated public desires for rising levels of mobility. Suburban dispersion of population was accommodated by city and county land use plans that were approved by the state. Roads were built or improved to accommodate rising traffic levels. Overuse of roads during peak periods was encouraged by average cost pricing rather than marginal cost pricing.

This chapter explains how each of these factors has affected travel and congestion.

3.2 Increase in Driving Age Population

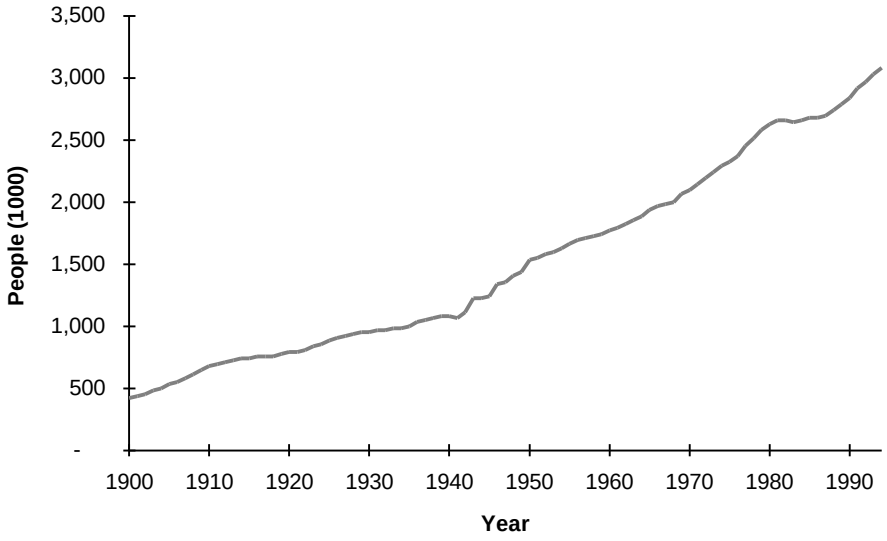
Oregon has experienced a large increase in the driving age population. This has been due to:

1. Growth of Oregon's population,
2. Increase in the percentage of the population that is of driving age, and
3. Increase in the percentage of the driving age population who drives.

Oregon's population has grown steadily over most of the 20th Century (Figure 20). Most recently, it has grown at the rates of:

- 2.4% per year from 1970 to 1980
- 0.2% per year from 1980 to 1985
- 1.4% per year from 1985 to 1990
- 1.3% per year from 1990 to 1995

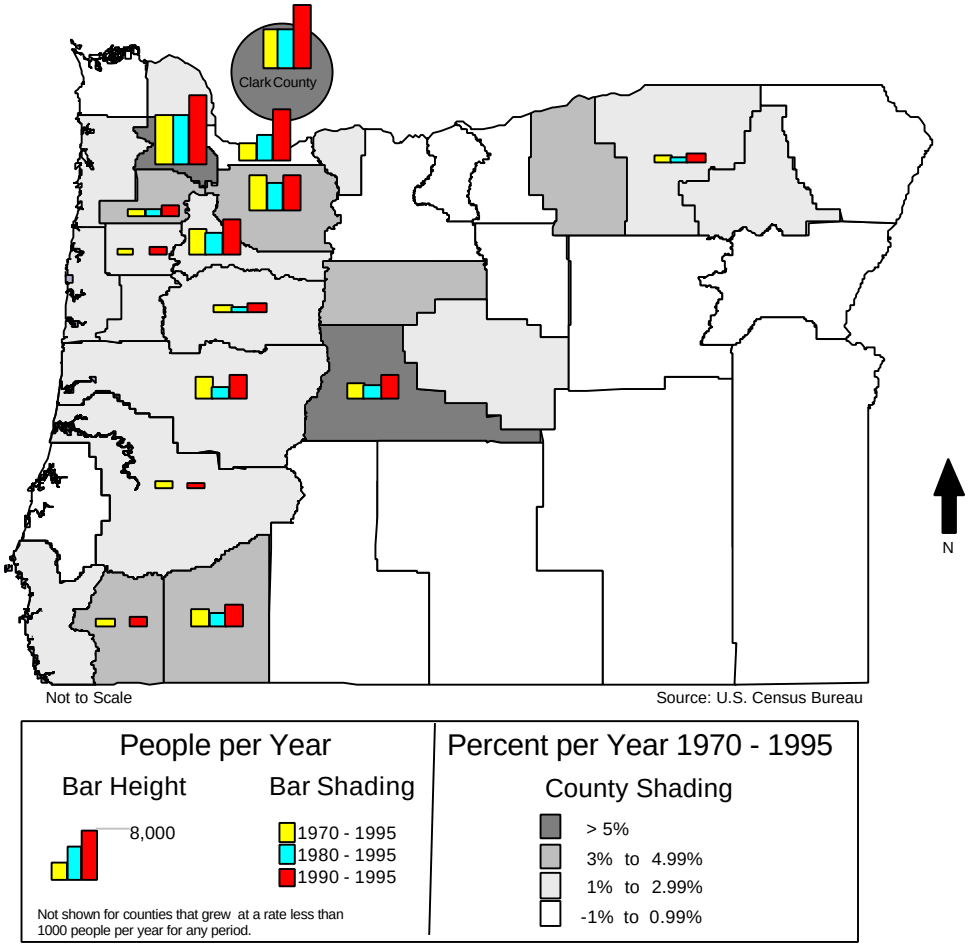
Figure 20
Population of Oregon, 1900 – 1995



Source: Census & Portland State University Center for Population Research and Census

Population growth has been unevenly distributed across the state (Figure 21, following page). The Portland metropolitan area has grown at a rapid rate and has received most of the state's growth. This is one of the one of the main reasons why congestion has grown faster in the Portland metropolitan area than elsewhere in the state. The population of Deschutes County has also grown rapidly. This may explain why people living in Central Oregon perceive congestion to be so bad (Table 3).

Figure 21
Population Growth in Oregon and Clark County Washington
1970 – 1995



The proportion of the state's population that is eligible to drive has also increased. In 1970, 73% of Oregon's population was 15 years or older. In 1995, 79% of the population was 15 years or older.

Finally, the proportion of the state's driving-age population that is licensed to drive has increased. In 1970, the ratio of drivers' licenses to driving age population was 0.86. By 1995, the number of drivers' licenses grew to exceed the driving age population.[10] Most of the growth of licensing occurred among women. In 1970, the ratio of the number licenses held by females to the population of driving-age females was 0.67. By 1995, the ratio had grown to 0.96.

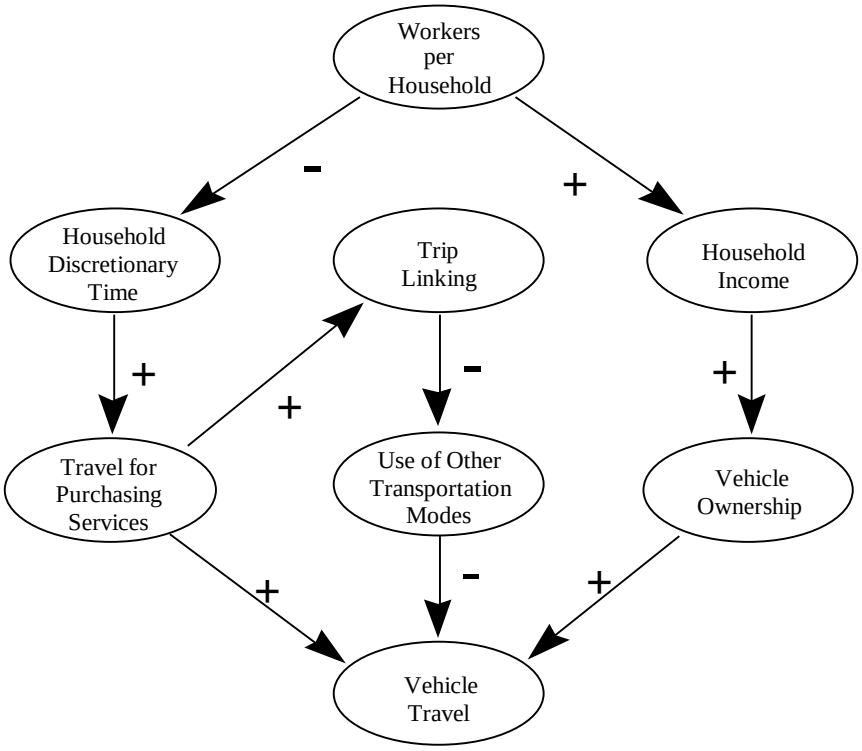
3.3 Increasing Employment

Households account for most vehicular travel. Increasing household employment and rising per capita incomes have increased household travel and traffic congestion in the following ways:

- Rising employment and lowered household sizes increased incomes and promoted automobile purchases and use. The state's recovery from recession in the early 1980s resulted in very high rates of per capita VMT growth.
- Rising employment resulted in substitution of increased purchases of services for reductions in household discretionary time. This resulted in increased travel.
- Households economized on travel by increasing their linking of vehicle trips. This contributed to reductions in carpooling and the use of public transportation.
- Increases in employment and trip linking placed more travel in the peak hours.

The combined effects of these factors on vehicular travel are summarized by Figure 22 and are described below.

Figure 22
Effect of Worker Increases on Vehicle Travel

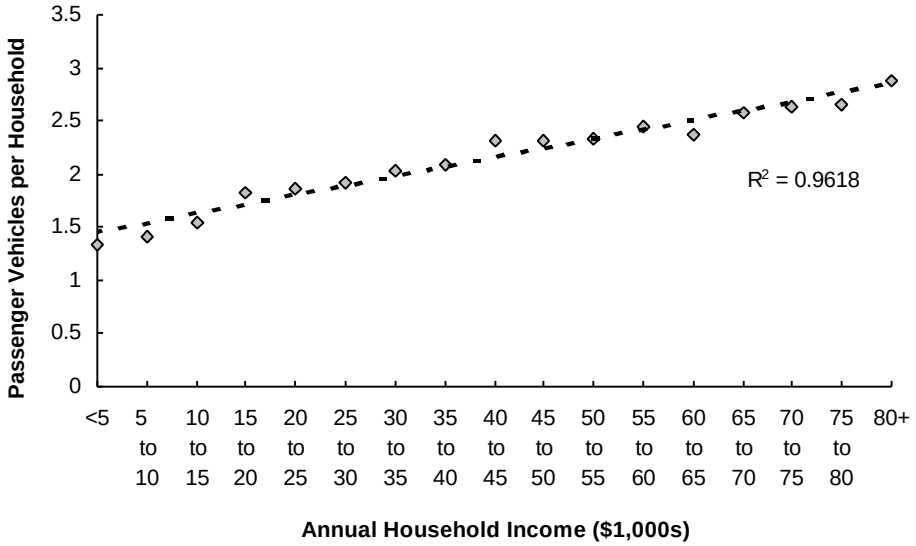


Factors affecting travel are shown in the ovals (e.g., workers per household)
Arrows show causal relations between factors (e.g., workers per household affects household income)
Plus signs indicate positive relationships (e.g., increasing workers per household results in increasing household income)
Minus signs indicate negative relationships (e.g., increasing workers per household results in decreasing household time.)

VMT growth over the past several decades was driven in large part by rapid rises in employment. This has been called the worker boom.[11] From 1975 to 1995, while the population of Oregon increased by 35%, the labor force increased by 59%. This increase in employment was primarily the result of the entry into the workforce of baby boomers and increasing numbers of women. The average number of employees per household in Oregon increased from 1.33 to 1.52 between 1970 and 1995.[12] Average per capita incomes increased by 53% in over that period.[13]

Rising employment and incomes fueled rising demand for automobiles. Figure 23 illustrates the very strong relationship between household income and vehicle ownership.

Figure 23
Vehicle Ownership and Household Incomes in the Western United States, 1990



Source: 1990 National Personal Transportation Survey, Western Census Region Data

A couple of basic principles of travel economics explain the connection between household income growth and increased use of automobiles. These principles appear to hold true for diverse cultures around the globe.[14]

1. Households devote a roughly constant proportion of their total expenditures to transportation. In developed countries the average is about 10 to 15 percent.
2. Households have travel time budgets that remain fairly constant over time. The average is between 1.0 and 1.5 hours per person per day.

Households increase their transportation expenditures as their incomes rise, but to satisfy their desires to increase mobility without violating their travel time budgets, they must use faster modes of transportation. Thus as household incomes have risen over the course of the 20th Century, people have devoted an increasing share of their travel budgets to automobile and airline travel and a decreasing share to travel by walking, bicycling and

public transportation. In recent decades, increases in employment have been responsible in large part for increasing household incomes.

While increasing employment has raised household incomes, it has also imposed greater burdens on household time budgets and has increased travel for purchasing services that were previously provided by members of the household (e.g., day care, food preparation, and house cleaning).[15] Businesses expanded to provide these services. For example, the number of fast food restaurants grew at almost three and a half times the rate of population growth in the Portland metropolitan area and at over four times the rate of population growth in the Eugene/Springfield metropolitan area.[16] Travel increased as household service expenditures increased.

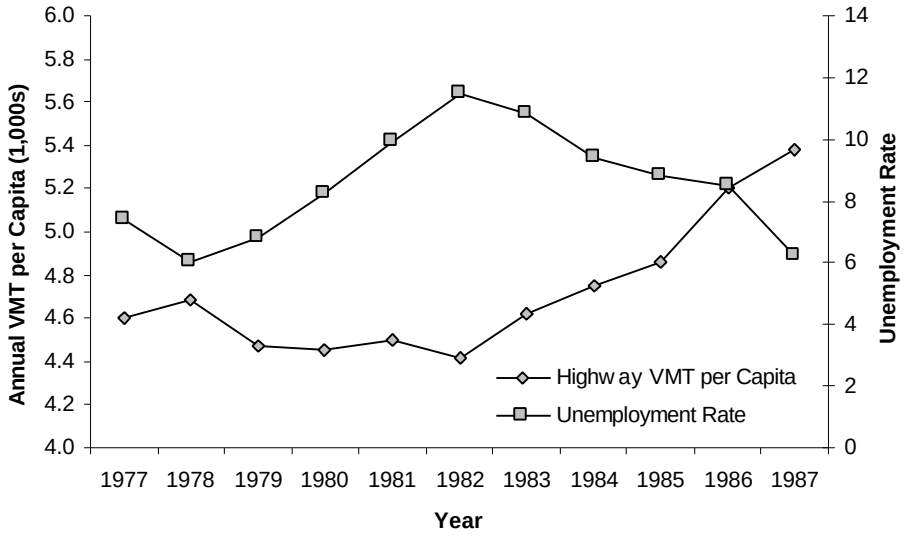
Households responded to the increased pressure on their travel budgets by using faster modes of travel (automobiles) and by increasing their linking of trips.[17] That is, they increasingly combined several activities into their automobile trips to reduce overall travel. For example, parents combined shopping and day care trips with their work trips to reduce the amount of time spent traveling to accomplish those activities. Increases in trip linking put public transportation and carpooling at a greater disadvantage. For example, carpooling in the United States dropped off dramatically from 20% of all commuters in 1980 to 13.4% of all commuters in 1990. The decline was particularly large for large carpools. Three-person carpools dropped by 40% and four-person carpools dropped by 50%. Most of the decline was due to the decline in carpooling among non-family members.[18]

The increase in workers per household and associated increases in trip-linking concentrated travel during peak periods. Commuting travel is focused in relatively narrow time periods and is fairly resistant to change. As people linked an increasing proportion of trip making to their work travel, even more travel was concentrated into the travel peaks, particularly the afternoon peak.[19]

In Oregon, much of the growth in VMT that occurred in the 1980s was an effect of Oregon's economic recovery. The recession in the early 1980s significantly reduced per capita VMT. The subsequent recovery contributed significantly to the rapid rate of growth in per capita VMT. Figure 24 illustrates the complementary relationship between employment and VMT. The growth rate of per capita VMT from the last year of the recession (1982) to 1990 was almost double the rate from the year prior to the start of the recession (1978) to 1990 (3.3% vs. 1.7% per year).

Although the recession and subsequent economic recovery were temporary deviations from long-term trends, their effects on VMT growth are worth mentioning because they generally went unrecognized in the early 1990s when important transportation policies were being adopted. At the time there was much consternation about the rapid rise of per capita VMT during the previous decade. This rapid growth of per capita VMT was commonly attributed to suburbanization but the relationship to the economic recovery was overlooked.

Figure 24
Comparison of VMT per Capita on State Highways and Oregon Unemployment Rate, 1977 - 1987



Source: ODOT Planning & Transportation Data Sections, PSU, Oregon Employment Department

3.4 Accommodation of Public Desires for Surburban Living

Although demographic and economic factors establish the fundamental demand for increased motor vehicle travel, public policies and programs influence the manifestation of the demand. Policies in Oregon have, until recent years, been oriented to accommodating demand. Lands were planned and developed for low-density suburban development that takes advantage of the increased mobility offered by automobiles. Roads were built and widened to accommodate rising traffic volumes. Road prices have remained low and reflected average costs rather than marginal costs.

Suburban development has been both a consequence of rising motor vehicle ownership and a cause of rising per capita VMT. Growing household incomes over the course of the 20th century fueled the demand for faster modes of transportation. The growing demand for faster travel was satisfied in urban areas primarily by automobiles and other motorized vehicles. Average urban travel speeds increased by more than three times as motorized vehicles became the dominant mode of urban transportation. As a result, the area around cities that became accessible for development increased by about nine times.[20] Automobiles and other motor vehicles made widespread suburban development possible and the public chose to enable rather than constrain that development. People took advantage of their newfound mobility by spreading out around the fringes of urban areas. Suburban development increased trip lengths and reduced the competitiveness of public transportation. Auto travel grew to dominate urban passenger travel.

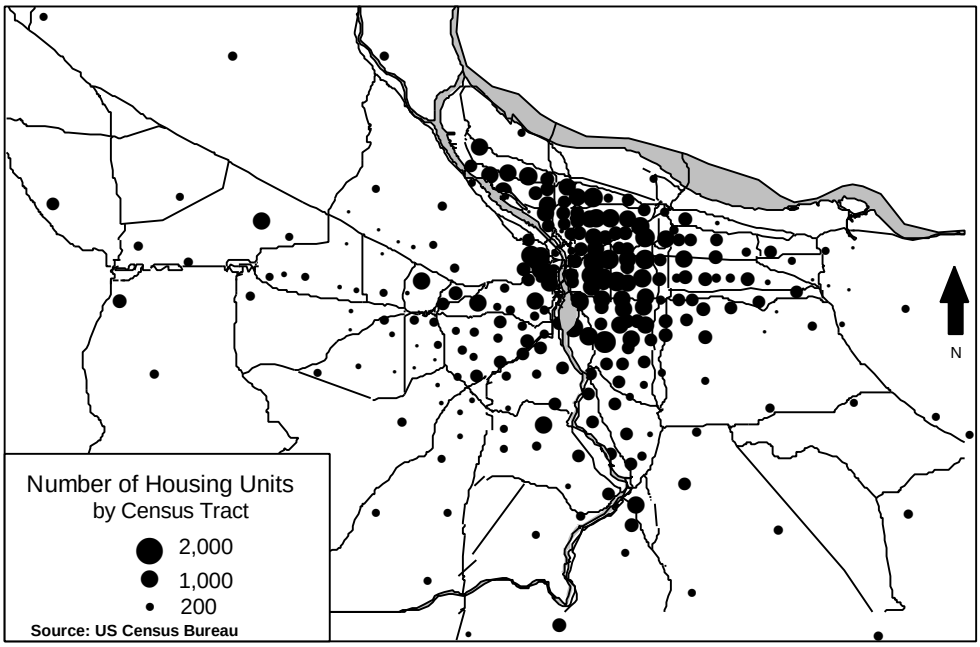
The low-density development patterns found in the United States differ from those of European and Asian cities, where automobile use has been constrained by much higher densities and public policies.[21] Even in Oregon, where land use laws are the most restrictive in the nation, cities and counties and the state Land Conservation and Development Commission approved plans that allowed large increases in suburban development.

Most new development in Oregon has occurred in suburban areas. Figure 25 illustrates this for the Portland Metropolitan area. During the 25-year period between 1970 and 1995, most of the population growth of the Portland-Vancouver metropolitan area occurred in suburban counties (Figure 21). Metropolitan population grew by 58%. The population of suburban counties (Clackamas, Clark, Washington) grew by 115%. The population of the central county (Multnomah) grew by 11%.

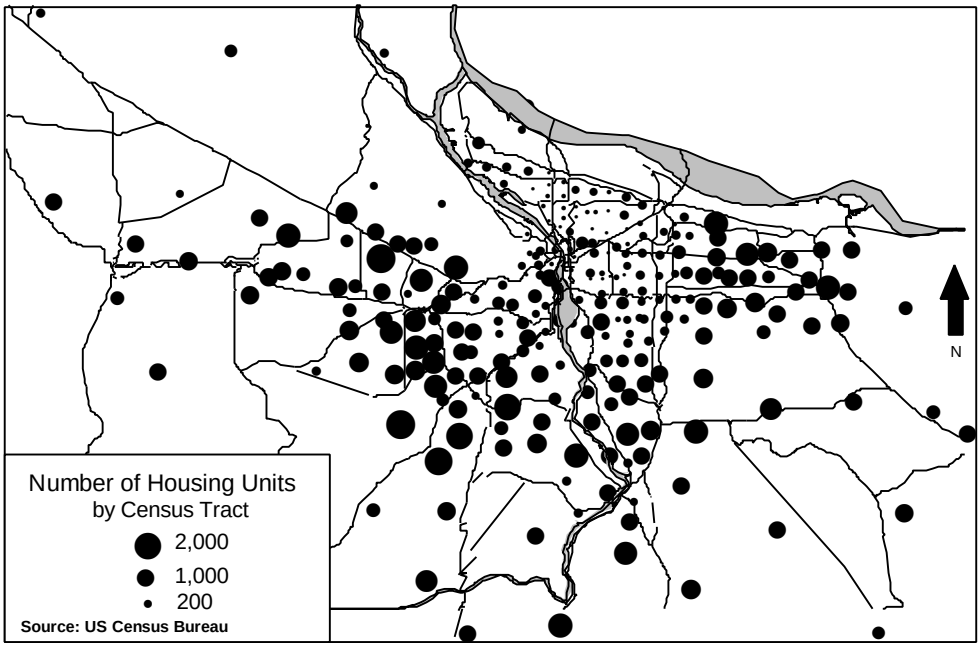
New employment, as well as housing, located predominantly in suburban locations. By 1990, two-thirds of all office space in the United States was located in suburban Edge Cities. Eighty percent of those Edge Cities came into existence in the last two decades.[22] In the Portland-Vancouver metropolitan area, overall employment grew by 148% from 1970 to 1995, suburban county employment grew by 359%, and central county employment grew by 56%.

Figure 25
Suburban Development in the Portland Metropolitan Area

Portland Metro Area Housing Built Before 1960



Portland Metro Area Housing Built After 1960



Suburban development has contributed to VMT increases by increasing average trip lengths and the proportion of trips made by motorized vehicles. It also contributed to the increasing concentration of congestion on arterials, particularly freeways. Suburban businesses and commercial areas are frequently located near freeways and arterials where exposure and accessibility is greatest.

Suburban development had the greatest impact on per capita VMT when the suburbs were relatively small. This was when the balance of housing and employment between central and suburban counties was changing most rapidly. The rate of per capita VMT growth due to suburbanization is declining as the suburban areas grow to contain the majority of metropolitan population. Table 11 illustrates this.

Table 11
Relative Effect of Suburban Growth on Metropolitan Per Capita VMT

Year	Item	Central County	Suburban Counties	Metropolitan Area	Change Between Time Periods	Ratio of Per Capita VMT Change to Population Change
0	Population	500,000	300,000	800,000	-	-
	Per Capita VMT	4,500	5,500	4,875	-	
10	Population	540,000	500,000	1,040,000	30.0%	0.072
	Per Capita VMT	4,500	5,500	4,981	2.2%	
20	Population	580,000	700,000	1,280,000	23.1%	0.058
	Per Capita VMT	4,500	5,500	5,047	1.3%	
30	Population	620,000	900,000	1,520,000	18.8%	0.048
	Per Capita VMT	4,500	5,500	5,092	0.9%	
40	Population	660,000	1,100,000	1,760,000	15.8%	0.041
	Per Capita VMT	4,500	5,500	5,125	0.6%	
50	Population	700,000	1,300,000	2,000,000	13.6%	0.036
	Per Capita VMT	4,500	5,500	5,150	0.5%	

Sources: Population – PSU Center for Population Research and Census (see text)
VMT – ODOT Planning and Transportation Data Sections (see text)

The example shown in Table 12 is hypothetical but is based on data from the Portland metropolitan area as follows:

- In 1970, the population of Multnomah County was 553,956 and the combined populations of Clackamas and Washington Counties were 326,277. The numbers were rounded to 500,000 and 300,000 for the central and suburban county listings.
- From 1970 to 1995, population of Multnomah County grew at a rate of about 3,500 persons per year. The population of Clackamas and Washington Counties grew at a rate of about 21,000 persons per year. The example uses population growth rates 4,000 and 20,000 person per year.
- The 1975 average annual per capita VMT in Multnomah County was about 4,600 and in Clackamas and Washington Counties was about 5,300. These estimates were computed by dividing the measured VMT on state highways in the counties by the statewide ratio of state highway VMT to total VMT (approximately 0.6), then

dividing the result by the county populations. The results were rounded to the nearest 500.

- The per capita VMT in the central county is about 20% less than in the suburban counties. A general rule of thumb is that per capita VMT is reduced by 25 to 30 percent when density is doubled (because of decreased automobile use and increased use of alternative modes of transportation).[23] Accordingly, the example might depict a situation where the average population density of the developed portions of the central county is almost twice the average population density of the developed portions of the suburban counties.

Table 11 also puts into perspective the relative effect of suburban development on per capita VMT. Assuming that the per capita VMT of central and suburban areas remains constant, average per capita VMT for a metropolitan area will change little as the suburbs grow. Average per capita VMT in the example increases by 3.5% over 20 years and 5.6% over 50 years.

The relative impact of suburban population dispersion on metropolitan VMT is also illustrated by the results of simulations of the effects of alternative growth plans for the Portland metropolitan area. Metro, the regional planning agency, adopted a plan that will counter suburban development trends by promoting growth in regional centers, town centers and along major transit lines. As Table 12 illustrates, the average metropolitan population density resulting from the plan is expected to be 70% higher than in 1990 and 39% higher than continuation of current trends would produce.

Table 12
Comparison of Average Densities of Portland Metropolitan Growth Scenarios, 2040

Scenario	UGB Acres	Population	Density	
			Per Acre	Per Square Mile
1990	234,000	1,032,471	4.4	2,820
Continuation of Current Trends	355,000	1,917,284	5.4	3,450
Adopted Concept	248,500	1,862,182	7.5	4,800

Source: Metro, "Concepts for Growth", June 1994 & "Metro 2040 Growth Concept", December 1994.

Metro estimated that the adopted growth concept would reduce per capita VMT for automobile travel within the metropolitan area by 5.2% over 50 years (from 1990 to 2040). The estimate reflects the effects of higher density as well as a quadrupling of transit ridership.[24]

Increases in per capita VMT due to suburbanization do not necessarily result in more congestion. Whether or not congestion is increased with suburbanization depends on whether road building in the suburbs can keep up with VMT increases. The following example illustrates this balance. Consider two cities that have the same population, occupy the same land area, and are growing at a rate that will double their populations in

50 years. In one city, the additional population will be accommodated by doubling the city's land area. In the other city, the additional population will be accommodated by doubling the city's population density. The city that doubles its density will have an average per capita VMT that is about 30% lower than the less dense city. Thus it will need about 30% fewer road lane-miles to serve future vehicle travel. But the cost of building roads will be higher in the denser city because land prices will be higher and the percentage of the urban area occupied by roadways will be 70% greater. If the road building cost in the denser city is 30% more than in the less dense city then it will be cheaper for the people living in to less dense to build enough roads to avoid congestion.

It appears that in the United States, denser metropolitan areas do have more difficulty providing enough roads to avoid congestion as population density increases. This is illustrated by Table 13, which compares travel, road supply and congestion for low-density metropolitan areas (persons/square mile less than or equal to 1000), and high-density metropolitan areas (persons/square mile greater than or equal to 4000). While the average per capita VMT decreases by 30% with a quadrupling of average density, the average number of road miles per capita decreases by about two-thirds. The net result is a 110% increase in the daily VMT per road mile.

Table 13
Comparison of Travel, Road Supply and Congestion for Low and High Density Urbanized Areas Having Populations Greater Than 100,000 in 1995

Measure	**Average for Urbanized Areas Having Densities**	
	Less Than or Equal to 1,000 Persons per Square Mile	**Greater Than or Equal to 4,000 Persons per Square Mile**
Daily VMT per Capita	27	19
Road Miles per Capita	6.6	2.2
Daily VMT per Road Mile	4190	8798

Source: Federal Highway Administration. *1995 Highway Statistics.* Table HM-72

3.5 Accommodation of Public Desires for Automobile Travel

Public transportation policy has been oriented towards accommodating rising demands for automobile travel. There has been extensive debate about the effect of public road building programs on travel demand. A commonly expressed viewpoint is that adding capacity to roads "induces" enough additional travel to use up all of the added capacity. This is a misperception. The emerging consensus among researchers of this subject is that while road building has "induced" additional VMT growth, it has had much less effect on VMT growth in the United States than have population, employment and income increases. Moreover, roadway projects in general have had a net effect of reducing congestion.[25]

"Induced" travel is the increase in VMT occurring as a result of additions to road capacity. Road improvements may increase VMT by increasing the number of vehicle trips or the average length of vehicle trips or both. Induced travel is fundamentally a consequence of reducing travel time. Highway capacity can "induce" demand to the extent that it reduces travel time to destinations that people want to get to. For example, a highway improvement may "induce" additional peak hour travel by reducing delay that previously discouraged some people from traveling during the peak. The same highway project might not increase daily travel if it does not reduce off-peak travel times.

People respond to travel time changes in a number of ways, some of which are more preferred that others. A survey of households living in the San Diego and San Francisco metropolitan areas showed the following order of preferences.[26]

1. Changing routes
2. Changing schedules
3. Combining trips
4. Changing travel modes
5. Changing destinations

The rapid growth of traffic on the freeway system and the concentration of congestion there are a testimonial to the effect of travel time on route choice. Freeways attract travel because they permit much faster traffic speeds than do other roads. The average speeds on uncongested urban freeways are typically greater than 55 miles per hour compared to average speeds of 30 miles per hour or less on signalized arterials. Since people try to reduce travel time, they choose to use freeways for any trip where they would save more time traveling on the freeway than they would lose accessing the freeway. As a result, freeways attract traffic until they reach capacity and speeds drop to those of other streets.

Interstate freeways have undoubtedly changed travel patterns and "induced" significant amounts of travel. They were a big addition to the road systems of metropolitan areas so they substantially increased average metropolitan travel speeds. Further capacity improvements to the freeway system will have much less effect because they will change average travel speeds much less.

A recent study of travel in the Milwaukee metropolitan area provides an indication of the relative effect of added highway capacity on VMT[27]. This study found highway capacity increases probably accounted for 6% to 22% of VMT growth that occurred in the Milwaukie metropolitan area between 1963 and 1991.

Over three-quarters of the growth of VMT in the Milwaukie metropolitan area was due to other factors such as population, employment and household income growth. These factors probably accounted for an even greater percentage of VMT growth in Oregon. Between 1970 and 1995, the population of the Portland-Vancouver metropolitan area grew by 59% and employment grew by 117%, while the population of the Milwaukie – Waukesha metropolitan area grew by 4% and employment grew 44%.[28]

Low road use fees have also accommodated road use in Oregon. Table 14, which compares automobile related taxes in Oregon with those of other western states, illustrates this. Oregonians pay less than a third of what Washingtonians pay to drive their cars. The relative cost is even lower when compared to other countries.[29]

Table 14
Comparison of Automobile-Related Taxes of Western States
March 1997

Tax	Oregon	Bordering States				Other Western States	
		Washington	California	Idaho	Nevada	Arizona	Montana
Gas Tax	24.6¢[1]	23.0¢	25.2¢[1]	25.0¢	28.6¢[1]	18.0¢	27.0¢
Registration and Related Fees	$15/year	$36/year	$29/year	$28/year	$33/year	$20/year	$16/year
Tax Equivalent (cents/gallon)	2.6¢	6.2¢	5.0¢	4.8¢	5.7¢	3.4¢	2.8¢
Average Ad Valorem Taxes	$0	$172/year	$148/year	$0	$78/year	$106/year	$152/year
Tax Equivalent (cents/gallon) [2]	0¢	29.6¢	25.5¢	0¢	13.4¢	18.2¢	26.2¢
Prorated Automobile Sales Tax[3]	$0	$191/year	$191/year	$123/year	$172/year	$160/year	$0
Tax Equivalent (cents/gallon)	0¢	32.9¢	32.9¢	21.2¢	29.6¢	27.5¢	0¢
Total Equivalent Cents Per Gallon	27.2¢	91.7¢	88.6¢	51.0¢	77.3¢	67.1¢	56.0¢

Source: Oregon Department of Transportation, Policy Section. March 7, 1997
Notes: 1 – California includes sales tax; Oregon and Nevada include average local option tax
2 – Based on estimated average of 581 gallons per year
3 – Prorated over eight years

Oregon's method of road financing encourages travel during congested time periods because it is based on average roadway costs. Road users are presented with the same fees whether they drive on heavily congested roadways or on uncongested roadways or whether they drive during peak travel times or during off-peak hours. This is unlike how many other public services are priced. For example, it costs more to make phone calls, use electricity, or fly at times of peak use. The result of average-cost pricing is that travelers are encouraged to overuse roads during peak times and under use them during off-peak times. Charging road users differential prices based on demand (congestion pricing) has been proposed as a method for more efficiently pricing road use and reducing peak hour congestion in Oregon.[30] Such a road-pricing method is being examined in the Portland metropolitan area.[31]

4: IMPLICATIONS

4.1 Introduction

Several of the trends that have been driving VMT growth are moderating. These include:

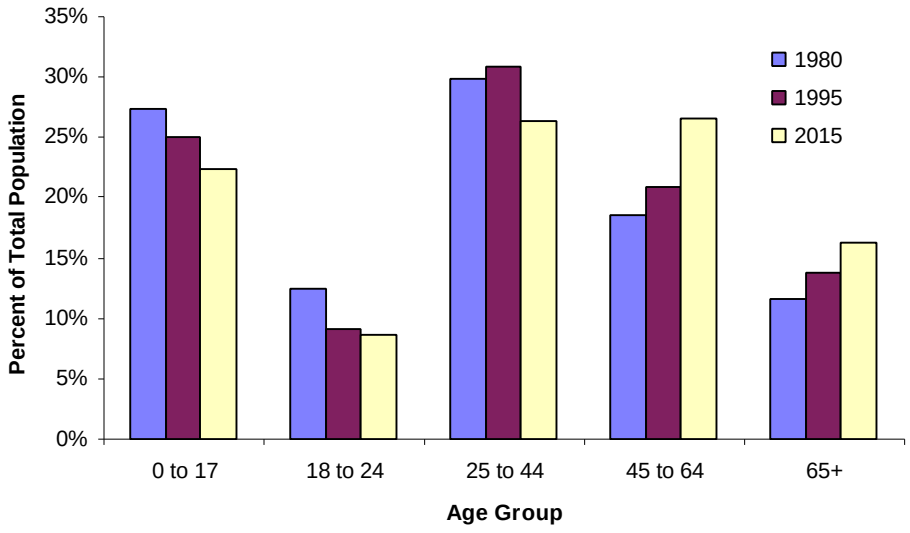
1. Quieting of the worker boom: Baby boomers have completed their entry into the workforce and the female labor force participation rate is stabilizing.
2. Saturation of motor vehicle ownership: Households increase VMT primarily by increasing their ownership of vehicles. The increase in vehicle ownership is slowing as the market is nearing saturation.

The implications of these changes are that per capita VMT will grow at lower rates than in the past but total VMT will continue to grow significantly as the state's population grows.

4.2 Quieting of the Worker Boom

There are now signs that the employment boom is dissipating. The proportion of the population that is of working age will decline as the baby-boomers retire (Figure 26). Part of the decline in workers due to baby-boomer retirement will be offset by an expected increase in the average retirement age.

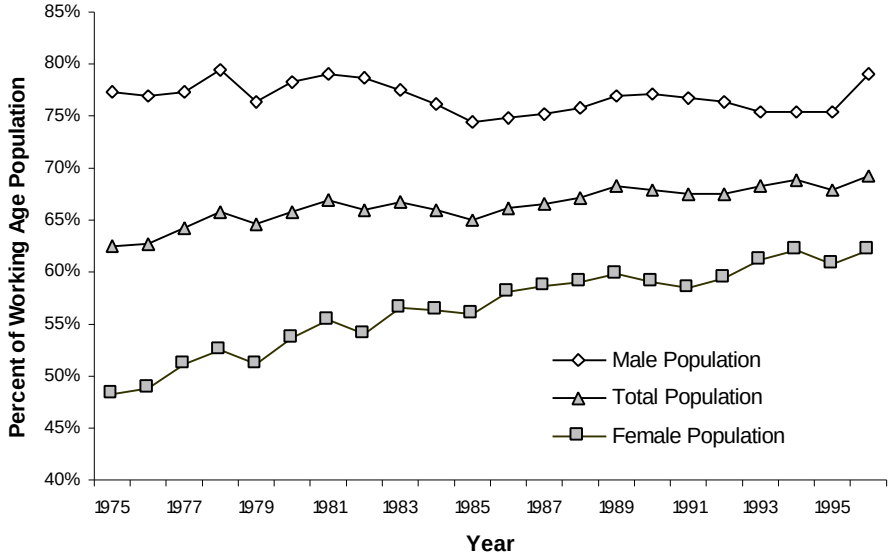
Figure 26
Changes in Age Structure of Oregon's Population
1980, 1995, 2015 (projection)



Source: Office of Economic Analysis, Oregon Department of Administrative Services. *Long-Term Population and Employment Forecasts for Oregon.* January, 1997

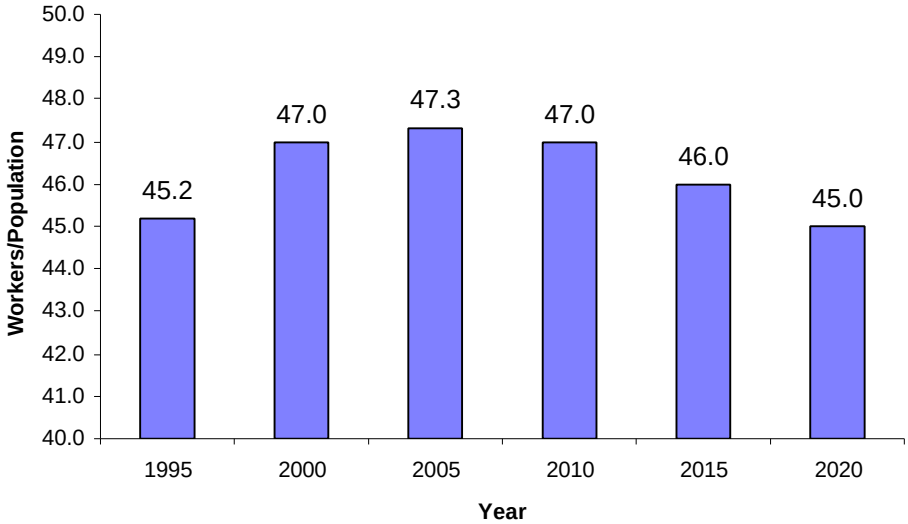
Labor force participation rates are also stabilizing as the rate of women entering the work force declines (Figure 27). The expected effect of these changes will be a short-term rise and a long-term decline in the ratio of workers to population (Figure 28).

Figure 27
Labor Force Participation Rates in Oregon, 1975 – 1996



Source: Oregon Employment Department

Figure 28
Present and Projected Employment-Population Ratios
For Oregon, 1995 - 2020



Source: Office of Economic Analysis, Oregon Department of Administrative Services. *Long-Term Population and Employment Forecasts for Oregon.* January, 1997

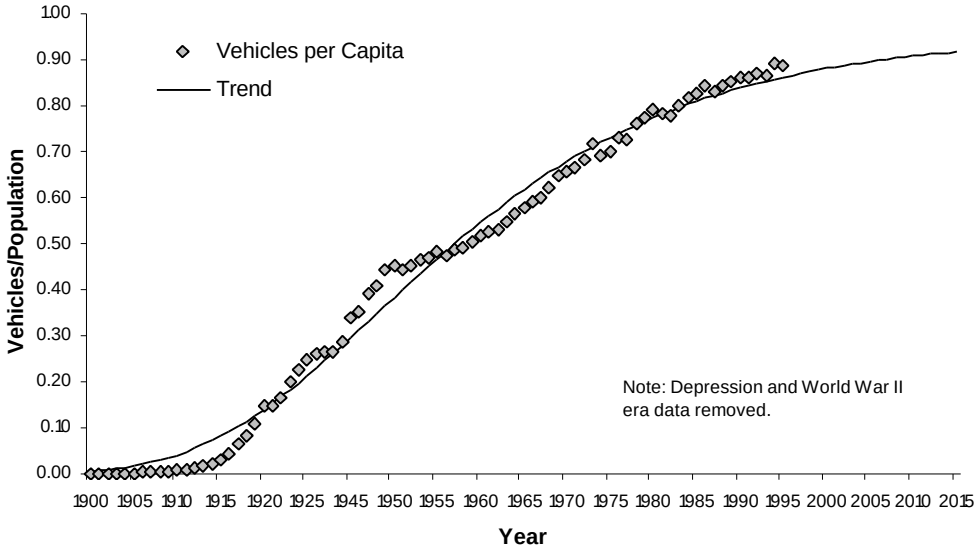
4.3 Saturation of Automobile Ownership

Motor vehicle use has increased primarily because the vehicle ownership rate has increased. The average number of miles driven per vehicle has remained fairly constant. The national average has stayed at about 11,000 miles per vehicle for several decades.[32] The rate in Oregon after recovery from the recession has remained fairly constant at about 11,000 miles per vehicle as well (Figure 6).

This trend is not likely to change for Oregon or the U.S. "Distance per year is the product of distance per trip and the number of trips per year. The National Personal Transportation Survey's *Summary of Travel Trends* reported an increase of only 0.16 km (0.1 mi.) in average trip length between 1969 and 1990. Trips per year per auto have actually declined during the same period."[33]

While miles driven per automobile have remained relatively unchanged for decades, automobile ownership rates have not. Automobile ownership has risen with increasing numbers of workers per household, rising incomes and an increasing fleet of older cars that are affordable to lower income households.[34] Researchers have noted that the U.S. population is nearing saturation of automobile ownership.[35] That appears to be the case in Oregon as well, where there is more than one registered passenger vehicle per licensed driver. The trend towards market saturation is illustrated by Figure 29, which shows the trend line flattening.

Figure 29
Long Term Trend in the Ratio of Motor Vehicles to Population
In Oregon, 1900 to 1995; Projection to 2015



Census; FHWA " Highway Statistics" Tables MV-202, MV-2

As motor vehicle ownership approaches saturation, increases in VMT per capita by motor vehicles will approach zero and total motor vehicle VMT will increase at the rate of population growth. In the more distant future, per capita motor vehicle use may even decline as people substitute faster modes of travel for the automobile.[36]

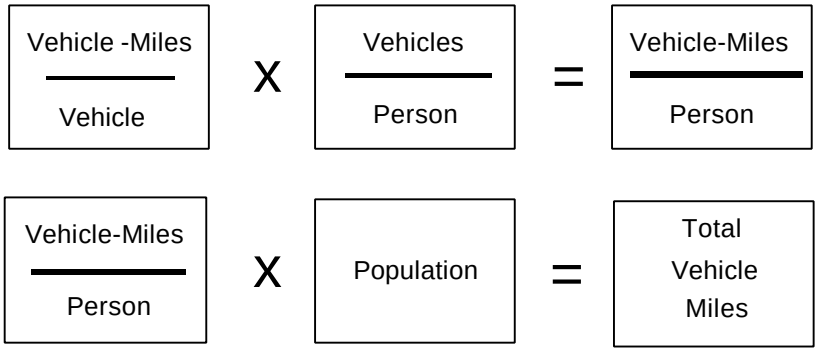
4.4 Projection of Future VMT

Total vehicle miles traveled by motor vehicles is the product of:

- The average number of miles traveled per vehicle,
- The average number of vehicles per capita, and
- The total population.

This is illustrated in Figure 30[37].

Figure 30
Model of Statewide VMT Growth



Over past years, increases in VMT have been driven by increases in population and vehicle ownership. As vehicle ownership approaches market saturation, population growth will become a larger and larger component of total VMT growth. Population growth will be the dominant factor driving the growth of travel in the future. Oregon's population has grown steadily over the course of the century except for the period of Oregon's economic recession in the early 80s. The State Office of Economic Analysis projects that over the next twenty years, Oregon's population will grow by about 30%. Motor vehicle ownership will increase by about 6% if it follows the trend line shown in Figure 29. Therefore, total VMT might increase by about 38% next 20 years.

4.5 Congestion Implications

There are positive and negative implications to the magnitude of the effect of population growth on the growth of VMT. On one hand, if the state adds highway capacity to reduce congestion, the cost per person will be lower than it would be if VMT per capita were rising more rapidly. On the other hand, if demand management is the primary response to rising congestion, a greater reduction in present levels of personal mobility will be necessary than would be the case if VMT per capita were increasing more rapidly. The challenges that the state faces in response to population growth pressures are illustrated by the following example for the Portland Metropolitan Area.

In 1995, there were 496 freeway lane-miles in Clackamas, Multnomah and Washington Counties (excluding I-84 in the Columbia Gorge). The ADT per freeway lane was about 18,800. In comparison, the ADT per freeway lane in the Los Angeles urbanized area was about 22,100 in 1995. By this measure, freeway congestion in the tri-county area was 85% of the level in Los Angeles.

Over the next 20 years, the tri-county area is projected to grow by 31%. At that rate of population growth, VMT in the tri-county area will grow by 23%; even if per capita miles traveled by automobiles decreases by 10% within the Metro urban growth and if all other VMT does not grow on a per capita basis.

If no new freeway lane-miles are added in the tri-county area and the proportion of travel occurring on the freeway system remains constant, the average density of freeway traffic would increase to about 23,200 ADT per lane. This amount is 5% higher than the 1995 level in Los Angeles. Keeping freeway congestion at present levels by adding freeway capacity would require the equivalent of 115 more freeway lane-miles. Maintaining present levels of freeway congestion by reducing personal automobile travel in the Metro UGB would require a 40% reduction in per capita VMT. This is shown in Table 15.

As this example shows, Oregon faces some difficult times ahead, particularly with congestion on the freeway system in the Portland Metropolitan Area. Congestion will grow significantly even with ambitious changes in land use patterns and reductions in per capita VMT.

Table 15
Projected 2015 Freeway Congestion in the Portland Metropolitan Area[1]
Assuming Transportation Planning Rule VMT Reductions
And No Freeway Lane Additions

Item in Portland Metro Area	Computation	Result	Change
1995 State Highway Daily VMT[2]		15,312,674	
1995 Proportion of VMT on State Hwy[3]		0.59	
1995 Total Daily VMT	15,312,674 / 0.59	25,953,685	
1995 Freeway VMT[4]		9,325,655	
Proportion of VMT on Freeways	9,325,655 / 25,953,685	0.36	
1995 Freeway Lane-Miles[5]		496	
1995 Freeway ADT per Lane	9,325,655 / 496	18,802	
1995 Population[6]		1,305,100	
Portion of Population in UGB[7]		0.91	
1995 Metro UGB Population	1,305,100 * 0.91	1,187,641	
1995 Internal Metro Auto DVMT per Capita[8]		12.8	
1995 Internal Metro Auto DVMT	12.8 * 1,187,641	15,201,805	
1995 External Metro and Non-Auto DVMT	25,953,685 - 15,201,805	10,751,880	
1995 External & Non-Auto DVMT per Capita	10,751,880 / 1,305,100	8.2	
2015 Population[9]		1,709,670	+31%
2015 Metro UGB Population	1,709,670 * 0.91	1,555,800	+31%
2015 Internal Metro Auto DVMT per Capita[10]	12.8 * 0.9	11.5	-10%
2015 External and Non-Auto DVMT per Capita		8.2	0%
2015 Internal Metro Auto DVMT	11.5 * 1,555,800	17,891,700	18%
2015 External Metro and Non-Auto DVMT	8.2 * 1,709,670	14,019,294	31%
2015 Total Daily VMT	17,891,700 + 14,019,294	31,910,994	23%
2015 Freeway Daily VMT	31,910,944 * 0.36	11,487,957	23%
2015 Freeway ADT per Lane	11,487,957 / 496	23,161	23%
Estimated Lane-Miles needed to maintain 1995 congestion level	(11,487,957 / 18,802)	611	23%
Estimated Internal Metro Per Capita Auto DVMT necessary to maintain 1995 congestion level	(25,953,685 - 14,019,294) / 1,555,800	7.7	-40%

Sources and Notes:

1 Includes Clackamas, Multnomah and Washington Counties

2 The analysis excludes I-84 in the Columbia Gorge

3 The statewide average of total VMT on the state highway system is about 59%. Source: ODOT Planning and Transportation Data Sections

4,5 Excludes I-84 VMT in the Columbia Gorge. Source: ODOT Planning and Transportation Data Sections

6 Includes entire county populations. Source: Portland State University, Center for Population Research and Census

7 In 1996, the ratio of Metro UGB to total county population was about 91%. The ratio in 1995 is assumed to be the same. Source: ODOT Planning Section, inventory for statewide transportation model

8 Metro estimated internal automobile per capita DVMT to be 12.4 in 1990 (Source: Metro. *Region 2040 Decisions for Tomorrow: Metro 2040 Growth Concept*. December 8, 1994). From 1990 to 1995, state highway VMT per capita grew by 3.6%, from 4,543 to 4,704 annual VMT per capita (Source: ODOT Planning and Transportation Data Sections). It is assumed that the internal metro UGB automobile per capita DVMT grew at the same rate (12.4 * 1.036 = 12.8).

9 Office of Economic Analysis, Oregon Department of Administrative Services. *Long-Term Population and Employment Forecasts for Oregon*. January 1997.

10 The Transportation Planning Rule, adopted by the Land Conservation and Development Commission of Oregon in 1991, requires a 10% reduction of internal per capita automobile miles traveled in 20 years. The Metro 2040 growth concept is expected to reduce internal per capita automobile travel by 5.2% over 50 years (from 1990 to 2040) assuming a quadrupling of transit ridership and a reduction of automobile mode split from 92% to 88%. (Source: Metro. *Region 2040 Decisions for Tomorrow: Metro 2040 Growth Concept*. December 8, 1994.

NOTES

[1] Lane-miles is a measure of the number miles of traffic lanes. For example, four miles of a four-lane highway would be sixteen lane miles.
[2] 15,000 ADT per lane is approximately equal to a volume to capacity ratio of 0.70, assuming that 10% of daily traffic occurs in the peak hour and an average capacity of a freeway lane of 2,000 to 2,200 vehicles per hour. This is approximately the boundary between level of service C and D.
[3] Texas Transportation Institute. Research Report 1131-8. *Urban Roadway Congestion – 1982 to 1993, Volume 2: Methodology and Urbanized Area Data.* August, 1996.
[4] The V/C data have been reported consistently for many years in five categories: <0.21, 0.21-0.40, 0.41-0.70, 0.71-0.95, >0.95. In 1989, the 0.71-0.95 category was split at 0.80.
[5] Texas Transportation Institute. August, 1996. "Mobility Study Summary." http://tti.tamu.edu/mobility/
[6] USDOT, Federal Highway Administration. 1995. NHI Course No. 15257. *Estimating the Impacts of Urban Transportation Alternatives.* December, 1995. VI-7 – VI-16
[7] Gordon, Peter, Harry W. Richardson, and Myung-Jin Jun. 1991. "The Commuting Paradox: Evidence from the Top Twenty." *Journal of the American Planning Association*, Vol.57, No. 4, Autumn 1991. 416-420.
Levinson, David M. and Ajay Kumar. 1994. "The Rational Locator: Why Travel Times Have Remained Stable." *Journal of the American Planning Association,* Vol. 60, No. 3, Summer 1994. 319-332.
[8] Levinson, David M. and Ajay Kumar 1994.
[9] This includes all rides on fixed route public transportation and dial-a-ride services offered to the general public. It does not include special needs transportation. Source: ODOT Public Transit Section
[10] Note: Oregon issues several types of driver's licenses. A person may be issued more than one license. Source (Licenses): Federal Highway Administration. *Highway Statistics*. Tables DL-22 (1995) & DL-201 (1970). Source (Population) U.S. Census Bureau.
[11] Pisarski, Alan E. 1987. *Commuting in America*. Eno Foundation for Transportation, Inc.
[12] There were about 692,000 households in Oregon in 1970. Source: U.S. Census Bureau. 1985. *Statistical Abstract of the United States.* p. 43.
There were 1,222,758 households in Oregon in 1995. Source: U.S. Census Bureau. http://www.census.gov/population/www/estimates/housing.html
Oregon's population in 1970 was 2,100,388 and in 1995 was 3,132,000. Source: Government Information Sharing Project. Oregon State University – Information Services. Regional Economic Information System: 1969 – 1995. http://sasquatch.kerr.orst.edu/reis-stateis.html
[13] Per capita income in 1997 dollars was $15,021 in 1970 and $22,960 in 1995. Source: ODOT Finance Branch
[14] Schafer, Andreas and David Victor. 1997. "The Past and Future of Global Mobility." *Scientific American,* Vol. 277, No. 4. October, 1977. 58 - 61

[15] Levinson, David and Ajay Kumar. 1995. "Activity, Travel, and the Allocation of Time." *Journal of the American Planning Association,* Vol. 61, No. 4, Autumn 1995. 458 - 470.
[16] Between 1970 and 1995, the populations of the counties comprising the Portland, Salem, Eugene, and Medford metropolitan areas grew by 48%, 68%, 41% and 74% while the phone book listings of fast food restaurants increased 167%, 132%, 200% and 233% respectively. Source: US Census Bureau and area phone books.
[17] Levinson, David and Ajay Kumar. 1995.
[18] Pisarski, Alan E. 1996. *Commuting in America II*. Eno Transportation Foundation, Inc. Landsdowne, VA. 61-62.
[19] Levinson and Kumar. 1995. p. 468.
[20] Pushkarev, Boris and Jeffrey Zupan. 1977. *Public Transportation and Land Use Policy*. Indiana University Press, Bloomington, p.5.
[21] Newman, Peter and Jeffrey Kenworthy. 1991. *Cities and Automobile Dependence: An International Sourcebook.* Gower Technical. Brookfield USA. 1991. See in particular Figure 3.2, page 49.
[22] Garreau, Joel. 1988. *Edge City*. Doubleday. New York. p. 5.
[23] Ewing, Reid. 1997. "Is Los Angeles-Style Sprawl Desirable?" *Journal of the American Planning Association,* Vol. 63, No. 1, Winter 1997. p.113.
[24] Metro. December 8, 1994. *Region 2040 Decisions for Tomorrow: Metro 2040 Growth Concept*. Portland, Oregon.
[25] Under certain conditions, addition of a new highway link may increase total travel time. This is Braess's Paradox.
[26] Dowling, Richard G. and Steven B. Colman. "Effects of Increased Highway Capacity: Results of a Household Travel Behavior Survey." Paper presented at the Transportation Research Board Annual Conference. January, 1997.
[27] Heanue, Kevin. "Highway Capacity and Induced Travel: Issues, Evidence and Implications." Paper presented at the Transportation Research Board Annual Conference. January, 1997.
[28] Government Information Sharing Project. Oregon State University – Information Services. Regional Economic Information System: 1969 – 1995. http://sasquatch.kerr.orst.edu/reis-stateis.html
[29] Pucher, John. 1988. "Urban Travel Behavior as the Outcome of Public Policy: The Example of Modal-Split in Western Europe and North America." *Journal of the American Planning Association* 54, no.4, Autumn 1988. 509-20. Pucher reports that the average annual taxation of a car in the United States in 1982 was $119. The average for nine European nations was $633. Table 4, p. 513.
[30] ECO Northwest. March, 1995. *An Introduction to Congestion Pricing for Oregon Policy Makers.* Report submitted to the Oregon Department of Transportation, Region 1.
[31] More information is available at Metro's web site: www.metro.dst.or.us/transpo/tros/tros.html
[32] Souleyrette, Reginald R., Hans, Garrison, Wazny. 1995. "Analysis of Trends Underlaying Urban/Regional Impacts of Traffic Growth." *Journal of Urban Planning and Development.* December, 1995. 158 - 171.

Lave, Charles. 1990. *Things Won't Get a Lot Worse: The Future of U.S. Traffic Congestion*. Institute of Transportation Studies and Department of Economics, University of California, Irvine, UCI-ITS-WP-90-2. February 1990.

[33] Souleyrette, Reginald R., Hans, Garrison, Wazny. 1995. p.163.

[34] Pisarski, Alan E. 1995. The Demography of the U.S. Vehicle Fleet: Observations From the NPTS. *1990 NPTS Special Reports on Trip and Vehicle Attributes*. February 1995. US Department of Transportation. Data from the NPTS indicates that vehicles are remaining in service longer. This has accounted for most of the growth of in the size of the vehicle fleet. This has made vehicle ownership more affordable for lower income households.

[35] Lave, Charles. 1990.

[36] Schafer, Andreas and David Victor. 1997.

[37] Souleyrette, Reginald R., Hans, Garrison, Wazny. 1995.