Street Connectivity:

An Evaluation of Case Studies in the Portland Region

June 22, 2004

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2004-11008-PLN

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INTRODUCTION

Street connectivity – the number of connecting streets in a given area – helps reduce the volume of traffic and traffic delays on major streets (arterials and major collectors), and ultimately improves livability in communities. By increasing the number of street connections or local street intersections in communities, bicycle and pedestrian travel also is enhanced since these modes of travel are local in nature and involve shorter trips.

Development trends during the 1960s and '70s encouraged building residential communities with few street connections and numerous cul-de-sacs. It was assumed that communities built with this type of street design had less traffic and fewer traffic delays on neighborhood streets. A recent Metro study found these assumptions to be false.

In 1997, Metro completed a street design study in which street connectivity impacts on potential vehicle traffic conditions along major streets were modeled and evaluated. The goal of the study was to test the premise that increasing local street connectivity improves local traffic flow. Specifically, Metro studied the effects on vehicle volumes, delay and trip length of street systems that have between six and 20 local street connections per mile to the major street system. The results of the study confirmed a number of evolving theories about the form and function of local and regional street systems. Most notably, the connectivity studies found that, in general:

> High levels of local street connectivity reduce the amount of local traffic on major streets.
>
> Overall reductions in vehicle hours of delay, vehicle miles of travel and average trip length occur in an area where high levels of local street connectivity exist.
>
> Traffic delay and volume is reduced at major street intersections in areas where high levels of local street connectivity exist.
>
> Increased levels of connectivity have diminishing returns for motorists – the benefit between moderate and low street connectivity exceeds that of between high and moderate.
>
> The most cost-effective method of improving regional street flow is achieved by providing a moderate level of connectivity, between 10 and 16 connections per mile.
>
> Some regional traffic (trip length great than 5 miles) will bypass congested areas by traveling on parallel local routes; most regional travel, however, will remain on major streets.

The study found some potential negative impacts associated with connectivity, including the diversion of traffic into residential neighborhoods and diminished capacity on major streets due to new intersections. These impacts can be mitigated in the following ways:

Impact: The diversion of traffic into residential neighborhoods.

Mitigation:

> Use signage to direct traffic to commercial areas on streets appropriately sized and designed for higher levels of traffic.
>
> Implement traffic management plans, including traffic calming.
>
> Avoid planning connections that clearly provide a convenient bypass of congested intersections.

Impact: Decrease in capacity on major streets

Mitigations:

Provide adequate distance of a local street connection from a congested intersection to allow for expected vehicle queue distances if allowing left turns.

Improve capacity by managing access, restricting movements at non-signaled intersections and driveways, and consolidating/restricting driveway accesses to intersecting local streets of the major street.

Coordinate signal timing and keep signalized intersections at a distance that allows for vehicle progression at posted speeds without stopping (typically 1/4 mile spacing on a two-way major street).

Further impacts and mitigation techniques applicable to environmentally sensitive areas are discussed in the Related Research section at the end of this report. (p. 17)

This report describes the benefits of increased local street connectivity, the legal basis for establishing a high degree of connectivity in neighborhoods and the results of Metro's street design study: the modeling and evaluation of connectivity impacts on traffic conditions on major streets. In addition, the report includes a discussion of more recent research on connectivity across stream corridors including impacts for pedestrians. Finally, the report reviews Metro connectivity standards for local jurisdictions in the Portland metropolitan area, and describes the technical assistance available in implementing those standards at the jurisdictional level.

Definition of connectivity

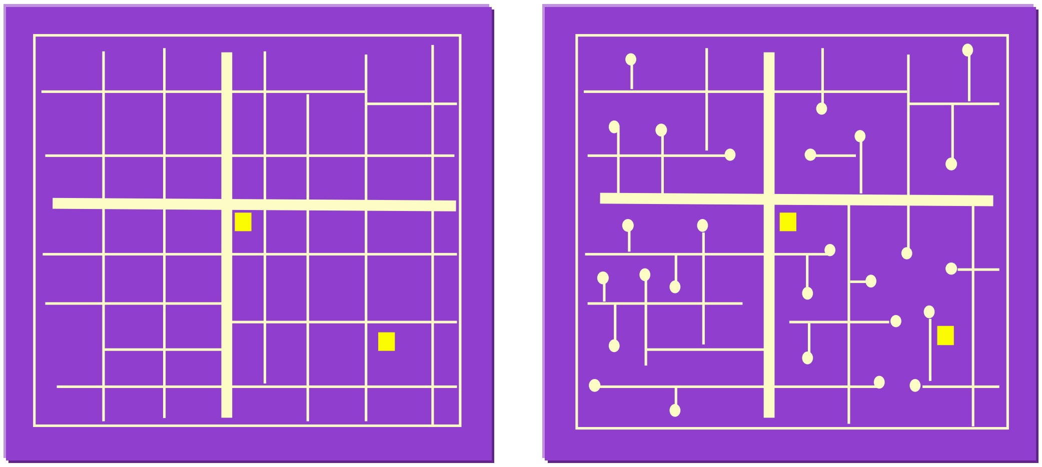
The term "street connectivity" suggests a system of streets with multiple routes and connections serving the same origins and destinations. Connectivity not only relates to the number of intersections along a segment of street, but how an entire area is connected by the system. An area with high connectivity has multiple points of access around its perimeter as well as a dense system of parallel routes and cross-connections within the area. Typically, parallel routes are classified and sized appropriately for local traffic to discourage longer distance through traffic.

An exemplary example of a well-connected street system is the traditional grid pattern seen in downtown Portland and in many other communities in the region. Grid street patterns result in dispersion of traffic throughout the system. While major arterials exist within the grid pattern, local travelers use interconnected local streets, freeing the arterials for the movement of longer distance travelers.

In contrast, conventional suburban development patterns provide a hierarchy of streets beginning with cul-de-sac and progressing to major arterials. Suburban street patterns are designed to collect traffic from residential neighborhoods and channel it to progressively higher street classifications at limited access points. This pattern of streets commonly results in large intersections at major junctions, greater congestion along major streets and an environment that discourages pedestrian and bicycle travel.

Figure 1 compares a cul-de-sac development with a low level of street connectivity and a modified grid with a high level of connectivity. The distance needed to travel between the two squares shown is much less in the well-connected street network.

Figure 1. Why Connectivity



Traditional Grid Design

Typical Cul-de-sac Design

This research and analysis defines connectivity in the *linear* terms of "intersection connections per mile." Metro defines connectivity in this way for local code recommendations. Developers can grasp this linear definition, "intersections per mile" or "intersections every 530 feet," easier than an areawide definition – "intersections per square mile." However, the analysis used in this study is based on areawide connectivity. Study areas were chosen with varying levels of intersections per square mile.

LEGAL BASIS FOR INCREASING STREET CONNECTIVITY

Several federal, state and regional statutes provide a basis for exploring the impacts of high levels of street connectivity.

Federal

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) emphasizes expanding participation in the transportation planning process and increasing cooperation among the jurisdictions that own and operate the regional transportation system. The partners in the Portland metropolitan region include 24 cities, three counties, Metro, Oregon Department of Transportation, Oregon Department of Environmental Quality, Port of Portland, TriMet, South Metro Area Transit, Canby Area Transit, Washington Regional Transportation Council, Washington Department of Transportation, Southwest Washington Air Pollution Control Authority and other Clark County governments.

As the federally designated metropolitan planning organization for the region, Metro coordinates metropolitan transportation planning efforts in partnership with these jurisdictions and citizens to help develop statewide and regional transportation plans. These plans must forecast future growth, identify needed transportation investments to meet this growth and ensure the maintenance and efficient operation of existing transportation systems during a 20-year period. The Oregon Transportation Plan guides the transportation system statewide and the Regional Transportation Plan (a Metro functional plan) guides the transportation system region-wide.

The 1998 Transportation Equity Act for the 21st century (TEA-21) reaffirmed the coordination requirements and emphasized the need to plan for bicyclists and pedestrians. Section 1202 in TEA-21 states, "Bicyclists and pedestrians shall be given due consideration in the comprehensive transportation plans developed by each metropolitan planning organization…Transportation plans and projects shall provide due consideration for safety and contiguous routes for bicyclists and pedestrians."[1]

State

The Oregon Transportation Planning Rule implements Goal 12: Transportation in Oregon's statewide planning program. The rule focuses on the link between land-use and transportation. The rule requires that planned transportation systems support land-use plans and travel patterns to achieve the state goal of compact, highly livable urban areas. The rule contains requirements designed to reduce reliance on the automobile and requires consideration of land-use policies when developing transportation plans. Cities and counties are required to revise development standards to promote public transportation, pedestrian and bicycle travel; orient new buildings toward major transit stops; and design local streets that are narrower and improve pedestrian circulation. The rule also requires that city and county transportation plans include policies that promote completion of local street networks. The rule requires that local and regional transportation system plans target the following goals:

Ten percent reduction in vehicle miles of travel per capita during the next 20 years and 20 percent during the next 30 years.
Less reliance on the automobile and a reduction in the number of people driving alone.
Ten percent reduction in the number of parking spaces per capita during the next 20 years.
Stronger connection between land-use and transportation planning.

Local and regional transportation system plans also must examine possible land-use solutions to transportation problems and identify multi-modal, system management and demand management strategies to address transportation needs.

Regional

The Regional Transportation Plan (RTP) forms the basis for policies contained within the Regional Framework Plan, including the policy for local street connectivity. The RTP responds to federal and state requirements and defines a balanced, multi-modal transportation system that supports the Region 2040 Growth Concept. The RTP implements Regional Framework Plan polices. Separate functional plans, such as the RTP, clearly identify the role that cities and counties will play in implementing the Regional Framework Plan.

Local street connectivity (Chapter 2.30, Regional Framework Plan). The Regional Framework Plan policy for local street connectivity requires transportation planners to establish 10 to 16 street intersections per mile as a minimum range for local street connectivity, with some exceptions. The number of street intersections should be greatest in the highest density mixed-use centers. Bicycle, pedestrian and emergency access connections on public easements or right of way should be considered when full street connections are not possible. Spacing between auto connections should be at least 10 connections per mile in mixed-use centers and residential areas, except where topography, barriers such as railroads or freeways or environmental constraints such as major streams and rivers prevent street extension.

CONNECTIVITY CASE STUDIES

Metro's street design work team, the travel forecasting staff and Metro's consultant on this study, Fehr and Peers Associates, Inc., developed five geographically representative case study scenarios for the purpose of evaluating the impact of street connectivity on local traffic. These subarea scenarios were evaluated with Region 2015 Growth Concept land-use assumptions and local or collector street connections at "low," "moderate" and "high" level of connections per mile. The Appendix contains the 2015 base networks for the low and high cases of street

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[1] TEA-21, Public Law 105-178, Section 1202 g). p.70, http://www.fhwa.dot.gov/tea21/tea21.pdf, accessed 7/24/03.

connectivity that were evaluated in the study. The study methodology and specific case study scenarios are described in Table 1.

Methodology

The study objective was to reflect the range of development patterns and street layout conditions existing within the Portland metropolitan region. The selected subarea scenarios represented different levels of existing street connectivity from low to moderate to high. The five subarea scenarios are representative of some of the types of areas that exist within the region and indicate how real-world traffic patterns might change with varying levels of street connections to the major street system.

Metro reviewed input from the street design work team and selected five subareas located in the following geographic areas: Bethany, West Portland, Inner Southeast, Mid-County and Sunnyside. Within each subarea, several intersections were identified for analysis under different levels of connectivity.

Description of geographic subareas

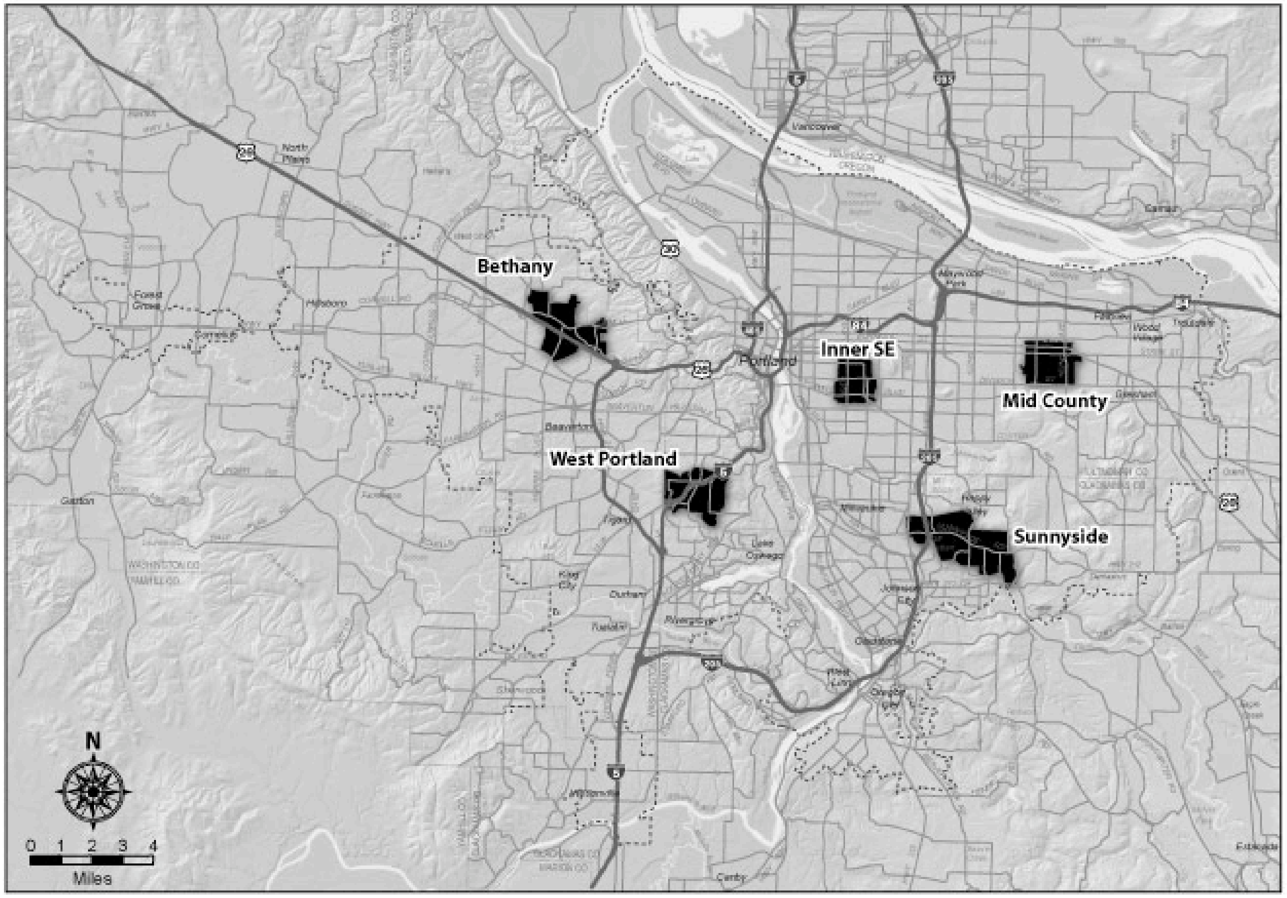
Table 1 describes the five geographic subareas identified for evaluation in this study. It also lists the low, moderate and high levels of connectivity evaluated for each of the subareas.

Table 1. Connectivity Case Studies – Subarea Scenarios

Subarea	Description	Levels of Connectivity Tested (intersections per linear mile)*
Bethany	Rapidly growing area with large tracts of vacant land oriented toward US 26. Existing subdivisions display low street connectivity.	Low: 6 (existing) Moderate: 10 High: 14
West Portland	Older suburban neighborhoods with some infill development oriented toward I-5 and Barbur Boulevard. Street connectivity within the older neighborhood is relatively high where topography permits.	Low: 12 (existing) Moderate: 16 High: 20
Inner Southeast	Urbanized older Portland neighborhoods with a highly connected local and arterial street system. 2040 Growth Concept corridor and main street designations exist along many arterials in this area.	Low: 12 Moderate: 16 High: 20 (existing)
Mid-County	Older suburban neighborhoods oriented along parallel Burnside, Stark and Division streets. Area includes the Rockwood town center at 181st Avenue and Burnside Street, and overall relatively high local and arterial street connectivity.	Low: 8 Moderate: 12 High: 16 (existing)
Sunnyside	This area includes rapidly developing tracts located near or along I-205 and Sunnyside Road. The street network in this area has low connectivity with rapid development occurring in closed street systems.	Low: 8 (existing) Moderate: 12 High: 16

* Street connectivity was estimated on an area-wide rather than on a linear arterial basis generally reflecting the opportunity to ingress or egress an area via available connections from local to regional streets. The “existing” situation represents the current street network with 2015 Growth Concept conditions (growth in population and employment).

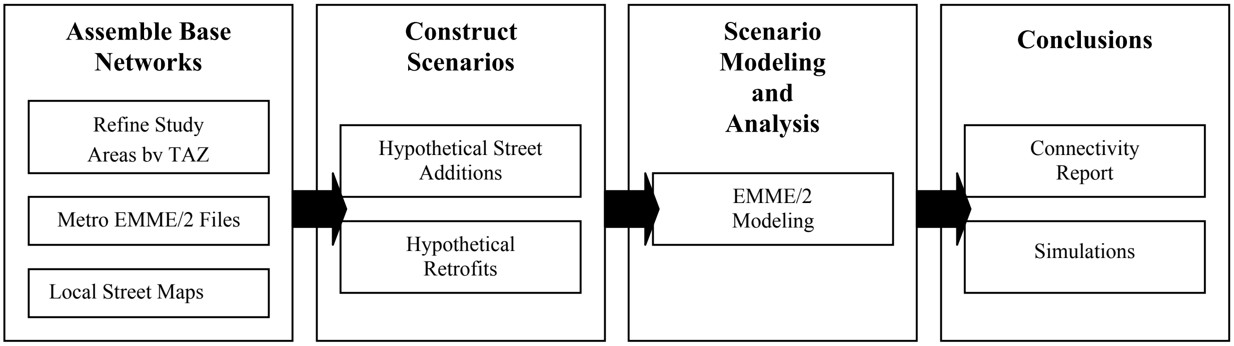
Figure 2. Case Study Locations in the Portland Metropolitan Region



Analysis tools

The study applied the Metro regional forecasting model as the primary analysis tool. The model forecasts traffic flow based on inputs of street and roadway network connectivity. First, the 2015 network database and subarea GIS-based maps were overlaid on aerial photographs. EMME/2 software was then used to prepare three network scenarios for each subarea, representing low, moderate and high levels of connectivity, as shown in Table 1. The traffic assignment component of the 2015 regional forecasting model was run three times, once for each of the low, moderate and high scenarios. See Figure 3 for a summary of this process.

Figure 3. Development of Model Scenarios



Evaluation criteria

Table 2 summarizes the evaluation criteria selected to review the results of the connectivity case studies. *Select link data* represents the impact of local and collector street connectivity on representative segments of major streets in the subarea. For the select links, results include average trip length, traffic volume, traffic mix and average travel time.

Zone data represents the compilation of all transportation analysis zones within each of the specific subareas. For the zone data, the results identify vehicle hours of delay, vehicle miles of travel and average trip length in miles.

Intersection approach volumes were summarized for selected high-volume intersections within each of the subareas. This data indicates the level of approach volumes to each intersection for the low, moderate and high connectivity case studies. From this data, general conclusions can be drawn about the impact of street connectivity on intersection delays and level of service measures.

Table 2. Connectivity Case Study Evaluation Measures

Evaluation Measure	Bethany	West Portland	Inner Southeast	Mid-County	Sunnyside
Select link data: Average trip length Average travel time Traffic volume Traffic mix (percentage of trips internal to the study area)	US 26 e/o Murray Murray Blvd. s/o US 26 Cornell between 142nd and Murray	I-5 between Barbur and Capitol Capitol s/o I-5 Barbur e/o Capitol	Powell e/o 39th 39th Avenue s/o Hawthorne	181st n/o Burnside Stark e/o 162nd Division e/o 162nd	Sunnyside e/o I-205 122nd n/o Sunnyside Sunnyside w/o 142nd
Zone data: Vehicle hours of delay Vehicle miles traveled Average trip length	aggregate subarea zone summaries Represented transportation analysis zones: 105, 106, 128, 131, 132, 133, 163, 164	aggregate subarea zone summaries Represented transportation analysis zones: 65, 66, 67, 68, 69, 70, 75	aggregate subarea zone summaries Represented transportation analysis zones: 778, 780, 799, 800, 801, 802	aggregate subarea zone summaries Represented transportation analysis zones: 571, 572, 573, 574, 588, 590, 591, 592, 593, 594, 595, 596, 602	aggregate subarea zone summaries Represented transportation analysis zones: 443, 444, 464, 465, 471, 472, 473, 475, 478, 479, 942, 943
Other: Intersection approach volumes	network review	network review	network review	network review	network review

Summary of evaluation results

The connectivity case study results generally supported the study hypothesis about street connectivity. Tables 3, 4 and 5 show a summary of the select link measures. Table 6 is a summary of the zone data representing the aggregate of all trips for each subarea. Finally, Table 7 shows intersection approach volumes.

Table 3 shows that:

- At 12 of the 14 select link locations, total traffic volumes decreased between the low and moderate scenarios.
- At 10 of the 14 select link locations, total traffic volumes decreased between the moderate and high scenarios.
- Traffic volumes decreased by an average of 4 percent to 9 percent between the low and high scenarios.
- Traffic volumes decreased significantly between the low and high scenarios on some individual streets, i.e. 69 percent on Southeast 39th Avenue.

Table 3. Change in Traffic Volume on Regional Roads

		Low Connectivity	Moderate Connectivity	% Change From Low	High Connectivity	% Change From Moderate
		P.M. Peak 2-hour Volume	P.M. Peak 2-hour Volume		P.M. Peak 2-hour Volume	
Subarea 1: Bethany						
Highway 26	e/o Murray	**10,648**	10,609	0%	10,584	0%
Murray Boulevard	s/o Highway 26	**5,287**	5,546	5%	5,690	3%
Cornell Road	142nd-Murray	**2,588**	2,271	-12%	2,171	-4%
Subarea 2: West Portland						
I-5	Barbur-Capitol	**9,803**	9,419	-4%	9,344	-1%
Capitol Highway	s/o I-5	**1,484**	883	-40%	1,546	75%
Barbur Boulevard	e/o Capitol	**3,411**	3,235	-5%	3,305	2%
Subarea 3: Inner Southeast						
Powell Boulevard	e/o 39th	1,669	1,248	-25%	**1,002**	-20%
39th Avenue	s/o Hawthorne	2,399	1,512	-37%	**742**	-51%
Subarea 4: Mid-County						
181st Street	n/o Burnside	3,610	3,520	-2%	**3,058**	-13%
Stark Street	e/o 162nd	2,501	2,434	-3%	**2,247**	-8%
Division Street	e/o 162nd	2,833	2,540	-10%	**2,522**	-1%
Subarea 5: Sunnyside						
Sunnyside Road	e/o I-205	**6,201**	4,402	-29%	3,637	-17%
122nd Avenue	n/o Sunnyside	**1,775**	1,526	-14%	1,288	-16%
Sunnyside Road	w/o 142nd	**1,823**	1,507	-17%	1,466	-3%
Average		**4,370**	**3,968**	**-9%**	**3,821**	**-4%**

The **bold** numbers show estimate base case or existing level of connectivity assumed within each subarea (current street network with 2015 population and employment forecasts).

Table 4. Traffic Composition on Regional Roads

		Low Connectivity				Moderate Connectivity				High Connectivity			
		P.M. Peak 2-hour Volume	%XX	%IXXI	%II	P.M. Peak 2-hour Volume	%XX	%IXXI	%II	P.M. Peak 2-hour Volume	%XX	%IXXI	%II
Subarea 1: Bethany													
Highway 26	e/o Murray	**10,648**	**86%**	**14%**	**0%**	10,609	86%	14%	0%	10,584	86%	14%	0%
Murray Boulevard	s/o Highway 26	**5,287**	**65%**	**34%**	**2%**	5,546	65%	34%	2%	5,690	64%	34%	2%
Cornell Road	142nd-Murray	**2,588**	**43%**	**52%**	**5%**	2,271	51%	43%	5%	2,171	56%	38%	6%
Subarea 2: West Portland													
I-5	Barbur-Capitol	**9,803**	**97%**	**3%**	**0%**	9,419	98%	2%	0%	9,344	98%	2%	0%
Capitol Highway	s/o I-5	**1,484**	**63%**	**33%**	**4%**	883	61%	35%	4%	1,546	64%	33%	3%
Barbur Boulevard	e/o Capitol	**3,411**	**65%**	**32%**	**3%**	3,235	62%	34%	4%	3,305	63%	33%	4%
Subarea 3: Inner Southeast													
Powell Boulevard	e/o 39th	1,669	89%	11%	0%	1,248	87%	12%	0%	**1,002**	**87%**	**12%**	**1%**
39th Avenue	s/o Hawthorne	2,399	58%	39%	3%	1,512	67%	30%	3%	**742**	**77%**	**23%**	**0%**
Subarea 4: Mid-County													
181st Street	n/o Burnside	3,610	75%	25%	0%	3,520	75%	25%	0%	**3,058**	**72%**	**28%**	**0%**
Stark Street	e/o 162nd	2,501	71%	27%	2%	2,434	72%	26%	2%	**2,247**	**71%**	**27%**	**2%**
Division Street	e/o 162nd	2,833	75%	24%	1%	2,540	85%	15%	0%	**2,522**	**85%**	**15%**	**0%**
Subarea 5: Sunnyside													
Sunnyside Road	e/o I-205	**6,201**	**16%**	**62%**	22%	4,402	17%	67%	16%	3,637	18%	69%	13%
122nd Avenue	n/o Sunnyside	**1,775**	**33%**	**62%**	6%	1,526	40%	56%	4%	1,288	42%	54%	4%
Sunnyside Road	w/o 142nd	**1,823**	**18%**	**72%**	10%	1,507	27%	72%	1%	1,466	24%	74%	2%
Average		**4,370**	**67%**	**29%**	**4%**	**3,968**	**73%**	**26%**	**3%**	**3,821**	**72%**	**26%**	**2%**

Note:

Volume	is 2015 PM traffic volume forecast
%XX	is percent of traffic flow that is external to external trips, with neither origin or destination within subarea.
%IXXI	is percent of traffic flow that is internal to external trips, or external to internal, with either origin or destination within subarea.
%II	is percent of traffic flow that is internal to internal trips, with both origin and destination within subarea.
	The **bold** numbers above show estimate base case or existing level of connectivity assumed within each subarea.

Table 4 displays the results of model forecast by percentage of trips on select roads in the study areas by the origin and destination type of trip:

(XX) beginning and ending outside of the study area
(IXXI) beginning but not ending in the study area or ending but not beginning in the study area
(II) beginning and ending in the study area.

These results are stratified by the level of tested street connectivity (high, moderate and low) within each study area.

For eight of the 14 select link locations, the percent of total trips that are external to external zone pairs – trips starting and ending outside a given study area – increases between the low and the high connectivity scenarios. This supports the theory that major streets serve fewer local oriented trips when local network connectivity is provided. However, the average change in composition between low and high connectivity cases was small – 5 percent. Most of the case studies had very low composition of short distance trips in the low connectivity scenarios, resulting in small or negligible change with increasing levels of connectivity. One case study (Sunnyside) reacted as expected, with the proportion of longer distance travel increasing an average of 8 percent, and short distance travel decreasing an average of 50 percent. This might be explained by the fact that the Sunnyside area is the one study area in which short distance trips make up a substantial proportion of the street's composition.

Table 5. Average Trip Length and Travel Time on Regional Roads

		Low Connectivity		Moderate Connectivity		% Change From Low		High Connectivity		% Change From Moderate	
		Avg. Trip Length (Miles)	Avg. Travel Time (Minutes)	Avg. Trip Length (Miles)	Avg. Travel Time (Minutes)	Avg. Trip Length (Miles)	Avg. Travel Time (Minutes)	Avg. Trip Length (Miles)	Avg. Travel Time (Minutes)	Avg. Trip Length (Miles)	Avg. Travel Time (Minutes)
Subarea 1: Bethany											
Highway 26	e/o Murray	**15.0**	**28.2**	15.0	28.1	0.0	0.0	15.0	28.2	0.0	0.0
Murray Blvd.	s/o Highway 26	**7.5**	**15.7**	7.4	15.5	0.0	0.0	7.5	15.6	0.0	0.0
Cornell Road	142nd-Murray	**5.7**	**13.1**	5.7	13.0	0.0	0.0	5.8	13.1	0.0	0.0
Subarea 2: West Portland										0.0	
I-5	Barbur-Capitol	**19.6**	**38.7**	20.0	39.3	0.0	0.0	20.0	39.3	0.0	0.0
Capitol Highway	s/o I-5	**6.1**	**15.3**	6.4	16.7	0.1	0.1	6.4	16.5	0.0	0.0
Barbur Blvd.	e/o Capitol	**8.1**	**20.0**	7.5	18.3	-0.1	-0.1	7.4	18.1	0.0	0.0
Subarea 3: Inner Southeast											
Powell Blvd.	e/o 39th	9.6	27.1	9.9	27.8	0.0	0.0	**9.4**	**26.9**	-0.1	0.0
39th Avenue	s/o Hawthorne	5.2	15.9	4.8	14.2	-0.1	-0.1	**5.0**	**14.6**	0.1	0.0
Subarea 4: Mid-County											
181st Street	n/o Burnside	8.0	17.5	8.0	17.4	0.0	0.0	**8.3**	**17.8**	0.0	0.0
Stark Street	e/o 162nd	9.0	20.2	9.2	20.2	0.0	0.0	**8.7**	**19.3**	-0.1	-0.1
Division Street	e/o 162nd	9.4	21.5	9.8	22.3	0.0	0.0	**10.0**	**22.7**	0.0	0.0
Subarea 5: Sunnyside											
Sunnyside Road	e/o I-205	**6.4**	**16.2**	7.3	16.5	0.2	0.0	7.5	16.6	0.0	0.0
122nd Avenue	n/o Sunnyside	**6.2**	**16.0**	6.0	14.8	0.0	-0.1	6.0	14.3	0.0	0.0
Sunnyside Road	w/o 142nd	**7.4**	**18.2**	8.8	19.7	0.2	0.1	8.9	19.7	0.0	0.0
Average		**8.8**	**20.3**	**9.0**	**20.3**	**0.0**	**0.0**	**9.0**	**20.2**	**0.0**	**0.0**
The **bold** numbers show estimate base case or existing level of connectivity assumed within each subarea (current street network with 2015 pop. and employment forecasts).											

Table 5 shows average vehicle hours of delay due to congestion, vehicle miles of travel and average trip length for each of the scenarios. Because major streets would be expected to handle a higher percentage of through traffic as local traffic decreases, the average travel time and distance would be expected to increase. The results show that average travel time increased slightly for six of 14 locations between the low and high connectivity scenarios.

Table 6. Zonal Data – Vehicle Hours of Delay, Vehicle Miles of Travel, and Average Trip Length

	Low Connectivity	Moderate Connectivity	% Change from Low	High Connectivity	% Change from Moderate
Subarea 1: Bethany					
Vehicle hours of delay	**495**	483	-2%	472	-2%
Vehicle miles of travel	**49,610**	49,136	-1%	48,757	-1%
Average trip length (miles)	**4.93**	4.88	-1%	4.84	-1%
Subarea 2: West Portland					
Vehicle hours of delay	**426**	418	-2%	409	-2%
Vehicle miles of travel	**30,944**	30,352	-2%	30,158	-1%
Average trip length (miles)	**4.93**	4.84	-2%	4.81	-1%
Subarea 3: Inner Southeast					
Vehicle hours of delay	403	377	-7%	**372**	-1%
Vehicle miles of travel	29,550	28,259	-4%	**27,492**	-3%
Average trip length (miles)	4.16	3.98	-4%	**3.87**	-3%
Subarea 4: Mid-County					
Vehicle hours of delay	356	344	-4%	**330**	-4%
Vehicle miles of travel	36,355	36,134	-1%	**35,873**	-1%
Average trip length (miles)	4.87	4.84	-1%	**4.80**	-1%
Subarea 5: Sunnyside					
Vehicle hours of delay	**1,869**	1,424	-24%	1,357	-5%
Vehicle miles of travel	**121,890**	120,066	-1%	119,203	-1%
Average trip length (miles)	**5.07**	4.99	-1%	4.96	-1%
Averages					
Vehicle hours of delay	710	609	-14%	588	-3%
Vehicle miles of travel	53,670	52,789	-2%	52,297	-1%
Average trip length (miles)	4.79	4.71	-2%	4.66	-1%

The **bold** numbers show estimate base case or existing level of connectivity assumed within each subarea (current street network with 2015 population and employment forecasts).

Table 6 displays the vehicle hours of delay, vehicle miles of travel and average trip length for each of the five subareas for the low, moderate and high connectivity case scenarios. While vehicle hours of delay show a substantial decrease (14 percent) between low and moderate levels of connectivity, the measures of vehicle miles traveled and average trip length show smaller reductions (1 to 2 percent). The reasons are:

(1) The majority of subarea trips are longer distance trips resulting in small changes in vehicle miles traveled and average trip length.
(2) The reduction in vehicle hours of delay indicates longer distance trips are using parallel routes to major streets.

These results, which show less overall travel delay where street connectivity is high, also suggest the same benefits would be derived for transit, which relies primarily on major streets. In addition, better street connectivity generally provides for a shorter, more direct walking trip between the transit stop on major streets and the trip origin or destination, which is often on the connecting local street system.

Table 7. Intersection Approach Volumes

	Low Connectivity	Moderate Connectivity	% Change From Low	High Connectivity	% Change From Moderate
	P.M. Peak 2-hour Volume	P.M. Peak 2-hour Volume		P.M. Peak 2-hour Volume	
Study Area 1: Bethany					
Murray/Cornell	**4,809**	4,344	-10%	3,184	-27%
Study Area 2: West Portland					
Taylors Ferry/Capitol	**2,214**	2,034	-8%	2,194	8%
Barbur / Capitol	**5,818**	5,383	-7%	5,594	4%
Study Area 3: Inner Southeast					
39th/Powell	2,923	1,460	-50%	**1,066**	-27%
Foster/Powell/52nd	4,975	4,586	-8%	**4,531**	-1%
Study Area 4: Mid-County					
181/Stark	5,712	5,670	-1%	**5,409**	-5%
Division/162nd	4,498	4,143	-8%	**4,177**	1%
Study Area 5: Sunnyside					
122/Sunnyside	**4,805**	4,326	-10%	3,989	-8%
82/Sunnyside	**7,909**	7,171	-9%	6,705	-6%
Average	**4,851**	**4,346**	**-10%**	**4,094**	**-6%**

The **bold** numbers show estimate base case or existing level of connectivity assumed within each subarea (current street network with 2015 population and employment forecasts).

Finally, Table 7 summarizes the intersection approach volumes at each of the subarea intersections selected for review.

The results show intersection approach volumes decrease between the low and high connectivity case scenarios (average decreases between 6 percent and 10 percent). In some cases, the differences are significant and would likely result in improved level of service and less delay at these intersections.

What explains this drop in intersection approach volumes? Primarily, local trips can use more direct routes on local streets with the more connected street system. In some locations, longer distance trips use parallel streets to avoid congested intersections. In some cases, this may be appropriate, however, this is an impact that must be considered and mitigated when traffic intrudes upon residential neighborhoods.

Conclusions

The results of the connectivity case studies indicate that moderate to high local street connectivity reduces traffic demand on the major streets and overall vehicle traffic demand across each of the five representative case study areas. Generally, the benefit between low to moderate levels of connectivity are greater than the benefit between moderate to high levels of connectivity, although the difference between moderate and high is still significant. There is a need for further study to test more varied land-use patterns. In a later study, the case studies should be further evaluated to investigate any conclusive findings by area typology or topography drawing further upon local understanding of each subarea.

Providing an interconnected street system can lead to some environmental and capacity impacts. The primary impacts are diversion of local and regional traffic into residential neighborhoods, and additional connecting intersections reducing the overall capacity of regional streets. However, with proper planning, these impacts can be mitigated or avoided altogether.

RELATED RESEARCH

Connectivity across stream corridors

In addition to its effect on traffic demand, the design of local street networks has great potential to impact the health and function of regional stream corridors. Increased street connectivity results in more impervious street surface coverage and hence, more stormwater runoff. In addition, increased connectivity requires construction of culverts and bridges, which affect riparian areas and stream habitats.

In 2001, Metro studied the tradeoffs between street connectivity and stream protection in conjunction with the development of the Pleasant Valley Concept Plan – a vision developed for a rural area with streams planned for future urban development. The objectives of the study were to test for the optimum level of spacing of stream crossings, evaluate the impacts on the major streets and assess the impacts on walking access to the "downtown" commercial district and to transit stops.

A conceptual layout of land uses was identified to serve growth in population and employment. Waterway constraints, including stream corridors and their riparian areas, were then identified. One hundred-foot buffers were provided on each side of the waterways. The proposed regional street network was identified, consisting of the existing rural collector system plus some planned future arterial and collector streets. The local street network was established but without any new crossings of stream corridors. The overall street system in the study area is proposed to have a relatively dense network. Local street connections to the major/regional streets range between 330 feet and 440 feet, with the ideal block size being approximately 200 to 400 feet.

After the development of the street network, waterway crossings of the local street networks were established. Three scenarios were developed with varying levels of stream crossings:

- **Low scenario:** Assumes the existing waterway crossings and only new major streets would be built across streams – no new local streets would be built across streams. This scenario resulted in 23 stream crossings in the area.

- **Medium scenario:** Assumes all of the crossings of the low scenario. It adds local street crossings so that each crossing is within 800-1,200 feet of one another. This resulted in 33 stream crossings in the area.

- **High scenario:** Assumes the crossings would retain the same connectivity as the proposed street network. The street network is planned to meet the regional standard of one connection every 530 feet. This resulted in 63 stream crossings in the area.

See Appendix for maps of the low, medium and high stream crossing scenarios.

Expectations

It was expected that in each scenario there would be the same combined traffic volume on all bridges, but that increased crossings would shift traffic from major to local crossings. Also, it was expected that there would be shorter trip lengths and less vehicle miles traveled overall with more local crossings

Results

The modeling showed that more local stream crossings would lead to lower volumes on major streets. However, it did not find a change in trip length or VMT between scenarios. The study found that traffic conditions on major streets improved in the high and moderate scenarios compared to the low scenario. However, there were diminishing returns. The benefits between moderate and low were much larger than between high and moderate.

More case studies with more varied land-use patterns are needed for more conclusive findings. The conclusions from the Pleasant Valley study are more appropriate for design guidelines than standards.

The study results provide the basis for the following design guidelines:

Provide stream crossings at an average of 800 to 1,200 foot spacing.

Plan stream crossings to link important community destinations. Strategic bridge placement is more important than simply the total number of bridges.

Provide pedestrian/bicycle crossings where full streets are not possible.

Use stream crossings as gateways and focal points for the community.

To minimize stormwater runoff and other stream impacts from increased street connectivity, the Regional Transportation Plan calls for the following "green street" techniques:

Choose locations for new stream crossings that minimize construction impacts.
  Determine potential bridge locations within the stream corridor where the environment already is in decline. Revitalize the surrounding natural environment as part of the bridge construction.
  Evaluate the potential for existing bridges or roadways to be closed and reclaimed as the result of a new project.

In areas where a pedestrian/bicycle connection is lacking, construct a separate, low-impacting facility to serve pedestrians and bicyclists, rather than widening existing vehicle bridges and culverts.

Provide the minimum street width necessary.

Use street trees and swales to intercept stormwater.

Use pervious paving for pedestrian/bicycle paths and low-volume streets.

Connectivity benefits for non-motorized modes
As part of the stream crossing study, the benefits of connectivity for pedestrians and bicyclists were evaluated. For each of the three scenarios, access to the town center from the neighborhood was measured. "Access" is defined as the percentage of the neighborhood within easy walking/bicycling distance (1/4 to 1/2 mile). The study found that increased connectivity yields increased access:

72 percent of the neighborhood was accessible from select locations in the surrounding neighborhoods.
74 percent was accessible in the moderate scenario.
99 percent was accessible in the high scenario.

Access increases because the distance that pedestrians and bicyclists have to travel decreases. In fact, the ratio of "actual walk distance" to "straight line distance" dropped from 1.4 in the low scenario to 1.18 in the high scenario. Finally, walking distance between key origins and destinations dropped 9 percent from the low to moderate scenarios, and 18 percent from the moderate to high scenarios.

These results show that pedestrians and bicyclists benefit greatly from street connectivity. While the benefits to motorists experience diminishing returns (rising more from low to medium than from medium to high), pedestrians and bicyclist benefits experience "increasing returns" (rising more from medium to high than from low to medium). This demonstrates the need for very high levels of pedestrian/bicyclist connectivity when increased road connectivity is not possible due to stream/environmental constraints. This can be achieved by providing low-impact foot/bicycle bridges and trails.

IMPLEMENTATION OF CONNECTIVITY GUIDELINES

The Regional Transportation Plan provides guidance to local jurisdictions regarding implementation of street design standards in regard to connectivity in the Portland metropolitan area. It directs cities and counties to perform specific tasks for planning higher levels of connectivity in new development.

The plan requires cities and counties to identify contiguous areas of vacant and under-developed parcels of five or more acres of planned or zoned residential or mixed-use development. With this information, local jurisdictions must prepare a conceptual local street plan that identifies the most important local street connections that will improve local access and preserve the integrity of the regional street system. This local street plan is then to be used in the development review and permitting process to ensure the construction of those local street connections to adjacent areas that promote a logical, direct and connected local street system.

In addition, local development codes for residential and mixed-use areas require street connections every 530 feet or less (with exceptions for certain barriers to providing connectivity). When full street connections are not possible the cities and counties must provide bike and pedestrian accessways on public easements or rights of way in lieu of streets. Spacing of accessways between full street connections should be no more than 330 feet (with exceptions for certain barriers).

Cities and counties also must limit the use of closed-end streets (cul-de-sacs) to situation where barriers prevent a connected street network. When built, these streets must be no longer than 200 feet, with no more than 25 residential units.

RTP requirements in stream corridors:

- Where streets must cross water features identified in Title 3 of the Urban Growth Management Functional Plan, crossings must be provided at an average spacing of 800 to 1,200 feet, unless habitat quality or length of crossing prevents a full street connection.

- Bike and pedestrian accessways that cross water features identified in Title 3 of the Functional Plan should have an average spacing no more than 530 feet, unless habitat quality or length of crossing prevents a connection.

- Cities and counties, TriMet, ODOT and the Port of Portland shall consider stream crossing design guidelines contained in the Green Streets Handbook for replacement or new construction of local street crossings on streams identified in Title 3 of the Functional Plan.

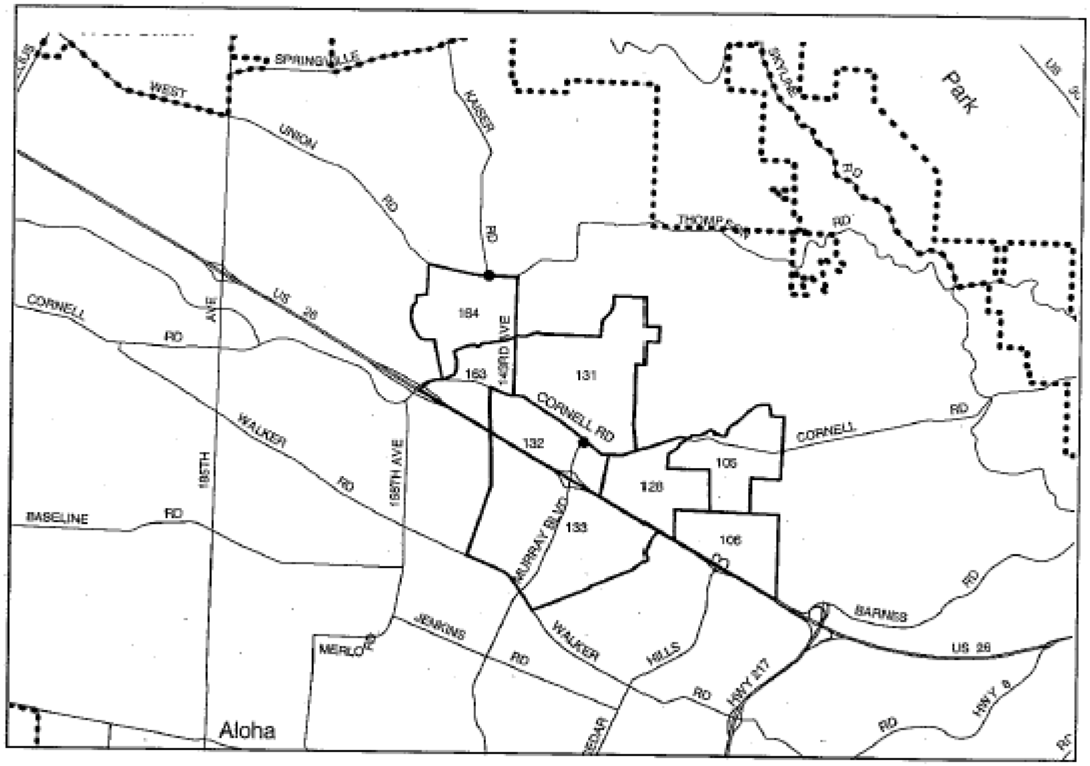
Both the Functional and the Regional Transportation plans provide more detail and guidance to local jurisdictions regarding street connectivity.

Appendix

Connectivity Case Studies: 2015 Base Network

Study Area 1: Bethany

The Bethany study area is characterized by rolling topography and contains many small stream corridors. Bethany is a rapidly growing area with large tracts of vacant land that are oriented toward US 26. Throughout the study area, much of the major street network is limited to two-lane rural roads. Existing subdivisions display relatively low street connectivity. While commercial development within the study area is limited, most existing commercial development is oriented toward US 26. In addition, a substantial amount of industrial/employment areas are designated along US 26. Freeway interchanges exist at Cedar Hills Boulevard, Murray Boulevard and Cornell Road.



Transportation Department
600 NE Grand Avenue
Portland, Oregon 97232-2736
HOTLINE 503 797 1900
FAX 503 797 1794
T.D.D. 503 797 1804

Represented Transportation Analysis Zones (TAZs):
105, 106, 128, 131, 132, 133, 163, 164

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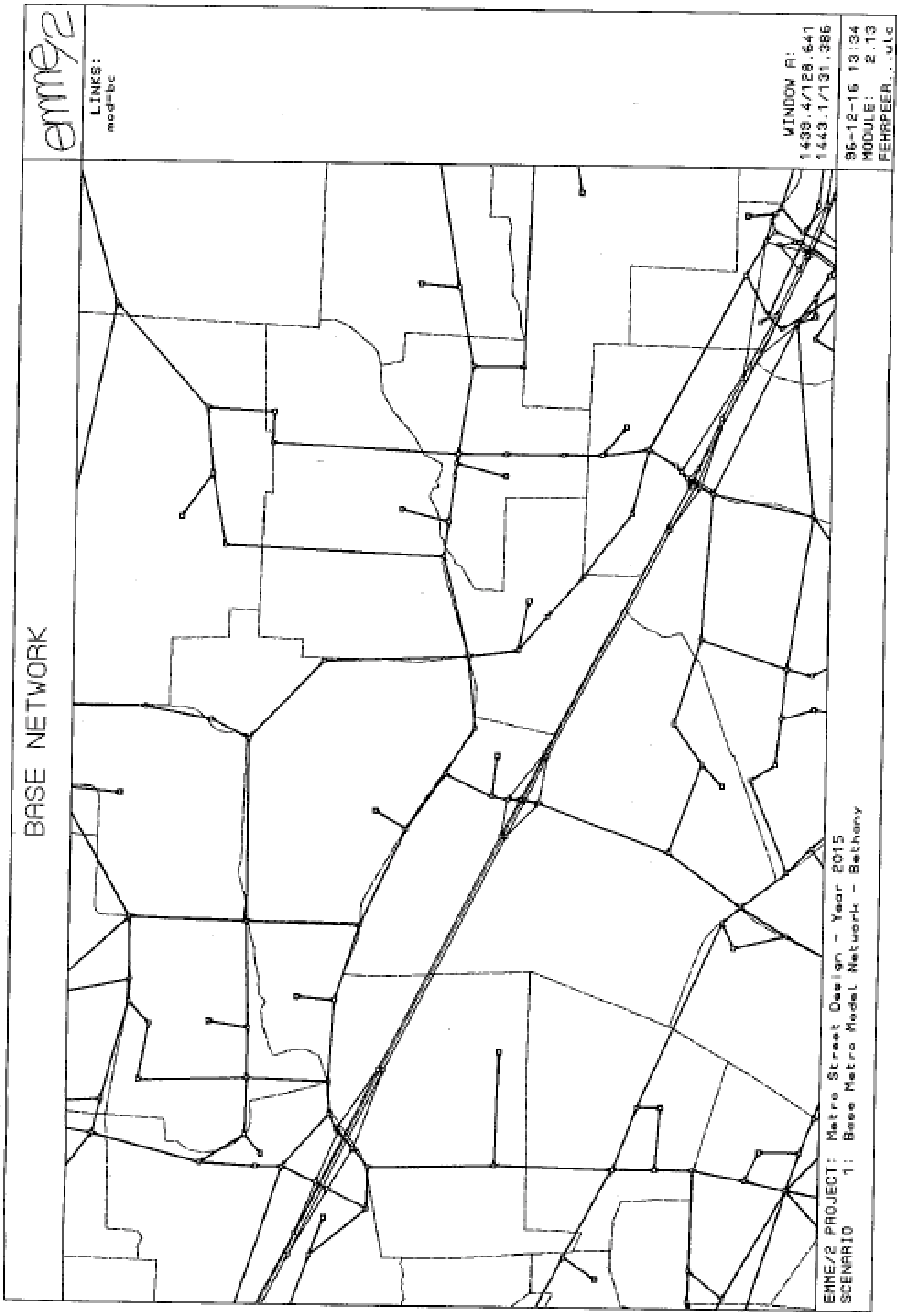
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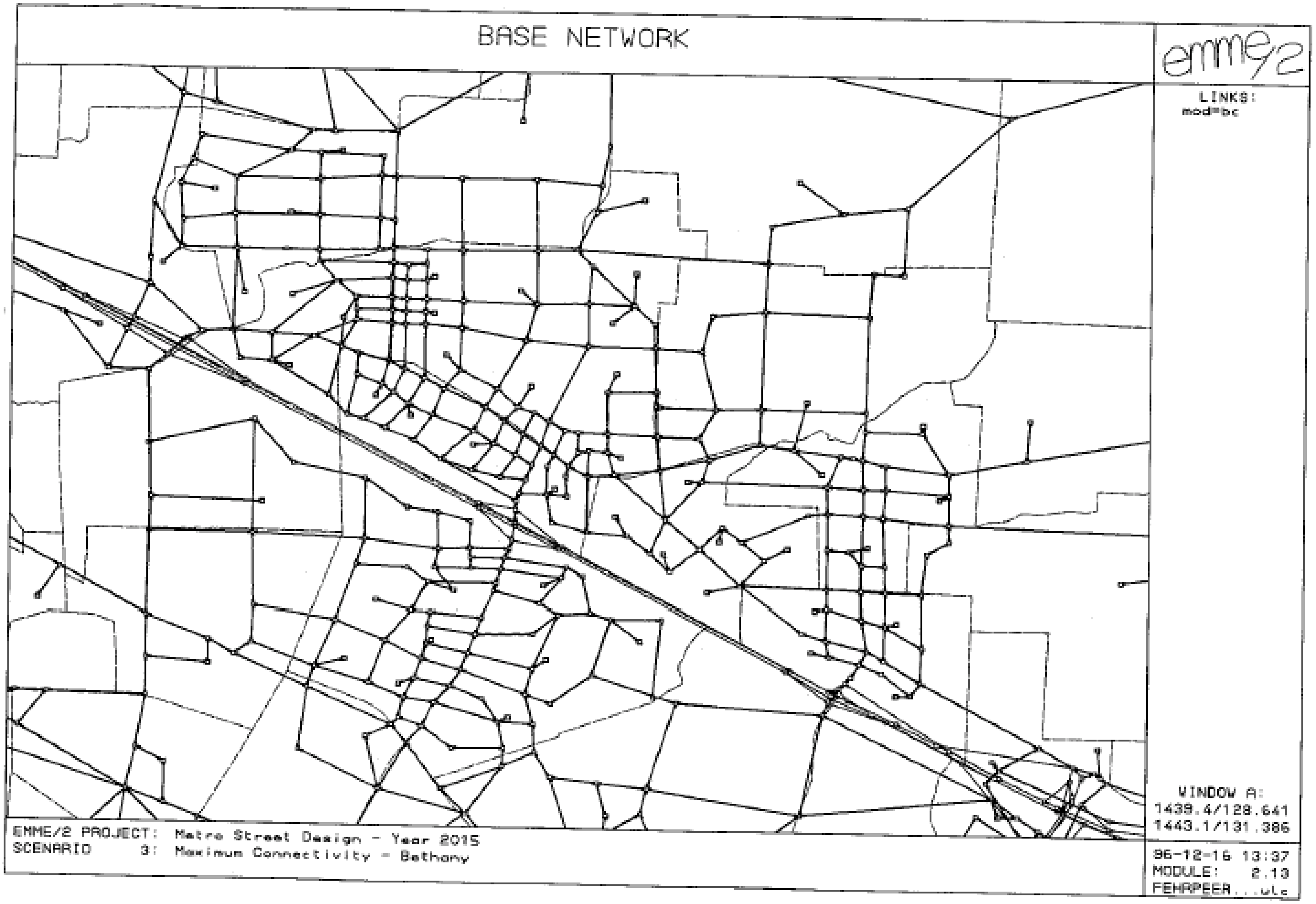
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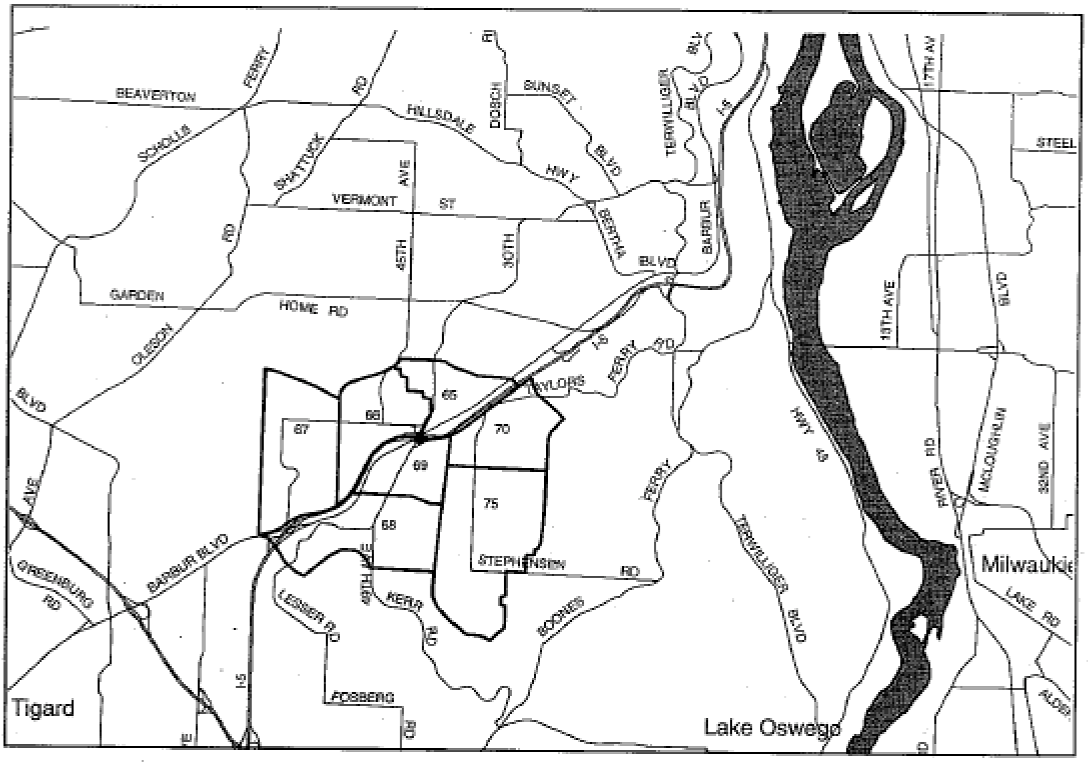
Study Area 2: West Portland

The West Portland study area is characterized by rolling, ocassionally steep terrain. The area is located in Portland's west hills and is oriented toward I-5 and Barbur Boulevard. The area contains older, suburban neighborhoods which have experienced some infill development. Street connectivity in the older neighborhoods of the study area is relatively high, where topography permits. Whereas newer subdivisions have somewhat lower street connectivity. The street network is a mix of some streets improved to urban standards, while some are improved only to rural standards. The study area includes 2040 Growth Concept land use components (e.g., West Portland town center, corridor designations along most arterials). Strip commercial development exists along much of Barbur Boulevard. Full freeway interchanges exist in Tigard (at Barbur Boulevard) and Capitol Highway/Taylors Ferry Road. There are partial freeway interchanges at Multnomah Boulevar and Terwilliger Boulevard.



Transportation Department
600 NE Grand Avenue
Portland, Oregon 97232-2736
HOTLINE 503 797 1900
FAX 503 797 1794
T.D.D. 503 797 1804

Represented Transportation Analysis Zones (TAZs):
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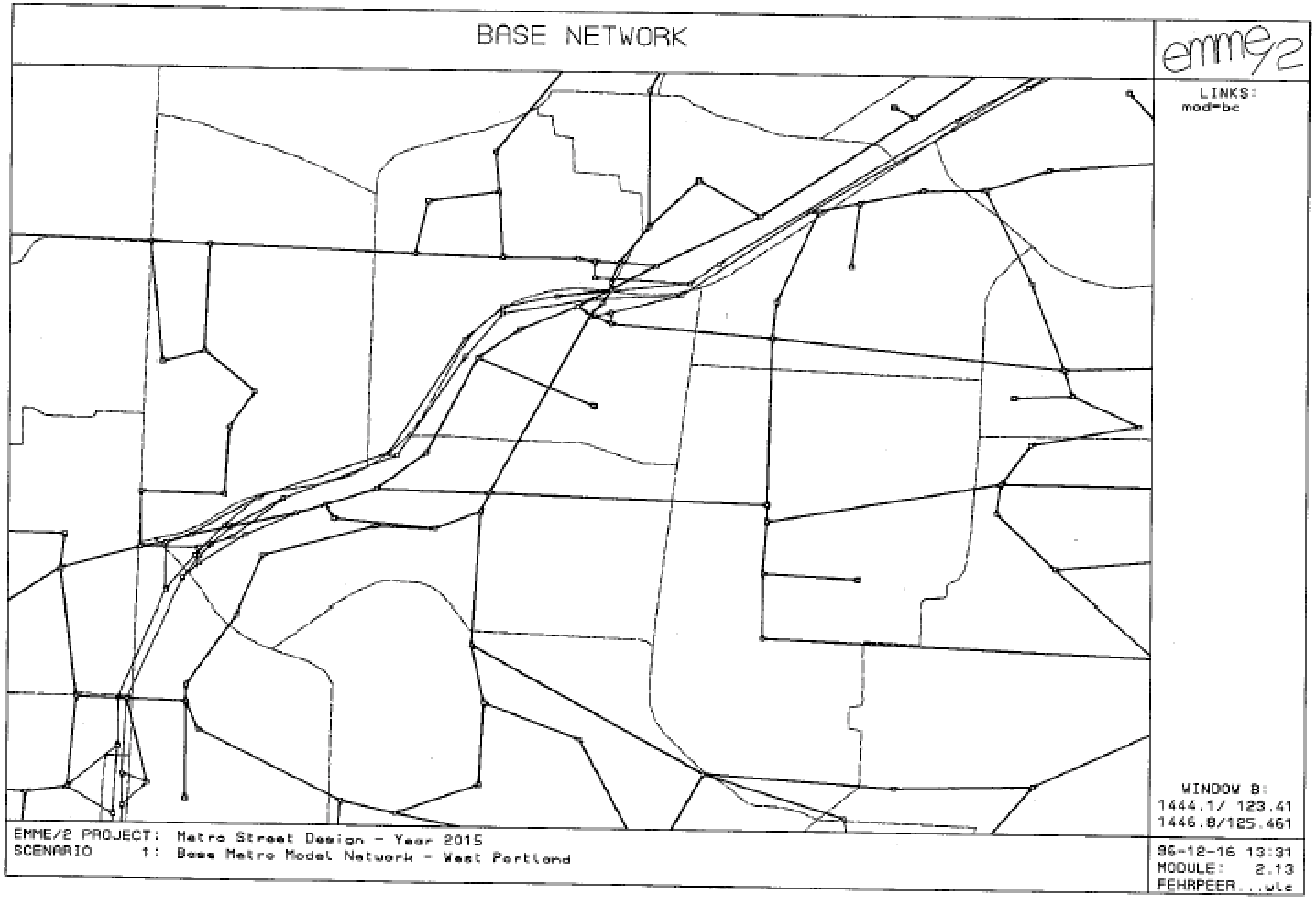
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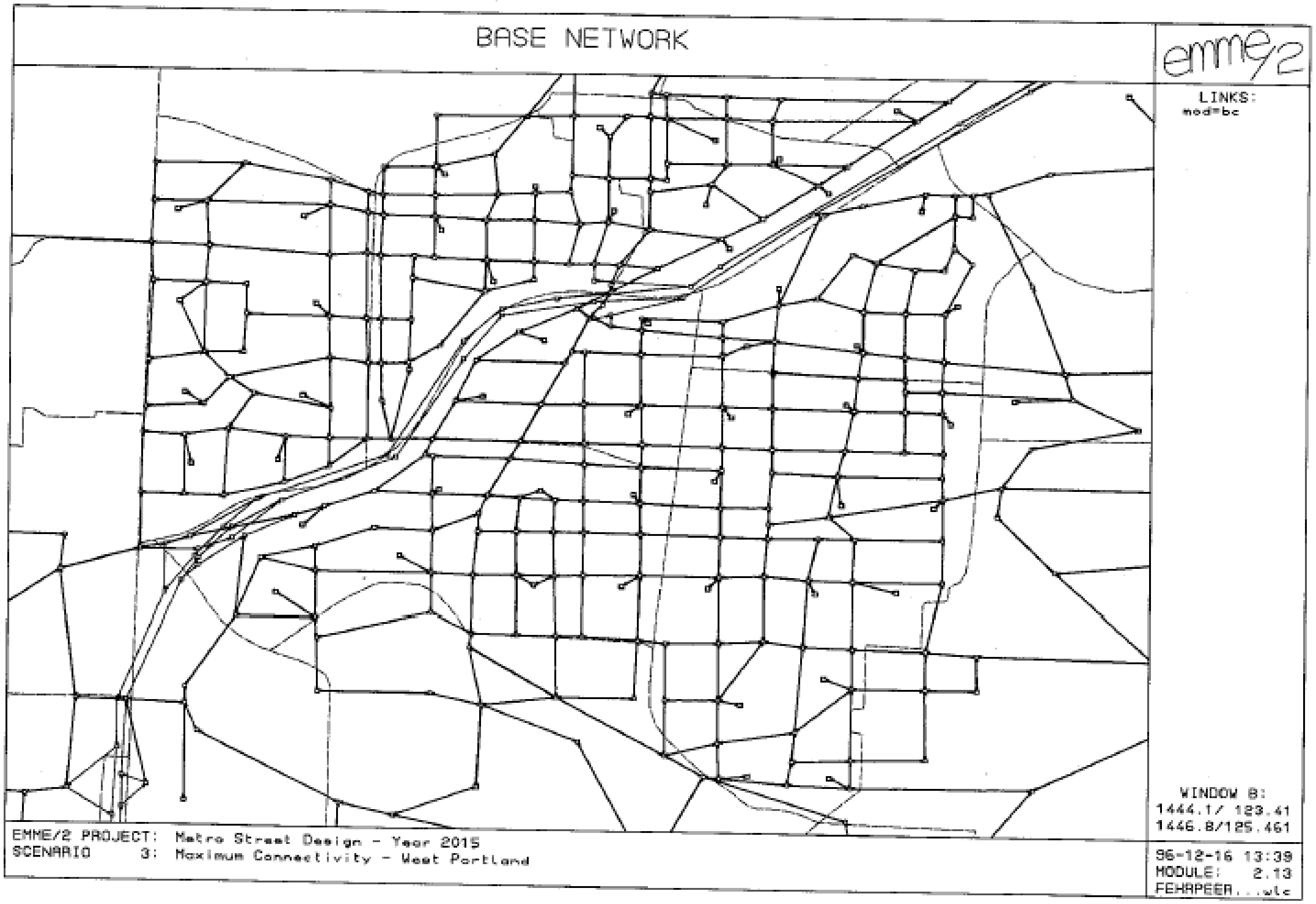
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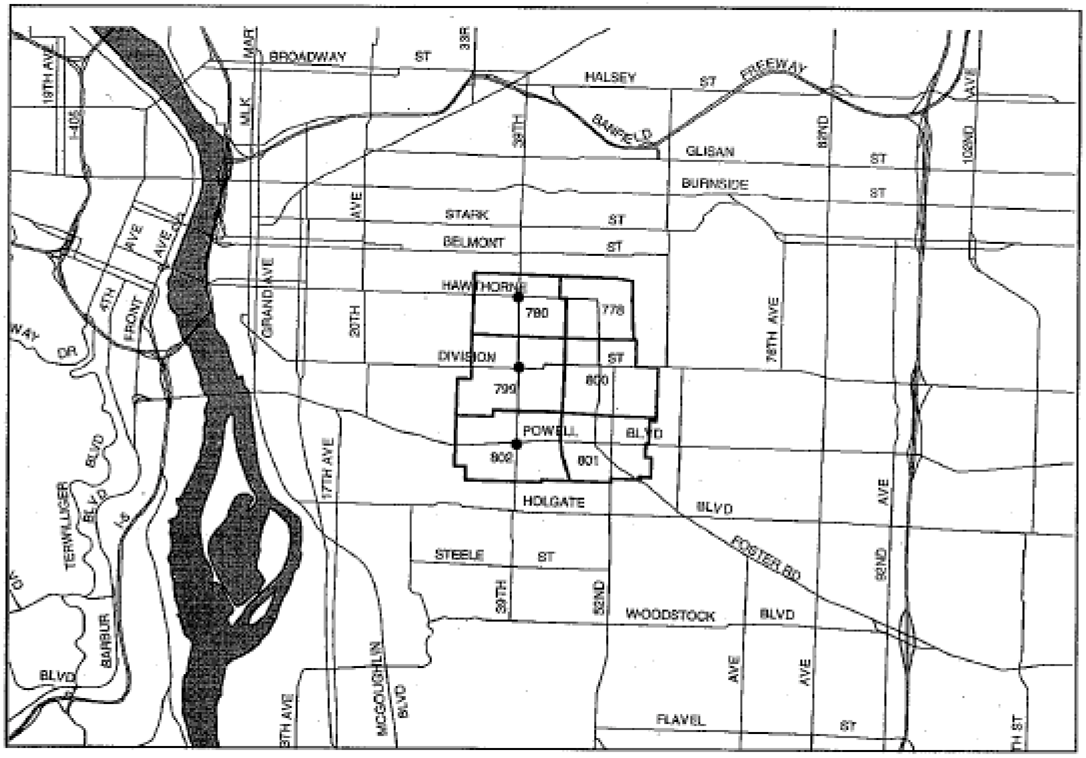
Study Area 3: Inner Southeast

The Inner Southeast study area contains very urbanized older Portland neighborhoods that are characterized by very flat or gently sloped terrain. The area relies on a highly connected local and arterial street system that is fully developed to urban standards. 2040 Growth Concept corridor and main street designations exist along many arterial routes in this area. Powell Boulevard (Highway 26) serves as a major traffic through-route. In addition, Foster Road, Powell Boulevard and 39th Avenue connect to freeways outside of the study area.



Transportation Department
600 NE Grand Avenue
Portland, Oregon 97232-2736
HOTLINE 503 797 1900
FAX 503 797 1794
T.D.D. 503 797 1804

Represented Transportation Analysis Zones (TAZs):
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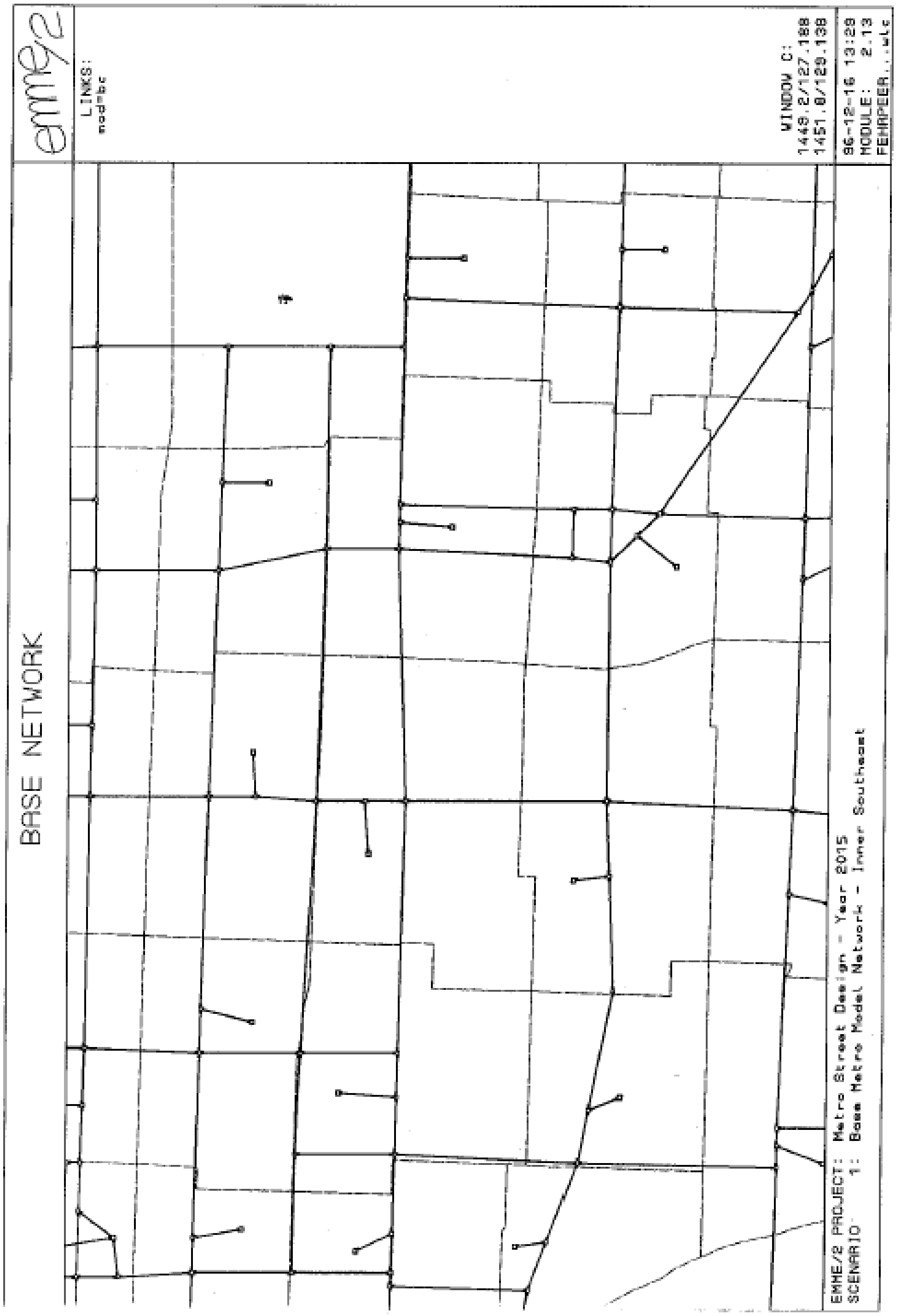
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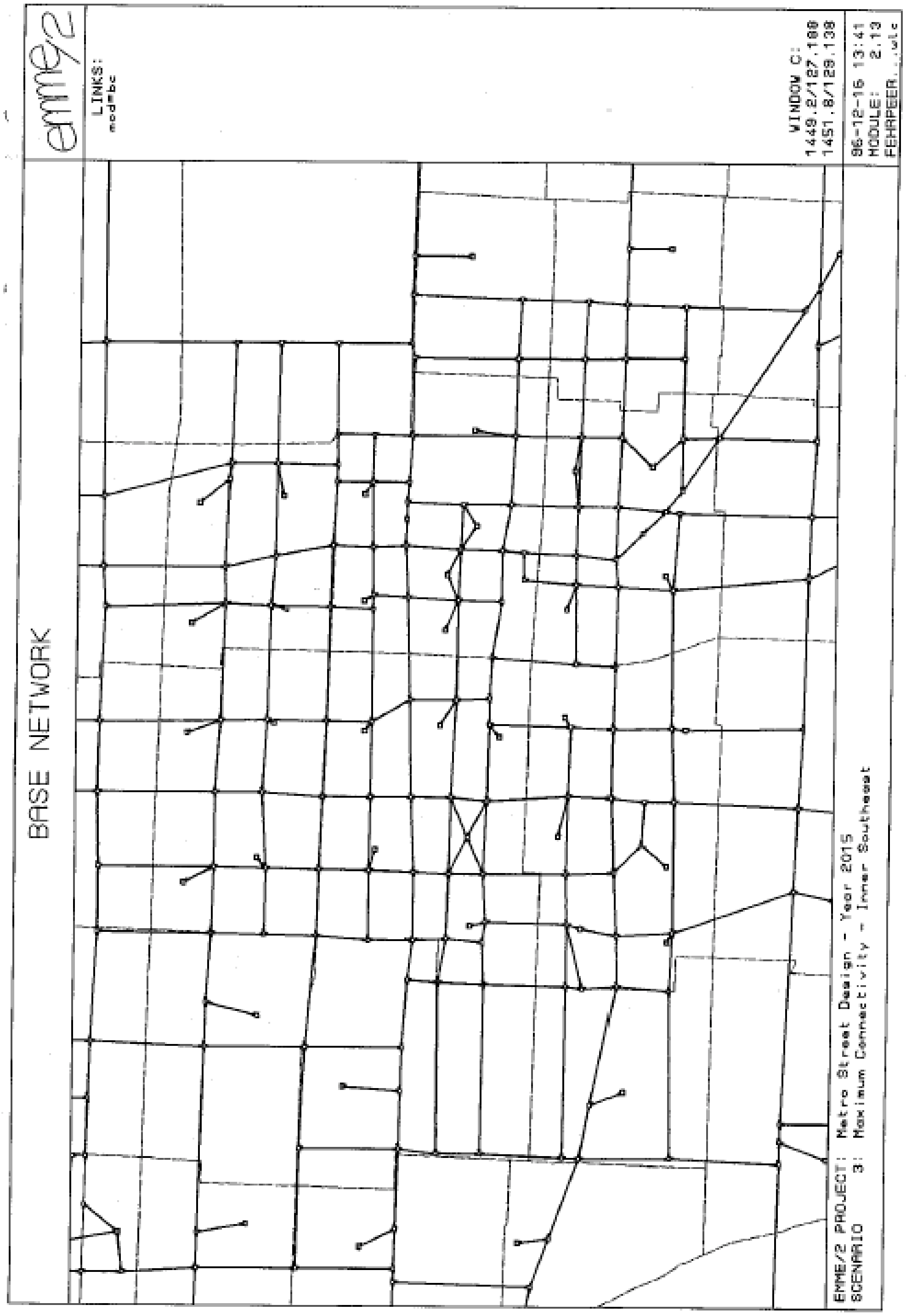
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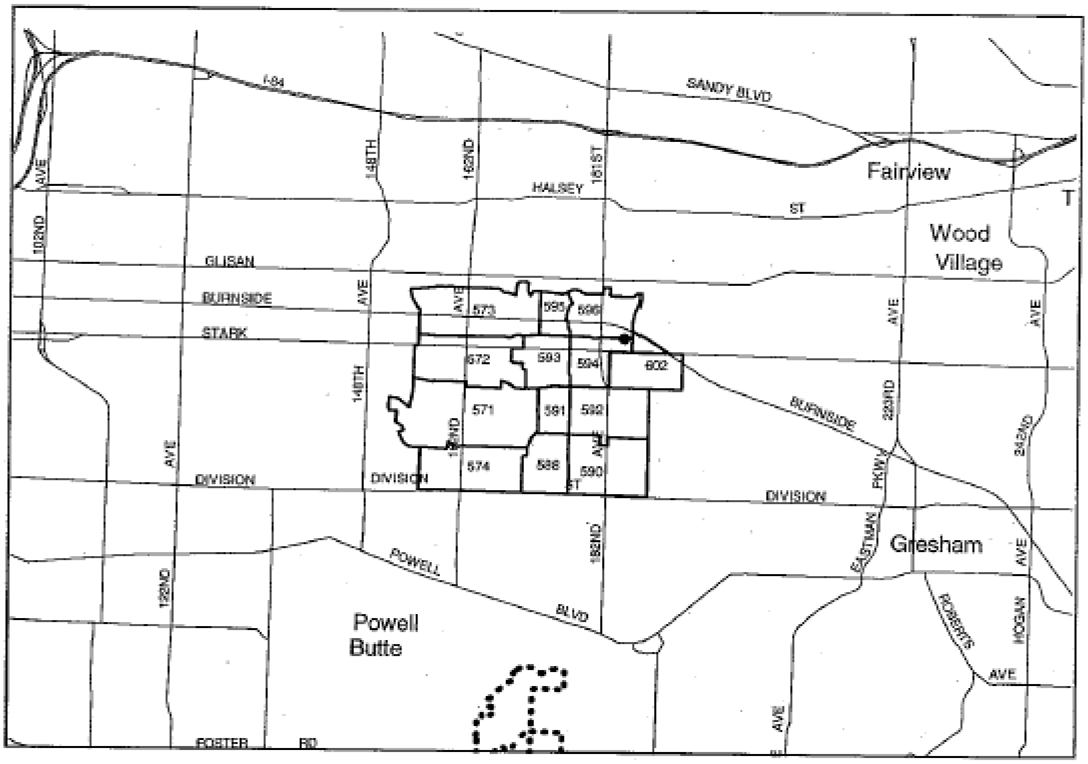
SCENARIO 3: Maximum Connectivity - Inner Southeast

Study Area 4: Mid-County

The Mid-County study area is characterized by mostly flat terrain with isolated hills. The area contains older, suburban neighborhoods which have experienced some infill development. Street connectivity among local and arterial streets is relatively high throughout the study area. Commercial strips exist along most arterial streets. A major industrial/employment area is located north of the study area. The study area includes the Rockwood town center at 181st and Burnside, along the MAX line. Halsey, 181st, Stark and Division serve as connections to freeways outside of the study area.



Transportation Department
600 NE Grand Avenue
Portland, Oregon 97232-2736
HOTLINE 503 797 1900
FAX 503 797 1794
T.D.D. 503 797 1804

Represented Transportation Analysis Zones (TAZs):
571, 572, 573, 574, 588, 590, 591, 592, 593, 594, 595, 596, 602

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Primary Activity Center

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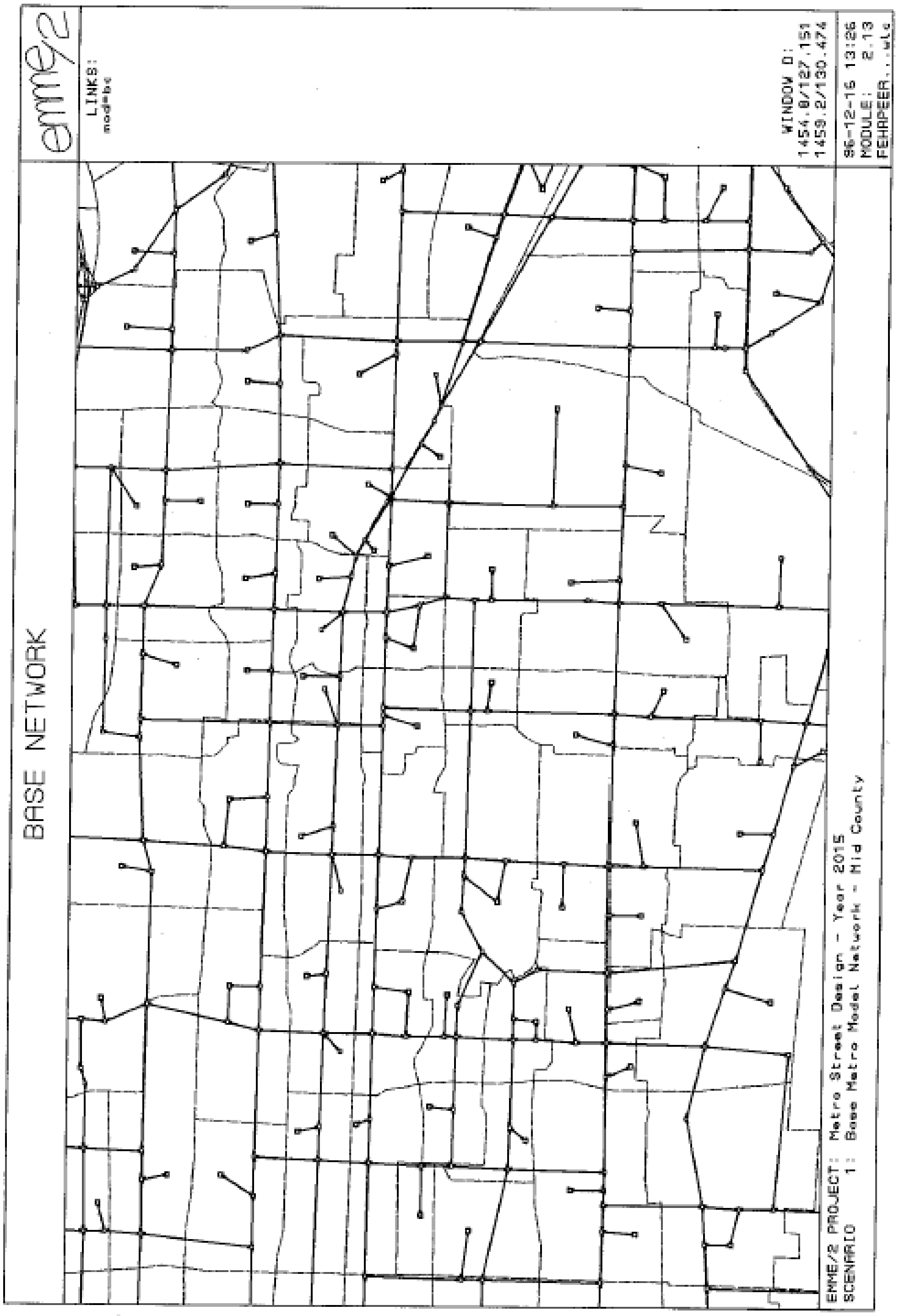emme/2
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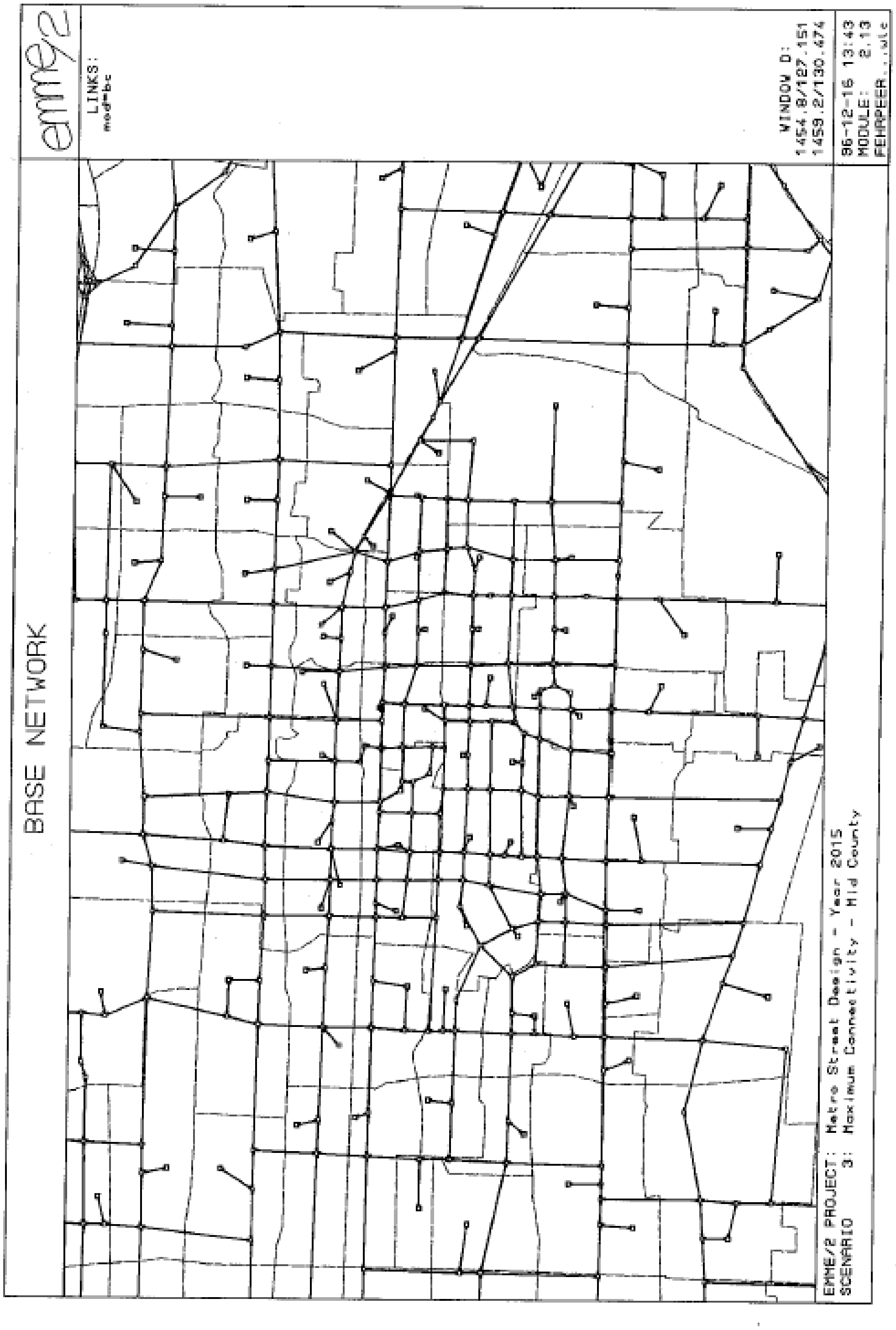
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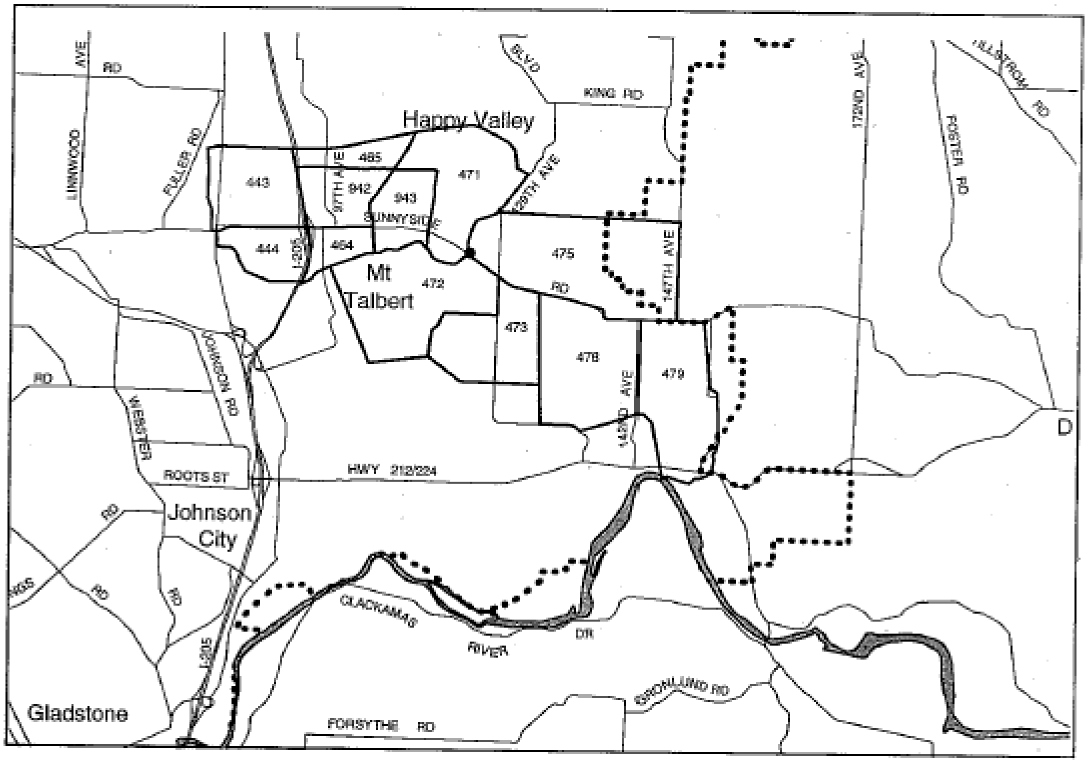
Study Area 5: Sunnyside

The Sunnyside study area is characterized by rolling, often steep terrain and contains many small stream corridors. The street network in this area has very low connectivity with rapid development occuring on closed street systems. Major regional through-routes in the study area include I-205 and Sunnyside Road. In general, many of the other regional routes are two-lane, rural roads. In addition, the Clackamas Regional Center is located on Sunnyside Road, west of I-205, and Sunnyside Road, east of the I-205 freeway, is designated as a corridor in the 2040 Growth Concept. A potential urban reserve has been identified to the east of the Sunnyside study area.



Transportation Department
600 NE Grand Avenue
Portland, Oregon 97232-2736
HOTLINE 503 797 1900
FAX 503 797 1794
T.D.D. 503 797 1804

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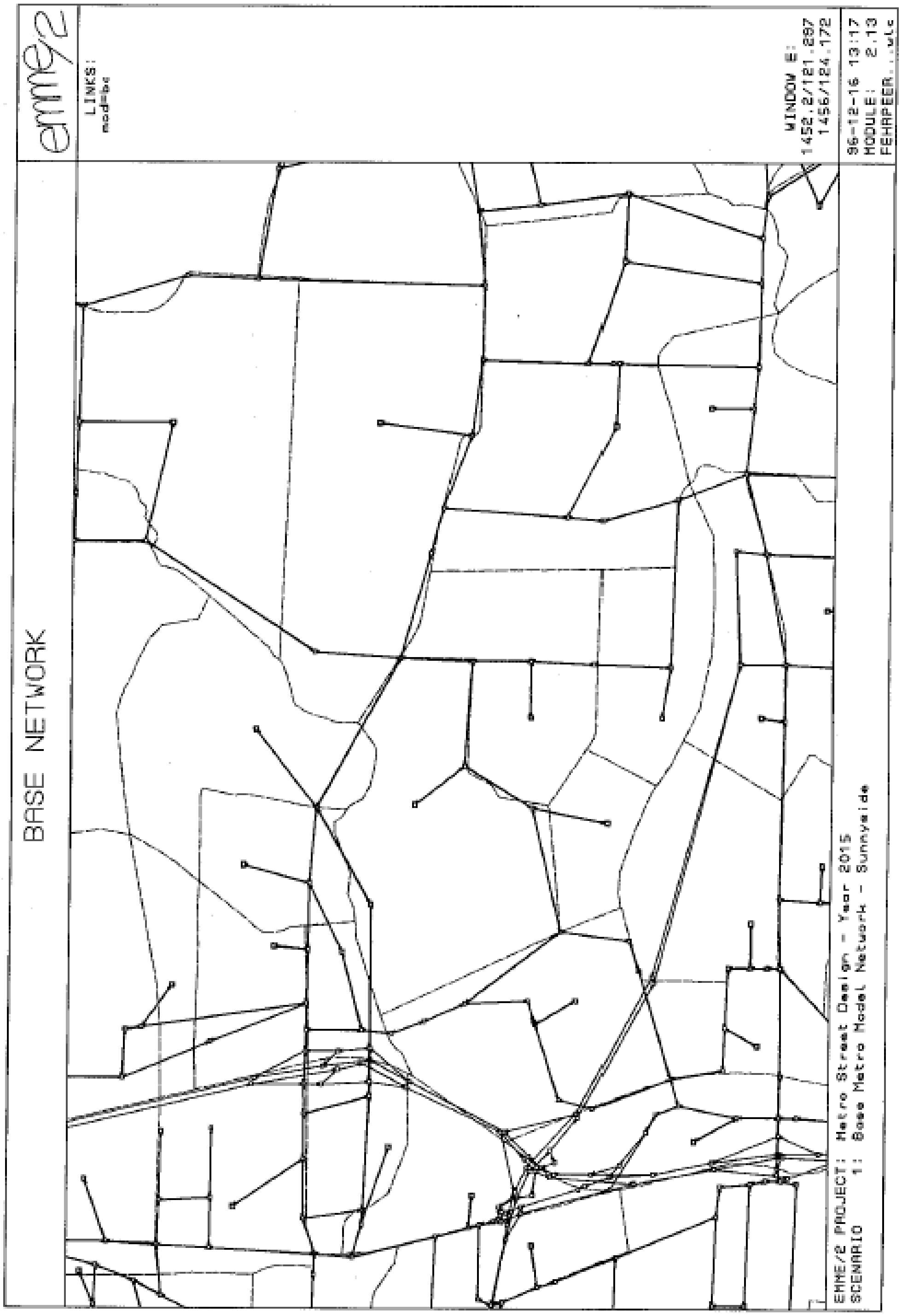
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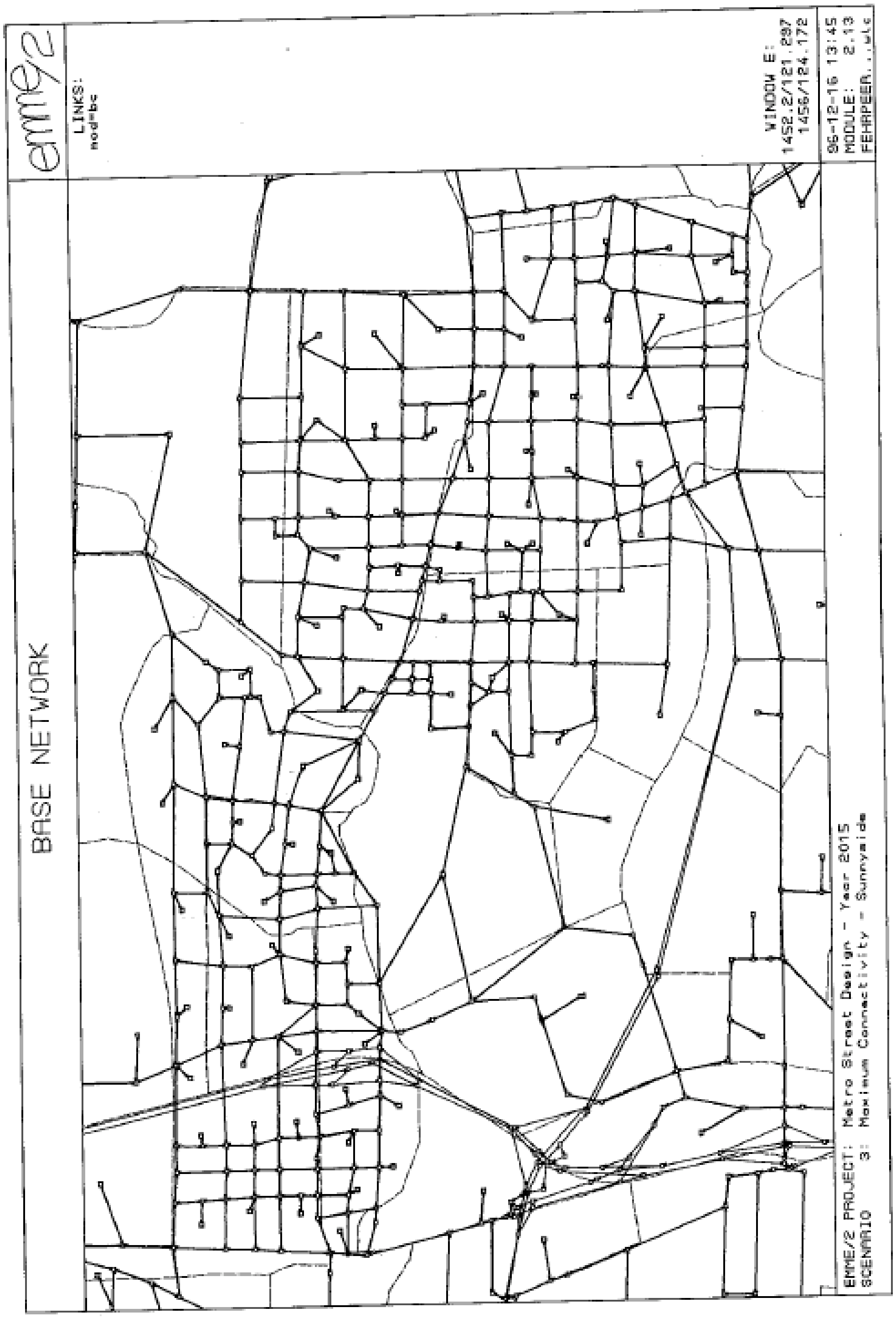
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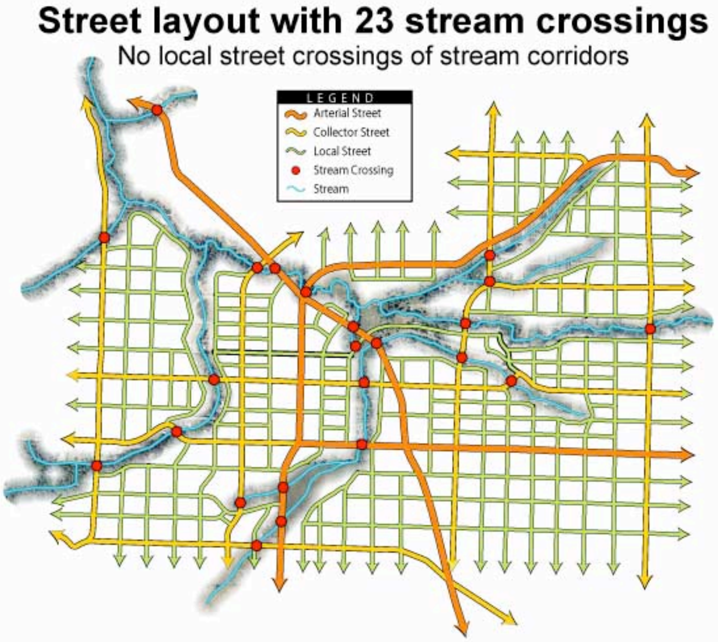
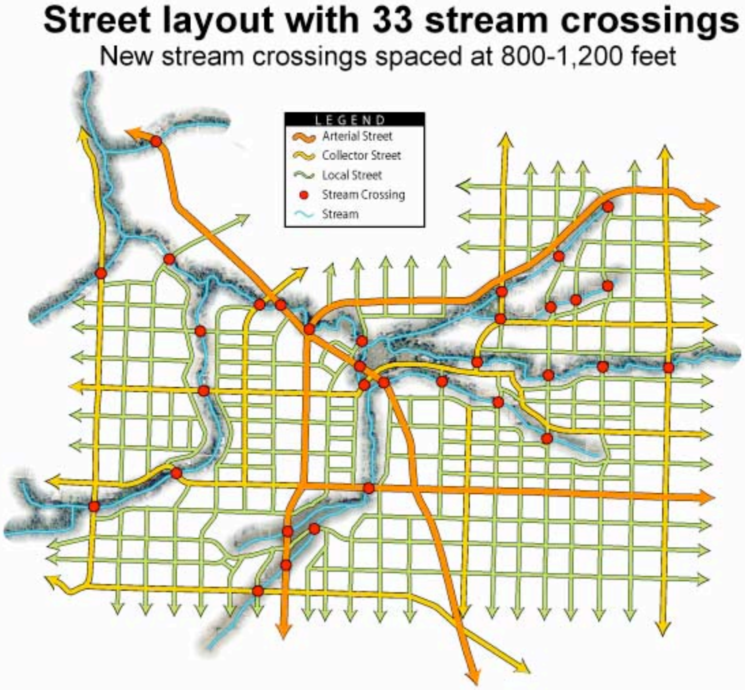
Stream Crossings Study: Connectivity Scenarios


Street layout with 23 stream crossings

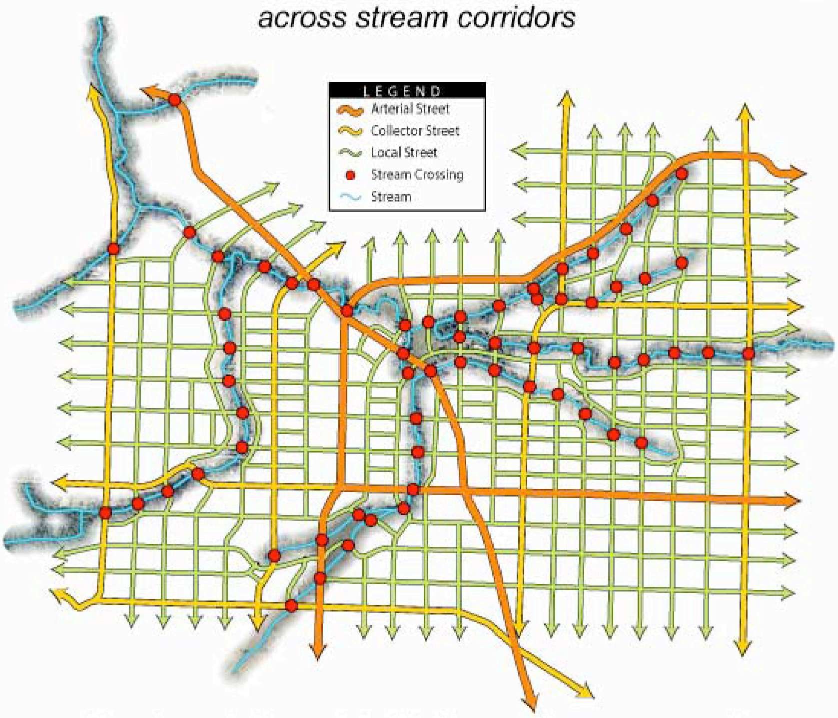
No local street crossings of stream corridors


Street layout with 33 stream crossings

New stream crossings spaced at 800-1,200 feet

Street layout with 63 stream crossings

Extend Metro street spacing standard (maximum of 520 feet)
across stream corridors



* Current Metro standards do not require local jurisdictions to extend streets across stream corridors

GLOSSARY

Accessway – A walkway that provides pedestrian and/or bicycle passage either between streets or from a street to a building or other destination such as a school, park or transit stop. Accessways generally include a walkway and additional land on either side of the walkway, often in the form of an easement or right of way, to provide clearance and separation between the walkway and adjacent uses. Accessways through parking lots are generally physically separated from adjacent vehicle parking or parallel vehicle traffic by curbs or similar devices and include landscaping, trees and lighting. Accessways that cross driveways are generally raised, paved or marked in a manner that provides convenient access for pedestrians.

Arterial street – A street designated to have the function of linking communities within the region and interconnecting major activity centers and industrial areas to the principal arterial highway system. These streets link major commercial, residential, industrial and institutional areas. Arterials usually carry between 10,000 and 30,000 vehicles per day and provide for higher speeds than collector and local streets. These streets are divided into major and minor classifications. Major arterials function to serve longer, through trips and serve more of a regional traffic function. Minor arterials function to serve shorter, more localized travel within a community. As a result, major arterials usually carry more traffic than minor arterials. Arterial streets are usually spaced about one mile apart.

Collector street – A street designated to carry traffic between local streets and arterials, or from local street to local street. These streets serve neighborhood traffic and commercial/industrial areas. Collectors provide local circulation alternatives to arterials, balancing movement with access to land uses. They provide both circulation and access within residential and commercial areas, helping to disperse traffic that might otherwise use the arterial system for local travel. Collectors usually carry between 1,000 and 10,000 vehicles per day. Collector streets are usually spaced at half-mile intervals, or midway between arterial streets. Speeds and volumes on collector streets are moderate.

Functional plan – A limited purpose multi-jurisdictional plan for an area or activity having significant district-wide impact upon the orderly and responsible development of the metropolitan area that serves as a guideline for local comprehensive plans consistent with ORS 268.390.

Growth Concept – A concept for the long-term growth management of the Portland metropolitan region, stating the preferred form of the regional growth and development, including if, where, and how much the urban growth boundary should be expanded, what densities should characterize different areas, and which areas should be protected as open space.

Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 – The federal highway/public transportation funding reauthorization that, among other features, funds the national highway system and gives states and local governments more flexibility in making transportation decisions. The act places significant emphasis on broadening public participation in the transportation planning process to include key stakeholders, including the business community, community groups, transit operators, other governmental agencies and those who have been traditionally underserved by the transportation system. Among other things, the act requires the metropolitan area planning process to consider such issues as land-use planning, energy conservation, intermodal connectivity and enhancement of transit service. The act integrates transportation planning with achievement of the air quality conformity requirements embodied in the Clean Air Act Amendments of 1990 and state air quality plans.

Level of service (LOS) – A qualitative measure used to describe operational conditions for how a roadway performs, measuring congestion as a share of the designed road capacity, and their perception by motorists and/or passengers. This measure of congestion assigns a grade according to how "full" a road is as compared to its design capacity. This system ranks levels of congestion from A to F, and generally describes these conditions in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, comfort, convenience and safety. LOS A is considered very good and represents virtually free flow conditions. LOS F is assigned to roads that fill to capacity and begin to fail. The LOS rating of A through F is used to describe the traffic flow on streets and highways and at intersections.

Local Comprehensive Plan – A generalized, coordinated land-use map and policy statement of the

governing body of a city or county that inter-relates all functional and natural systems and activities related to the use of land, consistent with state law.
Local street – A street designated to provide access to and from residences, small activity centers or businesses. Local streets usually carry fewer than 1,000 vehicles per day. Speeds on local streets are relatively low.

Major street – Arterials and major collector streets.

Metro – The regional government and designated metropolitan planning organization of the Portland metropolitan area, represents 1.3 million people who live in Clackamas, Multnomah and Washington counties and the 24 cities in the area. Metro is governed by a council president elected regionwide and six councilors elected by district. Metro provides transportation and land-use planning services and oversees regional garbage disposal and recycling and waste reduction programs. Metro manages regional parks and greenspaces and owns the Oregon Zoo. It also owns the Oregon Convention Center, and oversees operation of the Portland Center for the Performing Arts and the Portland Metropolitan Exposition (Expo) Center, all managed by the Metropolitan Exposition Recreation Commission.

Mixed-use areas – Compact areas of development that include a mix of uses, either within buildings or among buildings, and include residential development as one of the potential components.

Multi-modal – Having a variety of modes available for any given trip, such as being able to walk, ride a bicycle, take a bus or drive to a certain destination. In a transportation system, multimodal means providing for many modes within a single transportation corridor.

Oregon's Statewide Planning Goals – The 19 goals that provide a foundation for the state's land-use planning program. The 19 goals can be grouped into four broad categories: land-use, resource management, economic development and citizen involvement. Locally adopted comprehensive plans and regional transportation plans must be consistent with the statewide planning goals.

Oregon Transportation Plan (OTP) – The official statewide intermodal transportation plan that will set priorities and state policy in Oregon for the next 40 years. The plan, developed by the Oregon Department of Transportation through the statewide transportation planning process, responds to federal ISTEA requirements and Oregon's Transportation Planning Rule.

Regional Framework Plan – Required of Metro under its home-rule charter, the plan must address nine specific growth management and land-use planning issues (including transportation), with the consultation and advice of Metropolitan Policy Advisory Committee. To encourage regional uniformity, the plan shall also contain model terminology, standards and procedures for local land-use decision making that may be adopted by local governments.

Regional roads – Arterials and freeways within the subareas of this study.

Regional Transportation Plan (RTP) – The official intermodal transportation plan that is developed and adopted through the metropolitan transportation planning process for the metropolitan planning area.

Transportation analysis zone (TAZ) – A tool used to conduct transportation analyses. A TAZ usually consists of one or more census blocks, block groups or census tracts.

Transportation demand management (TDM) – Actions, such as ridesharing and vanpool programs, the use of alternative modes, and trip-reduction ordinances, which are designed to change travel behavior in order to improve performance of transportation facilities and to reduce need for additional road capacity.

Transportation Planning Rule (TPR) – The implementing rule of statewide land-use planning goal 12 dealing with transportation, as adopted by the state Land Conservation and Development Commission. Among its many provisions, the rule includes requirements to preserve rural lands, reduce vehicle miles traveled per capita by 20 percent in the next 30 years, reduce parking spaces and to improve alternative transportation systems.

Transportation system management (TSM) – Strategies and techniques for increasing the efficiency, safety, capacity or level of service of a transportation facility without increasing its size. Examples include, but are not limited to, traffic signal improvements, traffic control devices including installing medians and parking removal, channelization, access management, re-striping of high-occupancy vehicle lanes, ramp metering, incident response, targeted traffic enforcement and programs that smooth transit operations.

Transportation system plan (TSP) – A plan for one or more transportation facilities that are planned, developed, operated and maintained in a coordinated manner to supply continuity of movement between modes, and within and between geographic and jurisdictional areas.

Urban growth boundary (UGB) – The boundary around a metropolitan area outside of which no urban improvements may occur (sewage, water, etc.). It is intended that the UGB be defined to accommodate all projected population and employment growth within a 20-year planning horizon. A formal process has been established for periodically reviewing and updating the UGB so that it accurately reflects projected population and employment growth.

Urban Growth Management Functional Plan – A regional functional plan with requirements binding on cities and counties in the Metro region, as mandated by Metro's Regional Framework Plan. The plan addresses such issues as accommodation of projected regional population and job growth, regional parking management, water quality conservation, retail in employment and industrial areas and accessibility on the regional transportation system. All cities and counties within Metro's boundary shall adopt changes to local comprehensive plans and zoning codes to address these issues within 24 months after the adoption of the plan ordinance by the Metro Council.