MTI Report 03-03

Using Spatial Indicators for Pre- and Post-Development Analysis of TOD Areas: A Case Study of Portland and the Silicon Valley

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September 2004

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16. Abstract

Understanding how smart growth theories are translated into practice is an important endeavor for planners, researchers, and the general public to both evaluate past efforts and to plan for new ones. This study uses a series of spatial indicators to visualize and quantify eight transit-oriented development (TOD) areas in Portland and Silicon Valley. More specifically, this report uses a spatial-temporal analysis to measure transit usage, urban form, and socio-demographic change prior and subsequent to the incorporation of light rail and transit-oriented development policies in these two regions.

A particular focus of this research is on the consistency of the urban mobility infrastructure with pedestrian access to the transit stops because the capacity for transit users to walk to and from their transit point of entry is a critical component of the overall TOD concept. Three key techniques to visualize and quantify walkability are presented: street network classification, pedestrian catchment areas, and intersection intensities. While such measures have been used elsewhere, this paper introduces the idea of impedance, which is incorporated into each of these measures presenting a refined method of analysis that distinguishes between an auto-oriented and pedestrian-oriented street network.

The general results of this research show that: the change to non-automotive use for work trips is mixed and that Portland is developing much more consistently with smart growth principles than Silicon Valley. More specifically, the impedance-based walkability analysis challenges some theoretical extents of TOD theory, including: road types impact walkable service areas; actual areas of potential walkability are dramatically smaller than theoretical areas, with irregular coverage patterns; major roads present spatial barriers between areas of high connectivity and stations; and areas of high connectivity are often spatially separate from transit stops.

Finally, this report makes extensive use of geographic information system (GIS) technology to both visually and quantitatively capture a series of phenomena related to TOD areas. Focus has been placed on representing the visual images in ways that can enhance a broad understanding of the issues and in an effort to enhance potential participation of a broader public into the smart growth policy making process–an area of policy increasingly pursued in communities throughout the United States.

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EXECUTIVE SUMMARY

The project, *Using Spatial Indicators for Pre- and Post-Development Analysis of TOD Areas: A Case Study of Portland and the Silicon Valley*, seeks to achieve two main objectives: 1) use a spatial-temporal approach to determine whether transit-oriented developments result in increased transit usage and 2) to develop spatial indicators of a fine grain to evaluate the urban form of transit-oriented development areas. The purpose of goal one is to test whether TOD developments yield the transit goals originally sought. The purpose of goal two is to determine whether there are characteristics of urban form that can be spatially measured and to understand how such spatial indicators may link TOD theory to reality.

The primary focus of this project is the urban form surrounding individual transit stops, focusing on walkability surrounding those sites. Transit usage is dependent on a variety of factors including land use mix, density, quality of transit service, and other factors. One central component of transit use, and a key for TOD areas to match their theoretical potential, is the capacity to walk between a transit stop and the surrounding area. Past research has determined that maximum walking distances to access transit range from a quarter- to a half-mile. This research uses those distance ranges as a basis for analysis, and then alters them to reflect a pedestrian reality.

The research that follows shows two main trends: 1) substantive differences exist in terms of transit usage and socio-demographic characteristics between those who live in close proximity to transit or not and 2) that local urban form, in terms of the walkable mobility infrastructure, differs substantially across TOD areas, with some transit stops located in infrastructure environments quite hostile to pedestrian access. A key component to this analysis has been the classifying of the local street network into pedestrian-friendly and auto-dominant streets. Using such a classification provides a more nuanced look at how the predominant mobility infrastructure (the street network) works from a pedestrian viewpoint.

Above and beyond these policy task and policy-oriented findings, this research breaks ground by developing visual, spatial, temporal, and quantitative means to both plan and evaluate TOD siting decisions. Using small visual multiples of each TOD area and combining the visual element with a quantitative and textual overview, this research presents a more comprehensive method for planners, policy makers, and the general citizenry to engage in the process and evaluation of TOD area planning.

CONTEXT

OVERVIEW

The key goal of transit-oriented developments (TOD) is to provide an environment in which transit, walking, and some bicycling are the primary travel modes to reach a significant amount of one's daily needs and destinations. Within TOD (and smart growth more generally), there are three core elements to consider: density, land use mixture, and mobility infrastructure. The core theoretical image of this urban form is of a transit stop surrounded by quarter-mile concentric rings. Within the quarter- and half-mile rings, development is relatively dense, land uses are mixed, and there exists a mobility infrastructure that supports pedestrian movement. This research is predominantly focused on the third element–the pedestrian mobility infrastructure–and how the theory of concentric rings of walkability is translated into practice. Secondarily, this research also focuses on the transportation modal split around light rail transit stops between 1990 and 2000.

In translating the hypothetical concentric circles of walkability into an analysis of existing urban form around transit stops, the theory becomes compromised in two key ways. First, basing walking distances within concentric circles ignores the fact that people are not free to travel in any direction, but must travel along pathways. A quarter-mile zone from a transit stop based on walking would therefore not be a perfect circle. Understanding the actual shape of a walkable quarter-mile zone can give insight into the general pedestrian-friendliness of the urban form surrounding transit stops. Second, not all potential pedestrian pathways are of equal accessibility. If using a street network as a proxy for pedestrian mobility, it is clear that the existing hierarchy of street types (minor roads, arterials, major roads) is also relevant for pedestrians, and likely with an inverse relationship. That is, roads designated as appropriate for heavy volumes of automobiles may simultaneously be less desirable for pedestrian travel.

This research and report focuses on these two key elements (pattern and connectedness of the street network and the hierarchy of street types) in looking at eight TOD areas (four in Portland and four in Silicon Valley). Moreover, the change in urban form over time is incorporated by looking at the urban form before and after the development of the light rail systems in each region. An analysis of transit utilization mode of travel to work over time complements the urban form analysis. Finally, a spatial-temporal analysis of basic socio-demographic characteristics is presented for each region.

INTRODUCTION

The basic premise of transit-oriented developments (and smart growth efforts in general) is that a variety of land use factors affect travel patterns including density, land use mix, roadway connectivity and design, parking facilities design and building design.[1] Three key elements of TOD areas are appropriate density, diversity, and design of a community–the three D's of the built environment.[2] That is, the form, spatial location, and concentration of activities within an urban environment can influence transit ridership.

It is believed that good urban form can lead to a reduction of total transportation costs and auto usage, resulting in more livable communities.[3] For example, Bernick and Cervero found that the residents of more pedestrian-friendly neighborhoods were more likely to go by foot to the market.[4] Handy found that residents living in "traditional neighborhoods" made two-to-four more walk/bicycle trips per week to neighborhood stores than those living in nearby areas that were served mainly by automobile-oriented strip retail establishments, although there were similar rates of auto travel to regional shopping malls. A good walkable urban form, therefore, can be a key contributor to local mobility.[5] And because TOD areas represent both local and regional mobility, the streets and character of the immediate surroundings, the neighborhood linkage with the transit stop, as well the location of the neighborhood within the larger region may influence regional household travel behavior for neighborhood residents. Thus, the urban form at a neighborhood scale is an important variable that will allow a resident to exercise a non-automotive transportation choice, if such options are available.

THE MOBILITY INFRASTRUCTURE AND WALKABILITY

> Because transit riders begin and end their trips as pedestrians, the environment where people walk to and from transit facilities is a significant part of the overall transit experience. Common sense suggests that an unattractive or unsafe walking environment discourages people from using transit. Conversely, a safer and more appealing pedestrian environment may increase transit ridership.[6]

Often lost in the debate about transit-oriented development is the walking environment surrounding transit stops that allows users (and potential users) to access the transit system and local amenities surrounding individual stops. The larger debate tends to concentrate on the right mix of uses and density surrounding transit stops with the ultimate goal of understanding the impacts of land use on transit ridership. Yet, the capacity for transit users to walk to and from their transit point of entry is a critical component of the overall TOD concept. Pedestrian impediments to reaching a transit station become significant impediments to transit usage. That is, “Since all transit trips involve some degree of walking, it follows that transit-friendly environments must also be pedestrian friendly.” [7]

There are many potential pedestrian conditions that enhance or impede one’s ability or desire to reach a transit stop, including safety issues, the existence of appropriate paths, and an interesting viewscape at pedestrian scale.[8] One central component of a transit stop’s walkable service area, and one of the foci of this research, may be the most basic and central component of a walkable environment: the quality, connectivity, and accessibility of the road network. The road network represents the basic skeleton of the urban form, creating the range of opportunities and path choice that can make walking more or less desirable. In addition, the pattern and form of the street network defines the structure in which infill of the physical environment can take place.

The need to have deeper understanding of urban form and its impacts on local accessibility is crucial in land use planning. The mobility infrastructure serves as the “skeleton” of the community as it creates the routes for accessibility, places for physical structures, and the forums for community interaction; in sum, this skeleton is a key to understanding urban form. Southworth and Ben-Joseph observe that residential streets provide the public framework that shapes urban form and guides neighborhood life. From this perspective, then, Southworth and Ben-Joseph argue that the significant contemporary urban issues of today–congestion, pollution and community isolation–are inextricably linked to residential roads patterns. [9]

Calthorpe and Poticha state that a reduced or non-existent hierarchy of internal streets is the desired internal network type within an authentic TOD. They describe how streets designed for high automobile speeds are inappropriate in a mixed-use pedestrian-focused zone. In essence, they argue that the automobile and the pedestrian should be equals on the network, each having a place to traverse. [10]

Certain auto-oriented roads (freeways and major arterials) present impedances to pedestrians because the scale and feel of such roads negatively impact one’s ability or desire to cross or travel along them. By including the concept of impedance into the GIS-based qualitative visualization and quantitative analyses, the road network, route choice, intersection concentrations, and pedestrian-scaled environments can be more accurately identified and measured. Measuring the walkable environment around TOD areas can lead to an intra-urban level of analysis that allows one to capture the spatial qualities of the *Elemental City* perspective.[11]

The safest environment for pedestrians also should combine short blocks and frequent cross streets in order to create the maximum number of options for travel route and the most direct routes that have little or no out-of-direction travel.[12] Ewing suggests that a greater number of intersections give pedestrians an enhanced sense of freedom and control as they are not forced to take the same path to a given destination time after time. He also states that more intersections make a walk seem more eventful, since it is punctuated by frequent crossing of streets and that additional intersections may shorten the sense of elapsed time on walk trips since progress is judged to some extent against the milestones of reaching the next intersection. Such measures have been recently used to assess the level of sprawl across metropolitan areas.[13] At a very fine grain, and in an effort to create distinctions between types of development patterns, Jacobs provides comparative measurements of such things as numbers of intersections and cul-de-sacs across a small geographical area.[14] Krizek, in looking at more of a neighborhood scale, found that people who live in more walkable areas, referred to as areas with good "neighborhood accessibility," are more likely to walk and use transit than those who live in more traditional auto-oriented environments.[15] And increasingly, such concepts are being used to understand the connection between the built environment and physical activity–a connection largely dependant on the walkable nature of local neighborhoods.[16] Thus, measuring the walking infrastructure–the routes and choices available to pedestrians–at a fine grain is an important component in identifying or evaluating the likely potential and range of local, destination-oriented walking.

SPATIAL INDICATORS OF URBAN FORM

The urban form around a TOD is of key importance and the street network often acts as the skeleton for this urban form. The work on quantitatively analyzing the walkable urban skeleton has recently been pursued by a variety of scholars. Table 1 lists a series of spatial measures used to understand connectivity at a variety of spatial scales.[17]

Table 1 Measures of Connectivity Used in Research Literature

Measure	Literature
Block length (mean)	Cervero and Kockelman (1997)
Block size (mean area)	Hess et al. (1999) Reilly (2002)
Block size (median perimeter)	Song (2003)
Block density	Cervero and Kockelman (1997) Cervero and Radisch (1995) Frank et al. (2000) (census block density)
Intersection density	Cervero and Radisch (1995) Cervero and Kockelman (1997) (# dead ends and cul-de-sacs per developed acre) Reilly (2002)
Percent four-way intersections	Cervero and Kockelman (1997) Boarnet and Sarmiento (1998) Street density Handy (1996) Mately et al. (2001)
Connected Intersection Ratio	Allen (1997) Song (2003) Link-Node Ratio Ewing (1996)
Percent Grid	Boarnet and Crane (2001) Greenwald and Boarnet (2001)
Grid dummy variables	Crane and Crepeau (1998) Messenger and Ewing (1996)
Percent quadrilateral blocks	Cervero and Kockelman (1997)
Pedestrian Route Directness	Hess (1997) Randall and Baetz (2001)
Walking distance	Aultman-Hall et al. (1997) (mean, maximum, percent of homes meeting minimum standard)

Table Source: Dill, J. "Measuring Network Connectivity for Bicycling and Walking." Paper presented at the ACSP-AESOP, Leuven, Belgium. July 9, 2003. Used with author's permission.

Many of these street network-based analyses tend to treat all streets as equals, despite their different uses, qualities, and traffic volumes. For example, Krizek's innovative analysis of travel behavior using local measures of neighborhood accessibility looks only to the presence, absence, or concentration of certain street network characteristics, assuming that all streets and intersections are of equal quality and use. [18]

The methods presented in the following chapter begin to make some distinction in street type, thereby influencing other measures of walkability such as intersection and dead-end densities. Refining how these basic components of the street network are modeled is needed for better planning (or, more likely, evaluation of past planning) of TOD (or smart growth) principles.

VISUALIZING TOD AREAS

Visualizing this urban skeleton is also an important component of understanding walkability. Lynch identified five basic components of urban form–paths, edges, districts, nodes, landmarks–each of which can be visualized in terms of a walkable urban network. Paths can be thought of as minor roads; edges equate to freeways or other large roads (e.g., arterials) that impede pedestrian movement; districts can represent concentrated zones of walkable urban form; nodes represent street intersections; and landmarks represent key origins or destinations, such as a transit stop. Each of these elements can be measured and viewed spatially to present a qualitative opportunity to assess local environments in terms of walkability.[19]

In terms of pure visualization, Jacobs presents a unique method of visualizing the urban form by using a figure-ground technique of displaying the road skeleton that makes up different urban environments. Using the same scale and same visualization techniques, Jacobs shows the importance of the street network in framing and supporting walkable urban forms.[20] Southworth, et al. extends Jacobs' work by incorporating visual examinations of intersection patterns and quantifying several elements of the street network, leading to a spectrum of identifiable development types, based solely on the nature of the road network.[21] Bossard takes a different approach, focusing on visualizing neighborhoods with TOD potential using a series of schema to conduct visual, spatial analysis and comparative socio-demographic analyses. He focuses on using small multiple images to enhance the simultaneous visual analysis of multiple variables.[22]

Thus, in analyzing TOD areas from a spatial approach, this research focuses on the mobility infrastructure of TOD areas, utilizing a variety of spatial indicators to assess that infrastructure from a pedestrian perspective, and utilizes key visualization techniques to evaluate the performance of TOD areas statically and temporally over time.

STUDY DESIGN

This study's main objectives are to develop and utilize spatial indicators to measure the local walkable form around TOD areas, the change of this form over time, and the linkage between TOD development and transit usage. Specifically, this project was commissioned to conduct five main types of analyses on a total of four TOD areas (see Figure 2 for a visual diagram of the research design):

1. Street network analysis: The street network within the TOD areas was to be analyzed using a variety of spatial variables including the density of intersections and the length of road network per square mile. These measures provide indicators of accessibility–places with higher intersection densities and higher road lengths per square mile can be considered more walkable and transit-friendly because they are characteristics of places with more path choice. This analysis was to be conducted for the TOD sites prior to and after construction/designation.

2. Ped-shed analysis: Ped-sheds (re-named in this analysis as pedestrian catchment areas (PCA)) measure the accessibility of a given location based on a ratio of Euclidean distance to street network distance. This analysis calculates a number that represents how walkable a space is. This analysis was to be conducted for the TOD areas prior to and after construction/designation.

3. Transit ridership analysis: A key element of TOD areas is the utilization of public transit. Data on passenger loading and unloading for specific transit stops within TOD sites were to be analyzed (subject to availability) along the life of their existence. Using temporal data of this type can help one understand how transit usage has changed with the adoption of specific TOD sites. Census-based transit utilization at a variety of spatial scales was also to be used in a pre/post construction manner to understand the changes in travel behavior over time.

4. Street speeds analysis: Speeds (using road type as a proxy for actual speeds) along the road network within the case study TOD areas were to be analyzed to determine their consistency with walkability. Places with high automobile speeds are characteristic of locations more hostile to pedestrians. Pedestrian scale is important for transit ridership because TOD principles suggest that people walk to and from transit stops within TOD areas.

5. Socio-demographic analysis: A socio-demographic analysis of the TOD case study sites was to be conducted using 1990 and 2000 census data in order to compare the population and housing characteristics of the TOD sites. Examples of some of the socio-demographic variables include

average age and age distributions, racial mix, and average income and income spread, among others.

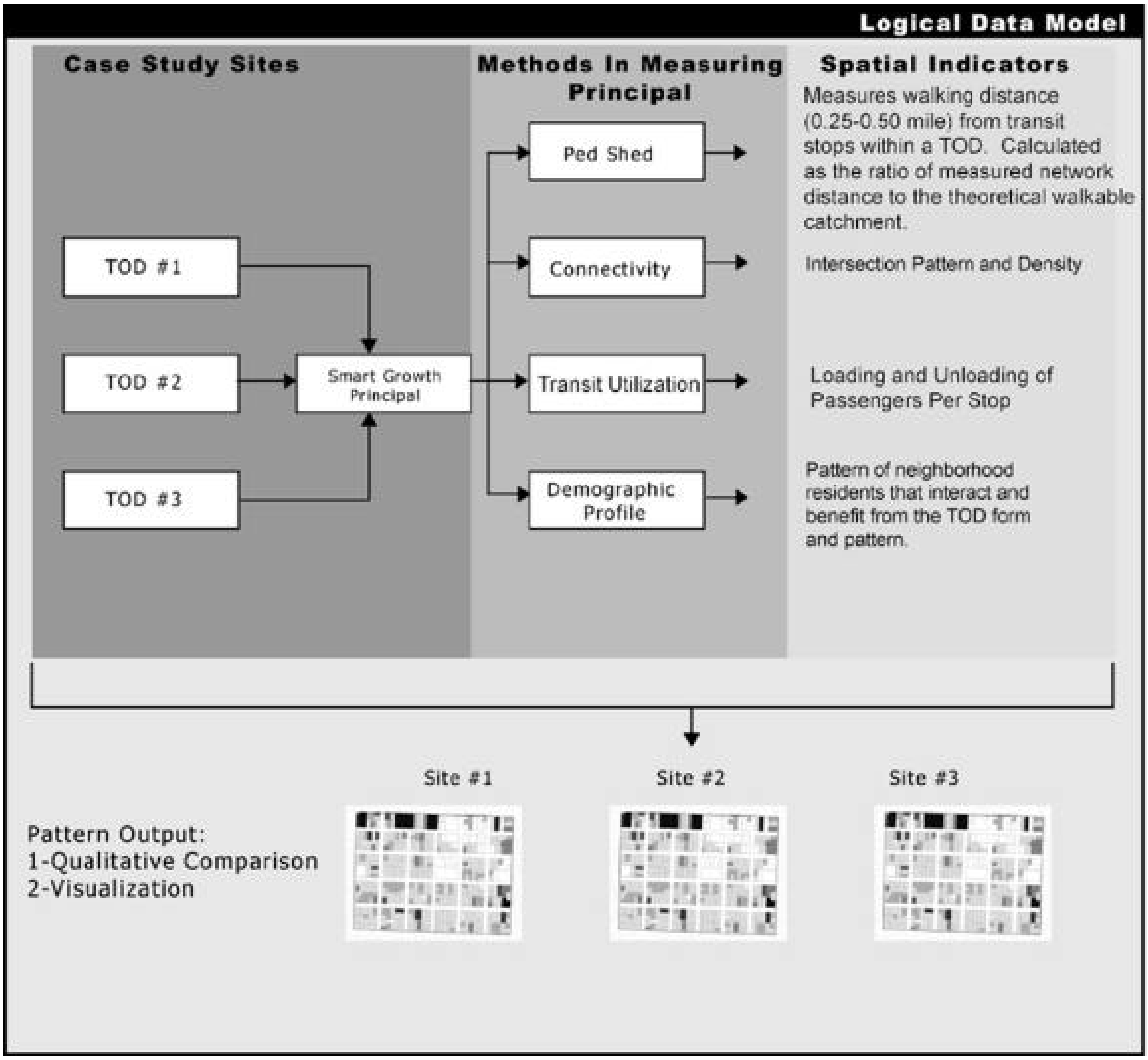


Figure 1 Research Figure Schematic (note that this research includes a comparison of eight cases, although only 3 are depicted in the image above.)

Walkable Urban Form

The street network can provide an indicator of a variety of pedestrian-related conditions, including areas with more path choice, fewer miles of auto-centric roads, and greater connectivity. In addition to refining the measurements to more accurately capture the urban feel a pedestrian would experience in a given environment, it is important that analyses be conducted in spatially explicit means and that results be analyzed at both a visual and a quantitative level. The patterns, forms, concentrations, and absences that result from a street and intersection analysis can be clearly understood from a visual analysis of the data. Understanding the spatial relationships between transit stops and the surrounding urban form on a map can provide clear insight into the pedestrian appropriateness of the transit environment. Moreover, comparisons across TOD areas are easily conducted, especially when spatial images are created with similar reference scales and symbology.

Quantitative analysis provides another means by which TOD areas can be evaluated, both individually and comparatively to other locations. Quantitative measures can lead to the development of acceptable thresholds of certain criteria, for example the minimum density of intersections per square mile that results in good pedestrian urban form. Quantitative analysis also provides a means for comparing sites across space and time, to consistently rank and compare performance without the bias that may result from visual, qualitative inspections. Developing good visual and quantitative measures of walkability can be a key component in planning and evaluating a variety of smart growth concepts.

In this light, six specific measures have been developed to quantitatively and visually examine the quality, proximity, and connectivity of the underlying urban skeleton in terms important to the principles articulated for smart growth TOD communities (see Table 4). In terms of quality, a street classification analysis looks at the quantity and location of pedestrian-friendly and pedestrian-hostile street types. In terms of proximity, pedestrian and impeded pedestrian catchment areas have been identified, giving insight into the likely walkable zone surrounding a transit stop given the existing street network and the street types in close proximity to the transit stop. For connectivity, intersection density analysis, impeded intersection density analysis, and intersection surfaces have been developed that give insight into the areas of good and poor pedestrian environments.

Table 2 Measurement Domains and Techniques

Measurement Domain	Analysis Technique
Quality	Street Classification Analysis
Proximity	a. Pedestrian Catchment Area (PCA) b. Impeded Pedestrian Catchment Area (IPCA)
Connectivity	a. Intersection Density Analysis b. Impeded Intersection Density Analysis c. Intersection Surfaces

Each of these measures are more deeply defined and illustrated in the section titled “Measures and Methods.”

Change Over Time

Often lacking in TOD analyses is the longitudinal component of change over time. While the theory of TOD areas speaks to sophisticated integration of a variety of land use, commercial, transportation, and social goals, the reality is that retrofitting existing urban or suburban spaces or even developing anew within a greenfield, the process to realize the full TOD potential takes time. Land uses change slowly, commercial investment takes time to occur and adjust to local conditions, and local populations grow over time. Thus, while taking a static reading of current conditions is informative and allows us to evaluate reality against theory, looking at change over time allows us to see if things are moving toward or away from TOD goals.

For this study, the 1990 and 2000 decennial censuses provide logical anchor points for the temporal analysis because the light rail systems in both Portland and Silicon Valley were built out in the interim years. Using these two census points, socio-demographic and transportation-related data can be analyzed relating to pre-construction and post-construction periods in terms of when the light rail and corresponding TOD areas were built. In terms of the walkability analyses, the TIGER [23] street centerline data for 1992 and 2002 were used for the pre- and post-construction analyses. [24]

Case Study Sites

Eight case study sites were chosen for analysis, four in the Portland region and four in Silicon Valley. The specific locations were chosen because they represented multiple desirable characteristics; most importantly that they were specifically designated as TOD areas, and they represent a range of development types. Table 3 lists the specific case study sites and the corresponding type of development they represent. Figure 2 and Figure 3 show overviews of the Portland and Silicon Valley regions, and the location of the case study TOD areas. These sites were chosen partly to reflect differing environments within which smart growth concepts are being implemented and partly to reflect the reliability of the measures across unique environments. Beaverton (OR) and Mountain View (CA) represent an in-fill TOD located within a very auto-centric, commercial shopping district. Orenco Station (OR) and Whisman (CA) are greenfield TOD areas master planned and implemented through the conversion of open space to mixed land uses. The Lloyd Center (OR) and Bonaventura (CA) are more urban commercial TOD areas, relatively close to downtown areas, and Gresham (OR) and Japantown/Ayer (CA) are TOD areas located in more traditional, pre-WWII gridded street neighborhoods.

Table 3 Case Study Sites

Portland	Silicon Valley	Development Type
Orenco Station	Whisman	Greenfield
Beaverton Central	Mountain View	In-fill
Lloyd Center	Bonaventura	Office/commercial
Gresham Central TC	Japantown/Ayer	Traditional neighborhood

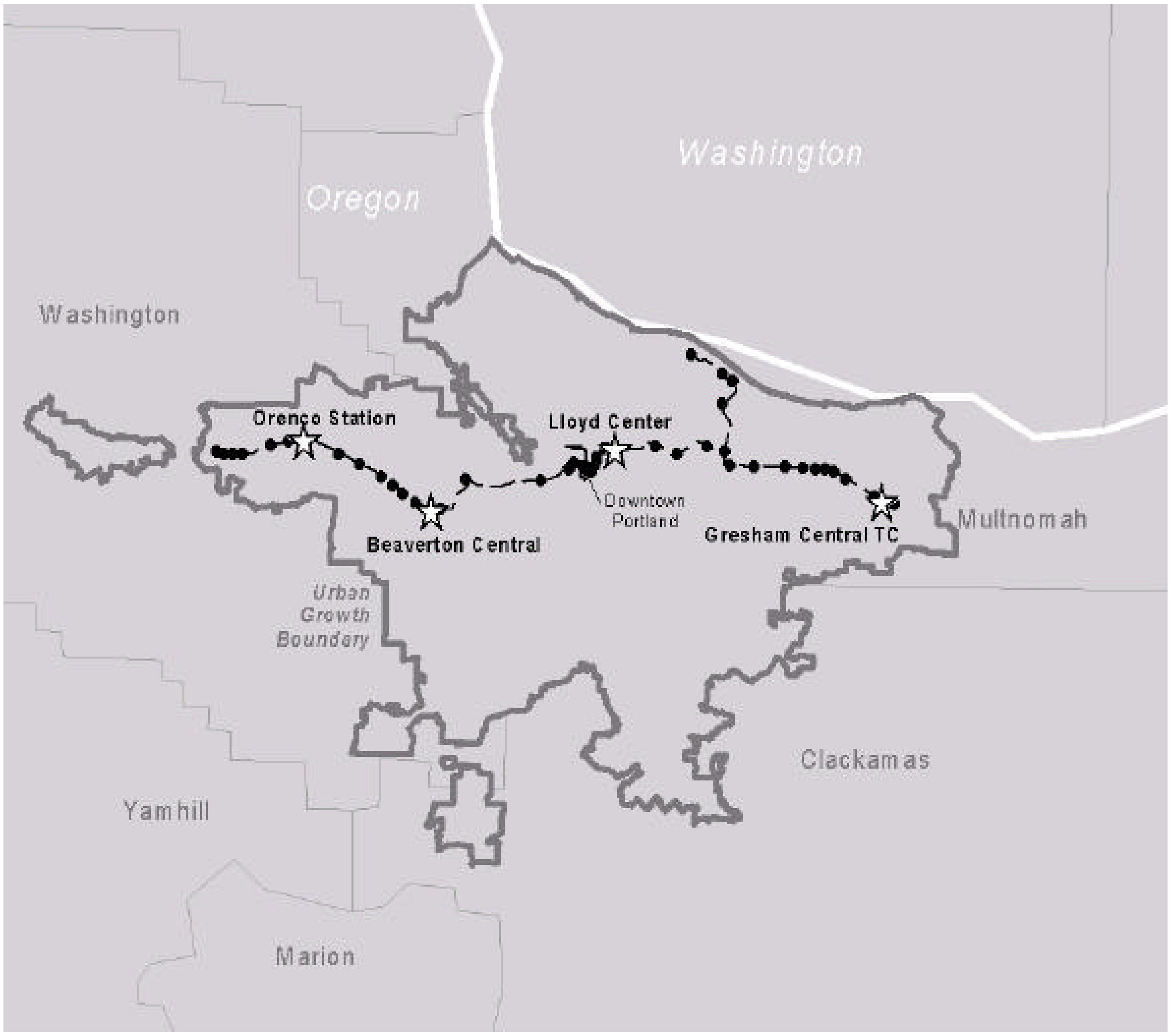


Figure 2 Portland Locator Map

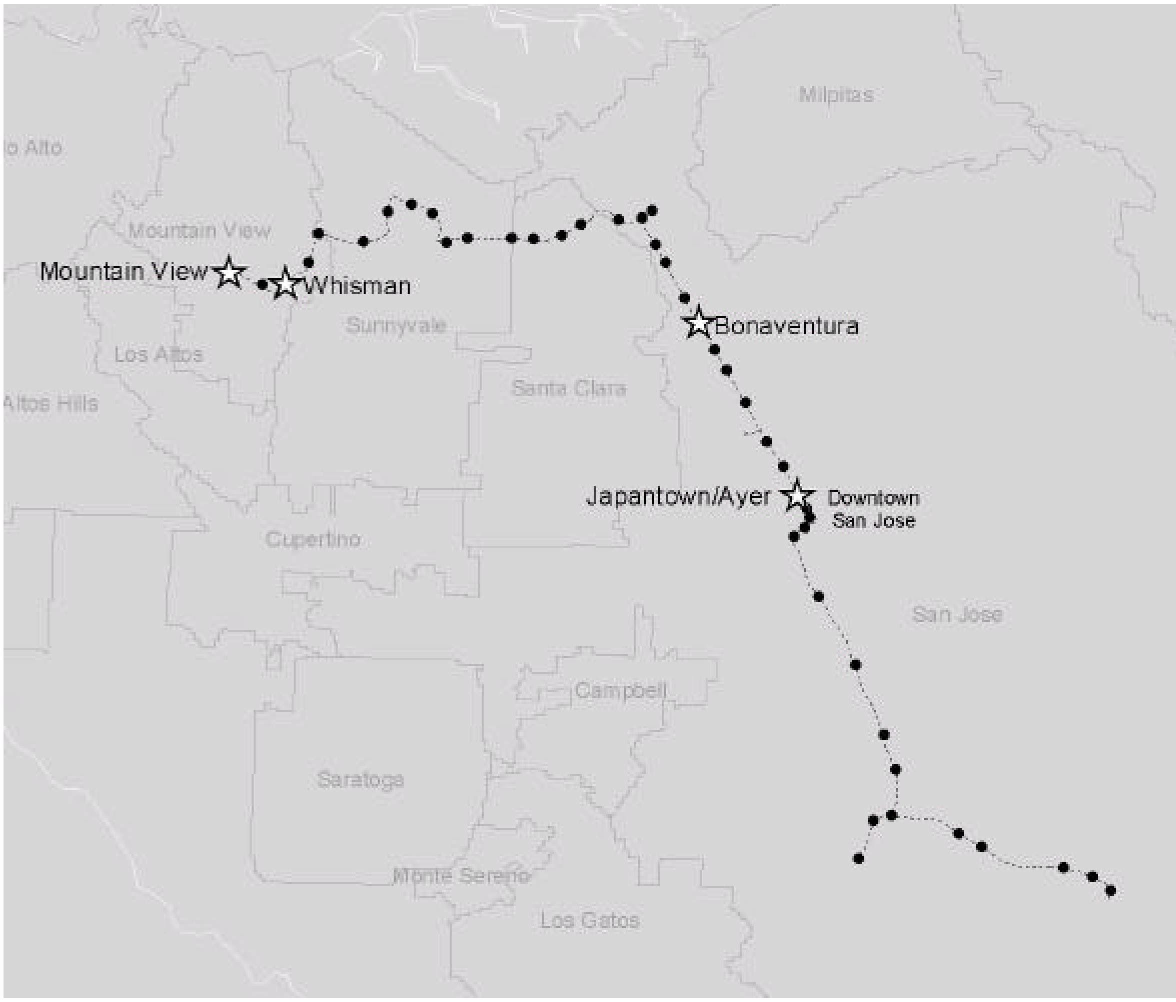


Figure 3 Silicon Valley Locator Map

Finally, some have called for additional TOD case studies to build our collective knowledge of these development types. This research, in part, addresses that desire.[25] Thus, the discussion below is meant to promote, visualize, and quantify a series of measures that can be used to plan or evaluate development patterns or urban form that are supposedly based, at least partially, on pedestrian-oriented principles. Moreover, Talen suggests that the ideas and plans that characterize smart growth have outpaced the ability of planners and designers to measure and quantify them.[26] This paper presents techniques designed to address some of the measurement challenges of smart growth, and to do it in a way that is generalizable, accessible, and useful to scholars and practitioners who are seriously engaging in these new development principles. The cases presented below are not meant to be used as critiques of specific places, although clearly, part of the process of understanding the measures is to relate their results to the places they measure in an evaluative fashion.

MEASURES AND METHODS

A total of eight case study sites have been analyzed: four in the Portland region and four in Silicon Valley. Ten unique analyses were conducted to understand the demographics, ridership performance, and walkability of the urban form surrounding the case study transit stops (see Table 4). All analyses were conducted over two distinct points of time, using the time frame of pre- and post-TOD construction as the central determinant of the selected timeframes. Eight of the ten analyses apply to urban form and were conducted at two geographical scales (quarter- and half-mile) to understand how theoretical conceptions of TOD play out at actual case study sites. Thus, for the urban form analysis, a total of 256 individual data points were derived (eight TOD areas x 2 time periods x 2 geographic scales x 8 variables). A description of each of these variables and analysis methods is presented in more detail below.

Table 4 Primary Analysis Categories

Main Variables	Purpose of Use
Census Analyses • Population counts and density • Race • Age • Household size • Income	To understand basic socio-demographic situations
Transit Ridership Analyses • Census based • Transit agency based	To understand the transit performance within TOD areas compared to non-TOD areas
Urban Form Analyses • Minor Roads (miles) • Major Roads (miles) • Intersection Density (per sq. mi.) • Dead-End Density (per sq. mi.) • Impedance-Based Intersection Density (per sq. mi.) • Impedance-Based Dead-End Density (per sq. mi.) • Pedestrian Catchment Area (ratio) • Impeded Pedestrian Catchment Area (ratio)	To understand the accessibility of transit stops to the surrounding area

1990 AND 2000 CENSUS ANALYSIS

Spatial Data

Census block groups for both 1990 and 2000 formed the basis for the census analyses. The data was divided into nine spatial units of analysis in the Portland area, including:

1. Orenco Station–Block groups that intersected a 1/4 mile zone of the transit stop were selected.

2. Beaverton–Block groups that intersected a 1/4 mile zone of the transit stop were selected.

3. Lloyd–Block groups that intersected a 1/4 mile zone of the transit stop were selected.

4. Gresham–Block groups that intersected a 1/4 mile zone of the transit stop were selected.

5. LRT–All block groups within 1/4 mile of the entire light rail line were selected; this gives an indication of the general ridership figures for all people living in close proximity to the rail line.

6. Non-LRT–All block groups within the urban growth boundary (UGB), but more than a 1/4 mile from the light rail line were selected; this gives the breakdown on people who do not live within easy walking distance of the light rail.

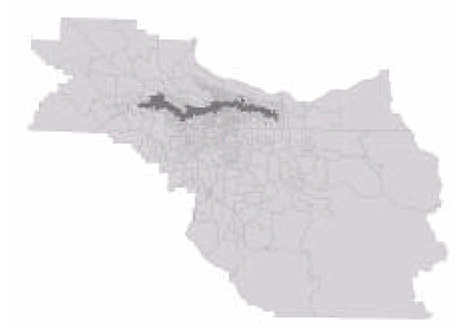
7. UGB–All block groups within or intersecting the UGB.

8. Non-UGB–All block groups outside of the UGB but within the Tri-County area.

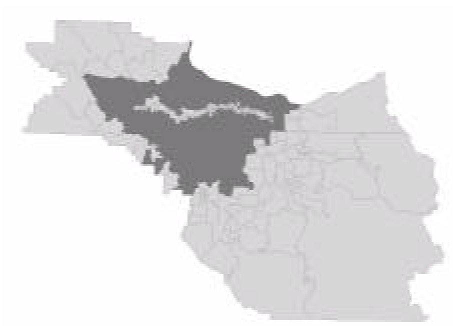
9. Tri-County–All block groups within the three-county Portland area.

Each of these nine units of analysis was spatially created via GIS. Block groups that intersected or were within any of the zones of interest were selected for analysis. Figure 4 illustrates these units of analysis for the Portland area. Summary Tape File 3 (STF3) was used for 1990 data analysis and Summary File 3 (SF3) was used for 2000 census analyses. Figure 5 illustrates the Silicon Valley units of analysis.

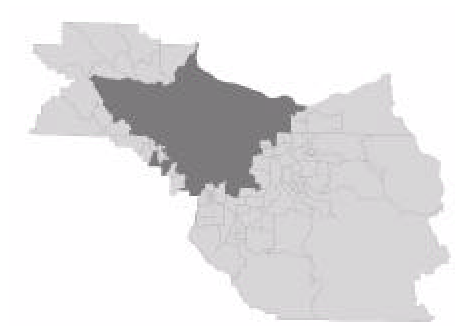
Block groups within a quarter mile of the transit stops.



Block groups within a quarter mile of the entire light rail line.



Block groups within the urban growth boundary, but more than quarter mile from the transit line.



Block groups within the urban growth boundary.

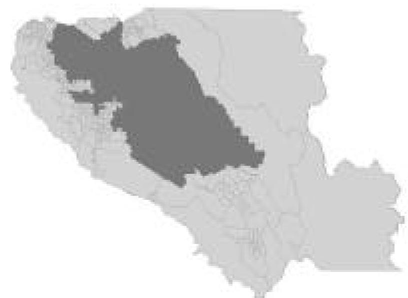
Block groups outside the urban growth boundary, but within the three county area.

Figure 4 Portland Census-Based Spatial Units of Analysis

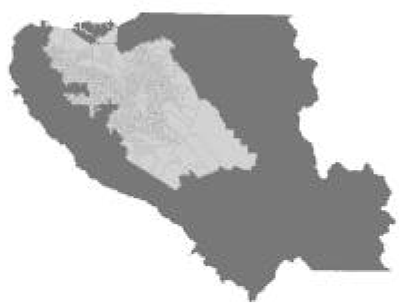
Block groups within a quarter mile of the transit stops.

Block groups within a quarter mile of the entire light rail line.

Block groups within the urban growth boundary, but more than quarter mile from the transit line.



Block groups within the urban growth boundary.



Block groups outside the urban growth boundary, but within the three county area.

Figure 5 Silicon Valley Census-Based Spatial Units of Analysis

SOCIO-DEMOGRAPHIC ATTRIBUTE DATA

A socio-demographic analysis of the TOD case study sites was conducted using 1990 and 2000 census data in order to compare the population and housing characteristics of the TOD sites. The following specific variables were used:

Table 5 Census Variables Used

Variable	Purpose of Inclusion
• Total Population • Population Density*	• To understand the size of the unit of analysis • To normalize the data for cross-comparison • To analyze density in light of TOD goals
• White Persons • Non-White Persons** • Hispanic Persons	• To understand basic racial composition
• Ages 0-17 • Ages 18-44 • Ages 45-64 • Ages 65 and over • Median Age	• To view static age cohort composition and to understand potential change in age cohorts over time as TOD areas developed
• Household Size	• To see if household size and transit accessibility are related
• Average Household Income	• To understand the basic financial situation

*derived through a GIS-based spatial calculation

**derived by subtracting the white population from the total population

TRANSIT RIDERSHIP

Transit ridership was derived in two ways: 1) via the 1990 and 2000 census and 2) from count data provided by the local transit authority. [27] The census data variable "Means to Work–Workers 16+" was used to compare journey to work modes of travel between the two censuses.[28] These two data sets are used as separate entities (rather than being integrated into a single analysis variable), meant to provide two different understandings of transit usage in the TOD areas. The same spatial units of analysis as described above were used.

WALKABLE URBAN FORM

Several types of urban form analyses were conducted in order to primarily understand the walkability of each TOD. The focus was on the street network as the primary means of pedestrian accessibility and special attention was given to the hierarchy of roads within a given TOD to test their consistency with TOD walkability principles. The three major categories for these analyses are street classification analysis, intersection analysis, and catchment area analysis (see Table 6). Each is described in more detail below.

Table 6 Walkability Variables

Walkability Analysis	What It Measures
Street Classification • Minor Roads (miles) • Major Roads (miles)	• The quantity of different types of streets within the TOD areas
Intersection Analysis • Intersection Density (per sq. mi.) • Dead-End Density (per sq. mi.) • Impedance-Based Intersection Density (per sq. mi.) • Impedance-Based Dead-End Density (per sq. mi.)	• The density of “good” and “bad” intersections within the TOD areas
Catchment Area Analysis • Pedestrian Catchment Area (ratio) • Impeded Pedestrian Catchment Area (ratio)	• The ratio between actual and theoretical walkable zones

STREET CLASSIFICATION ANALYSIS

Overview

Street Classification Analysis is an evaluation and categorization of street type and purpose along the road network within TOD areas. This analysis provides insight into the basic quality of certain paths and reflects the hierarchy of road types within the study zones.

Background

Locales with high automobile speeds or large volumes of traffic are characteristic of locations hostile to pedestrians. Peter Calthorpe has recently called for a change in how we classify roads, from an auto-centric design focus (minor, feeder, and arterial) to one that reflects accessibility principals. By identifying and classifying road types with relevant typology–ones that reflect accessibility design principles–researchers can make a more accurate assessment of road functionality. [29]

The Street Classification Analysis addresses this request by defining and exploring the relationship of “Impedance Roads,” or hostile roads, and “Accessible Roads,” or pedestrian-friendly roadways. An impedance road may spatially divide a community, splitting it into segments via a road that acts as a barrier. Identifying where these roads are reveals the spatial externality of the road placement. By spatially displaying where these roads are in map form, with accompanied metrics on quantity or share of road types, it is possible to create an accessibility profile base for impedance values.[30]

Figure 6 illustrates the process and results of identifying the variety of available paths. The top image represents a complete street network, the middle image highlights the location of impedance roads (roads classified as freeways or major arterials), and the bottom image illustrates the impact of removing impedance roads on using the road network to represent a pedestrian network. These images demonstrate the direct impact of auto-centric roads on pedestrian mobility, particularly evident by the increased number of dangling road segments, disconnected paths, and longer block faces.

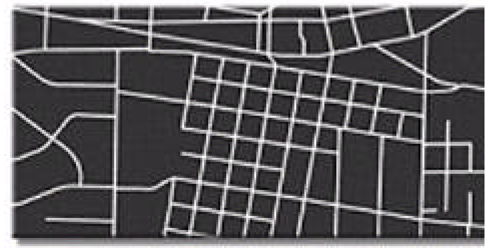
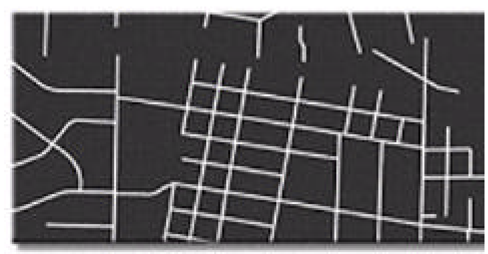
Unclassified Network	
Network Classified Identifying Impedance Roads	
Impact of Classification on Pedestrian Network	

Figure 6 Illustration of the Impact of Impedance Roads

INTERSECTION INTENSITY

Overview

The Intersection Intensity analysis examines the street network within the TOD sites based on the spatial location of certain types of intersections in order to capture the grain (density of intersections) and the interconnectedness (types of intersection) of a neighborhood.

Background

Intersections are a core set of data because they represent the number of choices available to a pedestrian and, from a spacial perspective, how these choices are arranged throughout the study zones. These measures provide indicators of accessibility. Areas with higher intersection densities, and/or more desirable intersection types (three- or four-way), can be considered more walkable because they are characteristics of places with a greater number of path choices for the pedestrians.

Theoretically, there should be a match between the location of the optimal pedestrian form and where the transit stop is located in order to maximize the pedestrian element of transit usage. Statistics such as intersection density (intersections per square mile) are important and increasingly used as a variable or urban analysis, although such statistics are often not used in spatially explicit ways. In urban form analysis it is valuable to know not only how many intersections there are per square mile, but also where the density of intersections fall within the study area. To understand more fully how these elements are related, two different types of analyses are presented below. The first method analyzes the concentration and location of “good” intersections (three- and four-way) and the location of dead-ends; the former represents environments with good pedestrian path choice and the latter representing a lack of mobility options. This analysis has two components as well, which are represented in the images on the left and right in Figure 7. The left image shows the location of intersections and dead-ends based on the assumption that all roads are equal. The image on the right is what results when the impedance roads are removed. Removing the impedance roads has two key effects. First, “good” intersections are reduced because a crossing of an impedance road no longer counts as an intersection: From a pedestrian point of view, reaching a major auto-centric road usually does not imply a full path choice-a pedestrian may choose to cross such a road, but is unlikely to travel along it. Second, dead-ends are increased; when a pedestrian road terminates at an impedance road, it can be considered a dead-end from the pedestrian point of view.

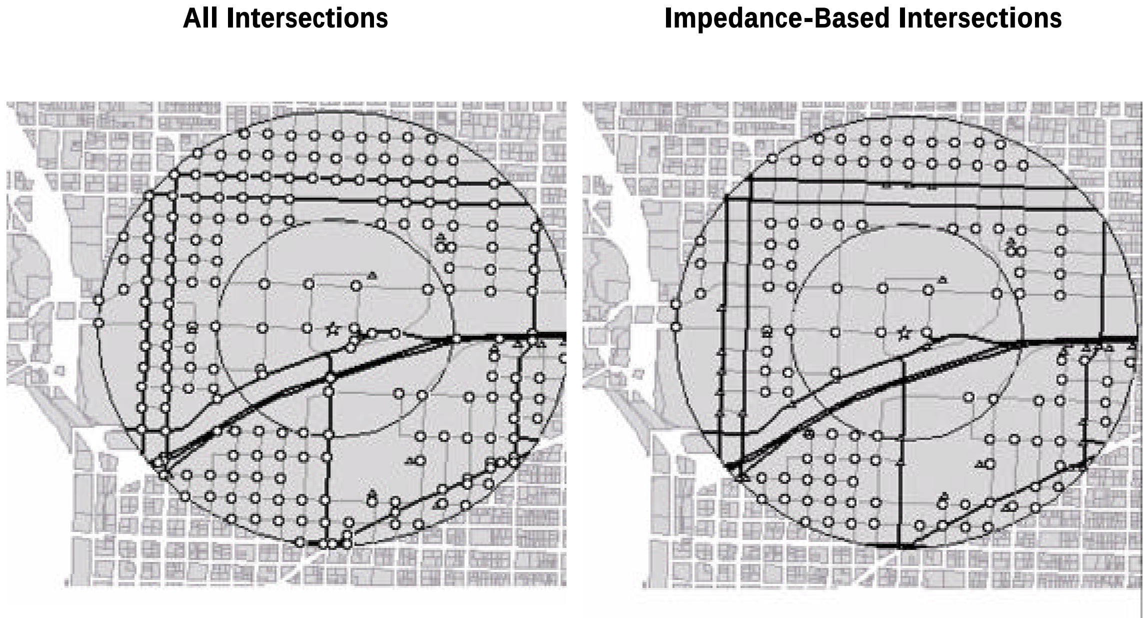


Figure 7 Intersection Comparison

The second intersection analysis method is purely visual in nature and displays density surfaces of desirable intersection types. A density surface map resembles a national weather map, but instead of showing areas of hot and cold weather, it shows areas of highand low intensities of intersections (see Figure 8). By creating density surfaces of the intersections, one can build on the intersection analysis by creating a qualitative, visual rendering of where the optimal intersections are found and how they relate to the spatial layout of the community. In such a manner, the grain of the community is visually apparent and available to assist in determining the level of connectivity and adjacency of the transit station to the larger community.

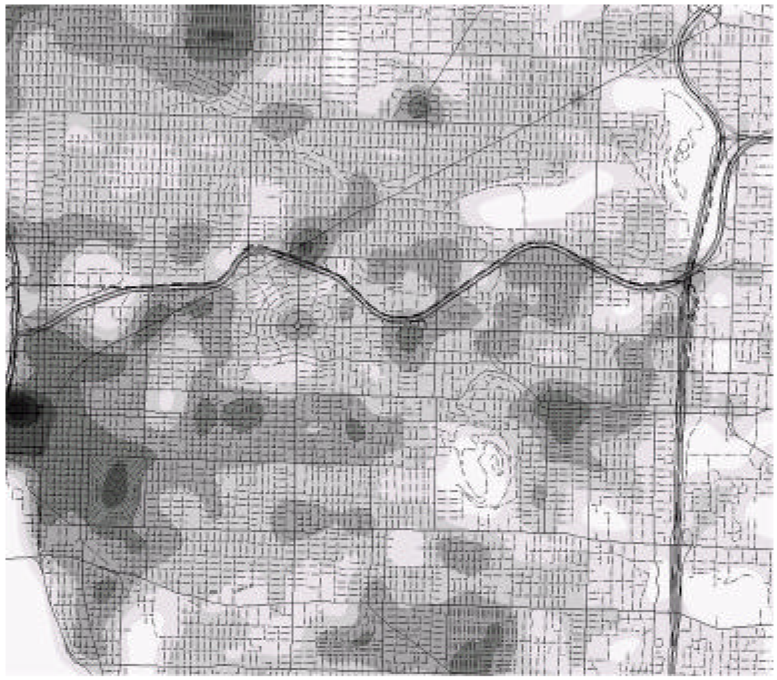


Figure 8 Intersection Surface Map (wth a local street network on top)

PEDESTRIAN CATCHMENT AND IMPEDED PEDESTRIAN CATCHMENT AREAS

"Pedestrian Catchment Areas," (also known as Ped-Sheds) are theoretical walkable zones that can be mapped to show the actual area and network within a five-minute (quarter-mile) or ten-minute (half-mile) walking distance from a transit stop. The data is presented as a ratio between the Euclidean distance and the network distance from a given point (e.g. transit station). The resulting maps are also highly visual estimates of an area's walkability. [31]

The Pedestrian Catchment Area (PCA) methodology focuses on capturing the coverage of a street network within the designated TOD and determining how accommodating that network is for pedestrian movement. The basic calculation of a PCA is to divide the area of a quarter-mile or half-mile circle by the area of the polygon that results by traveling a quarter- or half-mile from a transit stop along the street network (see Figure 9).

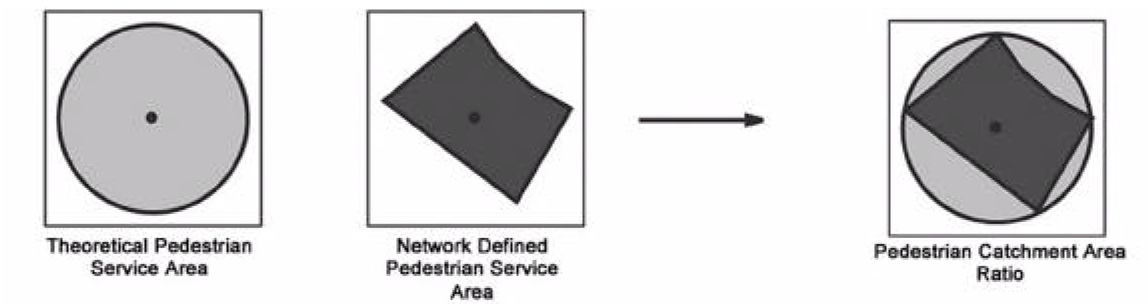


Figure 9 Diagram of Pedestrian Catchment Area Ratio Calculation

A pedestrian catchment area score of .60 or higher has been presented as reflecting a walkable network, meaning that a majority of the theoretical walkable area can actually be reached by moving along the actual street network.[32] A score of .80 would indicate a comprehensive grid network that encompassed an entire study zone and a score less than 0.30 reflects an inaccessible walking environment. Pedestrian catchment area ratios have been calculated in both the standard way (as described above) and by using the refined street network where "Impedance Roads" have been removed. This impeded pedestrian catchment area (IPCA) represents a new way to calculate and visualize an area that a pedestrian is potentially able to travel. That is, removing the impedance roads from the pedestrian catchment area analysis, it is possible to reflect the ability of a pedestrian to cross (assuming that there are crossing amenities) an impedance road, but not necessarily travel along it. By removing roads that are hostile to pedestrians to either cross or walk along, the IPCA provides an improved capacity to capture the pedestrian zone of a transit stop.

The decision of what is or is not an impedance road can be a difficult task to accomplish using existing spatially-referenced data, as a variety of facts, beyond the volume of automobiles, can effect road impedance. These include:

1. Presence or absence of sidewalks

2. Width of sidewalks

3. Nature of separation of sidewalk from moving traffic

    a. Sidewalk setback from road

b. Trees in sidewalk setback from road

c. Presence of parking lane at edge of road

d. Presence of guard rails/barriers/fences along edge of roads.

4. Ease of crossing road

a. Traffic light or stop sign and clear pedestrian walkway

b. Presence of safety islands and bulb outs to reduce length of exposed roadway crossings.

Nonetheless, the methods described in this chapter represent a series of techniques that can be readily and easily applied to any area in the country because the street network, as well as an embedded classification of that network, exists for every municipality in the United States and is available at no cost over the Internet. These techniques can eventually be more accurately applied when more detailed data on pedestrian networks exist, but in the interim, the approaches covered in this chapter represent a useful method for evaluating and planning how well the theory of TOD area development matches with the implementation in practice.

CASE STUDIES

PORTLAND METROPOLITAN AREA

The rationale for selecting Portland as the case study region stems from their planning approach to regional growth management and adherence to TOD development concepts. In 1990, voters gave Metro–the regional managing agency of Portland, Oregon–the authority to adopt a regional planning framework in accordance with the broad principals of smart growth, and specific detail of a TOD. This regional planning framework is called the Metro 2040 Growth Concept. A key component of the Metro 2040 Growth Concept focuses on creating compact communities around transit and redeveloping around existing station communities. The plans calls for an aggressive expansion of regional light rail (MAX Line) and bus service, with expected mode share splits for regional transit use to grow by over 300 percent. [33]

A specific feature of the regional planning effort is the Transit Station Area Planning (TSAP) program, which is a collaborative effort between Tri-Met (the regional transportation authority), Metro (the regional growth management body), the cities of Portland and Gresham, and Multnomah County (including affected cities contained within it). The goals of TSAP are to build support for TOD areas along the rail line and to promote opportunities for increasing the system's ridership. To date, the TSAP program has included market studies, coordination with other regional planning efforts, detailed station area plans, and design guidelines.[34] Included in the suite of objectives are:

- Rezoning station areas to transit supportive uses,
- Setting of minimum residential and commercial densities, and
- Application of a design overlay that requires pedestrian orientation.

The first segment, Eastside MAX, runs 15 miles east from downtown Portland to Gresham; it was completed in 1986. The second segment, Westside MAX, was built through wide stretches of undeveloped land from Portland city center to Hillsboro; it opened in 1998. Currently the entire system has 50 stations. As of September 2003, Tri-Met ridership has increased for 15 consecutive years and the MAX now has an average daily ridership of 79,600 boardings. [35]

SILICON VALLEY AREA

Paying service began on the Santa Clara Valley Transportation Authority's (VTA) light rail system in December 1987. The original nine-mile segment from Baypoint Station, at the extreme north of the city of Santa Clara, south through downtown San Jose was completed in June 1988. Service to the Tamien Station two miles south of downtown San Jose began in August 1990. The entire 20.8-mile line was completed in April 1991. The Tasman West line, which connects Mountain View to the existing light rail service, was completed in December 1999. Construction is already underway on a new line, the Tasman East/Capitol extension from Baypoint station north to the city of Milpitas. Currently, 46 stations make up the combined lines of the VTA light rail system.

When compared with other light rail lines in the U.S., San Jose's light rail vehicles appear quite underutilized. On average, San Jose light rail vehicles carry an average of 14.8 people, which is less than 57 percent of the national average. In addition, in 2000, the VTA carried 1,750 passengers per mile, less than half the national average (4,400) and only about a third of Portland's level (5,937).

READING THE WALKABILITY MAP

Each map below, unless otherwise specified, reflects post-construction data from the year 2002.[36] In order to streamline the presentation, maps for the pre-construction period are not shown, except to demonstrate specific issues, in which case they will appear in the next chapter. The spatial map images are designed more to orient the reader to the analysis technique, then to be used as a visual analysis tool. Below the maps are tables of data that resulted from the spatial analyses; these tables do contain data of pre- and post-construction time periods. Each table further delineates the data into quarter-mile (0.00-0.25) and half-mile (0.00-0.50) distances. Data at the half-mile distance is inclusive of everything inside of that circle (i.e., it does not represent the unique band of space between a quarter- and a half-mile from the transit stop).

Each TOD is presented at a 1" = 8,000' scale (intersection surface maps are at 1" = 12,000'), so the spatial extent remains constant across images, enhancing the reliability of the measures across locations (and potentially across time). Maps should be viewed for the general patterns that emerge and to compare patterns across study sites in order to understand the impacts of the presence and location of impedance roads. Each map includes two circles, representing quarter-mile and half-mile radii from the transit stop. Outside of the circles, tax lots are shown in order to have some sense of the urban pattern beyond the traditional TOD walking distances. Within these circles, the background of the maps is a solid gray, enhancing the visualization of the key variable being represented, but sacrificing the underlying form communicated by tax lot size and location. Figure 10 displays the legend for the symbols used in the maps.

Figure 10 Map Symbols

PORTLAND: ORENCO STATION

Orenco Station is on the western portion of the MAX line and represents a greenfield development planned and built specifically with transit-oriented and walkability principles in mind. The existing built areas have won numerous design awards for their attention to neighborhood amenities, community form, and architectural style. Until 2003, most of what has been built begins about a quarter-mile north of the transit stop. Access to the stop from the built-out areas necessitates the crossing of a major east-west arterial road and then a walk through a series of undeveloped and generally unkempt lots along a road that will some day provide access to these lots. Figure 11 shows two photographs of the Orenco Station area. In 2003, the land immediately adjacent and south of the transit stop has begun to be aggressively developed at medium to high density, affording much better light rail access than the existing developed areas.

The view looking north from the transit stop to the existing Orenco Station community, which is quite far in the background. Until 2003, land adjacent to the stop to the south was vacant. Currently, it is being aggressively developed at high densities.

Medium- to high-density development typical within the Orenco Station neighborhood.

Figure 11 Orenco Station TOD

Demographics

In the transition from greenfield to TOD, Orenco Station underwent some fairly significant demographic changes (Table 7). Population density increased over 250 percent to 1,747 people per square mile. That population became more diverse as well, transforming from 97 percent white to 80 percent, including a five-percent increase in the Hispanic population. The median age over the decade dropped by three years with the predominant shift in age coming in an increase of people in the 18-44 age cohort. Over this period, average household income increased almost 40 percent to almost $62,000 in the year 2000.

Table 7 Socio-Demographic Characteristics of Orenco Station, 1990-2000

Orenco Station	People	Density (people/ sq. mile)	White	Non-White	Hispanic	Ages 0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	3,521	477	97.3%	2.7%	1.5%	28.1%	44.0%	22.9%	5.0%	32.7	2.8	$ 44,912
2000	7,976	1,747	79.6%	20.4%	6.8%	27.4%	52.6%	16.6%	3.4%	29.9	2.6	$ 61,777
1990-2000	4,455	1,270	-17.7%	17.7%	5.3%	-0.7%	8.6%	-6.3%	-1.6%	-2.8	-0.2	$ 16,864

Transit Ridership–Census

In 1990, when Orenco Station was a mostly undeveloped greenfield site, the automobile accounted for 100 percent of all work trips (Table 8). In 2000, however, after the light rail line was extended outward and Orenco Station was developed as a TOD, automobile use decreased, accounting for only 86.5 percent of work trips. The new train accounted for about five percent of this change, while new bus service accounted for 2.5 percent, and biking and walking accounted for another 2.5 percent. In terms of TOD goals, the construction of Orenco Station changed the relative mobility choices of about seven-and-a-half percent of the population to either take the train, bike, or walk.

Table 8 Orenco Station, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	100.0%	0.0%	0.0%	0.0%	0.0%
2000	86.5%	2.5%	4.9%	2.4%	3.7%
1990-2000	-13.5%	2.5%	4.9%	2.4%	3.7%

Transit Ridership–Metro

In the first four years of Orenco Station's existence, weekday boardings increased by 58 percent to an average of 735 boardings per day (Table 9). The land around the transit stop was still mostly undeveloped in 2002, and it is likely that, as this greenfield development matures, transit ridership will continue to increase.

Table 9 Orenco Station, Daily Weekday Boardings, 1990-2000

1998	2002	Change 1989-2002	% Change 1989-2002
465	735	270	58%

Street Classification

Figure 12 shows the 2002 street network for the Orenco Station area with one map showing all streets and the other map classifying the roads into minor and major categories.

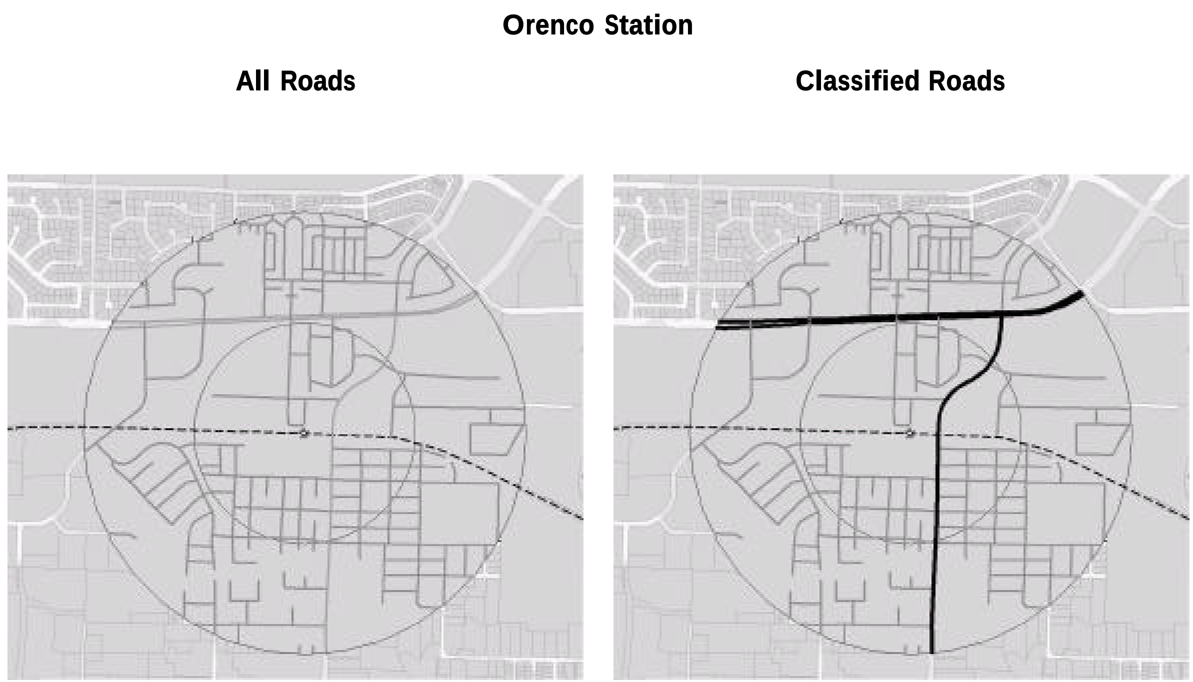


Figure 12 Orenco Station Street Classification

The Orenco Station network is irregular in pattern with clustered areas of grid and modified grid patterns. The impedance roads are sparse in coverage and are minimal in quantity, but the single pair bisects the study area. The walkable roads are abundant in the half-mile study area and are less prevalent in the quarter-mile study area. Table 10 lists the quantities of road types and the change over time.

Table 10 Orenco Station Street Classification

	Distance from transit stop (miles)	
	0.00 - 0.25	0.00 - 0.50
1993		
Minor Roads (miles)	1.2	5.1
Major Roads (miles)	0.8	2.8
2002		
Minor Roads (miles)	5.1	16.3
Major Roads (miles)	0.6	2.7
1993-2002		
Minor Roads (miles)	3.8	11.2
Major Roads (miles)	-0.2	-0.1
1993-2002 (percent change)		
Minor Roads (miles)	312%	218%
Major Roads (miles)	-26%	-5%

In 1993, Orenco Station was mostly open space, as reflected by the low number of roads. By 2002, however, the quantity of roads had increased quite dramatically. More importantly, the increase in roads was dominated by minor, walkable roads at both the quarter-mile (+312 percent) and half-mile distances (+218 percent) at the same time that auto-centric roads actually decreased slightly over the same time. As a master-planned greenfield development, special thought was given to the road network as space to accommodate multiple uses, and is characterized by the dominance of minor, pedestrian-friendly road segments.

Catchment Areas

Figure 13 shows the 2002 pedestrian catchment areas (PCA) and the impeded pedestrian catchment areas (IPCA) for Orenco Station.

Orenco Station

PCA–Quarter- & Half-mile **IPCA–Quarter- & Half-mile**

Figure 13 Orenco Station Pedestrian and Impeded Pedestrian Catchment Areas

The pedestrian catchment area at Orenco Station is generally limited in its coverage and is confined mostly to the northern section of the study site. The quarter-mile zone is comprised of only three road segments and fails to provide much neighborhood level function. The half-mile PCA is larger, but not widespread. The Orenco Station IPCA is very small and extremely limited in its coverage. The service area is completely located on the northern side of the study areas, incorporating only a small share of the total potential of the theoretical service areas. This example demonstrates the severe impacts of the types of paths available to a pedestrian on their accessibility. Table 11 lists the PCA and IPCA ratios for Orenco Station.

Table 11 Orenco Station Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	**Distance from transit stop (miles)**	
	0.00 - 0.25	**0.00 - 0.50**
1993		
Pedestrian Catchment Area (PCA)	0.48	0.51
Impeded Pedestrian Catchment Area (IPCA)	0.21	0.16
2002		
Pedestrian Catchment Area (PCA)	0.26	0.39
Impeded Pedestrian Catchment Area (IPCA)	0.16	0.14
1993-2002 change*		
Pedestrian Catchment Area (PCA)	-0.22	-0.12
Impeded Pedestrian Catchment Area (IPCA)	-0.05	-0.02
1993-2002 (percent change)*		
Pedestrian Catchment Area (PCA)	-46%	-24%
Impeded Pedestrian Catchment Area (IPCA)	-22%	-14%

* Change over time data for Orenco Station is not a useful measure due to methodological limitations of the spatial calculation. This problem is discussed more fully in the appendix.

For Orenco Station, the key quantitative figures to concentrate on are the 2002 PCA and IPCA ratios. In 1993, the Orenco Station was mostly undeveloped land and due to some methodological limitations of the spatial analysis method, the 1993 ratios do not offer a good base for a temporal look at the walkable environment. The limitation occurs in greenfield or large in-fill types of situations where the extent and coverage of the road network was minimal at the initial data point and where the road network is quite a distance from the eventual transit stop location. The result, in the case of Orenco Station, is that in the 1993 data analysis (where no real station existed), the PCA and IPCA ratios were based on starting one's trip from the nearest available road, even though it was some distance from the transit stop location. In

2002, when more roads had been constructed, including ones that were adjacent to the transit station, the total distance one could travel from the transit stop was reduced. That is, in 2002, one's distance traveled began at the transit stop, whereas in 1993, one's travel would have started at the nearest road. The discrepancy in starting places leads to the erroneous ratios of the initial data points in the Orenco Station area. That said, 2002 data does provide a good reflection of the local environment and can be used as a base for future temporal analyses.

In terms of the 2002 data, Orenco Station scores relatively poorly for the pedestrian catchment area (PCA) at the quarter-mile (0.26), but much better at the half-mile (0.39), although still under the level considered the minimum for good walkability (0.60). When looking at the 2002 IPCA, the zone of walkability when accounting for the presence of auto-centric arterials, the ratio between this walkable zone and a Euclidean-based area shrinks considerably at both the quarter- and half-mile distances. At the quarter-mile, the IPCA ratio of 0.16 is 39 percent smaller than the PCA of 0.26, while at the half-mile the IPCA ratio of 0.14 is 65 percent smaller than the PCA ratio of 0.39, meaning that the presence of arterials has a major impact on the likely zone of walkability to or from the transit stop.

Intersection Analysis

Figure 14 visualizes the intersection intensities for Orenco Station.

Orenco Station

Intersection Intensities **Impedance-Based Intersection Intensities**

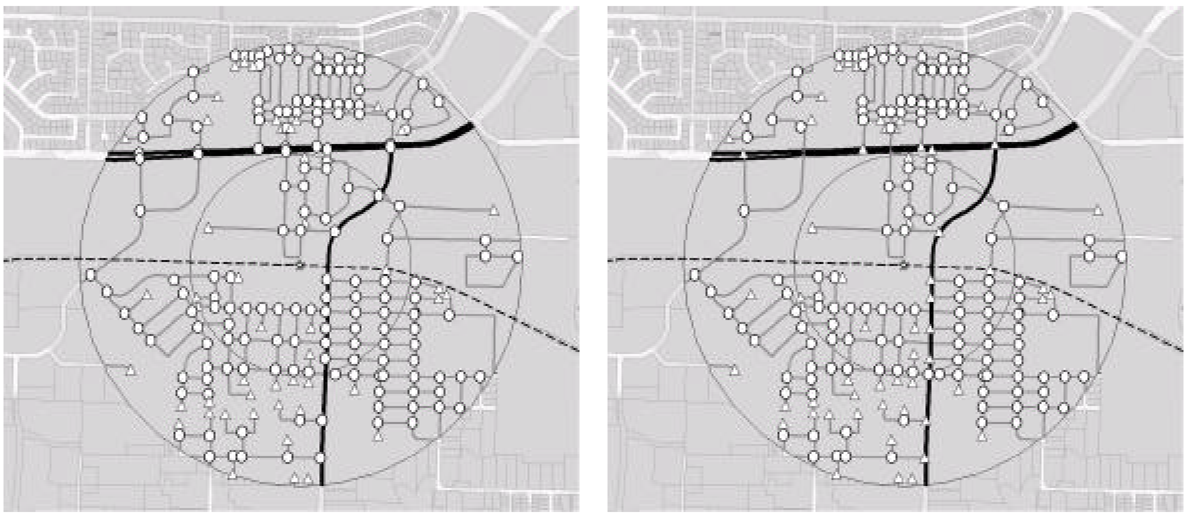


Figure 14 Orenco Street Intersection Intensities

Orenco Station in an interesting case in that its density of intersections is very high at both scales, across both data sets, and across space, implying good walkability across the TOD. Yet, dead-ends, often recognized as an impediment to walkability, are also very high. As a greenfield development, some of the dead-ends represent areas where existing streets terminate at vacant lots, which conceivably will be developed and integrated in the near future. Table 12 lists the quantitative figures for the intersection intensity analysis.

Table 12 Orenco Station Intersection Intensities

Distance from transit stop	0.00 - 0.25	0.00 - 0.50
1993		
Intersection Density (per sq. mi.)	112.0	103.1
Dead-End Density (per sq. mi.)	5.1	20.4
Impedance-Based Intersection Density (per sq. mi.)	20.4	26.7
Impedance-Based Dead-End Density (per sq. mi.)	25.5	30.5
2002		
Intersection Density (per sq. mi.)	244.4	212.5
Dead-End Density (per sq. mi.)	50.9	61.1
Impedance-Based Intersection Density (per sq. mi.)	203.6	187.1
Impedance-Based Dead-End Density (per sq. mi.)	76.4	76.4
1993-2002		
Intersection Density (per sq. mi.)	132.4	109.4
Dead-End Density (per sq. mi.)	45.8	40.7
Impedance-Based Intersection Density (per sq. mi.)	183.2	160.4
Impedance-Based Dead-End Density (per sq. mi.)	50.9	45.9
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	118%	106%
Dead-End Density (per sq. mi.)	900%	200%
Impedance-Based Intersection Density (per sq. mi.)	900%	600%
Impedance-Based Dead-End Density (per sq. mi.)	200%	150%

There are three key pieces of information contained in Table 12:

1. **The high density of intersections in 2002**. In 2002, Orenco station had a higher intersection density at both the quarter- and half-mile distances than all other Portland areas, except the half-mile Lloyd Center area. Moreover, the impedance-based intersection densities

far outscore any of the other TOD areas, reflecting a tight network of internal neighborhood streets deliberately built within this greenfield development.

2. **The relatively low drop off between "regular" intersection densities and impedance-based intersection densities**. In 2002, there was a relatively low reduction in intersection density when intersections based on the presence of major roads were removed. This small drop-off reflects the relatively low impact and ratio the major arterials have in relation to the presence of minor roads.

3. **The positive change over time in intersection densities**. In 1993 the Orenco Station area had the lowest intersection densities of any of the Portland case study areas, yet within a decade it had the highest densities, doubling the overall intersection density at both geographic scales. This change over time reflects the explicit pedestrian-oriented planning that was a focus of the greenfield development. Also, although the number of dead-ends increased dramatically (they started with a low *n*, so the increase may be a bit distorted), many of these dead-ends are where streets temporarily terminate at vacant lots. A future analysis conducted after Orenco Station is fully built out will most likely see a reduction in these dead-ends as the vacant lots get converted to more mixed use or residential housing consistent with the other development in the area.

Intersection Surface Map

The Orenco Station area is characterized by three pockets that contain high levels of internal street connectivity defined by a high density of "good" intersections. The dark pocket to the north of the transit stop is the primary area that has been developed over the last decade and Figure 15 shows how deliberately the area was developed with walkability principles in mind. There is another pocket of relatively high internal connectivity just south of the transit stop and a third pocket that begins about a half-mile south of the transit stop. As of 2002, much of the area immediately south of the transit stop remained undeveloped, although it is currently experiencing rapid development. It is likely that future calculations would show a considerable increase in the islands of walkability.

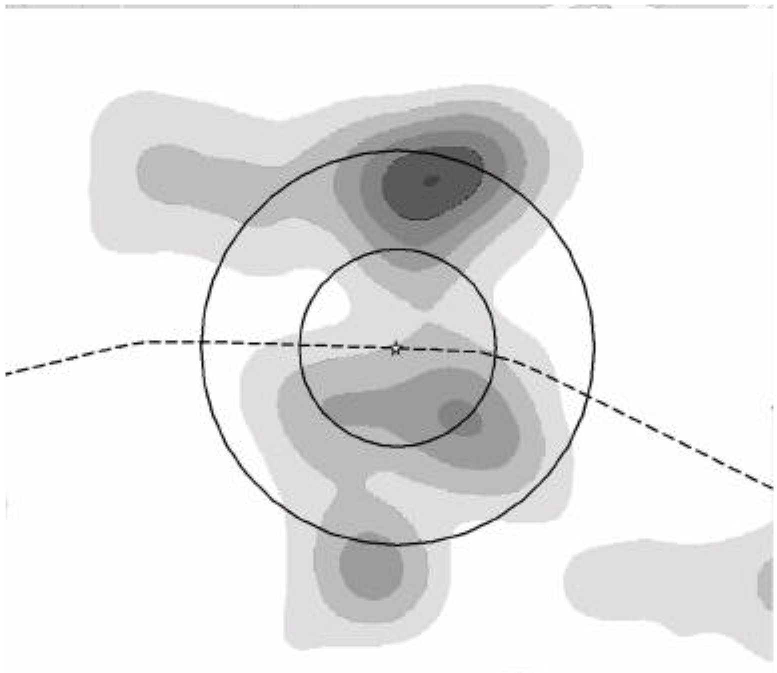


Figure 15 Orenco Station Surface Map

PORTLAND: BEAVERTON

Figure 16 Beaverton TOD Arterials

Demographics

In 2000, Beaverton had the highest population density of the four Portland TOD areas (4,065 people per square mile), which also represented a 26 percent increase in density compared to 1990 (Table 13). Similar to Orenco Station, the population became more diverse with a 14 percent increase of the non-white population share, including a big increase of 17 percent in the Hispanic share of the population. The median age decreased by a bit more than two years over the decade, with a small increase in population share of the 0-17 and 45-64 age cohorts. The over-65 age cohort saw the biggest share decline (down by 2.6 percent), while the 18-44 age cohort saw a small decline. Household size increased slightly, and the average household income increased by 28 percent to almost $37,000.

Table 13 Socio-Demographic Characteristics of Beaverton, 1990-2000

Beaverton	People	Density (people/ sq. mile)	White	Non-White	Hispanic	Ages 0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	13,294	3,284	86.2%	13.8%	4.5%	18.6%	52.9%	14.3%	14.2%	31.3	2.1	$ 28,768
2000	15,957	4,065	72.4%	27.6%	22.1%	20.8%	51.4%	16.2%	11.6%	29.1	2.3	$ 36,728
1990-2000	2,663	781	-13.8%	13.8%	17.5%	2.2%	-1.5%	1.8%	-2.6%	-2.2	0.3	$ 7,961

Transit Ridership–Census

Beaverton also experienced a change in travel mode to work with the introduction of the light rail line in the mid 1990s (Table 14). In 2000, train ridership for work trips went from zero to 5 percent. Bus ridership during this time period increased by about the same amount as well (4.6 percent), resulting in an overall decrease of 8.4 percent in automobile use as the means of travel to work. Biking and walking also decreased slightly over this time period.[37]

Table 14 Beaverton, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	81.2%	7.5%	0.0%	6.5%	4.8%
2000	72.8%	12.1%	5.1%	5.9%	4.2%
1990-2000	-8.4%	4.6%	5.1%	-0.6%	-0.6%

Transit Ridership–Metro

From 1998 to 2002, the Beaverton Central transit stop saw a 272 percent increase in daily weekday boardings (Table 15). However, the total number of boardings at Beaverton is the lowest of the four Portland TOD areas.

Table 15 Beaverton, Daily Weekday Boardings, 1998-2002

1998	2002	Change 1989-2002	% Change 1989-2002
178	662	484	272%

Street Classification

Figure 17 illustrates the 2002 Beaverton TOD road network, both unclassified and classified.

Beaverton Central

All Roads **Classified Roads**

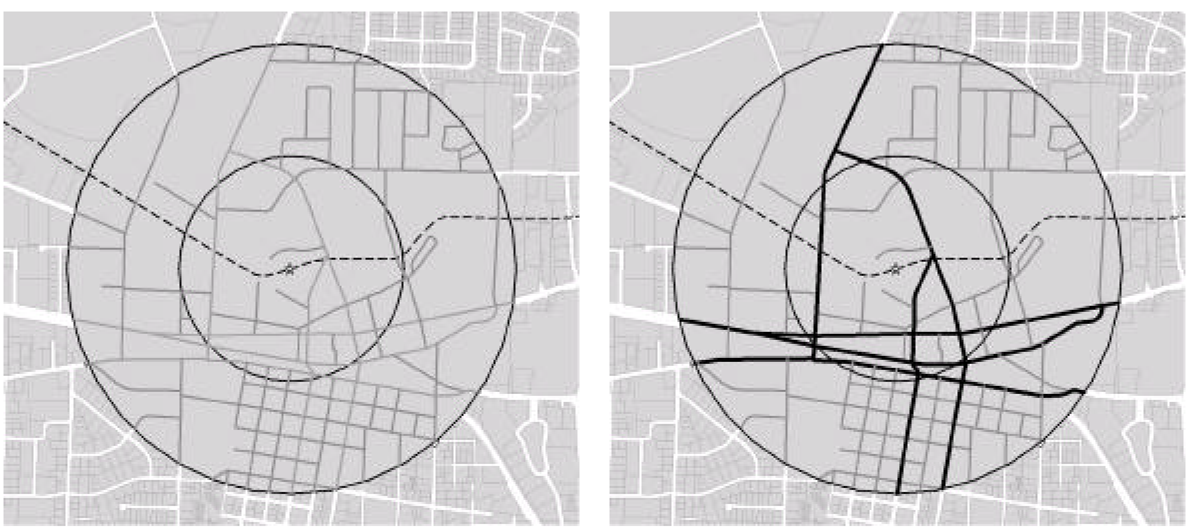


Figure 17 Beaverton Central Street Classification

The network that defines the Beaverton transit stop service area is a mix between a grid and post-World War II pattern. The grid pattern is mostly in the southern part of the study area and is located 1/4 mile beyond the transit stop. There are an abundance of impedance roads, concentrated primarily between the transit stop and the gridded road network. The road network within 1/4 mile of the transit stop is fairly limited. Table 16 lists the quantities of these street types as well as their change over time.

Table 16 Beaverton Central Street Classification

	Distance from transit stop (miles)	
	0.00 - 0.25	0.00 - 0.50
1993		
Minor Roads (miles)	1.6	10.1
Major Roads (miles)	2.5	5.0
2002		
Minor Roads (miles)	2.2	11.3
Major Roads (miles)	2.5	5.2
1993-2002		
Minor Roads (miles)	0.6	1.2
Major Roads (miles)	0.0	0.1
1993-2002 (percent change)		
Minor Roads (miles)	40%	12%
Major Roads (miles)	0%	3%

One key statistic of the above table is the high quantity of major (impedance) roads compared to minor roads. At the quarter-mile distance, theoretically of the highest likely walkability, the mileage of major roads exceeds that of minor roads. Moreover, their circular pattern creates a cage-like effect on the transit stop, potentially limiting pedestrians to get beyond even that quarter-mile distance. However, there has been some positive movement within this quarter-mile zone, in that the quantity of minor roads did increase by 40 percent without any increase in major roads over the last decade.

Catchment Areas

Figure 18 displays the PCA and IPCA for the Beaverton Area.

Beaverton Central

PCA–Quarter- & Half-mile **IPCA–Quarter- & Half-mile**

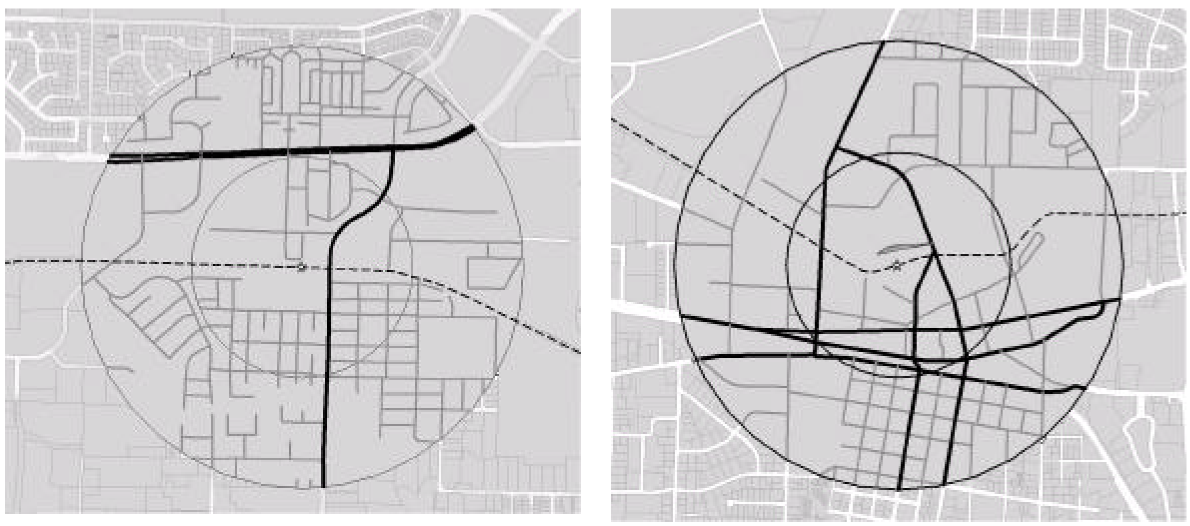


Figure 18 Beaverton Pedestrian and Impeded Pedestrian Catchment Areas

The PCA has a generally circular shape indicating reach in all directions from the transit stop at both geographic scales of analysis. At the half-mile network zone, the shaded area extends only minimally beyond the circular quarter-mile zone, although it does reach the grid street pattern to the south, indicating potential connectivity with places that are characteristic of TOD goals. The IPCA, however, is non-existent, covering only a small sliver of area just north of the transit stop. The IPCA illustrates two insights. The first observation is the severity in which the service areas have been reduced by the network reclassification, so much so that there is almost no walkable service area. Secondly, by considering auto-dominant roads as hostile walking environments, the walkable service area from or to the transit station no longer includes the area of tight street grids to the south of the transit station–the exact area that TOD principles (and smart growth ideals more generally) promote as good urban, pedestrian and transit-friendly form. Thus, the presence of major arterials creates a complete disconnect between the transit stop and a supportive urban form just over a quarter-mile away. Table 17 gives the ratios for each measure.

Table 17 Beaverton Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	**Distance from transit stop (miles)**	
	0.00 - 0.25	0.00 - 0.50
1993		
Pedestrian Catchment Area (PCA)	0.39	0.53
Impeded Pedestrian Catchment Area (IPCA)	0.24	0.07
2002		
Pedestrian Catchment Area (PCA)	0.21	0.41
Impeded Pedestrian Catchment Area (IPCA)	0.00	0.00
1993-2002 change		
Pedestrian Catchment Area (PCA)	-0.18	-0.12
Impeded Pedestrian Catchment Area (IPCA)	-0.24	-0.07
1993-2002 (percent change)*		
Pedestrian Catchment Area (PCA)	-47%	-23%
Impeded Pedestrian Catchment Area (IPCA)	-100%	-100%

* Change over time data for Beaverton is not a useful measure due to methodological limitations of the spatial calculation. This problem is discussed more fully in the appendix of this report.

The 2002 PCA for Beaverton is minimal at the quarter-mile (0.21) and slightly better within the half-mile service area (0.41), but still under the theoretical desired minimum for this type of ratio (0.60). As mentioned above, the IPCA score at both scales is 0.00, meaning that there is no walkability at the Beaverton station. Currently (in 2003/2004) there is construction of a commercial/office complex situated directly at the transit stop, which will be serviceable by those riding the light rail and exiting at Beaverton. However, the presence of the major arterials surrounding the transit stop will continue to restrict any to or from movement beyond these immediate destinations.

Intersection Analyses

Figure 19 shows the spatial distribution of intersections and dead-ends for the Beaverton area.

Beaverton

Intersection Intensities **Impedance-Based Intersection Intensities**

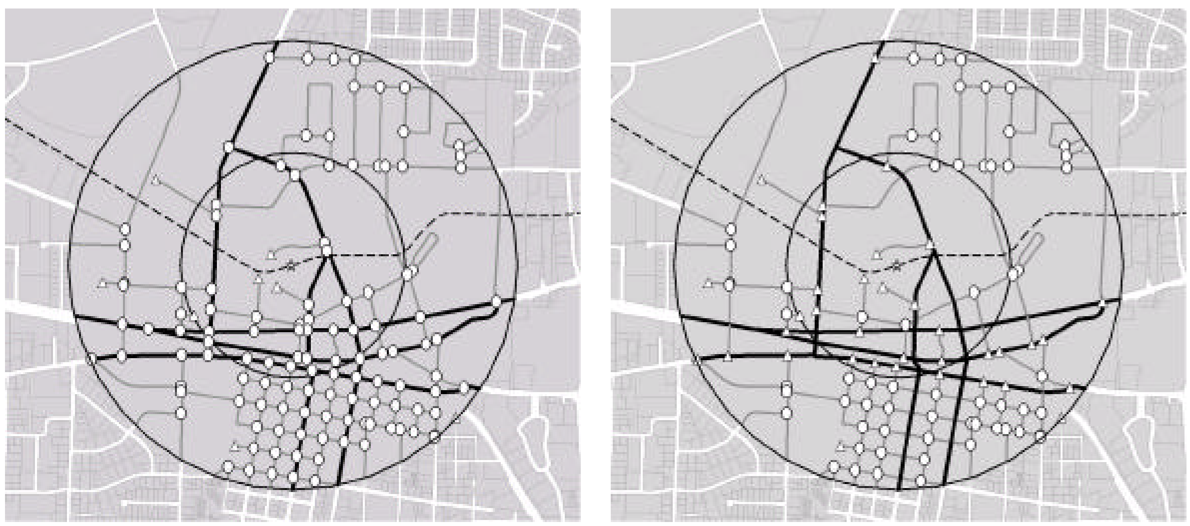


Figure 19 Beaverton Intersection Intensities

The tight grid street pattern to the south of the Beaverton transit stop is clearly illustrated on the above maps. When the major arterial roads are removed from the identification of good intersections (three- and four-way), however, a reduction of the number of intersections is clearly visible. Every instance where a minor road touches a major road, an intersection is removed, visualized by the loss of white circles between the map on the left and the right.

Table 18 gives the figures reflecting these changes.

Table 18 Beaverton Intersection Intensities

Distance from transit stop	**0.00 - 0.25**	**0.00 - 0.50**
1993		
Intersection Density (per sq. mi.)	147.6	148.9
Dead-End Density (per sq. mi.)	5.1	12.7
Impedance-Based Intersection Density (per sq. mi.)	20.4	71.3
Impedance-Based Dead-End Density (per sq. mi.)	50.9	35.6
2002		
Intersection Density (per sq. mi.)	147.6	150.2
Dead-End Density (per sq. mi.)	20.4	11.5
Impedance-Based Intersection Density (per sq. mi.)	20.4	78.9
Impedance-Based Dead-End Density (per sq. mi.)	91.6	47.1
1993-2002		
Intersection Density (per sq. mi.)	0.0	1.3
Dead-End Density (per sq. mi.)	15.3	-1.2
Impedance-Based Intersection Density (per sq. mi.)	0.0	7.6
Impedance-Based Dead-End Density (per sq. mi.)	40.7	11.5
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	0%	1%
Dead-End Density (per sq. mi.)	301%	-10%
Impedance-Based Intersection Density (per sq. mi.)	0%	11%
Impedance-Based Dead-End Density (per sq. mi.)	80%	32%

Beaverton represents the most radical illustration of the importance of impedance roads in deriving intersection densities. Intersections derived from an unclassified street network result in relatively high densities of good intersections at both the quarter-mile (147.6) and half-mile (150.2) service areas. Similarly, the number of dead-ends is quite low at both scales. In contrast, when impedance streets are taken into account, the intersection density drops severely; in fact, at the quarter-mile, the dead-end density exceeded the intersection density by more than a factor of four in 2002. At the half-mile, intersections outnumber dead-ends, but at levels unfavorable to general walkability throughout the TOD.

In terms of change over time, the local street network has not been favorably altered in terms of walkability principles. Dead-ends within a quarter-mile increased significantly (albeit from a small initial *n*) and impedance-based, or pedestrian-perceived, dead ends increased at both scales over the decade.

Intersection Surface Map

The Beaverton intersection surface map (Figure 20) shows a connectivity island south of the transit stop, beginning within a quarter-mile of the stop and extending beyond the half-mile distance. To the north, however, there is a connectivity "hole"–a large swath of area that lacks internal connectivity and is thus not designed with walkability principles in mind. In essence, half of the area surrounding the transit stop lacks good pedestrian urban form.

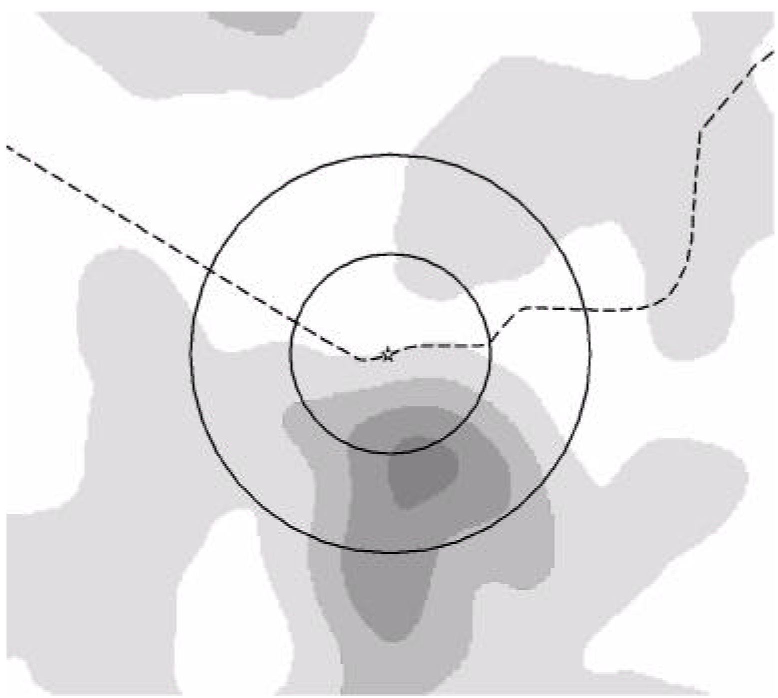


Figure 20 Beaverton Intersection Map

PORTLAND: LLOYD CENTER

Demographics

The Lloyd Center experienced the greatest absolute increase in population density from 1990-2000–an increase of 1,700 people per square mile and equal to the total population density of Orenco Station in 2000 (Table 19). The Lloyd Center also experienced an increase in ethnic diversity with a six percent increase in the non-white population share and a 3.3 percent increase in the Hispanic population share. The Lloyd Center maintained a relatively high median age in 2000 (41.6 years), but perhaps the most significant change in the Lloyd Center area was the reduction in median age by seven years over the decade. There was a substantial increase in share of population in both the 18-44 and 45-64 cohorts and a corresponding substantial decrease in those aged 65 or older. Household size increased slightly and the average household income increased by about 50 percent.

Table 19 Socio-Demographic Characteristics of Lloyd Center, 1990-2000

						Ages						
Lloyd Center	People	Density (people/ sq. mile)	White	Non-White	Hispanic	0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	1,636	2,045	84.9%	15.1%	1.4%	5.3%	43.0%	6.7%	45.0%	48.7	1.4	$21,700
2000	4,683	3,784	78.9%	21.1%	4.7%	7.3%	55.5%	17.8%	19.4%	41.6	1.7	$32,303
1990-2000	3,047	1,739	-6.0%	6.0%	3.3%	2.0%	12.5%	11.1%	-25.6%	-7.1	0.3	$10,602

Transit Ridership–Census

The Lloyd Center, due to its close proximity to downtown, has traditionally had high levels of non-automobile mobility choices. As such, in 1990 only 51 percent of the population used a car as the primary means to work while about 28 percent used some form of transit and 17 percent of people biked or walked as a means to get to work (Table 20). Over the 1990s, this figure did not change. Moreover, the number of train users remained constant (the light rail spur that served Lloyd Center was opened in the late 1980s). One interesting change over the decade, however, was the increase in the numbers of people walking and biking as their primary means of travel. These human powered mobility choices substituted mostly for bus travel, and can perhaps be explained by the in-migration of a younger population interested in an urban landscape with close proximity to downtown.

Table 20 Lloyd Center, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	51.0%	25.5%	2.6%	17.4%	3.5%
2000	50.5%	20.8%	3.1%	21.4%	4.2%
1990-2000	-0.5%	-4.7%	0.5%	4.0%	0.7%

Transit Ridership–Metro

From 1989 to 2002, daily boardings at the Lloyd Center transit stop has consistently increased (Table 21), with almost 4,000 daily boardings in 2002. Over this time period, daily usage of the Lloyd Center stop (for all purposes) increased by 179 percent.

Table 21 Lloyd Center, Daily Weekday Boardings, 1989-2002

1989	1991	1994	1998	2002	Change 1989-2002	% Change 1989-2002
1,418	1,632	1,912	3,016	3,957	2,539	179%

Street Classification

Figure 21 shows the 2002 street classifications for the Lloyd Center.

Lloyd Center

All Roads **Classified Roads**

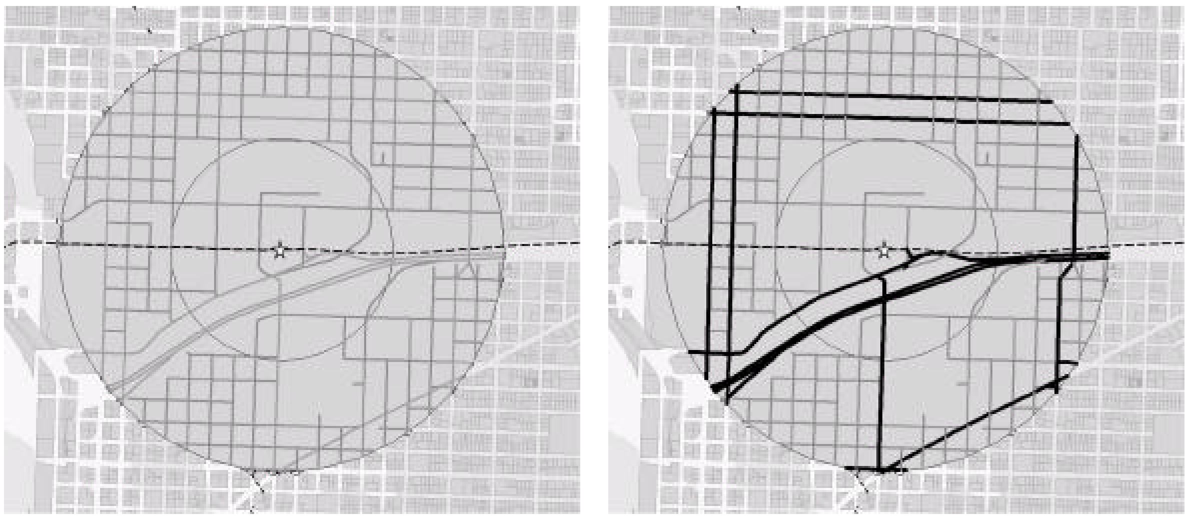


Figure 21 Lloyd Center Street Classifications

The Lloyd Center has the most comprehensive grid network pattern of any Portland case study community. The pattern is fairly regular across the area with most of the paths within the band between a quarter- and a half-mile. Within the quarter-mile study area there are many fewer roads that do not have a grid pattern. The impedance roads are very prevalent and dissect the study area in several locations. Table 22 lists the quantities of each type of roads.

Table 22 Lloyd Center Street Classification

	Distance from transit stop (miles)	
	0.00 - 0.25	0.00 - 0.50
1993		
Minor Roads (miles)	4.4	21.0
Major Roads (miles)	1.7	6.3
2002		
Minor Roads (miles)	3.5	17.8
Major Roads (miles)	2.2	8.4
1993-2002		
Minor Roads (miles)	-0.9	-3.2
Major Roads (miles)	0.5	2.1
1993-2002 (percent change)		
Minor Roads (miles)	-20%	-15%
Major Roads (miles)	31%	33%

The dense road network can be seen by looking at the quantity of minor roads within a half-mile of the transit stop, 21.0 miles in 1993–far more than any other Portland case study. Yet, the abundance of major roads also surpasses that of the other sites. As a negative trend, both within the quarter- and half-mile zones, minor roads have decreased simultaneously with the increase of major roads over the decade, a trend that can be seen as contrary to the walkability principles of TOD environments.

Catchment Areas

Figure 22 shows the PCA and IPCA maps for the Lloyd Center.

Lloyd Center

PCA–Quarter- & Half-mile **IPCA–Quarter- & Half-mile**

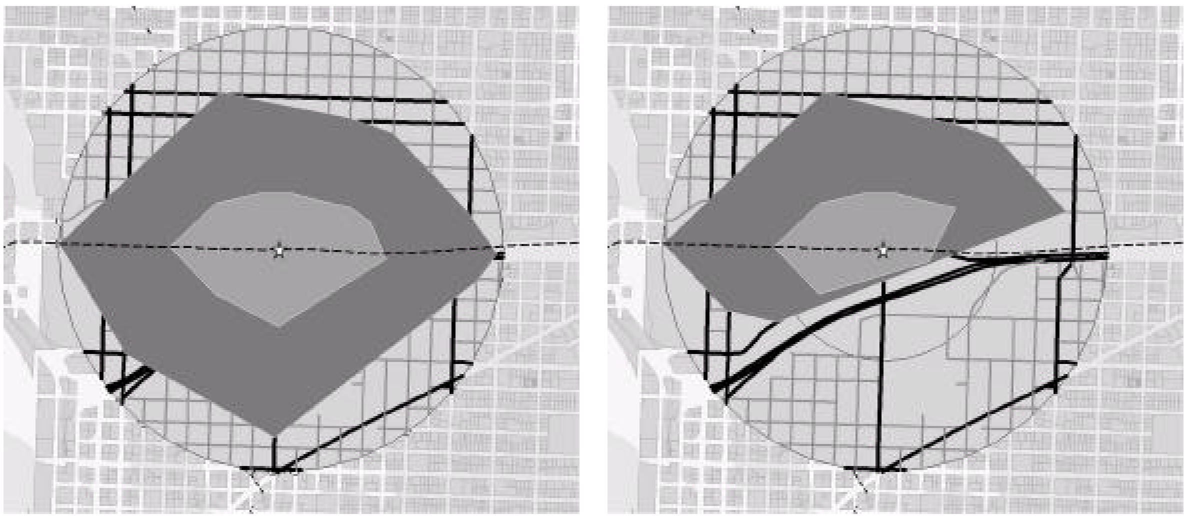


Figure 22 Lloyd Center Pedestrian and Impeded Pedestrian Catchment Areas

The service areas that have been defined for the Lloyd Center have a fairly large coverage, reflecting the presence of a street network grid pattern throughout most of the area–especially at the half-mile zone. The Lloyd District IPCA radically illustrates the effect that impedance roads have on a walkable service area, confining pedestrian access exclusively to the northern section of the study extent. The restricted pedestrian access is due to the frequency of impedance paths (a freeway and major arterials) on the network and the removal of them from the modeling. The northern area has a relatively good service extent for walking, although it too is truncated by abundant impedance arcs.

Table 23 gives the quantitative PCA and IPCA measurements.

Table 23 Lloyd Center Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	**Distance from transit stop (miles)**	
	0.00 - 0.25	0.00 - 0.50
1993		
Pedestrian Catchment Area (PCA)	0.41	0.48
Impeded Pedestrian Catchment Area (IPCA)	0.37	0.39
2002		
Pedestrian Catchment Area (PCA)	0.47	0.49
Impeded Pedestrian Catchment Area (IPCA)	0.30	0.34
1993-2002 change		
Pedestrian Catchment Area (PCA)	0.06	0.01
Impeded Pedestrian Catchment Area (IPCA)	-0.07	-0.05
1993-2002 (percent change)		
Pedestrian Catchment Area (PCA)	14%	1%
Impeded Pedestrian Catchment Area (IPCA)	-19%	-12%

In 2002, both the quarter-mile (0.47) and half-mile (0.49) represent moderate walking environments compared to theoretical minimum scores for walkability (0.60). The tight grid network of streets leads to extended network-based walking areas, giving pedestrians a multitude of path choices in every direction from the transit stop. In terms of the IPCA, scores at both the quarter-mile (0.30) and half–mile (0.34) decline quite a bit. Both declines are directly caused by the presence of a number of major auto-oriented roads (including a freeway and major surface roads to traverse that freeway).

In terms of change over time, the IPCA became slightly worse (-19 percent and -12 percent at the quarter- and half-mile zones respectfully), primarily due to the reclassification and reorientation of some roads from minor to major.

Intersection Analyses

Figure 23 shows the spatial distribution of intersections and dead-ends for the Lloyd Center.

Lloyd Center

Intersection Intensities **Impedance-Based Intersection Intensities**

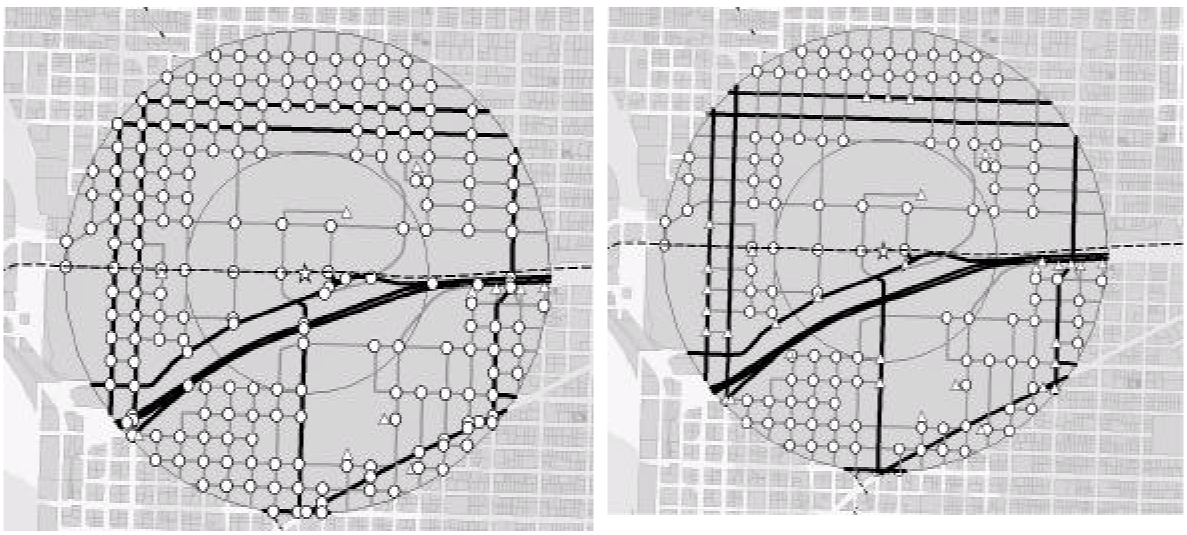


Figure 23 Lloyd Center Intersection Intensities

The concentration and spatial location of intersections within the Lloyd District clearly capture the grain of the area: large block commercial, office, and parking in close proximity to the transit stop, and traditional, tight grid residential uses just beyond the quarter-mile zone. Of particular interest in this example, is the change in intersection density when impedance roads are included; walkability, in terms of intersections, becomes very limited at the quarter-mile TOD area because of the existence of a high number of auto-centric road segments. Table 24 lists the quantitative results of these measures.

Also, in the Lloyd District area, there is a large shopping mall just north of the transit stop. This mall has a variety of implications for accessibility between it and the transit stop. First, there exists no clear pedestrian path between the transit stop and the mall, with access to the mall oriented toward a street-level parking lot that faces the transit stop. Second, during the hours for which the mall is open, one could argue that it presents an interesting set of corridors for one to walk through. However, during the hours that it is closed, the mall presents a formidable pedestrian barrier to those who wish to make a linkage between the transit stop and the area beyond the mall.

Table 24 Lloyd Center Intersection Intensities

Distance from transit stop	0.00 - 0.25	0.00 - 0.50
1993		
Intersection Density (per sq. mi.)	137.5	273.6
Dead-End Density (per sq. mi.)	20.4	12.7
Impedance-Based Intersection Density (per sq. mi.)	106.9	180.7
Impedance-Based Dead-End Density (per sq. mi.)	20.4	31.8
2002		
Intersection Density (per sq. mi.)	106.9	258.4
Dead-End Density (per sq. mi.)	5.1	15.3
Impedance-Based Intersection Density (per sq. mi.)	61.1	146.4
Impedance-Based Dead-End Density (per sq. mi.)	20.4	42.0
1993-2002		
Intersection Density (per sq. mi.)	-30.5	-15.2
Dead-End Density (per sq. mi.)	-15.3	-1.2
Impedance-Based Intersection Density (per sq. mi.)	-45.8	-34.3
Impedance-Based Dead-End Density (per sq. mi.)	0.0	10.2
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	-22%	-6%
Dead-End Density (per sq. mi.)	-75%	-8%
Impedance-Based Intersection Density (per sq. mi.)	-43%	-19%
Impedance-Based Dead-End Density (per sq. mi.)	0%	32%

In both 1993 and 2002, the Lloyd Center represented an interesting mix of realities in terms of intersection densities. At both time periods (except the 1993 Orenco Station which was mostly undeveloped openspace), the Lloyd Center had the lowest intersection density within the first quarter-mile of the transit stop, but the highest intersection density within a half-mile zone. This contrast in figures reflects the differences of urban form in proximity to the transit stop versus the area beyond a quarter-mile. The transit stop is immediately surrounded by a number of large block office buildings, a decent sized park, a large shopping mall, and a large parking lot. Many of these locations represent key destinations, but do not contribute well to high intersection densities. Beyond the quarter-mile zone, the land use turns to residential built upon a very tight street grid with frequent intersections at the ends of small blocks.

When taking the arterials into account, the pedestrian-perceived intersections drop quite a bit in both 1993 and 2002, reflecting a more limited zone of mobility than would otherwise be present if all roads were equal.

Finally, in terms of change over time, the Lloyd Center environment has declined in terms of intersection densities (-22 percent at a quarter-mile), resulting from the overall elimination of some of the local road network. In the impedance-based calculations, intersections have declined at both geographic scales (-43 percent at the quarter-mile and -19 percent at the half-mile) as a result of the redesignation of some minor roads as arterials. Such a redesignation also resulted in an increase (32 percent) in pedestrian-perceived dead ends at the half-mile zone.

Intersection Surface Map

The Lloyd Center intersection surface map (Figure 24) shows three interesting phenomena. First, the entire area is represented with a good degree of internal street connectivity (identified by the absence of white spaces) in contrast to the other Portland TOD areas that contained wide swaths of poor pedestrian urban form. Second, the area immediately surrounding the transit stop and occupying the entire quarter-mile theoretical service area is a pedestrian “hole” as compared to areas further away. TOD theory suggests the opposite to be true–that transit stops be located in areas with higher degrees of walkability than those areas further away. The idea of a pedestrian hole does not necessarily imply that it is an unattractive place for pedestrians. On the contrary, in the case of the Lloyd Center, the hole exists due to the presence of a park and a shopping mall–two land uses that many people would enjoy walking through to access the transit stop. The pedestrian hole does illustrate, however, the disconnect between TOD theory and practice in that the area of least connectivity is in highest proximity to the transit stop. The third interesting component is the relative uniform coverage of good pedestrian environments in all directions from the transit stop. Once one gets beyond the quarter-mile hole, there are areas of good internal street connectivity in every direction.

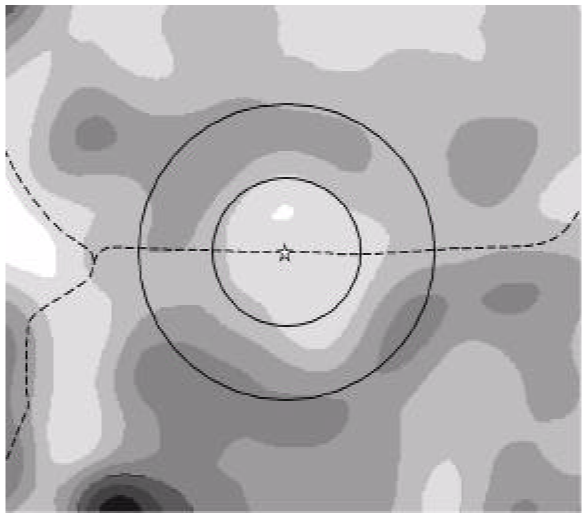


Figure 24 Lloyd Center Intersection Surface Map

PORTLAND: GRESHAM CENTRAL TRANSIT

Demographics

Like the other Portland TOD areas, Gresham also saw an increase (34 percent) in population density between 1990 and 2000 (see Table 25). Gresham saw a fairly substantial shift in ethnic diversity with a 16 percent increase in its non-white population share (to 22 percent) and a 15 percent increase in its Hispanic population share. Also, in a similar fashion to the other Portland TOD areas, median age decreased (by 1.4 years) resulting from a decrease in the over 65 population share (-5.3 percent) and an increase in the 18-44 age cohort (4.5 percent). Average household size increased by 27 percent, the lowest of any of the Portland TOD areas.

Table 25 Socio-Demographic Characteristics of Gresham, 1990-2000

						Ages						
Gresham	People	Density (people/ sq. mile)	White	Non-White	Hispanic	0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	2,777	2,496	94.5%	5.5%	6.6%	26.4%	41.7%	14.7%	17.2%	32.7	2.4	$25,426
2000	3,715	3,338	78.1%	21.9%	21.2%	24.8%	46.2%	17.1%	11.9%	31.3	2.5	$32,357
1990-2000	938	843	-16.4%	16.4%	14.6%	-1.6%	4.5%	2.4%	-5.3%	-1.4	0.2	$6,931

Transit Ridership–Census

Like the Lloyd Center, the eastern MAX spur served Gresham beginning in the late 1980s. Unlike the Lloyd Center, however, train use is relatively light by those who live in close proximity to the transit stop (Table 26). Over the decade of the 1990s, automobile use increased as the means of travel to work, but increased at a rate similar to those of bus and train usage. Biking and walking remained constant and was the second highest rate of the four Portland TOD areas.

Table 26 Gresham, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	83.8%	1.9%	2.1%	6.6%	5.6%
2000	85.1%	3.1%	3.2%	6.5%	2.1%
1990-2000	1.3%	1.2%	1.1%	-0.1%	-3.5%

Transit Ridership–Metro

Daily weekday ridership at the Gresham transit stop also consistently increased from 1989 through 2002 (Table 27). In fact, ridership has increased 217 percent over this time period. Ridership at Gresham is lower than the Lloyd Center (they are both on the eastern spur), but is higher than the newer, but more specifically designed TOD areas at Orenco Station and Beaverton.

Table 27 Gresham, Daily Weekday Boardings, 1989-2002

1989	1991	1994	1998	2002	Change 1989-2002	% Change 1989-2002
460	558	706	933	1,459	999	217%

Street Classification

Figure 25 shows the street pattern and classification for Gresham Central Transit Center.

Gresham Central Transit Center

All Roads **Classified Roads**

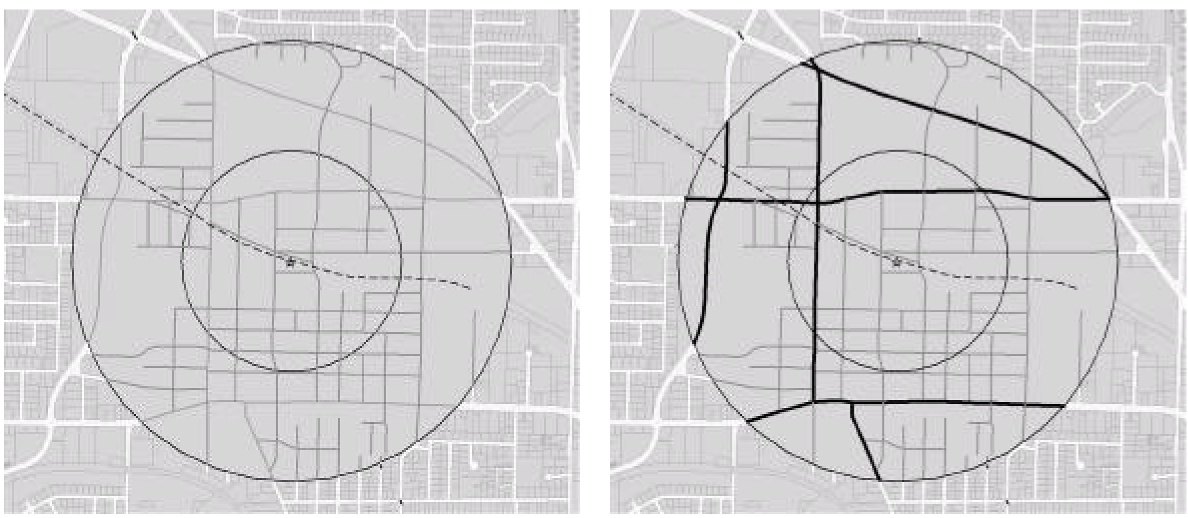


Figure 25 Gresham Street Classification

Gresham is an area developed prior to World War II and has a street pattern that generally follows a grid typical of that era. This grid is predominantly to the south and east of the transit stop and there are no major roads between the transit stop and the grid. There are a number of major roads, some within the quarter-mile area, and beyond them the minor road network becomes quite limited. Table 28 lists the quantitative numbers for this TOD.

Table 28 Gresham Street Classification

	Distance from transit stop (miles)	
	0.00 - 0.25	0.00 - 0.50
1993		
Minor Roads (miles)	4.9	12.2
Major Roads (miles)	1.0	4.9
2002		
Minor Roads (miles)	4.7	11.8
Major Roads (miles)	1.0	4.6
1993-2002		
Minor Roads (miles)	-0.16	-0.36
Major Roads (miles)	0.00	-0.30
1993-2002 (percent change)		
Minor Roads (miles)	-3%	-3%
Major Roads (miles)	0%	-6%

The pre-WWII aspect of the Gresham area is reflected by the lack of change in miles of minor or major roads over the last decade; the urban network infrastructure was well established and has not undergone any transformation or alteration to enhance walkability over the last ten years. In terms of the current layout of the area, Gresham has a quite high number of minor roads within both the quarter- and half-mile zones. Major roads within a quarter-mile of the transit stop is relatively low, although within a half-mile, about 29 percent of all roads are classified as major arterials.

Catchment Areas

Figure 26 shows the PCA and IPCA maps for Gresham.

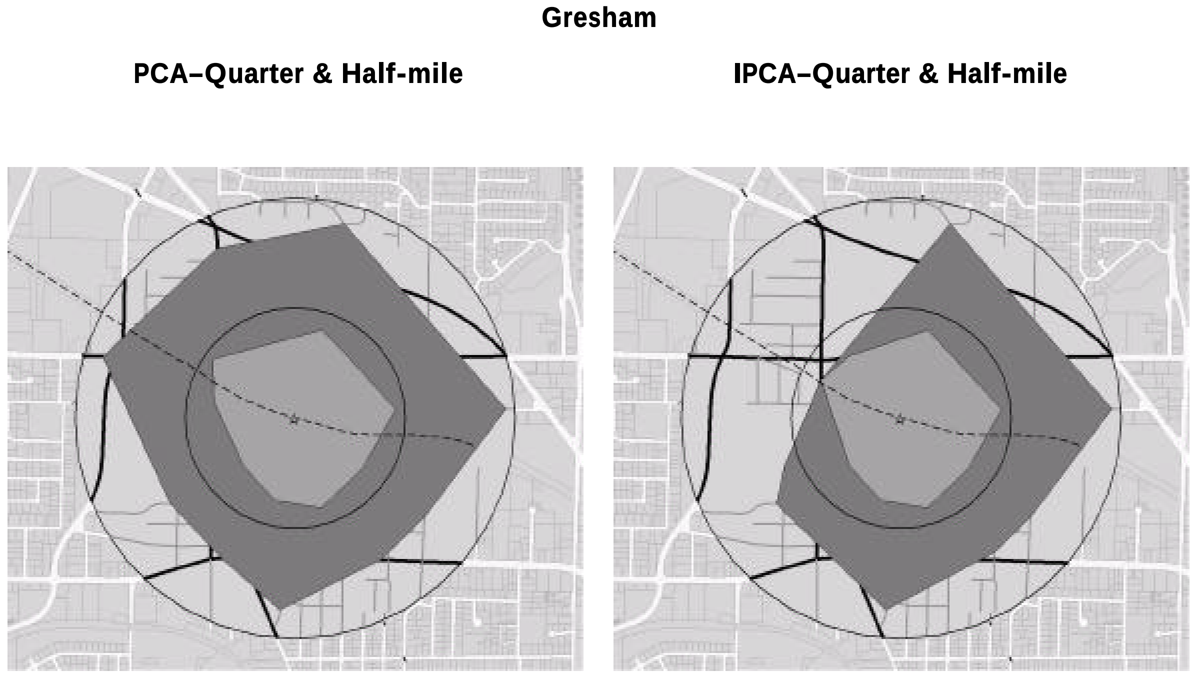


Figure 26 Gresham Pedestrian and Impeded Pedestrian Catchment Areas

Coverage for both the PCA and IPCA are relatively strong for Gresham, with good coverage from the transit stop outward along the street network. The IPCA gets truncated in the northwest section due to the presence of some major roads, but the rest of the area surrounding the transit stops (where no major arterials exist) receives good coverage. Table 29 gives the quantitative results.

Table 29 Gresham Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	**Distance from transit stop (miles)**	
	0.00 - 0.25	0.00 - 0.50
1993		
Pedestrian Catchment Area (PCA)	0.60	0.63
Impeded Pedestrian Catchment Area (IPCA)	0.56	0.49
2002		
Pedestrian Catchment Area (PCA)	0.57	0.62
Impeded Pedestrian Catchment Area (IPCA)	0.54	0.47
1993-2002 change		
Pedestrian Catchment Area (PCA)	-0.03	-0.01
Impeded Pedestrian Catchment Area (IPCA)	-0.02	-0.02
1993-2002 (percent change)		
Pedestrian Catchment Area (PCA)	-4%	-2%
Impeded Pedestrian Catchment Area (IPCA)	-4%	-4%

Of the four Portland case studies, Gresham's PCA ratios are the only ratios in line with the theoretical minimum for walkable urban form (0.60). In 2002, the quarter-mile PCA (0.57) and half-mile PCA (0.62) reflect the pre-WWII pedestrian-oriented street pattern. The IPCA scores for the quarter-mile (0.54) and half-mile (0.47) also remain relatively strong, reflecting the absence of arterials throughout most of the zone in close proximity to the transit stop. As a very positive sign, the area of highest walkability potential, within a quarter-mile of the transit stop, remains relatively constant between the PCA and IPCA measurements indicating that the close-in urban form is very pedestrian supportive for the Gresham TOD.

In terms of change over time, there was a slight reduction in PCA and IPCA ratios from 1993 to 2002, due to the elimination of several small minor street segments.

Intersection Analyses

Figure 27 shows the intersection and dead-end densities for the Gresham TOD.

Gresham

Intersection Intensities **Impedance-Based Intersection Intensities**

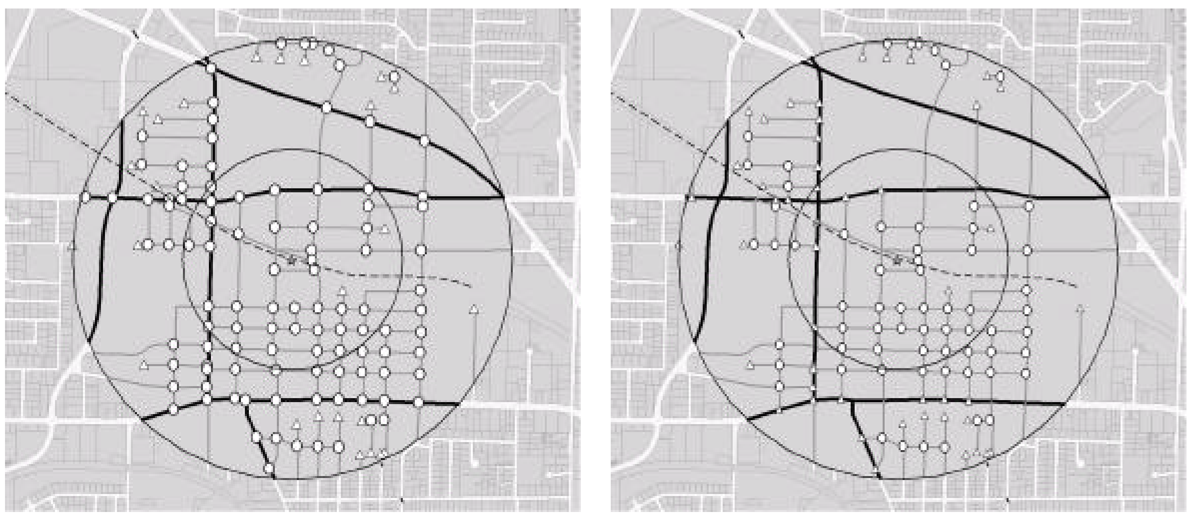


Figure 27 Gresham Intersection Intensities

The grid street pattern is reflected in the regular pattern of intersections throughout much of the southern portion of the Gresham TOD area. Similarly, the lack of such an urban skeleton is quite visible to the north of the transit stop. To the north and west of the transit stop, the impact of impedance roads on the location of intersections and dead-ends is also quite apparent, with many intersections converted to dead-ends as minor streets terminate at an arterial on the west side or cross over an arterial in the northern area. Quantitative results are presented in Table 30.

Table 30 Gresham Intersection Intensities

Distance from transit stop	0.00 - 0.25	0.00 - 0.50
1993		
Intersection Density (per sq. mi.)	198.5	145.2
Dead-End Density (per sq. mi.)	10.2	38.2
Impedance-Based Intersection Density (per sq. mi.)	147.6	86.5
Impedance-Based Dead-End Density (per sq. mi.)	35.6	61.1
2002		
Intersection Density (per sq. mi.)	188.4	133.6
Dead-End Density (per sq. mi.)	10.2	31.8
Impedance-Based Intersection Density (per sq. mi.)	137.4	82.7
Impedance-Based Dead-End Density (per sq. mi.)	40.7	62.4
1993-2002		
Intersection Density (per sq. mi.)	-10.1	-11.6
Dead-End Density (per sq. mi.)	0.0	-6.4
Impedance-Based Intersection Density (per sq. mi.)	-10.2	-3.8
Impedance-Based Dead-End Density (per sq. mi.)	5.1	1.3
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	-5%	-8%
Dead-End Density (per sq. mi.)	0%	-17%
Impedance-Based Intersection Density (per sq. mi.)	-7%	-4%
Impedance-Based Dead-End Density (per sq. mi.)	14%	2%

Intersection Surface Map

The Gresham intersection surface map (Figure 28) shows moderate intersection density in a broad coverage pattern. The transit stop itself is in close proximity to the area of highest connectivity and that area is relatively large. Connectivity decreases outside of the quarter-mile zone to the north and east.

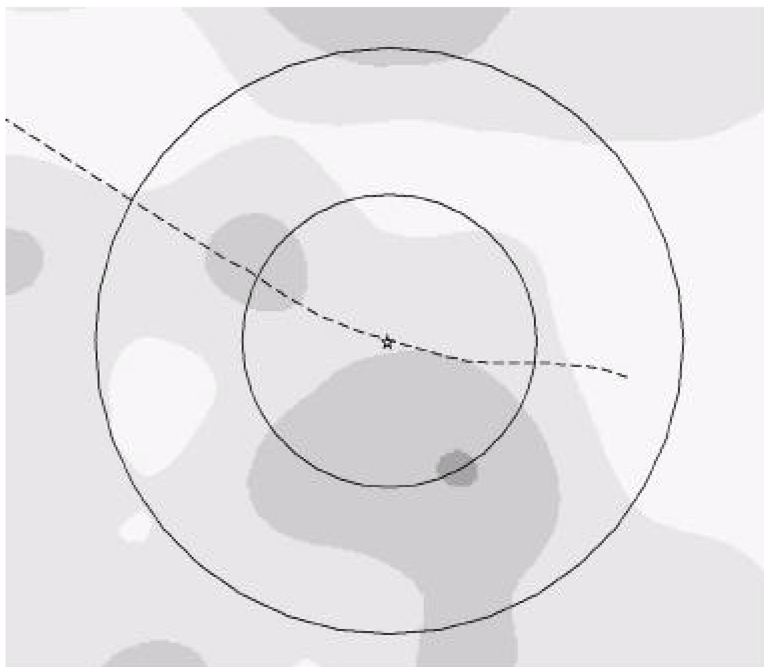


Figure 28 Gresham Intersection Surface Map

SILICON VALLEY: MOUNTAIN VIEW

Mountain View became a preferred residential location for single professionals working in the high technology field in Silicon Valley during the 1990s. The Mountain View location provided good access to a variety of employment locations, as well as a variety of offerings attractive to young professionals. Caltrain, a heavy-rail commuter train serving a large area between Gilroy to the south and San Francisco to the north, provides service between Mountain View and San Francisco in less than an hour, further enhancing the attractiveness of this location.

Demographics

Over the 1990s, population density near the Mountain View transit stop increased by 1,569 (30 percent) people per square mile, representing a positive, transit-supportive change (see Table 31). The area became more ethnically diverse as well, adding 9.4 percent to the non-white population share so that almost forty percent of the population was non-white. The median age increased seven years over the decade–a substantial increase caused by a big decrease in youth (-10.2 percent) and a healthy increase in those aged 45-64 (+10.6 percent). Household size decreased by almost 40 percent to 1.7 persons per household. Finally, income increased almost 70 percent over the decade.

Table 31 Socio-Demographic Characteristics of Mountain View, 1990-2000

Mountain View	People	Density (people/ sq. mile)	White	Non-White	Hispanic	Ages 0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	1,494	5,255	72.7%	27.3%	22.6%	14.6%	58.6%	17.2%	9.6%	33.1	2.3	$37,779
2000	1,940	6,824	63.3%	36.7%	8.6%	4.4%	62.4%	27.8%	5.5%	40.3	1.7	$64,351
1990-2000	446	1,569	-9.4%	9.4%	-13.9%	-10.2%	3.7%	10.6%	-4.1%	7.2	-0.6	$26,572

Transit Ridership–Census

The light rail station in Mountain View did not open until the latter half of the 1990s, which may partly explain the relatively low share of the population using a train as the primary means of getting to work. On the other hand, the pedestrian/bike share of close to seven percent may reflect that the local TOD area is a fairly walkable location (see Table 32). The share of trips made by bus is relatively low in the Mountain View area and declined by almost half between 1990 and 2000, with some of this share decline offset by the new train service to the area.

Table 32 Mountain View, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	82.5%	3.3%	0.0%	7.0%	7.2%
2000	82.2%	1.9%	0.8%	6.5%	8.6%
1990-2000	-0.3%	-1.4%	0.8%	-0.5%	1.4%

Transit Ridership–Valley Transportation Authority

Actual average daily boardings at the Mountain View light rail station is consistent with many of the other TOD areas researched in this report. Somewhat surprisingly, boardings fell slightly (by three percent) between 2000 and 2002 (see Table 33). As a relatively new light rail transit stop, close to an accessible downtown mixed use commercial area, one may have expected that there would have been more of an influx of choice riders into the area.

Table 33 Mountain View, Daily Weekday Boardings, 2000-2002

2000	2002	% Change 2000-2002
846	820	-3%

Street Classification

Mountain View

All Roads **Classified Roads**

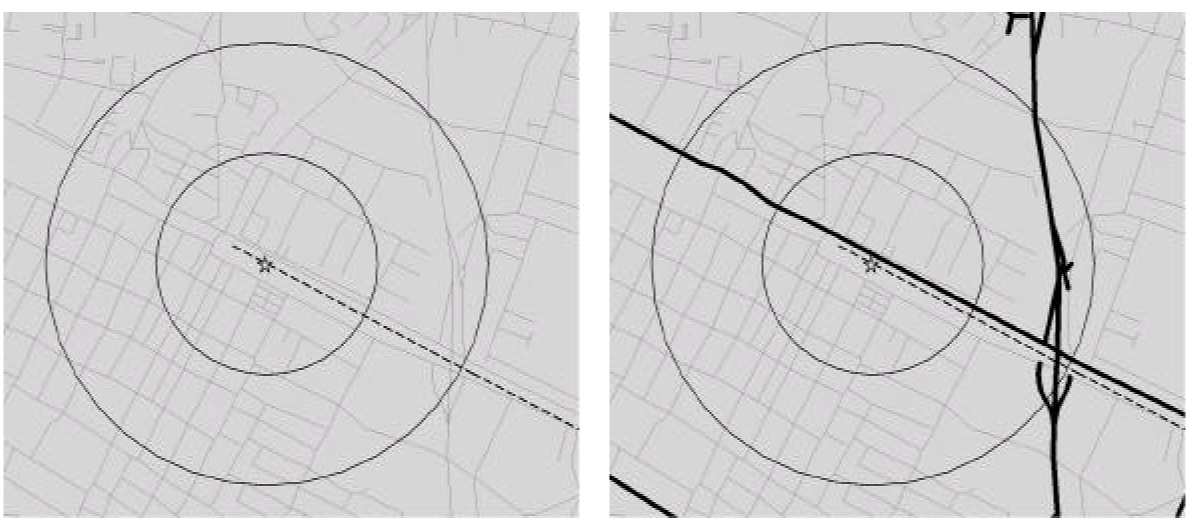


Figure 29 Mountain View Street Classification

Two main arterials cross the Mountain View TOD area, each with a different effect. The arterial to the east of the transit stop is relatively far away (about a half-mile) and therefore does not really impact the internal situation close to the stop. The other arterial, running east to west, bisects the TOD exactly in half. The combination of the train tracks and this arterial results in very few north-south pedestrian crossings within the TOD area.

Table 34 Mountain View Street Classifications

	Distance from transit stop (miles)	
	0.00 - 0.25	0.00 - 0.50
1993		
Minor Roads (miles)	4.4	14.7
Major Roads (miles)	0.5	2.8
2002		
Minor Roads (miles)	4.7	15.1
Major Roads (miles)	0.7	2.7
1993-2002		
Minor Roads (miles)	0.3	0.4
Major Roads (miles)	0.2	-0.1
1993-2002 (percent change)		
Minor Roads (miles)	8%	3%
Major Roads (miles)	32%	-2%

Quantitatively, Mountain View does quite well in terms of the high-quantity minor roads and the low quantity of major roads. Over time, little was changed in this street network infrastructure, meaning that the light rail system was placed within a relatively established urban form.

Catchment Areas

Assuming all streets as equal, the PCA for Mountain View is fair, with about a third of the quarter-mile zone being covered as a walkable area and about a half of the half-mile zone covered. The IPCA at both scales is identical to the PCA, highlighting the fact that even though a major impedance road is present, alternative travel paths are available to minimize the impedance road's influence on walkability (see Figure 30).

Mountain View

PCA–Quarter- & Half-mile **IPCA–Quarter- & Half-mile**

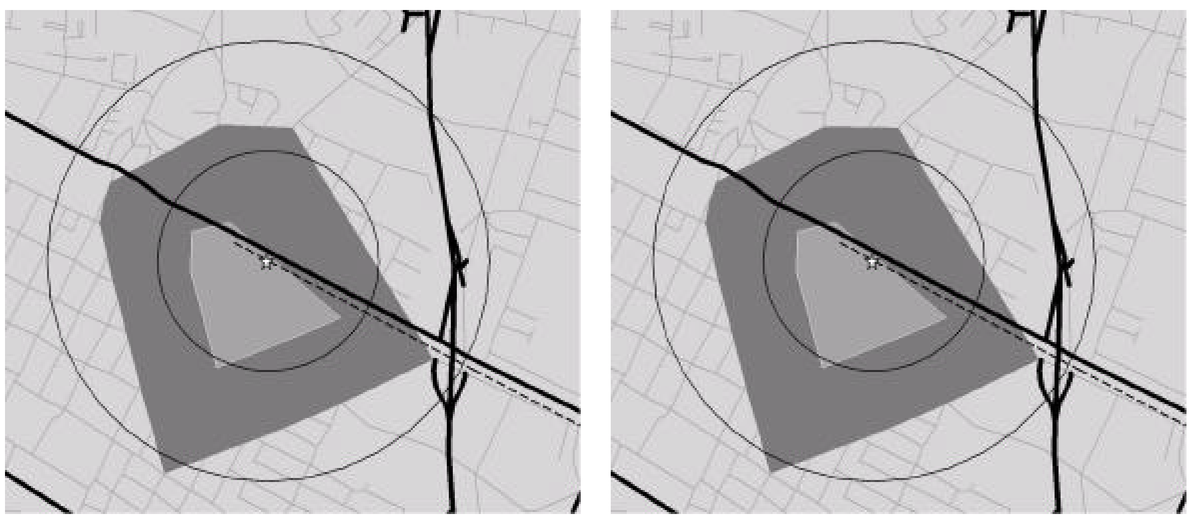


Figure 30 Mountain View Pedestrian and Impeded Pedestrian Catchment Areas

Quantitatively, the PCA at the half-mile shows relatively good pedestrian connectivity and access with scores around 0.50, which indeed captures the general feel of the area (see Table 35). The quarter-mile scores reflect rather limited walkability, reflected in part by the presence of train-oriented parking lots that limited the types of path choice critical to the PCA analysis. The PCA and IPCA scores in 2002 are the same, reflecting a minimal influence of the one impedance road to the area's walkability. The main impedance road (Central Expressway) flows from the southeast to the northwest and is not greeted with any perpendicular impedance roads close to the transit stop. A walkable road exists close to the transit stop that allows a pedestrian to easily cross Central Expressway. Once crossed, there is another pedestrian-friendly road (Willowgate St.) that parallels the expressway, giving broad access to the area near the transit stop. The change over time figures are somewhat meaningful for Mountain View in that the IPCA figure significantly increases from 1992 to 2002, reflecting an effort to make the TOD area consistent with TOD principles.[38]

Table 35 Mountain View Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	**Distance from transit stop (miles)**	
	0.00 - 0.25	0.00 - 0.50
1993		
Pedestrian Catchment Area (PCA)	0.30	0.50
Impeded Pedestrian Catchment Area (IPCA)	0.24	0.25
2002		
Pedestrian Catchment Area (PCA)	0.31	0.48
Impeded Pedestrian Catchment Area (IPCA)	0.31	0.48
1993-2002 change		
Pedestrian Catchment Area (PCA)	0.01	-0.02
Impeded Pedestrian Catchment Area (IPCA)	0.07	0.23
1993-2002 (percent change)		
Pedestrian Catchment Area (PCA)	3%	-4%
Impeded Pedestrian Catchment Area (IPCA)	32%	92%

Intersection Analyses

The majority of intersections are located in the western half of the Mountain View study zone, with areas of higher concentration to the south and west of the transit stop (see Figure 31). Due to the relative lack of major arterials through this area, there is not much visual difference between the intersection map based on all streets and the intersection map based only on minor walkable roads. The most prevalent difference between these two visual displays is the elimination of intersections where minor roads cross with arterials.

Mountain View

Intersection Intensities **Impedance-Based Intersection Intensities**

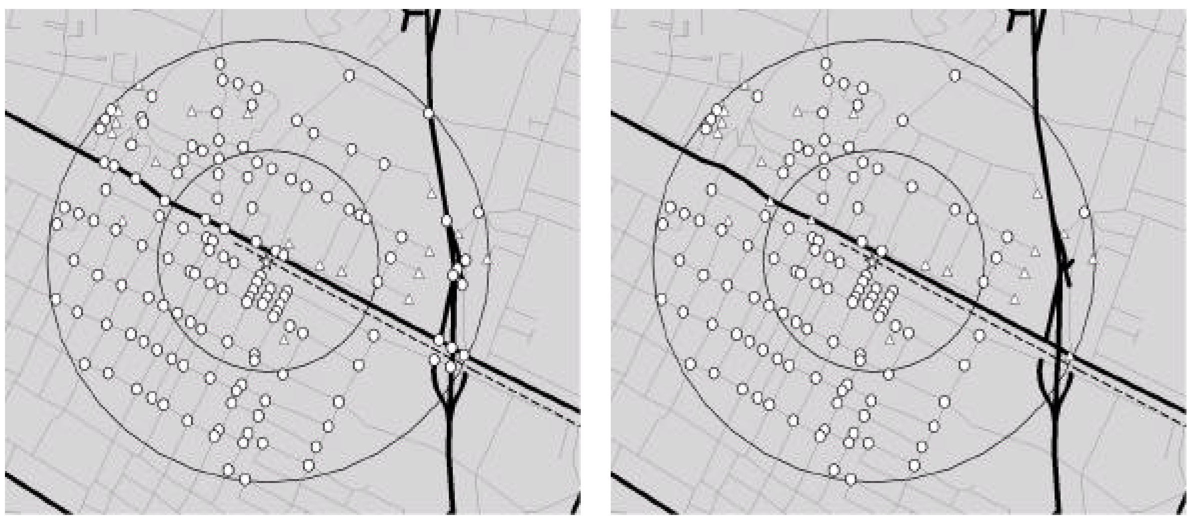


Figure 31 Mountain View Intersection Intensities

From a quantitative approach (see Table 36), minor changes in the street configuration from 1992 to 2002 resulted in a fairly healthy increase in the density of all intersections (36 percent) and in impedance-derived good intersections (26 percent). The absolute figure in 2002 (249.5 intersections per square mile) is quite high, reflecting a generally good pattern of connectivity within the TOD. Also, the density of dead-ends, using both sets of base data, is relatively low, again representing an area characterized by positive connectivity.

Table 36 Mountain View Intersection Intensities

Distance from transit stop	0.00 - 0.25	0.00 - 0.50
1993		
Intersection Density (per sq. mi.)	183.3	157.8
Dead-End Density (per sq. mi.)	20.4	22.9
Impedance-Based Intersection Density (per sq. mi.)	173.1	11.1
Impedance-Based Dead-End Density (per sq. mi.)	25.5	28.0
2002		
Intersection Density (per sq. mi.)	249.5	178.2
Dead-End Density (per sq. mi.)	20.4	24.2
Impedance-Based Intersection Density (per sq. mi.)	218.9	143.8
Impedance-Based Dead-End Density (per sq. mi.)	20.4	26.7
1993-2002		
Intersection Density (per sq. mi.)	66.2	20.4
Dead-End Density (per sq. mi.)	0.0	1.3
Impedance-Based Intersection Density (per sq. mi.)	45.8	12.7
Impedance-Based Dead-End Density (per sq. mi.)	.5.1	-1.3
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	36%	13%
Dead-End Density (per sq. mi.)	0%	6%
Impedance-Based Intersection Density (per sq. mi.)	26%	10%
Impedance-Based Dead-End Density (per sq. mi.)	-20%	-5%

Intersection Surface Map

The intersection surface map illustrates the concentration of good intersections to the west of the transit stop with an area of higher density just to the southwest of the transit stop (see Figure 32). Unlike many of the other TOD areas in this study, in the Mountain View case, the transit stop is actually located immediately within the area of highest connectivity. It is important to note that much of the TOD area to the east is represented by areas of minimal connectivity, in contrast to the notion of a circular zone of development close to transit stops.

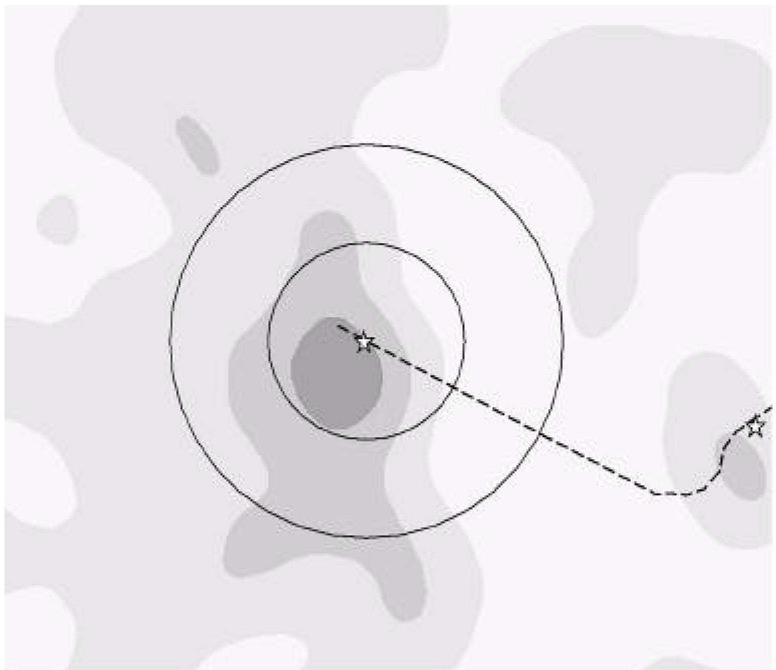


Figure 32 Mountain View Intersection Surface Map

SILICON VALLEY: WHISMAN

Demographics

Whisman, which transformed from a greenfield site to a TOD during the 1990s, saw its population density increase by 1,120 people per square mile, representing an almost 750 percent increase (see Table 37). More than half (62.5 percent) of the population in 2000 was non-white, the average age was 31.5, and the average household income was quite high at almost $112,000.

Table 37 Socio-Demographic Characteristics of Whisman, 1990-2000

Whisman	People	Density (people/ sq. mile)	White	Non-White	Hispanic	Ages 0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	148	159	50.0%	50.0%	0.0%	0.0%	91.2%	4.1%	4.7%	32.0	1.6	$44,531
2000	1,268	1,361	37.5%	62.5%	4.0%	7.4%	66.9%	22.9%	2.8%	31.5	2.3	$111,897
1990-2000	1,120	1,202	-12.5%	12.5%	4.0%	7.4%	-24.3%	18.8%	-1.9%	-0.5	0.7	$67,366

Transit Ridership–Census

Whisman was a greenfield in 1990 and the TOD area came into existence at the end of the 1990s, which explains the lack of journey to work data in 1990 and the low share of non-car uses in 2000 (see Table 38). For the census 2000 data, no train or bus users were recorded, and only a 2.4 percent share of Whisman residents walked or biked as their primary journey to work transportation mode.

Table 38 Whisman, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	0.0%	0.0%	0.0%	0.0%	0.0%
2000	94.7%	0.0%	0.0%	2.4%	2.9%
1990-2000	94.7%	0.0%	0.0%	2.4%	2.9%

Transit Ridership–Valley Transportation Authority

In terms of daily boardings, the absolute numbers at Whisman are quite low (see Table 39), which can be partly explained by the relative newness of the transit stop and the fact that some of the greenfield site has yet to be developed.

Table 39 Whisman, Daily Weekday Boardings, 2000-2002

2000	2002	% Change 2000-2002
90	94	4%

Street Classification

Two immediate observations are apparent when looking at the classification of the street network in the Whisman area (see Figure 33). First, the relative dearth of a street infrastructure is apparent. The open, non-street spaces reflect the slow change in the composition of the area from greenfield site in 1990 to active TOD in 2000. The second observation is the presence of two significant arterials bounding the east and southern portions of the quarter-mile fringe.

Whisman

All Roads **Classified Roads**

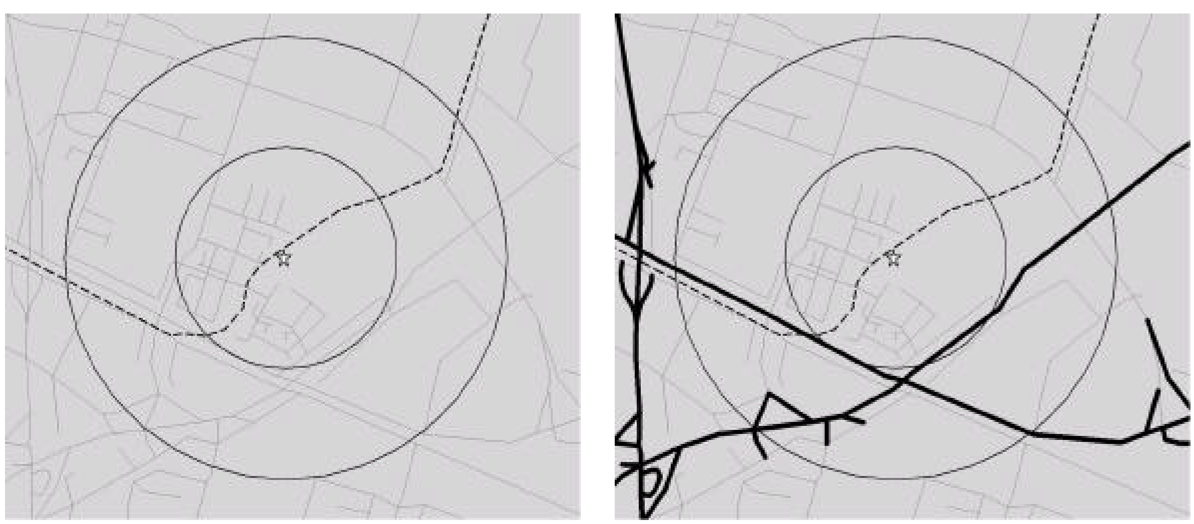


Figure 33 Whisman Street Classification

From a quantitative standpoint, the absolute lengths of minor roads remains quite small while major roads occupy a more significant amount of path type within the Whisman TOD area (see Table 40). Looking at the change over time between 1992 and 2002, the transformation from greenfield to TOD can be seen as the street infrastructure developed. Major roads remained constant over this time, implying that this auto infrastructure existed prior to the development of the area as a TOD. Minor roads, on the other hand, increased quite significantly at the quarter-mile (347 percent). At the half-mile, there was only a small increase in minor roads, which may change as the greenfield site continues to build out.

Table 40 Whisman Street Classification

	Distance from transit stop (miles)	
	0.00 - 0.25	0.00 - 0.50
1993		
Minor Roads (miles)	0.6	6.2
Major Roads (miles)	.04	2.3
2002		
Minor Roads (miles)	2.7	8.5
Major Roads (miles)	0.6	2.5
1993-2002		
Minor Roads (miles)	2.1	2.3
Major Roads (miles)	0.2	0.2
1993-2002 (percent change)		
Minor Roads (miles)	347%	37%
Major Roads (miles)	60%	11%

Catchment Areas

The PCA and IPCA are the same for the Whisman area and both represent relatively poor walkability (see Figure 34). A primary reason for the relatively small coverage areas is the lack of any mobility infrastructure to the east and north of the transit stop. Presumably, this absence of infrastructure will change as empty parcels transform into TOD-aligned development patterns. Also, given the current limited amount of street coverage, the arterials to the south and east of the Whisman transit stop do not come into play; one cannot travel from the transit stop to beyond the arterials in a semi-direct way, resulting in similar PCA and IPCA coverage areas. As the parcels develop, the arterials will have more influence on the likely zones of walkability.

Whisman

PCA–Quarter- & Half-mile **IPCA–Quarter- & Half-mile**

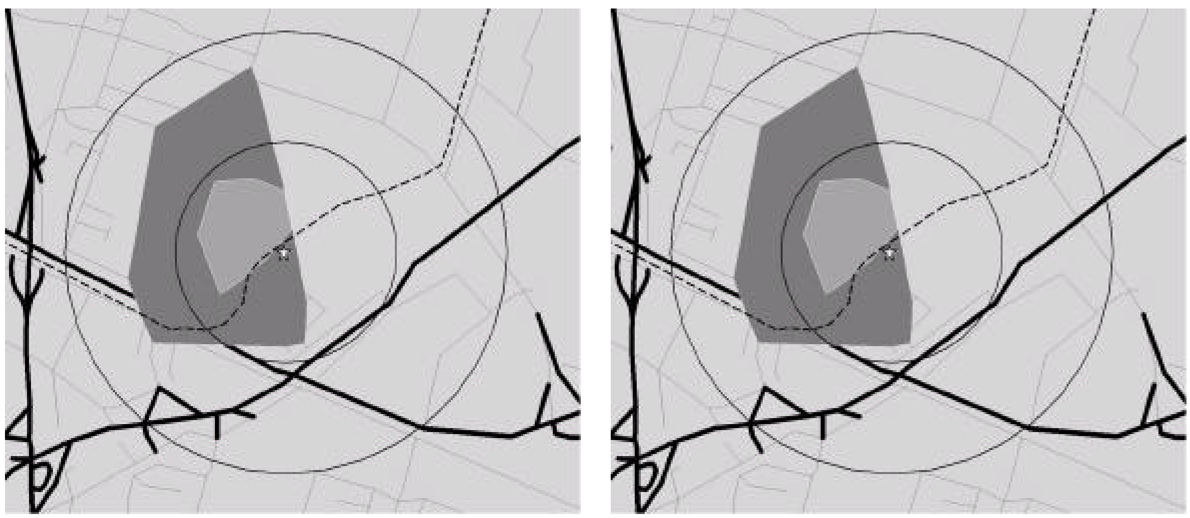


Figure 34 Whisman Pedestrian and Impeded Pedestrian Catchment Areas

For greenfield sites such as Whisman, the quantitative results for the pre-development data point are not meaningful, and consequently, neither is the change over time (see Table 41). What is of interest is the static figure of 2002, which shows poor (and identical) PCA and IPCA scores at the quarter-mile area (0.19) and half-mile area (0.24). Currently, these measures show that Whisman is characterized by an incomplete walkability infrastructure, although this may change as empty parcels develop. Including a subsequent data point (i.e. 2012), will show how changes over time in the alteration of the mobility infrastructure affect the likely zones of walkability from this transit stop.

Table 41 Whisman Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	Distance from transit stop (miles)	
	0.00 - 0.25	**0.00 - 0.50**
1993		
Pedestrian Catchment Area (PCA)	0.20	0.38
Impeded Pedestrian Catchment Area (IPCA)	0.04	0.06
2002		
Pedestrian Catchment Area (PCA)	0.19	0.24
Impeded Pedestrian Catchment Area (IPCA)	0.19	0.24
1993-2002 change		
Pedestrian Catchment Area (PCA)	-0.01	-0.14
Impeded Pedestrian Catchment Area (IPCA)	0.15	0.18
1993-2002 (percent change)		
Pedestrian Catchment Area (PCA)	-5%	-37%
Impeded Pedestrian Catchment Area (IPCA)	326%	319%

Intersection Analyses

As described above, Whisman is characterized by a relative lack of street infrastructure, which necessarily impacts connectivity as illustrated by the presence of good intersections. In the two images below, there is a clear, and relatively dense, collection of intersections in close proximity to the Whisman station (see Figure 35). There are also large swaths of land without any intersections, resulting in lower overall averages. Where development has occurred within this greenfield area, it appears that it is being done with a consideration of walkability principles, represented by the close collection of intersections.

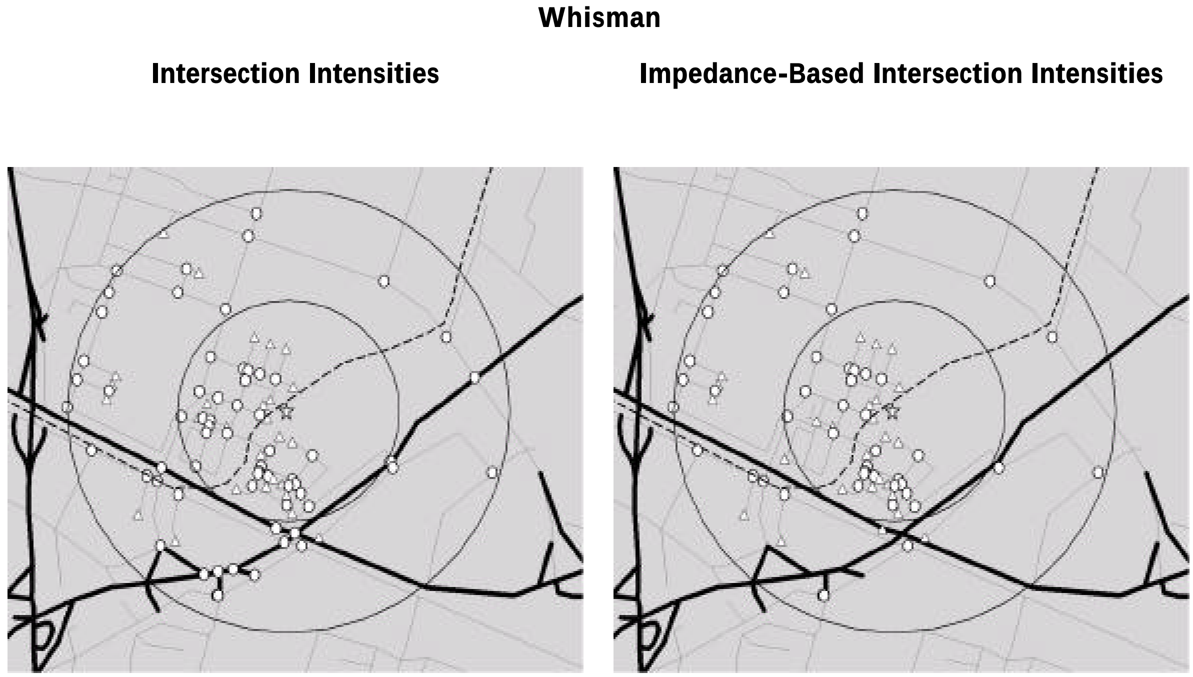


Figure 35 Whisman Intersection Intensities

Perhaps the most significant element of the quantitative calculation of Whisman intersection and dead-end density is the relative low intersection density per square mile, especially as compared to other sites within this study (see Table 42). As mentioned above, however, it is likely that this number will increase as the area is further built out.

Table 42 Whisman Intersection Intensities

Distance from transit stop	**0.00 - 0.25**	**0.00 - 0.50**
1993		
Intersection Density (per sq. mi.)	15.3	47.1
Dead-End Density (per sq. mi.)	0.0	7.6
Impedance-Based Intersection Density (per sq. mi.)	5.1	30.5
Impedance-Based Dead-End Density (per sq. mi.)	5.1	19.1
2002		
Intersection Density (per sq. mi.)	152.7	84.0
Dead-End Density (per sq. mi.)	96.7	34.4
Impedance-Based Intersection Density (per sq. mi.)	122.2	61.1
Impedance-Based Dead-End Density (per sq. mi.)	91.6	35.6
1993-2002		
Intersection Density (per sq. mi.)	137.5	36.9
Dead-End Density (per sq. mi.)	96.7	26.7
Impedance-Based Intersection Density (per sq. mi.)	117.1	30.5
Impedance-Based Dead-End Density (per sq. mi.)	86.5	16.5
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	900%	78%
Dead-End Density (per sq. mi.)	no data	350%
Impedance-Based Intersection Density (per sq. mi.)	2300%	100%
Impedance-Based Dead-End Density (per sq. mi.)	1700%	87%

Intersection Surface Map

The Whisman intersection surface map is quite interesting for two reasons (see Figure 36). First, the areas of highest intersection connectivity are all within a quarter-mile of the transit stop, representing a fairly consistent linkage between theory and practice. This connection is especially encouraging given that the site has been a greenfield development designed explicitly with TOD theory in mind. To have practice reflect the theoretical notions of good urban connectivity represents a positive symbiotic relationship between research and practice. The second interesting component of this image is the relative lack of any street connectivity between a quarter- and half-mile away from this site. This lack of connectivity is due in part to undeveloped parcels of land, which will conceivably be developed in the near future with patterns similar to those already in place.

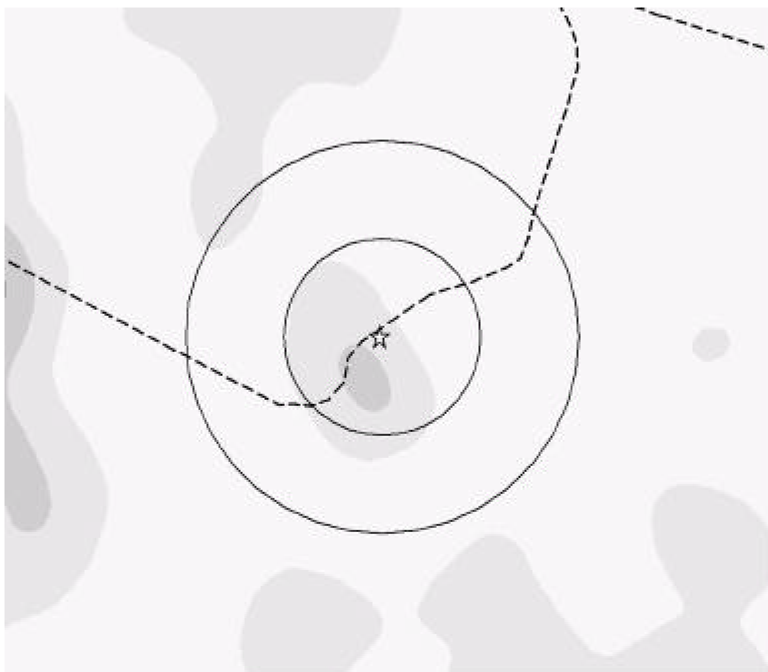


Figure 36 Whisman Intersection Surface Map

SILICON VALLEY: JAPANTOWN/AYER

Demographics

Japantown/Ayer is the only one of the case study sites that actually lost population during the 1990s (see Table 43). In 2000, almost 70 percent of the population was non-white, representing a share shift of 28 percent from white to non-white from 1990 to 2000. The median age, which was already high in 1990, increased substantially in 2000 (+17.5 years) to 58.2 years old. Household size in Japantown/Ayer is also quite low (1.6 in 2000) and average household income is quite low ($9,451 in 2000). Thus, Japantown/Ayer can be characterized as more of a retirement area, represented by an older population with a low (and probably fixed) income.

Table 43 Socio-Demographic Characteristics of Japantown/Ayer, 1990-2000

						Ages						
Japantown/ Ayer	People	Density (people/ sq. mile)	White	Non-White	Hispanic	0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	1,318	6,778	60.0%	40.0%	36.9%	15.3%	38.5%	14.3%	32.0%	40.7	1.8	$7,981
2000	1,022	5,256	32.0%	68.0%	30.4%	1.2%	41.9%	7.7%	49.2%	58.2	1.6	$9,451
1990-2000	-296	-1,522	-28.0%	28.0%	-6.5%	-14.1%	3.4%	-6.6%	17.2%	17.5	-0.2	$1,470

Transit Ridership–Census

According to census data on journey to work, the share of workers reported to have traveled by bus (-5.6 percent) or rail (-2.3 percent) declined from 1990 to 2000, while the share of car utilization (+4.7 percent) increased during this time (see Table 44). The bus ridership share, however, remained relatively strong in 2000 at 17.4 percent. Conversely, the share of pedestrian and bicycle modes increased (+1.7 percent) from a relatively high initial share (9.6 percent to 11.3 percent).

Table 44 Japantown/Ayer, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	60.8%	23.0%	2.5%	9.6%	4.1%
2000	65.5%	17.4%	0.2%	11.3%	5.6%
1990-2000	4.7%	-5.6%	-2.3%	1.7%	1.5%

Transit Ridership–Valley Transportation Authority

In terms of actual boardings at the Japantown light rail stop, there has been a gradual rise in usage over the last eight years, resulting in a 12 percent overall increase since the stop's opening (see Table 45).

Table 45 Japantown/Ayer, Daily Weekday Boardings, 1989-2002

1994	2000	2002	% Change 1994-2002
492	509	550	12%

Street Classification

Figure 37 shows the basic layout of the street pattern in the Japantown TOD area, as well as the spatial presence of impedance roads. This TOD is characterized by a relatively traditional street grid throughout much of the area, especially on the eastern half of the zone. Two main impedance roads exist in parallel with each other, one dissecting the area almost in half and the other at the outer half-mile edge on the west. It is interesting to note that no perpendicular impedance roads exist, thus limiting pedestrian obstacles.

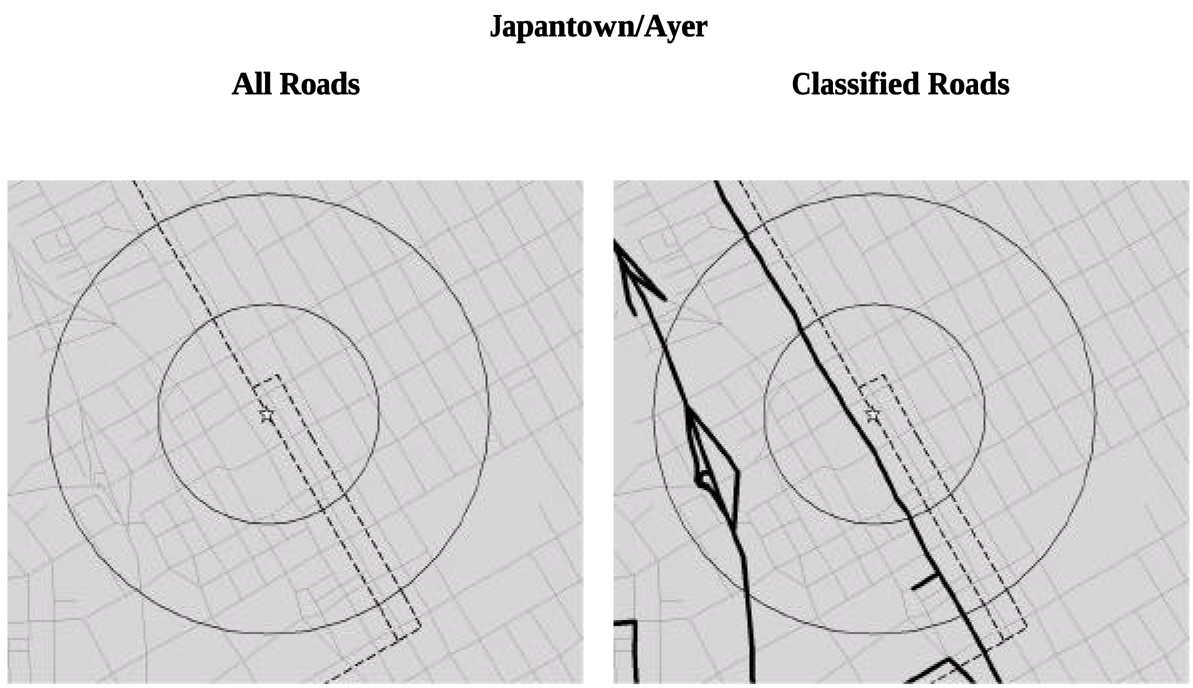


Figure 37 Japantown/Ayer Street Classification

Table 46 quantitatively characterizes the different road types within the Japantown TOD area. The key components of these numbers are: 1) the high proportion of minor to major streets, reflecting the visual representation of the area in the preceding maps; and 2) the classification of these roads did not radically change from 1990 to 2000, leaving intact what appears to be a good, traditional walking and transit-supportive environment. It is also important to note that although the quantity of major roads within a quarter-mile of the transit area did increase by 90 percent from 1990 to 2000, the actual quantity (0.2 miles) is very slight.

Table 46 Japantown/Ayer Street Classification

	Distance from transit stop (miles)	
	0.00 - 0.25	**0.00 - 0.50**
1993		
Minor Roads (miles)	4.6	16.5
Major Roads (miles)	0.3	2.3
2002		
Minor Roads (miles)	4.4	16.5
Major Roads (miles)	0.5	2.3
1993-2002		
Minor Roads (miles)	-0.3	0.1
Major Roads (miles)	0.2	0.1
1993-2002 (percent change)		
Minor Roads (miles)	-6%	0%
Major Roads (miles)	90%	2%

Catchment Areas

The PCA and IPCA at both the quarter- and half-mile distances for the Japantown/Ayer TOD area illustrate exceptional coverage (see Figure 38). The layout of the traditional street grid yields a walkable zone around the transit stop that covers much of the theoretical (circular) zone of interest. Furthermore, the shapes of these polygons are symmetrical, indicating a similar network infrastructure in all directions from the transit stop. Thus, the PCA and IPCA is of both large size and symmetrical shape–the two key indicators of this type of analysis on the walkability of the TOD area.

Japantown/Ayer

PCA–Quarter- & Half-mile **IPCA–Quarter- & Half-mile**

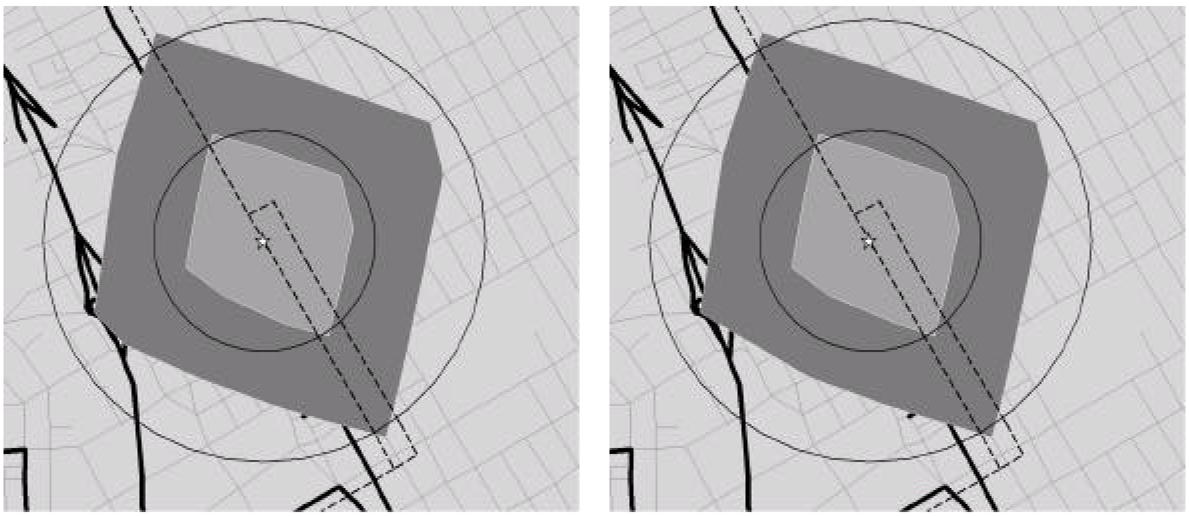


Figure 38 Japantown/Ayer Pedestrian and Impeded Pedestrian Catchment Areas

The Japantown/Ayer TOD area is the only one of the eight case studies in this report that exceeded the theorized minimum score of 0.60 for both the PCA and IPCA at both the quarter- and half-mile distances (see Table 47), quantitatively reflecting the visual analysis made possible by the preceding maps.

Table 47 Japantown/Ayer Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	**Distance from transit stop (miles)**	
	0.00 - 0.25	0.00 - 0.50
1993		
Pedestrian Catchment Area (PCA)	0.61	0.64
Impeded Pedestrian Catchment Area (IPCA)	0.61	0.63
2002		
Pedestrian Catchment Area (PCA)	0.61	0.65
Impeded Pedestrian Catchment Area (IPCA)	0.61	0.64
1993-2002 change		
Pedestrian Catchment Area (PCA)	0.00	0.01
Impeded Pedestrian Catchment Area (IPCA)	0.00	0.01
1993-2002 (percent change)		
Pedestrian Catchment Area (PCA)	1%	1%
Impeded Pedestrian Catchment Area (IPCA)	0%	2%

Intersection Analyses

Figure 39 shows the distribution of intersections and dead-ends across the Japantown/Ayer TOD area. Intersections are spread relatively uniformly and in relative close proximity throughout the study zone. When impedance-derived intersections are removed, there is a loss of intersections in the central part of the study area.

Japantown/Ayer

Intersection Intensities | **Impedance-Based Intersection Intensities**

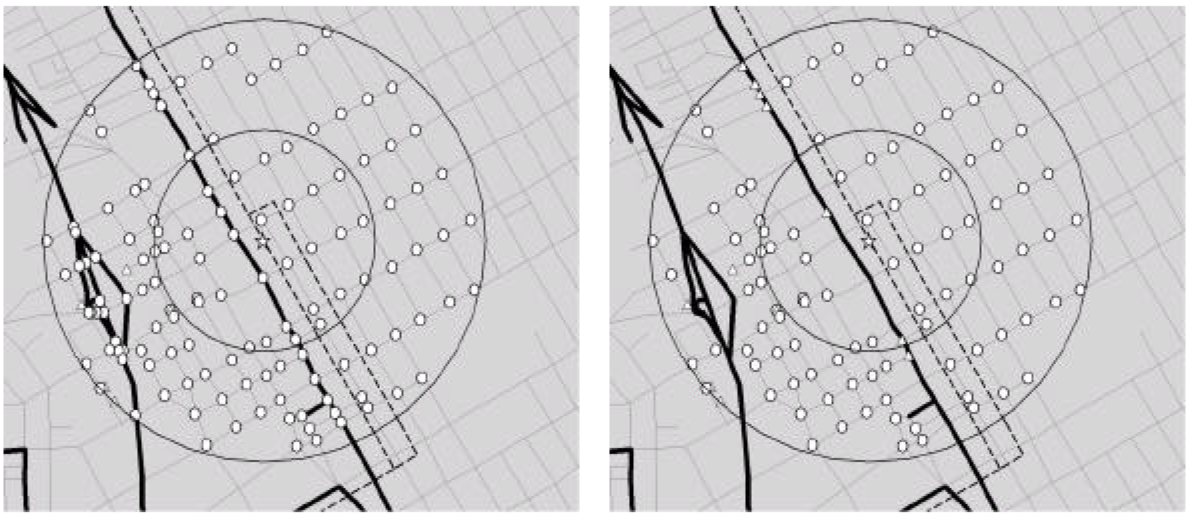


Figure 39 Japantown/Ayer Intersection Intensities

Table 48 quantitatively describes the intersection intensities within the Japantown/ Ayer TOD area. The overall intersection density is both good and consistent between the quarter- (157.8) and half-mile (164.2) distances in 2002. When incorporating the presence of impedance roads, the intersection densities decrease (relatively mildly compared to other case study sites in this report) at both the quarter-mile (-30.5 per square mile) and half-mile (-42.0 per square mile). In terms of dead ends, the Japantown/ Ayer TOD area is characterized by a relatively low dead-end density. Even when incorporating impedance-road derived dead-ends, the density remains quite low at both the quarter-mile (20.4) and half-mile (17.8) in 2002. Thus, this relatively good score on impedance-based intersection density and relatively low score on impedance-based dead-end density, serves to characterize the Japantown/Ayer TOD area as one that successfully achieves good internal connectivity.

Table 48 Japantown/Ayer Intersection Intensities

Distance from transit stop	0.00 - 0.25	0.00 - 0.50
1993		
Intersection Density (per sq. mi.)	162.9	161.6
Dead-End Density (per sq. mi.)	10.2	11.5
Impedance-Based Intersection Density (per sq. mi.)	142.5	119.6
Impedance-Based Dead-End Density (per sq. mi.)	15.3	21.6
2002		
Intersection Density (per sq. mi.)	157.8	164.2
Dead-End Density (per sq. mi.)	10.2	8.9
Impedance-Based Intersection Density (per sq. mi.)	127.3	122.2
Impedance-Based Dead-End Density (per sq. mi.)	20.4	17.8
1993-2002		
Intersection Density (per sq. mi.)	-5.1	2.5
Dead-End Density (per sq. mi.)	0.0	-2.5
Impedance-Based Intersection Density (per sq. mi.)	-15.3	2.5
Impedance-Based Dead-End Density (per sq. mi.)	5.1	-3.8
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	-3%	2%
Dead-End Density (per sq. mi.)	0%	-22%
Impedance-Based Intersection Density (per sq. mi.)	-11%	2%
Impedance-Based Dead-End Density (per sq. mi.)	33%	-18%

Intersection Surface Map

Figure 40 shows an intersection surface map of good intersections within and around the Japantown/Ayer TOD area. This map reinforces the characterizations derived from the previous maps and tables of the street network, the walkable zone, and the spatial allocation of intersections and densities. In this map, much of the area within both the quarter-mile and half-mile zones is characterized by a moderately high level of connectivity (as derived by the density of good intersections). The area just north and west of the transit stop–stretching from within a quarter-mile to beyond a half-mile from the transit stop–however, does not enjoy a similar level of connectivity.

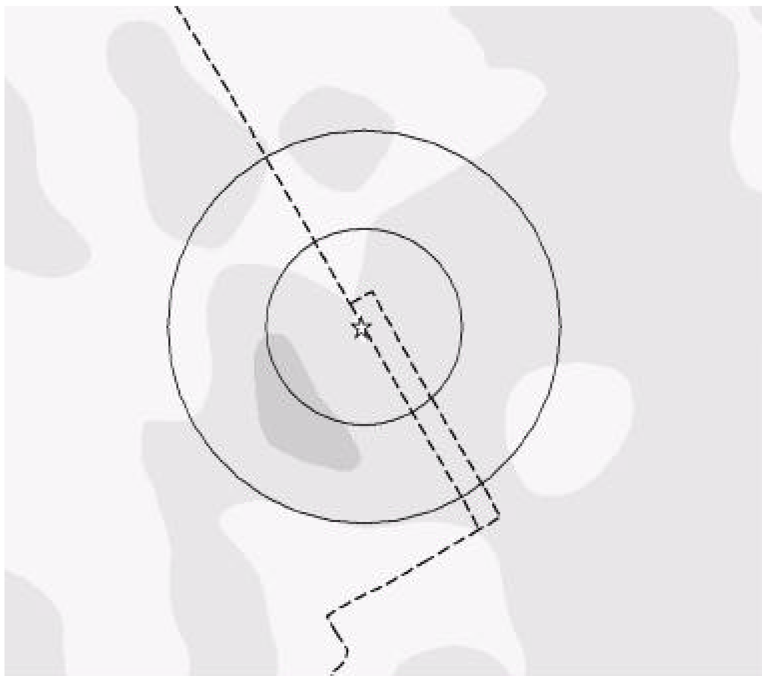


Figure 40 Japantown/Ayer Intersection Surface Map

SILICON VALLEY: BONAVENTURA

Demographics

Bonaventura went from an area with no development and population to an area of significant development during the 1990s (see Table 49). The housing and population boom in this area was characterized by an equal influx of white and non-white persons, people with an average age of 32.5, and with a high median income of almost $100,000.

Table 49 Socio-Demographic Characteristics of Bonaventura, 1990-2000

						Ages						
Bonaventura	People	Density (people/ sq. mile)	White	Non-White	Hispanic	0-17	18-44	45-64	65+	Median Age	Household Size	Average Household Income
1990	7	3	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	42.5	1.0	$23,750
2000	3,699	9,248	50.0%	50.0%	5.7%	3.7%	69.1%	23.9%	3.3%	32.5	2.0	$97,098
1990-2000	3,692	9,245	-50.0%	50.0%	5.7%	3.7%	-30.9%	23.9%	3.3%	-10.0	1.0	$73,348

Transit Ridership–Census

The Bonaventura TOD area had a zero percent share of local residents using the train as the primary means to get to work in 2000 (see Table 50). The share of bus riders declined in half over the decade to 4.3 percent of journey to work trips in 2000. Cycling and walking did increase from zero to a three percent share over the decade, while the car share declined by almost four percent.

Table 50 Bonaventura, Means of Travel to Work, Workers 16+, 1990-2000

	Car	Bus	Train	Bike/Ped	Other
1990	91.5%	8.5%	0.0%	0.0%	0.0%
2000	87.7%	4.2%	0.0%	3.0%	5.1%
1990-2000	-3.8%	-4.3%	0.0%	3.0%	5.1%

Transit Ridership–Valley Transportation Authority

In terms of actual boardings at the Bonaventura light rail stop, the area has seen a 12 percent overall increase in its first eight years of operations, although total numbers are relatively low (see Table 51). The rise in ridership has not been linear, though, with average daily boardings in 2000 below that in 1994 or 2002.

Table 51 Bonaventura, Daily Weekday Boardings, 1994-2002

1994	2000	2002	% Change 1994-2002
352	326	394	12%

Street Classification

Figure 41 shows the street pattern within the Bonaventura TOD area. Two key elements are quickly apparent: 1) the street infrastructure is rather sparse; and 2) a key perpendicular set of impedance roads exists in close proximity to the transit stop. Both of these factors may indicate that the environment is not really suitable for good pedestrian accessibility.

Bonaventura

All Roads **Classified Roads**

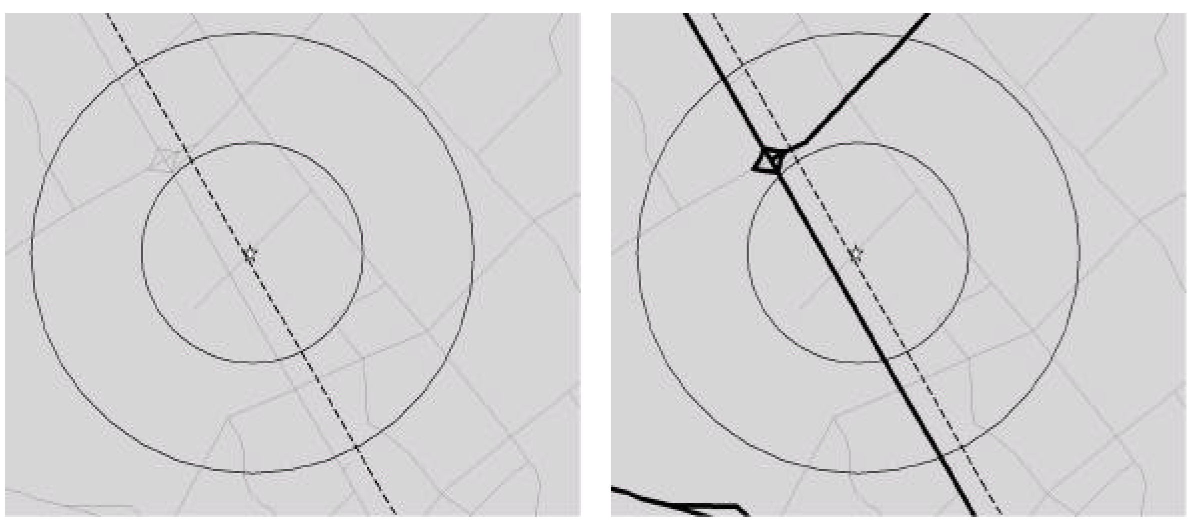


Figure 41 Bonaventura Street Classification

Table 52 quantitatively lists the number and types of street segments within the quarter- and half-mile zones. Indeed, the overall quantity of street paths is extremely low compared to the other case study sites in this report. Moreover, the ratio between minor and major streets is quite poor. At the quarter-mile, there is almost the same amount of major roads (0.5 miles) as minor roads (0.8 miles). At the half-mile, the ratio is better, but still poor at two miles of minor roads for every mile of major.

Table 52 Bonaventura Street Classification

	Distance from transit stop (miles)	
	0.00 - 0.25	**0.00 - 0.50**
1993		
Minor Roads (miles)	0.8	3.5
Major Roads (miles)	0.5	1.2
2002		
Minor Roads (miles)	0.8	3.3
Major Roads (miles)	0.5	1.6
1993-2002		
Minor Roads (miles)	-0.03	-0.26
Major Roads (miles)	0.02	0.39
1993-2002 (percent change)		
Minor Roads (miles)	-4%	-7%
Major Roads (miles)	5%	32%

Catchment Areas

Figure 42 shows the Pedestrian Catchment Areas for Bonaventura, and the presence of impedance roads affects the results quite significantly. For the PCA map, the coverage of the walkable pedestrian zone is decent, especially at the quarter-mile, where it seems that almost half of the theoretical circular TOD zone is covered by the walkable zone. The shapes of the PCA at both the quarter- and half-miles is also somewhat positive, showing decent symmetry, which means that pedestrian coverage extends out from the transit site in all directions. The images change radically for the IPCA, however. Due to the presence of impedance roads, the paths that a pedestrian could travel from the transit stop are quite limited, thereby severely truncating the zone of likely walkability.

Bonaventura

PCA–Quarter- & Half-mile **IPCA–Quarter- & Half-mile**

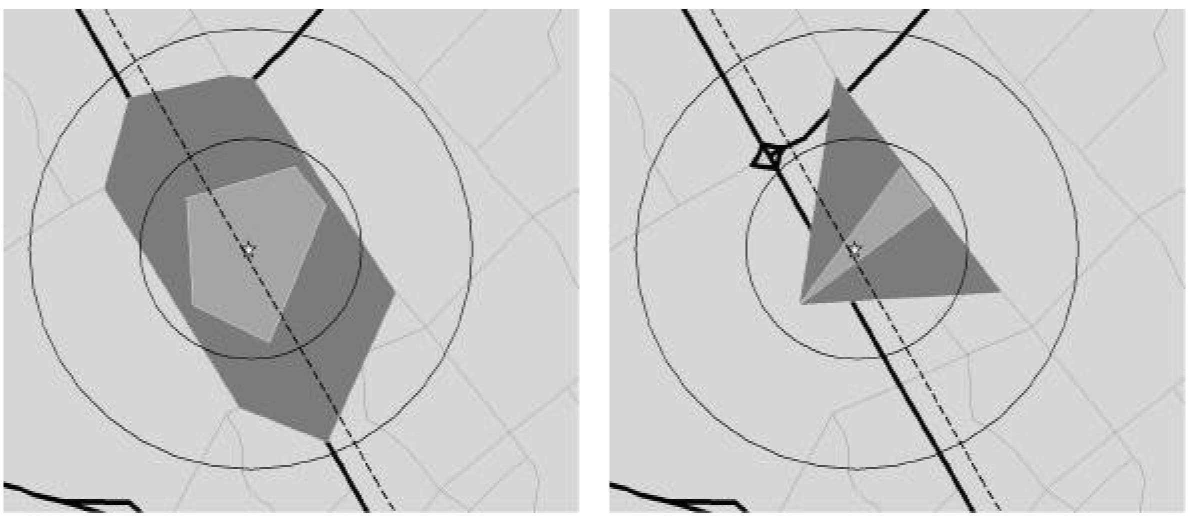


Figure 42 Bonaventura Pedestrian and Impeded Pedestrian Catchment Areas

When treating all roads as equal, the PCA scores are decent at both the quarter-mile (0.42) and half-mile (0.41) (see Table 53). It is important to note that the scores are decent even though the previous maps illustrated a relative lack of path infrastructure in the area. In some ways the PCA analysis can result in a decent score even with a limited path network, as long as those paths are optimally situated. It is important, then, that although the PCA can be an important visualization and measurement tool, it is more effective if used with a combination of other techniques. When the presence of auto-dominant roads is considered for Bonaventura, the walkability measures drop significantly. The IPCA scores are quite low at the quarter-mile (0.11) and half-mile (0.15), reflecting a very poor walking environment when only pedestrian-friendly routes are considered.

Table 53 Bonaventura Pedestrian and Impeded Pedestrian Catchment Areas

Figures are ratios of the network defined pedestrian service area to the theoretical full circle pedestrian service area	**Distance from transit stop (miles)**	
	0.00 - 0.25	0.00 - 0.50
1993		
Pedestrian Catchment Area (PCA)	0.43	0.41
Impeded Pedestrian Catchment Area (IPCA)	0.00	0.36
2002		
Pedestrian Catchment Area (PCA)	0.42	0.41
Impeded Pedestrian Catchment Area (IPCA)	0.11	0.15
1993-2002 change		
Pedestrian Catchment Area (PCA)	0.00	0.00
Impeded Pedestrian Catchment Area (IPCA)	0.11	-0.21
1993-2002 (percent change)		
Pedestrian Catchment Area (PCA)	-1%	0%
Impeded Pedestrian Catchment Area (IPCA)	no data	-58%

Intersection Analyses

Figure 43 shows the location and dispersion of intersections and dead-ends. As expected (given the previous maps on the street network), the presence of good intersections is quite low and diffuse. When eliminating intersections that result when a minor and major road meet (image on the right), the lack of a walkable infrastructure becomes clear.

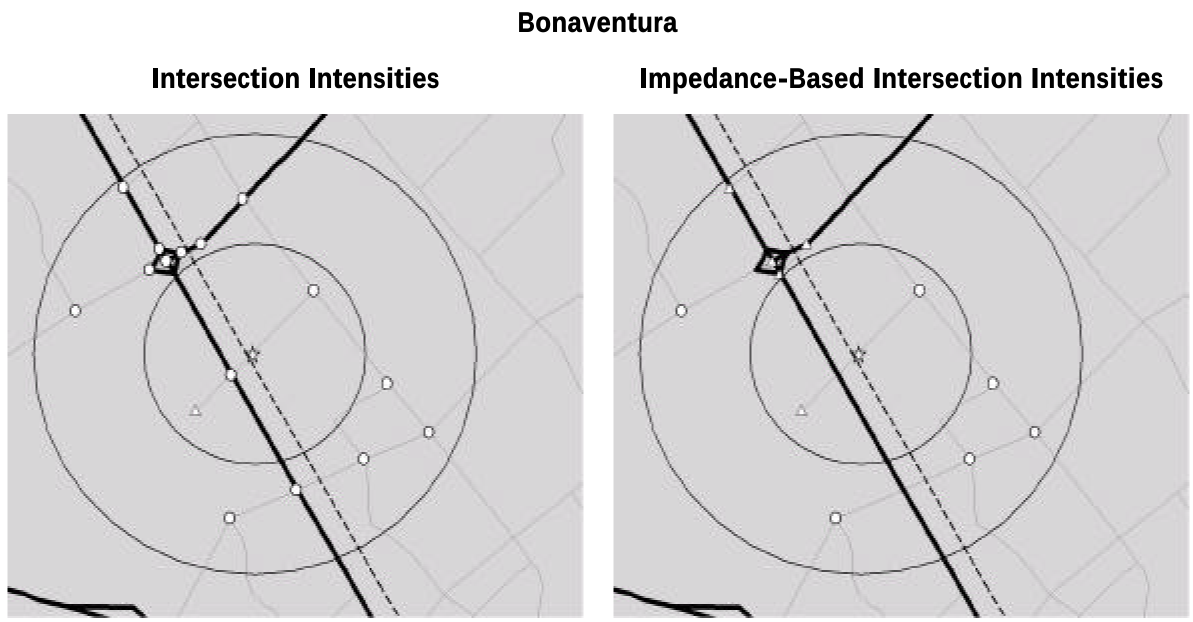


Figure 43 Bonaventura Intersection Intensities

The key figures in Table 54 pertain to the situation in 2002 where the density of intersections is very low, reflecting a real lack of connectivity in the area. The rest of the numbers in this table are not so important given the low n, or the low number of intersections and dead-ends in the area to begin with, making changes over time or comparisons of different intersections or dead-end types not very useful.

Table 54 Bonaventura Intersection Intensities

Distance from transit stop	0.00 - 0.25	0.00 - 0.50
1993		
Intersection Density (per sq. mi.)	10.2	17.8
Dead-End Density (per sq. mi.)	5.1	1.3
Impedance-Based Intersection Density (per sq. mi.)	0.0	7.6
Impedance-Based Dead-End Density (per sq. mi.)	0.0	1.3
2002		
Intersection Density (per sq. mi.)	10.2	19.1
Dead-End Density (per sq. mi.)	5.1	1.3
Impedance-Based Intersection Density (per sq. mi.)	5.1	7.6
Impedance-Based Dead-End Density (per sq. mi.)	5.1	6.4
1993-2002		
Intersection Density (per sq. mi.)	0.0	1.3
Dead-End Density (per sq. mi.)	0.0	0.0
Impedance-Based Intersection Density (per sq. mi.)	5.1	0.0
Impedance-Based Dead-End Density (per sq. mi.)	5.1	5.1
1993-2002 (percent change)		
Intersection Density (per sq. mi.)	0%	7%
Dead-End Density (per sq. mi.)	0%	0%
Impedance-Based Intersection Density (per sq. mi.)	no data	0%
Impedance-Based Dead-End Density (per sq. mi.)	no data	400%

Intersection Surface Map

Finally, Figure 44 shows the connectivity of the Bonaventura TOD area based on the concentration of good intersections. In this case, the image is uniform in shade and is of the lightest shade, indicating that 1) little street connectivity exists within the TOD area; and 2) there are no areas of good walkable infrastructure even in moderate proximity (beyond a half-mile) of the Bonaventura transit stop.

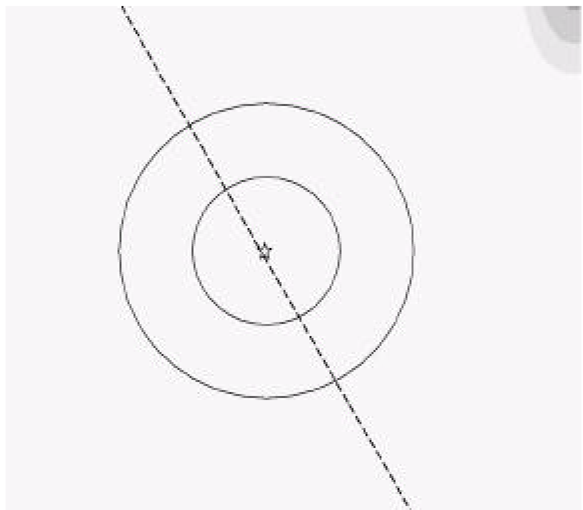


Figure 44 Bonaventura Intersection Surface Map

ANALYSIS

TRANSIT USAGE

Looking at the census-derived transit data at multiple spatial scales can help give insight into the performance of the TOD areas under study as well as the overall transit performance along the entirety of the light rail line. Much of the analysis below focuses more on the Portland region than the Silicon Valley region, although the techniques and types of analyses can be replicated for the Silicon Valley area if desired. Table 55 presents journey-to-work data using the nine Portland spatial scales illustrated in Figure 4. Briefly, those scales are: the four Portland TOD areas, a zone along the light rail line (LRT), the entire area within the urban growth boundary (UGB) but not near the light rail line (Non-LRT), the UGB, the three-county outside of the UGB (Non-UGB), and the entire three county area.

Table 55 Travel Mode, Journey to Work, Workers 16+, Portland Area, 2000

	TOD Supportive Modes*	Bike/Ped	Train	Bus	Car	Other
Orenco	7.4%	2.4%	4.9%	2.5%	86.5%	3.7%
Beaverton	10.9%	5.9%	5.1%	12.1%	72.8%	4.2%
Lloyd	24.5%	21.4%	3.1%	20.8%	50.5%	4.2%
Gresham	9.7%	6.5%	3.2%	3.1%	85.1%	2.1%
LRT	11.8%	8.1%	3.7%	9.0%	74.1%	5.1%
Non-LRT	4.4%	3.6%	0.9%	6.5%	83.7%	5.4%
UGB	5.6%	4.3%	1.3%	6.9%	82.3%	5.3%
Non-UGB	2.8%	2.5%	0.3%	1.0%	89.5%	6.8%
Tri-County	5.3%	4.1%	1.2%	6.4%	83.9%	5.4%

* Combination of “Bike/Ped” and “Train” Categories

Looking at Table 55, many interesting patterns emerge. Perhaps the most significant pattern is that each of the TOD sites (and the area along the light rail line in general) can attribute over 10 percent of its work trip modal share to train usage, biking, or walking– the three key modes of travel for TOD areas. For the area within the entire UGB, only about five percent of trips are attributed to these three categories. Thus, it appears that development in close proximity to light rail does in fact have a positive correlation with non-automobile modes of travel.

In terms of the Portland TOD areas, the Lloyd Center had the most non-auto trips and Beaverton had the highest light rail usage. The Lloyd Center also has a very high bike/ped share of travel mode, reflecting both its proximity to the urban core and the general walkability of its area based on the connectivity and pattern of its road infrastructure.

Orenco Station and Gresham, both of which are relatively distant from downtown Portland, had similar (to each other) and high rates of automobile usage–higher than even the non-LRT areas. Orenco Station, however, does have a high modal share of train usage compared to all the other spatial categories, which is most likely explained by the explicit TOD emphasis placed on that greenfield development site. Moreover, the area of Orenco Station that has been built is actually fairly distant from the transit stop (beyond a quarter-mile), so as the Orenco area sites closer to the transit stop fill in, it is likely that this share of trips made by light rail will increase substantially.

Looking at the differences between people who live near the transit line versus those who live further away (but within the UGB) is also quite interesting. Living close to the transit line results in nine percent fewer work trips made by the car, three-and-a-half percent more trips made by bus, three percent more trips made by light rail, and four-and-a-half percent more trips made by foot or bike. Thus, it seems that proximity to light rail and buses does indeed reduce the overall percentage of automobile-oriented work trips, although proving such causality is not the primary intention of this research.

It is also instructive to look at the differences between the UGB and Non-UGB areas. One would expect that locations outside the UGB would have less access to transit and residents would be less likely to walk or bike to work, and indeed this is the case. Seven percent more trips outside the UGB are made by car, and there is very little transit use at all.

Looking at the change over time is also quite interesting (see Table 56). As mentioned previously, the transformation from a relatively undeveloped, greenfield area into the Orenco Station TOD resulted in a significant decrease in the percentage share of work trips made by car. Looking at all four Portland sites however, Lloyd Center and Gresham both performed worse in 2000 compared to 1990 than any other regional spatial measure. In the Lloyd Center, the share for car use dropped only slightly and in Gresham, the car use share actually increased, representing the only one out of the nine spatial measures where the share of car usage went up as a percentage of the modal split from 1990 to 2000. On the other hand, walking and biking shares increased four percent in the Lloyd Center, building on an already high modal split percentage.

Table 56 Changes in Travel Mode Shares, Journey to Work, Workers 16+, Portland Area, 1990-2000

	TOD Supportive Modes*	Bike/Ped	Train	Bus	Car	Other
Orenco	7.4%	2.4%	4.9%	2.5%	-13.5%	3.7%
Beaverton	4.4%	-0.6%	5.1%	4.6%	-8.4%	-0.6%
Lloyd	4.5%	4.0%	0.5%	-4.7%	-0.5%	0.7%
Gresham	1.0%	-0.1%	1.1%	1.2%	1.3%	-3.5%
LRT	1.3%	-1.1%	2.4%	0.9%	-2.5%	0.3%
Non-LRT	0.7%	0.1%	0.6%	-0.2%	-1.5%	0.9%
UGB	0.6%	-0.2%	0.9%	0.0%	-1.4%	0.8%
Non-UGB	-0.1%	-0.1%	0.0%	0.4%	-0.2%	-0.1%
Tri-County	0.6%	-0.2%	0.8%	0.1%	-1.4%	0.7%

* Combination of “Bike/Ped” and “Train” Categories

Living near the light rail line led to a two-and-a-half percent increase in train usage and a corresponding two-and-a-half percent decrease in auto-oriented work trips during the decade. Modal split did not really differ for those living within the UGB compared to those outside the UGB as most modal shares changed less than 1 percent from 1990 to 2000.

DEMOGRAPHIC CHARACTERISTICS

Table 57 and 58 list the demographic characteristics of the Portland area at the nine spatial scales for both 2000 and for the period 1990-2000. Looking at the 2000 data, all four Portland case study TOD areas are lower in population density than the light rail area in general (which is to be expected since none of the case study sites are located in the downtown core) and all (except Orenco) are denser than the non-light rail areas within the UGB. As a greenfield development, Orenco Station is likely to quickly surpass the general population density within the UGB as more planned development units are built.

Orenco Station and Beaverton both have younger median ages than the other sites and younger than any of the other spatial units of analysis. The Lloyd Center by far has the oldest median age and the smallest average household size.

In 2000, those living close to light rail were more ethnically diverse and had a higher Hispanic population than those living further from light rail. Those living near light rail tended to have fewer youth, but more young professional age residents. And those living near light rail were on average seven years younger than those living away from light rail. In terms of household income, those living near light rail had lower incomes (almost by half) than those who did not live in close proximity to light rail.

In terms of change over time, the entire Portland region became more ethnically diverse between 1990 and 2000, but areas closer to light rail and three of the four case study sites became more diverse than the region as a whole. In the TOD areas, and in the light rail area in general, the population became younger over the decade, in contrast to the rest of the region, which became substantively older. Household size increased in three of the four TOD areas and along the light rail line in general in contrast with the region as a whole, which remained relatively stable in terms of age. This age and household size difference between light rail areas and the rest of the region may imply an attraction of the more urban, transit friendly environments to young, working families. Interestingly, household income increased in each of the four case study sites, but did not increase for the light rail region as a whole over the decade. Also, incomes at each TOD site were less than the increase experienced in non-light rail areas within the UGB.

The combination of these trends–younger age, higher income, and more transit, biking and walking use compared to the larger region–most likely implies that the development of transit-accessible areas is attracting young professionals who are desirous of such an environment. That is, an in-migration of individuals or families who deliberately choose transit-friendly environments is occurring, thereby allowing for a greater proportion of Portland residents to exercise their self-selected choice of living environments. If the increased train, bike, and foot usage were due to the construction of the TOD environments, one would see average ages remaining stable over time or increasing as people age in place. That the average age declined substantially over the decade, and that the 18-44 age cohort experienced the biggest increases in numbers, implies that people are moving into these TOD areas explicitly for the transit-oriented amenities the environments offer.

Table 59 and Table 60 summarize the demographic data for the Silicon Valley TOD areas and other spatial scales. In contrast to the Portland area, population density close to the light rail is less in Silicon Valley than the population density of areas further away from the light rail line. And of the case study TOD areas, only Bonaventura has a population density above the average for the light rail line (and remember that the walking infrastructure within the Bonaventura area was the poorest of all the Silicon Valley sites). In terms of ethnicity, the Santa Clara urbanized area is slightly more non-white than white, which is also reflected in the areas close to the light rail as well as areas further away. Of the four Silicon Valley TOD areas, only Whisman has a majority white population, while Bonaventura is evenly split. The median age for the entire region is about 34 years of age, with both Mountain View (40) and Bonaventura (58) exceeding the countywide average.

In terms of change over time, the area outside of the light rail line, but within the urbanized area actually become denser in terms of population than those areas within a quarter-mile of the light rail line–a clear disconnect between TOD theory and practice. Three of the four TOD areas (all except Japantown/Ayer), however, did increase in population density, although two of those sites were undeveloped land in 1990. The share of the non-white population increased at all spatial scales between 1990 and 2000. Median age remained somewhat constant for most spatial scales, although Japantown/Ayer added 17.5 years to its median age, indicating that it is increasingly a place for retirees. Japantown/Ayer is characterized by the best walking environment, as delineated by the maps and tables previously discussed, which indicates an appropriate connection between urban form and the mobility needs of the local residents.

Table 57 Socio-Demographic Characteristics of Portland Area, 2000

						Age					Household	
	People	Density (people per sq. mi)	White	Non-White	Hispanic	0-17	18-44	45-64	65+	Median Age	Size	Average Income
Orenco	7,976	1,747	80%	20%	7%	27%	53%	17%	3%	29.9	2.6	$61,177
Beaverton	15,957	4,065	72%	28%	22%	21%	51%	16%	12%	29.1	2.3	$36,728
Lloyd	4,683	3,784	78%	22%	5%	7%	56%	18%	19%	41.6	1.7	$32,303
Gresham	3,715	3,338	78%	22%	21%	25%	46%	17%	12%	31.3	2.5	$32,357
LRT	199,812	4,218	78%	22%	13%	22%	47%	20%	11%	33.6	2.3	$34,890
Non-LRT	1,120,120	11,976	82%	18%	7%	24%	42%	23%	10%	40.2	2.5	$58,401
UGB	1,319,932	1,976	82%	18%	8%	24%	43%	22%	10%	40.2	2.5	$58,401
Non-UGB	124,287	52	93%	7%	6%	27%	35%	27%	10%	39.5	2.8	$49,696
Tri-County	1,444,219	470	83%	17%	8%	25%	42%	23%	10%	39.5	2.5	$49,676

Table 58 Socio-Demographics Change, Portland Area, 2000

						Age					Household	
	People	Density (people per sq. mi)	White	Non-White	Hispanic	0-17	18-44	45-64	65+	Median Age	Size	Average Income
Orenco	4,455	1,270	-18%	18%	5%	-1%	9%	-6%	-2%	-2.8	-0.2	$16,864
Beaverton	2,663	781	-14%	14%	18%	2%	-1%	2%	-3%	-2.2	0.3	$7,961
Lloyd	3,047	1,739	-6%	6%	3%	2%	13%	11%	-26%	-7.1	0.3	$10,602
Gresham	938	843	-16%	16%	15%	-2%	4%	2%	-5%	-1.4	0.2	$6,931
LRT	21,184	1,506	-12%	12%	8%	1%	-1%	3%	-3%	-1.8	0.1	$114
Non-LRT	233,194	320	-7%	7%	5%	-1%	-3%	5%	-2%	5.4	0.0	$20,621
UGB	254,378	370	-8%	8%	5%	0%	-3%	5%	-2%	5.3	0.0	$21,154
Non-UGB	15,550	7	-4%	4%	2%	-2%	-5%	7%	0%	4.6	-0.1	$8,869
Tri-County	269,928	88	-8%	8%	5%	0%	-3%	5%	-2%	4.6	0	$12,072

Table 59 Socio-Demographic Characteristics, Silicon Valley, 2000

	People	Density (people per sq. mi)	White	Non-White	Hispanic	Age					Household	
						0-17	18-44	45-64	65+	Median Age	Size	Average Income
Mountain View	1,940	6,824	63%	37%	9%	4%	62%	28%	5%	40.3	1.7	$64,351
Whisman	1,268	1,361	38%	63%	4%	7%	67%	23%	3%	31.5	2.3	$111,897
Bonaventura	3,699	9,248	50%	50%	6%	4%	69%	24%	3%	32.5	2.0	$97,098
Japantown	1,022	5,256	32%	68%	30%	1%	42%	8%	49%	58.2	1.6	$9,451
LRT	155,855	7,952	46%	54%	28.8%	22.5%	44.7%	24.9%	7.9%	34	2.7	$67,989
Non-LRT	1,043,917	9,353	49.3%	50.7%	25.9%	-1%	41.8%	23.4%	10.3%	33	2.6	$84,764
Urbanized Area	1,199,772	9,151	49.7%	50.3%	26.6%	0%	46.4%	19.9%	8.8%	34	2.6	$70,243
Santa Clara County	1,682,585	1,304	53.8%	46.2%	21.4%	0%	44.7%	21.0%	9.5%	34	2.9	$74,335

Table 60 Socio-Demographics Characteristics Change, Silicon Valley, 1990-2000

						Age					Household	
	People	Density (people per sq. mi)	White	Non-White	Hispanic	0-17	18-44	45-64	65+	Median Age	Size	Average Income
Mountain View	446	1,569	-9%	9%	-14%	-10%	4%	11%	-4%	7.2	-0.6	$26,572
Whisman	1,120	1,202	-12%	13%	4%	7%	-24%	19%	-2%	-0.5	0.7	$67,366
Bonaventura	3,692	9,245	-50%	50%	6%	4%	-31%	24%	3%	-10	1.0	$73,384
Japantown	-296	-1,522	-28%	28%	-7%	-14%	3%	-7%	17%	17.5	-0.2	$1,470
LRT	16,701	871	-25%	25%	3.5%	0.1%	-1.4%	2.1%	-0.8%	0.0	-0.1	$27,792
Non-LRT	76,912	689	-15.8%	15.8%	3%	-0.4%	-1.9%	0.0%	2.3%	0.0	0.6	$35,904
Urbanized Area	93,613	716	0.0%	0.0%	3.4%	0.3%	0.0%	-1.1%	0.8%	0.0	-0.36	$22,592
Santa Clara County	185,008	150	-15.1%	15.1%	0.4%	0.8%	-1.6%	0.0%	0.8%	0.0	0.0	$26,220

Table 61 and Table 62 add one additional variable to the analysis mix: number of households. In a densifying area, especially in areas explicitly identified to be densified such as TOD areas, one would expect the household density to increase. This increase could be attributed to one of two things: an increase in the construction of new units or the subdivision of existing units into more, but smaller units. In either case, the result is a capacity to increase the number of people living in a given space over time.

Table 61 shows just such a pattern in the Portland area. In terms of absolute number of households, the Beaverton TOD area has the highest number.[39] In terms of household density in 2000, however, the Lloyd Center was the densest. That the Lloyd Center was the densest in 2000 is not surprising given the relative urban location, close to downtown Portland, that it occupies. Household density in closer proximity to the light rail line was more than twice as high compared to areas more than a quarter-mile away, but still within the Urban Growth Boundary (UGB). And, as one would expect (and hope), household density is significantly higher within the UGB than outside of it. In terms of average people per household, the Lloyd Center is the only spatial scale to be under two (1.7), while Orenco Station had the highest (2.6) people per household of any of the four case study sites. There is no real difference in household size compared to the location of the light rail line.

Perhaps of more interest is the direction and magnitude of change in household density over the 1990s. Orenco Station, a greenfield development initiated during the 1990s, saw an increase in household density of 288 percent–a figure partly attainable due to relatively low initial 1990 numbers (not shown), but impressive nonetheless. Perhaps more impressive is the household densification of the Lloyd Center (+140 percent), since it has been an urbanized and developed area for a long time. Areas in close proximity to light rail had a higher household densification (+49 percent) compared to areas beyond the light rail line (+10 percent), and overall, the areas within the UGB had a slightly higher rate of household densification (+22 percent) compared to areas outside of the UGB (+19 percent).

Table 62 shows mixed results in terms of densification of households. In three of the four case study TOD areas, household density did increase from 1990 to 2000 (Japantown saw a decrease). In contrast to the Portland area, however, areas further from the light rail line grew more dense (+20 percent) in terms of households per area than those locations closer to the light rail line (+18 percent).

Table 61 Change in Household Density and Size, Portland, 1990-2000

	2000				1990-2000 (percent change)			
	People	Households (HH)	HHs/sq. mi.	People/HH	People	Households (HH)	HHs/sq. mi	People/HH
Orenco	7,976	3,051	668	2.6	127%	140%	288%	-6%
Beaverton	15,957	6,832	1,740	2.3	20%	7%	10%	12%
Lloyd	4,683	2,799	2,262	1.7	186%	140%	55%	19%
Gresham	3,715	1,466	1,317	2.5	34%	25%	25%	7%
LRT	199,812	85,817	1,811	2.3	12%	7%	49%	5%
Non-LRT	1,120,120	439,725	709	2.5	26%	15%	10%	10%
UGB	1,319,932	525,542	787	2.5	24%	23%	22%	1%
Non-UGB	124,287	43,919	18	2.8	14%	19%	19%	-4%
Tri-County	1,444,219	569,461	185	2.5	23%	22%	22%	0%

Table 62 Change in Household Density and Size, Silicon Valley 1990-2000

	2000				1990-2000 (percent change)			
	People	Households (HH)	HHs/sq. mi.	People/HH	People	Households (HH)	HHs/sq. mi	People/HH
Mountain View	1,940	1,175	4,134	1.7	30%	79%	79%	0%
Whisman	1,268	541	581	2.3	757%	488%	488%	46%
Bonaventura	3,699	1,834	4,584	2.0	52,743%	26,094%	163,612%	102%
Japantown	1,022	636	3,271	1.6	-22%	-11%	-11%	-13%
LRT	155,855	58,813	3,001	2.7	12%	17%	18%	-5%
Non-LRT	1,043,917	401,507	3,597	2.6	-8%	20%	20%	-10%
Urbanized	1,119,772	456,187	3,479	2.6	8%	20%	20%	-9%
Non-Urbanized	482,813	165,347	1,545	2.9	23%	17%	17%	5%
County	1,682,585	576,228	447	2.9	12%	11%	11%	1%

WALKABILITY COMPARISON

Table 65 presents the quantitative walkability results for each Portland TOD at both the quarter- and half-mile scale. One of the most immediately interesting results is the high level of intersection density for the Orenco Station area (244 per square mile) at the quarter-mile distance. This high density in 2000 is testament to the explicit TOD design that this greenfield development employed. Moreover, new developments, close to the transit stop, with their own internal street networks are currently under construction and will inevitably push this intersection density higher over the next decade. Intersection density remains high in the half-mile area and is joined by the Lloyd Center as the two highest scoring urban forms in terms of internal connectivity. By contrast, the Lloyd Center scores the worst in connectivity at the quarter-mile distance where much of the space is occupied by a large parking lot and shopping mall, decreasing the internal connectivity of the space.

When the presence of auto-oriented roads is considered, Orenco Station's internal connectivity remains high with a quarter-mile intersection density above 200, and a half-mile density just below 200 intersections per square mile. In contrast, Beaverton's quarter-mile intersection density is about 150 when all streets are considered equal. However, when arterials serving as barriers are considered, the quarter-mile intersection density drops significantly to only 20 intersections per square mile. From a pedestrian point of view, therefore, Beaverton offers almost no path choice within a quarter-mile of the transit stop–exactly counter to the goals of TOD development. Of the four Portland TOD areas, only Orenco and Lloyd perform well at the half-mile radius when considering the impact of impedance roads on street connectivity.

The capacity to have good internal connectivity is dependent on the presence of an adequate number of roads, especially minor roads. Minor roads are more likely to be walkable than major roads. At the quarter-mile, both Orenco and Gresham have relatively high levels of internal streets, while at the half-mile, Orenco and Lloyd have the most local streets. The ratio between minor and major roads is also instructive in understanding the walking friendliness of each TOD. Table 63 and Table 64 show the actual ratios between minor and major roads in each TOD area with higher ratios representing more pedestrian-friendly environments. In the pedestrian-unfriendly Beaverton, for example, there are actually more auto-oriented roads than minor roads within a quarter-mile of the transit stop, resulting in a ratio that is less than one. At the Lloyd Center, there is also a substantive quantity of major roads–about the same as Beaverton, although because Lloyd Center has more local roads, its ratio at the quarter-mile is above one. In contrast, there are almost no major roads within the Orenco Station area at either scale and Gresham also has a positive ratio between minor and major roads. As a result, Orenco has very high ratios at both geographic scales, and Gresham has a disproportionately high ratio at the quarter-mile–the distance of primary importance according to TOD theory and thought.

Table 63 Minor to Major Road Ratio, Portland, 2000

	Quarter Mile	Half-Mile
Beaverton	0.9	2.2
Orenco	8.9	6.1
Lloyd	1.6	2.1
Gresham	4.9	2.6

Table 64 Minor to Major Road Ratio, Silicon Valley, 2000

	Quarter Mile	Half-Mile
Mountain View	7.2	5.6
Whisman	4.7	3.4
Bonaventura	1.6	2.0
Japantown/Ayer	8.9	7.1

Table 65 and Table 66 list all the walkability measures for each TOD area. Looking at impedance-based dead-end densities (both true dead-ends and "virtual" dead-ends from a pedestrian point of view), Beaverton again emerges as a pedestrian-unfriendly location, with four times as many dead-ends as intersections within a quarter-mile of the transit stop. At the half-mile, Beaverton's impedance dead-end density is fairly consistent with the other Portland TOD areas, indicating a marked improvement in the street connectivity as one goes further out from the transit stop.

Finally, the Pedestrian Catchment Area (PCA) scores clearly represent the walkable nature of each of the Portland TOD areas. Of the eight scales (four sites x two scales), only Gresham and

Japantown meet the minimum desired ratio of 0.6 as determined by the Congress for New Urbanism.[40] That said, in walking the areas surrounding Gresham and Lloyd, both feel fairly pedestrian-friendly in terms the amount of both intersections and paths available, so it may be that a ratio near or above 0.50 is a more accurate representation of good walkable urban form. With such a measure, both Orenco Station (0.26/0.39) and Beaverton (0.21/0.41) are categorized by the PCA as being less than ideal. In Orenco Station, even though it scores well in quantity of minor streets and internal connectivity, the PCA performs poorly because there really is only one access path leading north from the transit stop. Thus, to get south of the transit stop, one first needs to travel north to the nearest intersection. This unidirectional path choice negatively restricts one's capacity to travel a full quarter-mile in any direction from the transit station. And although this negative urban form is likely to be "fixed" as new developments and internal street grids are developed, the PCA result for Orenco demonstrates the importance of a variety of exit or entry points from a given transit stop, especially from a pedestrian point of view.

Beaverton's PCA score suffers from similar phenomena to that of Orenco Station, with only one exit point emanating from the transit stop. There is currently new construction on the opposite side of the transit station, so it is likely that this PCA score would improve in a future iteration. That said, Beaverton's IPCA score–the distance one is likely to travel solely on pedestrian-friendly routes–is not likely to improve over time unless major alterations to the street network are undertaken. Beaverton's IPCA score is zero, meaning that it is impossible to get to or from the Beaverton transit stop without walking along a major auto-oriented road. There is a current development being constructed called "The Round" immediately adjacent to the transit stop that presumably will serve as a destination for some workers and shoppers. But, to travel by foot beyond "The Round" (about one-eighth of a mile), one would be confronted with a network of wide, intersecting streets with heavy volumes. It is therefore unlikely that this stop will represent a destination for anyone traveling in any way other than car or train, because it is simply too hostile an environment to reach by foot or bike.

Of the eight TOD areas, only Gresham and Japantown maintain a relatively high IPCA score (0.54/0.47), meaning that there is a relatively light presence of major roads close to the transit stop. This mobility infrastructure of Gresham is quite interesting given that it is the terminus for the eastern portion of the light rail line. As the terminus point, it could be a stop surrounded by a series of large park-and-ride lots. While there is such a lot close to the transit stop, the remaining urban form is quite conducive and consistent with the walkability principles inherent in TOD theory.

IPCA scores for Orenco station are of special interest as well. The new greenfield developments within Orenco Station have a high degree of internal connectivity and have been designed with pedestrian principles in mind. However, as of 2000, in order to reach these developments, one had to either cross or walk along a major auto-oriented road, thereby creating a disconnect between the internal connectivity of a development and the spatial proximity of such a development to the transit station. This spatial disconnect is represented in the low IPCA score for Orenco (0.16/0.14).

By looking at these eight different measures of the mobility infrastructure, one can begin to gain a more nuanced appreciation of the spatial context and the pedestrian friendliness of each environment. Knowing the quantity of local roads is important and understanding their internal connectivity measured by intersections can make the analysis more insightful. While this internal connectivity is important, a truer connectivity can be determined by introducing a hierarchy of street types identifying pedestrian-friendly and pedestrian-hostile environments. And finally, understanding the spatial proximity and access between areas of high connectivity and the transit location provides another indication of how well connected the theories of TOD development are with the built environments that are implemented. The following chapter will continue these themes, but through a visual analysis that provides additional clarity on the relationship between these individual measurements and between the collection of measurements and the resulting spatial performance.

Table 65 Comparative Walkability Analysis, Portland, 2000

	Beaverton Central		Orenco Station		Lloyd District		Gresham Central Transit	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**	**0.00-0.25**	**0.00-0.50**	**0.00-0.25**	**0.00-0.50**	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	2.2	11.3	5.1	16.3	3.5	17.8	4.7	11.8
Major Roads (miles)	2.5	5.2	0.6	2.7	2.2	8.4	1.0	4.6
Intersection Density (per sq. mi.)	147.6	150.2	244.4	212.5	106.9	258.4	188.4	133.6
Dead-End Density (per sq. mi)	20.4	11.5	50.9	61.1	5.1	15.3	10.2	31.8
Impedance-Based Intersection Density (per sq. mi.)	20.4	78.9	203.6	187.1	61.1	146.4	137.4	82.7
Impedance-Based Dead-End Density (per sq. mi)	91.6	47.1	76.4	76.4	20.4	42.0	40.7	62.4
Pedestrian Catchment Areas (ratio)	0.21	0.41	0.26	0.39	0.47	0.49	0.57	0.62
Impeded Pedestrian Catchment Area (ratio)	0.00	0.00	0.16	0.14	0.30	0.34	0.54	0.47

Table 66 Comparative Walkability Analysis, Silicon Valley, 2000

	Mountain View		Whisman		Bonaventura		Japantown/Ayer	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**	**0.00-0.25**	**0.00-0.50**	**0.00-0.25**	**0.00-0.50**	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	**4.7**	**15.1**	**2.7**	**8.5**	**0.8**	**3.3**	**4.4**	**16.5**
Major Roads (miles)	**0.7**	**2.7**	**0.6**	**2.5**	**0.5**	**1.6**	**0.5**	**2.3**
Intersection Density (per sq. mi.)	**249.5**	**178.2**	**152.7**	**84.0**	**10.2**	**19.1**	**157.8**	**164.2**
Dead-End Density (per sq. mi)	**20.4**	**24.2**	**96.7**	**34.4**	**5.1**	**1.3**	**10.2**	**8.9**
Impedance-Based Intersection Density (per sq. mi.)	**218.9**	**143.8**	**122.2**	**61.1**	**5.1**	**7.6**	**127.3**	**122.2**
Impedance-Based Dead-End Density (per sq. mi)	**20.4**	**26.7**	**91.6**	**35.6**	**5.1**	**6.4**	**20.4**	**17.8**
Pedestrian Catchment Areas (ratio)	**0.32**	**0.5**	**0.19**	**0.2**	**0.42**	**0.4**	**0.61**	**0.65**
Impeded Pedestrian Catchment Area (ratio)	**0.20**	**0.23**	**0.19**	**0.2**	**0.11**	**0.15**	**0.61**	**0.64**

REFLECTIONS, IMPLICATIONS AND RECOMMENDATIONS

VISUALIZING WALKABILITY THROUGH SMALL MULTIPLES

Visualizing TOD areas spatially is an important component in planning and evaluation because the visualization allows for a spatially explicit investigation and comparison of various phenomena that can get lost in the pure quantification of important concepts. Visualizing TOD areas through the above measures (path classification, intersection intensities, and pedestrian catchment areas), for example, can provide valuable insight into the spatial location of the transit stop relative to the existence of both pedestrian-oriented street infrastructure and auto-centric routes.

The images presented and analyzed previously in this report focused on a single variable and looked at that variable across multiple cases. Alternatively, understanding a single TOD in depth is also a worthy exercise, and can be accomplished by viewing all images for a single TOD as small multiples at the same time. That is, rather than compare a single attribute (e.g. the PCA) across a series of TOD areas, one could look at the multiple images for a single TOD and conduct a more in-depth visual analysis of one particular site.

Figure 45 represents a visual walkability analysis schema used to conceptualize the analyses opportunities through an integrated investigation of the individual walkability methods described in the preceding chapters. Included in this schema are the key questions that can guide analysis across images and are what Bossard calls "Multiple Themes at a Common Scale Schema."[41]

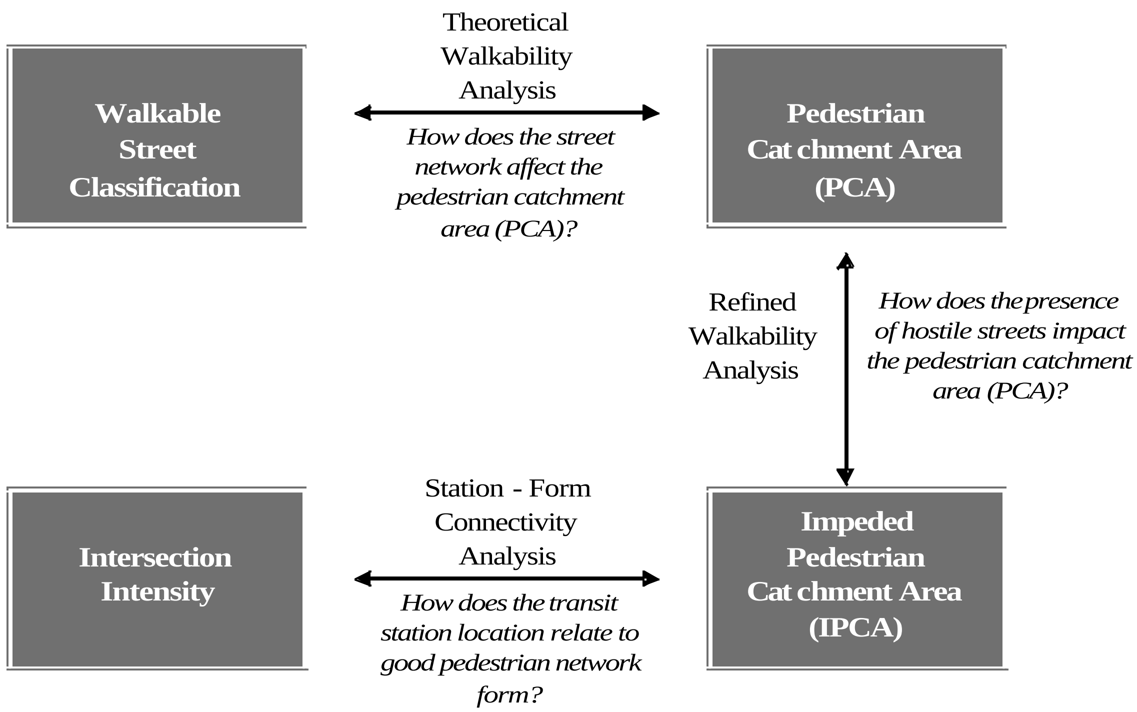


Figure 45 Theoretical Schema of Visual Analysis

Figure 46 fleshes out the conceptual schema with actual map images for a single case study site (Lloyd Center, Portland).

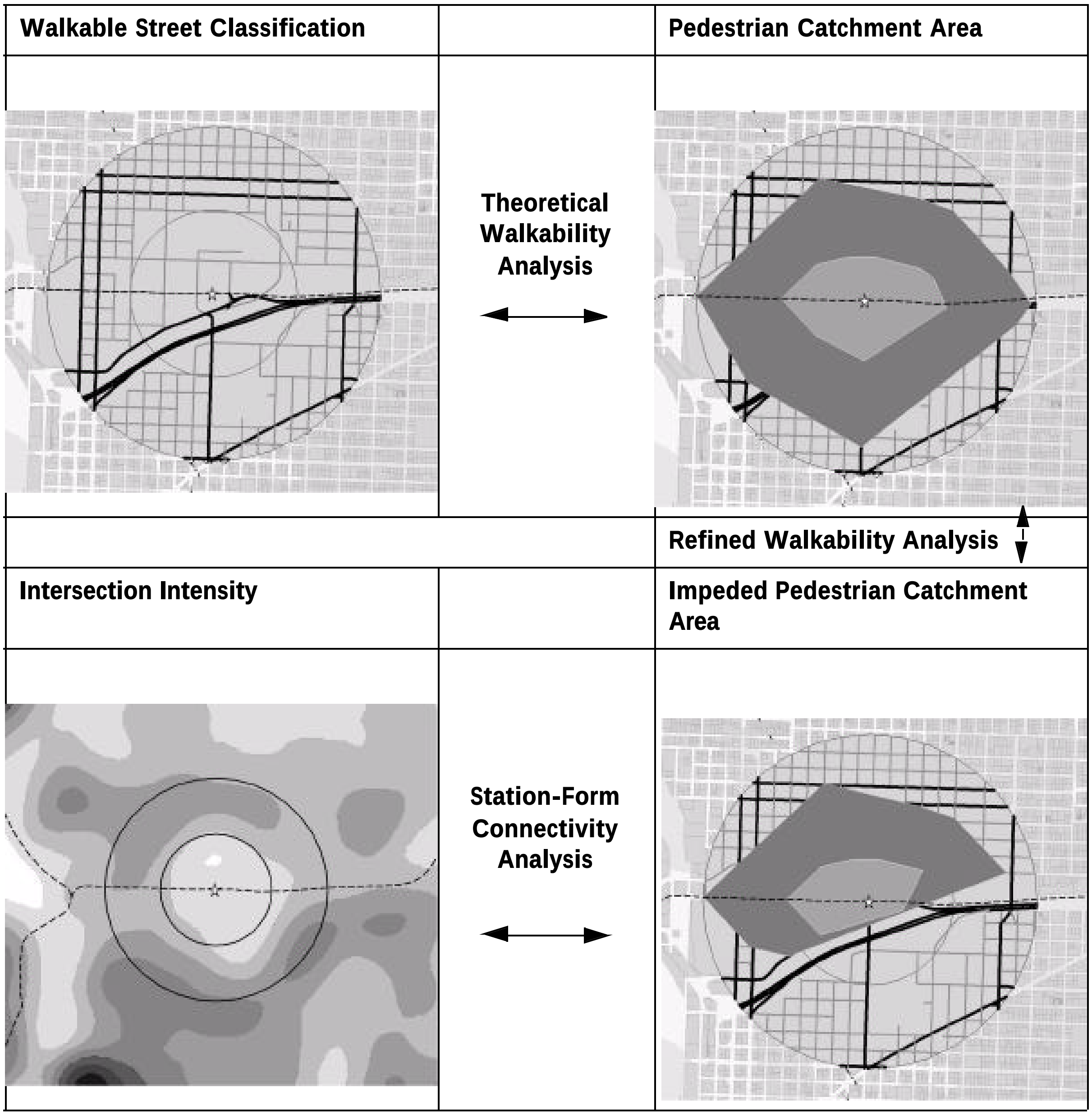


Figure 46 Example of Visual Analysis Schema

At least three key types of analyses results:

1. Theoretical Walkability Analysis

Walkable Street Classification → *Pedestrian Catchment Area Map*

In this analysis, one can look at the general street network (classified by quarter-mile, half-mile, and impedance characteristics) and compare the theoretical walkable zone ("as the crow flies") to the zone one can actually reach by walking along the street network starting from the transit stop. This analysis can give one the initial sense of how the street skeleton affects pedestrian mobility. In this case, it appears that the theoretical quarter- and half-mile walking distances are relatively achievable by walking along the existing street network.

2. Refined Walkability Analysis

Pedestrian Catchment Area Map → *Impeded Pedestrian Catchment Area Map*

PCA → *IPCA*

By comparing the Pedestrian Catchment Area with the Impeded Pedestrian Catchment Area, one can begin to see how large, auto-centric streets affect the area a pedestrian is likely to access. This analysis gives insight into the effect that transit stop placement and the spatial location of auto-oriented roads have on the potential zone of walkability. In this case, the walkable area shrinks by half and becomes truncated by major auto-centric roadways.

3. Station–Form Connectivity Analysis →

Impeded Pedestrian Catchment Area Map *Intersection Intensity Map*

In this analysis, the IPCA and the intersection intensity analyses are compared in order to understand the relationship between optimal pedestrian environments (in terms of path connectivity) and the likely walkability zones surrounding a transit stop. That is, is the location of good, pedestrian-oriented mobility infrastructure congruent with the area of potential walkability from a transit stop? This analysis provides a fundamental examination of some of the core underpinnings of how we think about TOD areas (and smart growth more broadly). In this case, where there are good examples of pedestrian-oriented street grids, some are within the likely walkable zone, and some are potentially cut off by major impedances. Moreover, much of the good pedestrian areas north of the transit stop are just beyond the walkable zone, suggesting perhaps that the transit line may have been more appropriately routed about a quarter-mile further north. With such a re-routing, the commercial zone of the Lloyd District (shown by a “hole” in the intersection surface map) would still have been accessible by foot, while the pedestrian-oriented street network to the north would have enjoyed better transit accessibility.

CASE STUDY WALKABILITY SCHEMAS

Figure 46 displayed four key visual representations of the Lloyd Center to envision walkability within TOD areas. It should be noted that walkability analyses as presented here are necessarily subjective in nature and dependent on a variety of elements. In this report, one might have honest disagreement about what constitutes a significant barrier or impediment to walkability, especially when much of a pedestrian infrastructure is not categorized or measured in standardized ways. Some of these unmeasured elements include street width (in general or at crossing points), presence of crosswalks or crossing signals, length or responsiveness of traffic signals to pedestrians, volume of traffic to face (going straight or turning), etc. Due to these non-standardized ways of thinking about walkability, the methods presented in this report are best used when the various maps for each site are presented together, supplemented by both a qualitative and quantitative textual description. This is the approach presented below for the remaining seven case study sites.

Walkability Schema–Orenco Station (Portland)

Figure 47 displays the four main TOD area walkability maps for Orenco Station, while all the quantitative figures for Orenco Station are displayed in Table 67. Taken together, these four maps tell an interesting story of this greenfield development as of 2002. Following the images from upper left to right, down and back left, it is evident that there are a fair number of minor streets in the area characterized by pockets of minor roads in very close proximity to each other. The presence of the variety of minor roads leads to a fairly good potential walkable area around the transit stop, although the zone is concentrated to the north of the stop because there are no direct paths leading from the stop southward. Two major roads do exist, intersecting each other at the quarter-mile point north of the transit stop. This intersection of impedance roads cuts off the TOD area beyond a quarter-mile to the northeast, resulting in a revised zone of likely walkability that is much smaller than if one were to treat all streets as equal pedestrian routes. Finally, there are really three different pockets of good street connectivity throughout the TOD area; however, due to the limited access from the transit stop to the south and the presence of the major impedance roads, two of those three pedestrian zones are not likely to have a transit connection. [42]

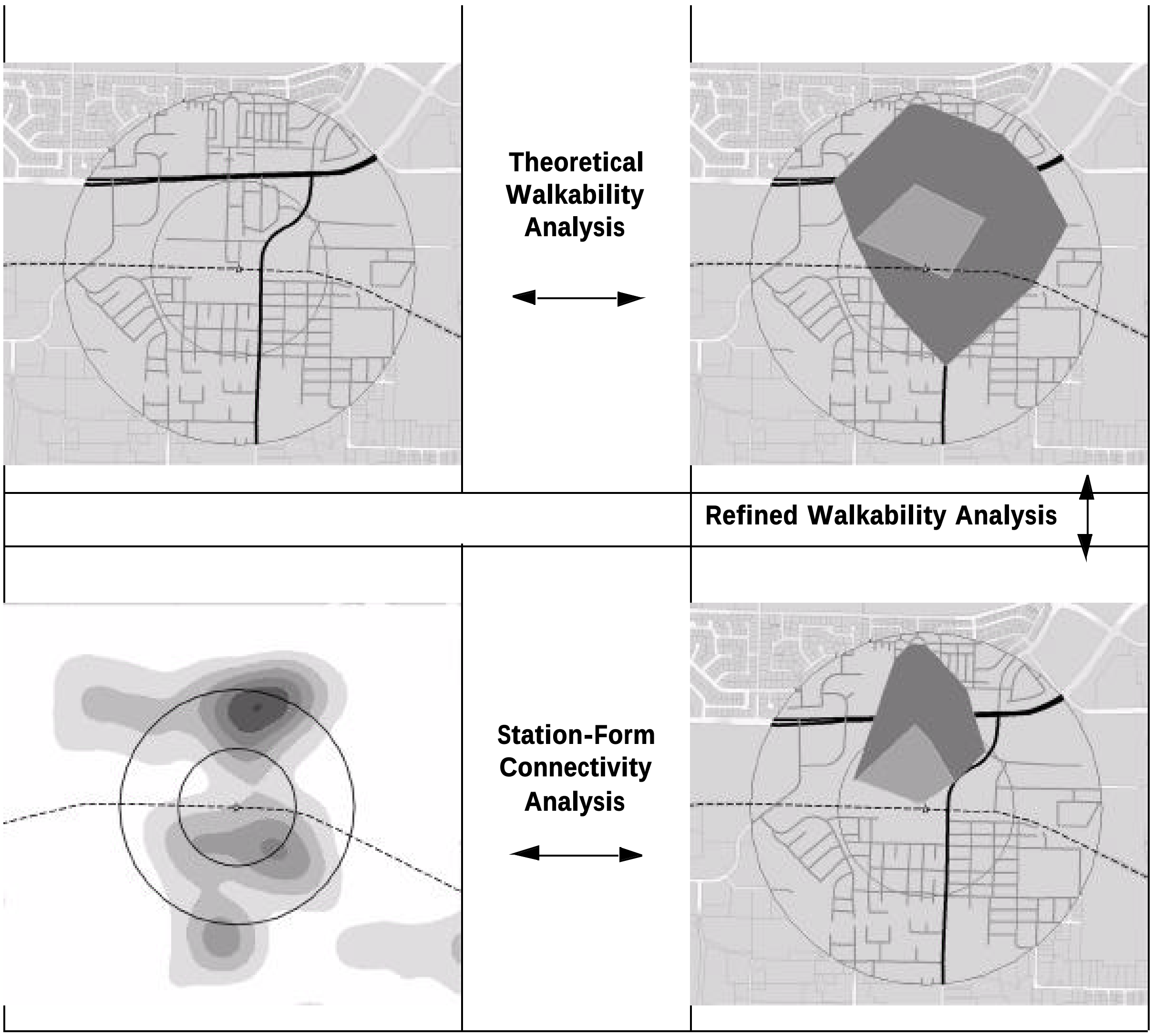


Figure 47 Walkability Schema, Orenco Station, 2000

Table 67 Walkability Statistics, Orenco Station, 2000

	Orenco Station	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	5.1	16.3
Major Roads (miles)	0.6	2.7
Intersection Density (per sq. mi.)	244.4	212.5
Dead-End Density (per sq. mi.)	50.9	61.6
Impedance Based Intersection Density (per sq. mi.)	203.6	187.1
Impedance Based Dead-End Density (per sq. mi)	76.4	76.4
Pedestrian Catchment Area (ratio)	0.26	0.39
Impeded Pedestrian Catchment Area (ratio)	0.16	0.14

Walkability Schema–Beaverton (Portland)

Figure 48 shows each map for Beaverton, while Table 68 lists each of the quantitative measurements for the area. In terms of the spatial representation of the TOD area, a mixture of street types and patterns characterizes Beaverton. Closest to the transit stop, there is a relative lack of minor roads and a high quantity of major roads, with the major roads completely encircling the transit stop. To the south, there is an area of higher concentration of minor roads laid out in a more traditional pre-WWII street pattern. Treating all roads as equals, the pedestrian coverage is decent and extends in all directions. However, when one considers the major roads as impedances or barriers to pedestrian travel, then the area of likely pedestrian access is essentially completely eliminated. That is, it is impossible to access the Beaverton transit stop without traveling along and crossing major auto-oriented roads. This lack of access is disappointing, because just to the south of the major east-west impedance roads, is an island of good pedestrian-friendly street connectivity. Unfortunately, the presence of the auto-dominant roads completely cuts off pedestrian access between the transit stop and this pedestrian-friendly urban form.

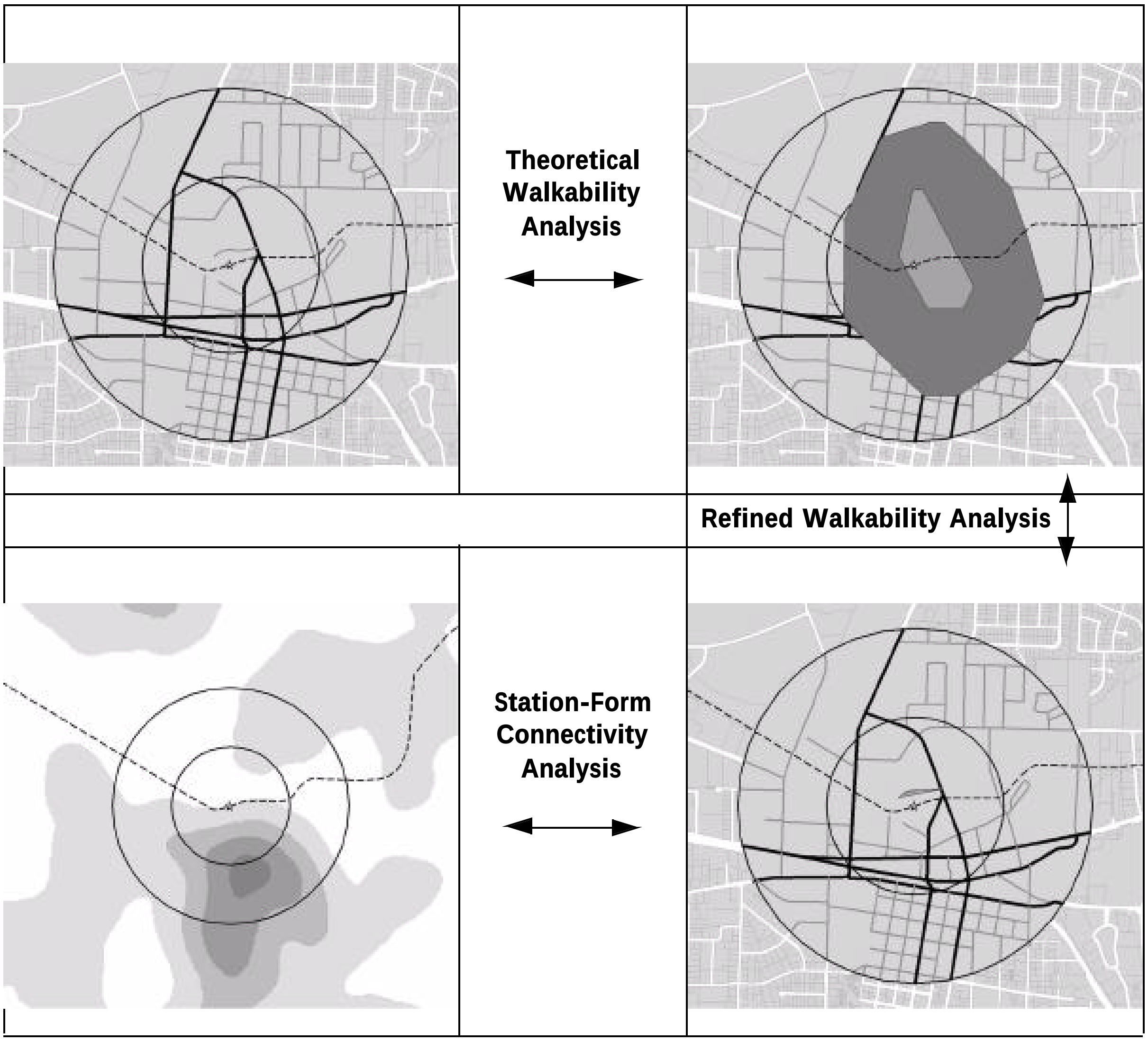


Figure 48 Walkability Schema, Beaverton, 2000

Table 68 Walkability Statistics, Beaverton, 2000

	Beaverton Central	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	2.2	11.3
Major Roads (miles)	2.5	5.2
Intersection Density (per sq. mi.)	147.6	150.2
Dead-End Density (per sq. mi.)	20.4	11.5
Impedance Based Intersection Density (per sq. mi.)	20.4	78.9
Impedance Based Dead-End Density (per sq. mi)	91.6	47.1
Pedestrian Catchment Area (ratio)	0.21	0.41
Impeded Pedestrian Catchment Area (ratio)	0.00	0.00

Walkability Schema–Gresham (Portland)

The series of maps (and table) for the Gresham TOD area are quite interesting (see Figure 49 and Table 69). Looking only at the street layout and type, there seems to be conflicting patterns on two dimensions. On the dimension of street layout, there seems to be a fairly dense, regular street network pattern within the quarter-mile concentric circle, a phenomena consistent with TOD theory. Outside of this quarter-mile distance, however, the street pattern becomes irregular and loose. On the dimension of street type, there seems to be a fairly high prevalence of impedance roads. Most of these auto-dominant roads are between the quarter- and half-mile distances from the transit stop.

Treating all streets as equal, the reachable walking zone around the transit stop is quite large and symmetrical, representing an environment that is potentially accessible from all directions. When considering auto-dominant roads as pedestrian impedances, the likely zone of walkability remains fairly large, but becomes less symmetrical with the northwest area being truncated. That is, this northwest area is accessible by pedestrians only if they travel along and across a major road.

The intersection surface map shows that there is decent internal connectivity of the street network within the quarter-mile concentric circle, again showing consistency between theory and practice. Moreover, most of the area of good connectivity falls within the IPCA–the zone of likely walkability that considers the location of pedestrian-friendly and -hostile street segments. In sum, the maps show a pedestrian-friendly Gresham TOD area that generally reflects reality.

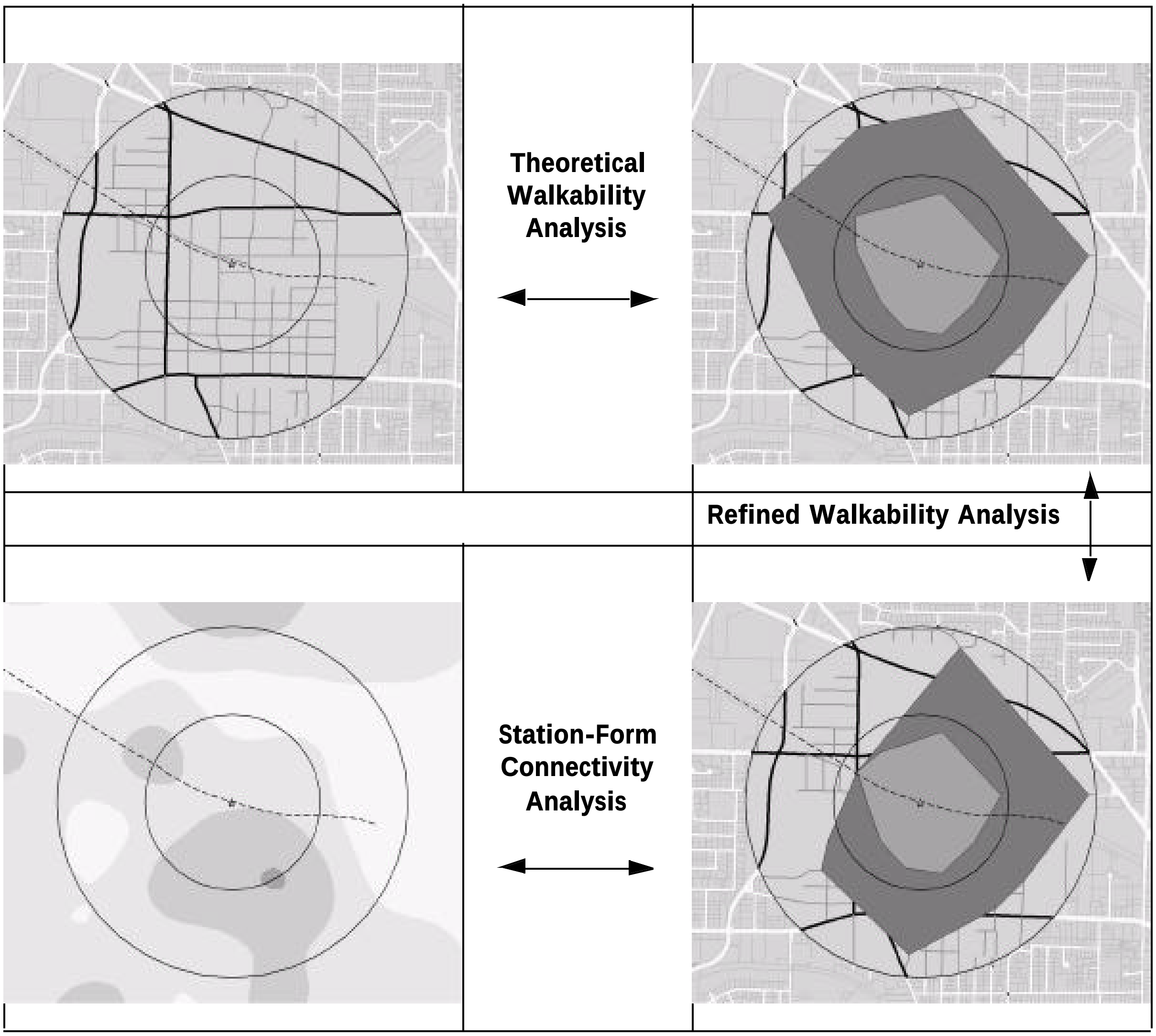


Figure 49 Walkability Schema, Gresham, 2000

Table 69 Walkability Statistics, Gresham, 2000

	Gresham	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	407	1108
Major Roads (miles)	1.0	4.6
Intersection Density (per sq. mi.)	188.4	133.6
Dead-End Density (per sq. mi.)	10.2	31.8
Impedance Based Intersection Density (per sq. mi.)	137.4	82.7
Impedance Based Dead-End Density (per sq. mi)	40.7	62.4
Pedestrian Catchment Area (ratio)	0.57	0.62
Impeded Pedestrian Catchment Area (ratio)	0.54	0.47

Walkability Schema Whisman (Silicon Valley)

Whisman is a greenfield development and the fact that it is not completely built out is represented in the maps and table (see Figure 50 and Table 70). The location of the transit stop compared to the existing street network is in some ways a bit inconsistent with theoretical TOD goals in that major streets are within close proximity of the transit stop, essentially cutting off access to the southern area beyond a quarter-mile. That said, the street network built thus far within a quarter-mile of the transit stop seems to be somewhat tight and walkable. The lack of a complete street network within the Whisman TOD area results in a potential walkable zone that is somewhat limited and asymmetrical–all of the walkability occurs to the west of the transit stop. There are few opportunities to cross the major arterials, so the potential walkable zone to the south is naturally limited. The final map–the intersection surface map–illustrates the explicit effort of the Whisman TOD area planning effort to create good internal street connectivity. The area of highest connectivity, which also compares favorably with other TOD areas, is within the quarter-mile concentric circle. Much of the band between a quarter-mile and half-mile have poor connectivity characteristics, although this may change over time as the greenfield site is more fully built out.

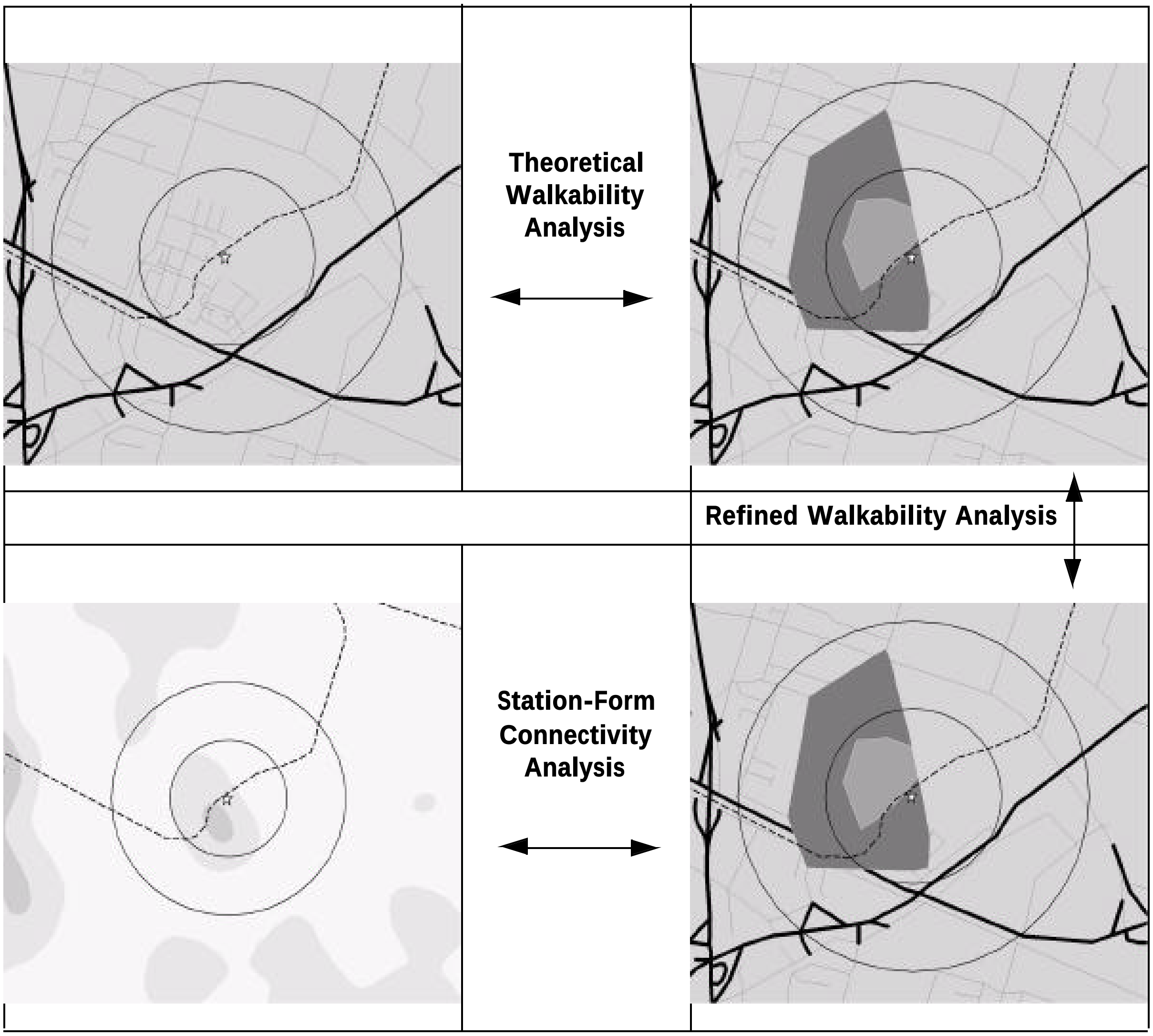


Figure 50 Walkability Schema, Whisman, 2000

Table 70 Walkability Statistics, Whisman, 2000

	Whisman	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	2.7	8.5
Major Roads (miles)	0.6	2.5
Intersection Density (per sq. mi.)	152.7	84.0
Dead-End Density (per sq. mi.)	96.7	34.4
Impedance Based Intersection Density (per sq. mi.)	122.2	61.1
Impedance Based Dead-End Density (per sq. mi)	91.6	35.6
Pedestrian Catchment Area (ratio)	0.19	0.2
Impeded Pedestrian Catchment Area (ratio)	0.19	0.2

Walkability Schema–Mountain View (Silicon Valley)

The Mountain View TOD area performs fairly well in terms of walkable potential (see Figure 51 and Table 71). The street pattern is fairly tight and extends to much of the TOD area. There are, however two impedance roads within the zone. One north-south impedance road is at the eastern edge of the half-mile concentric circle, and while it acts as a barrier to get beyond the half-mile, it is on the maximum side of how far people are likely to walk to access the transit stop. The other impedance road travels east-west and borders the transit stop itself. This road acts as an impedance primarily because there are limited access points to cross it, thereby making many people’s walking route more indirect. Once on the northern side of this impedance road, there is a parallel minor road, so the impedance is mainly in terms of limited crossing points. As a result of the limited crossing points, the zone of likely walkability (PCA and IPCA) are asymmetrical, favoring access to the south. The presence of impedance roads, though, does not impact the actual shape or scores for the IPCA. Finally, the intersection surface map shows that the transit stop is within a quarter-mile of a zone of intensely positive internal street connectivity (downtown Mountain View)–representing a good linkage between theory and practice.

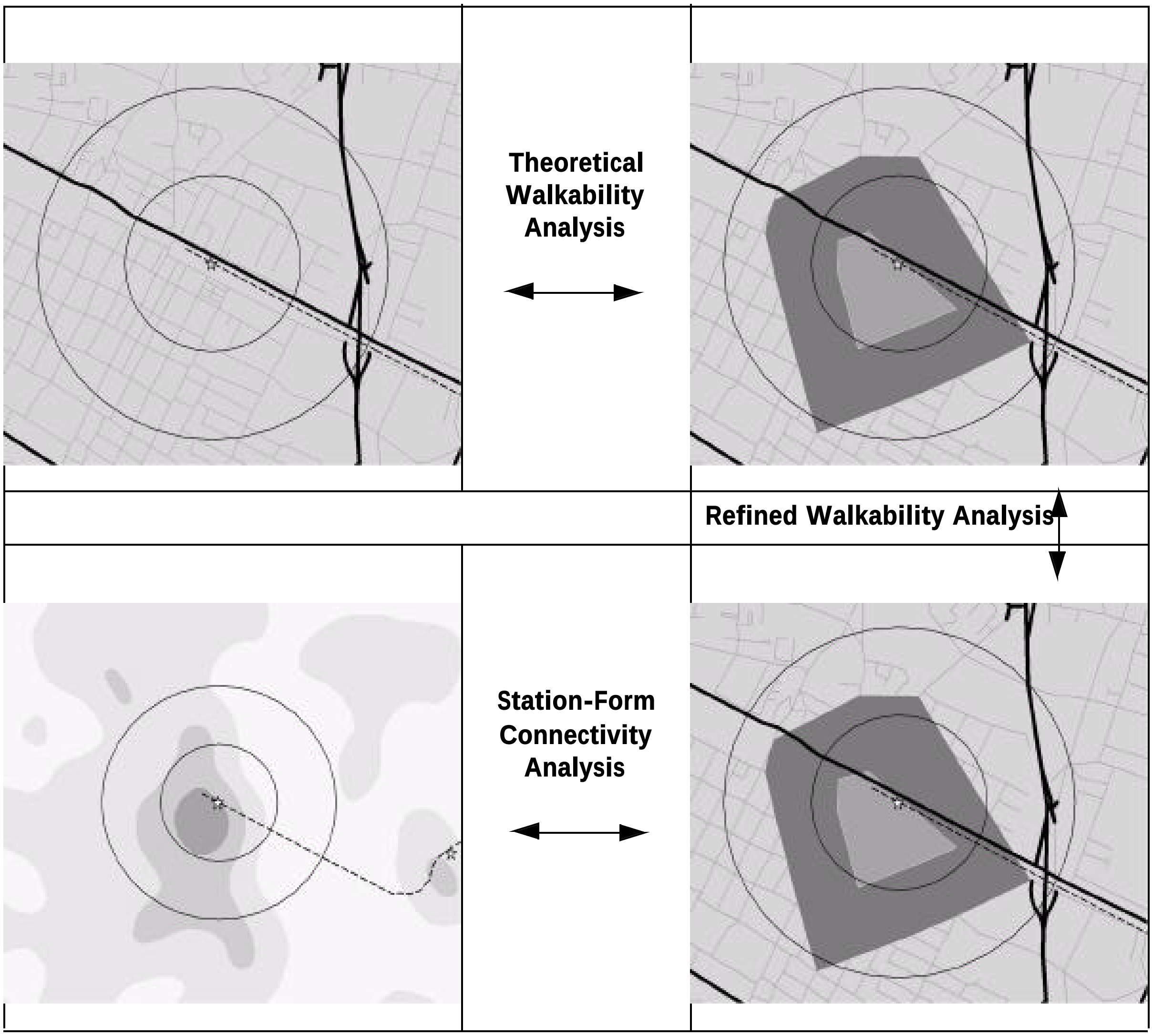


Figure 51 Walkability Schema, Mountain View, 2000

Table 71 Walkability Statistics, Mountain View, 2000

	Mountain View	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	4.7	15.1
Major Roads (miles)	0.7	2.7
Intersection Density (per sq. mi.)	249.5	178.2
Dead-End Density (per sq. mi.)	20.4	24.2
Impedance Based Intersection Density (per sq. mi.)	218.9	143.8
Impedance Based Dead-End Density (per sq. mi)	20.4	26.7
Pedestrian Catchment Area (ratio)	0.31	0.48
Impeded Pedestrian Catchment Area (ratio)	0.31	0.48

Walkability Schema Japantown/Ayer (Silicon Valley)

The Japantown/Ayer TOD area is mostly represented by a very regular patterned street network grid (see Figure 52). This visual pattern, along with the quantitative results that are derived from the spatial representation (see Table 72), represent an area that has good pedestrian characteristics. Much like the Mountain View TOD area, there are two impedance roads that bisect the Japantown/Ayer area, one of which is alongside the transit stop itself. Unlike Mountain View, there are numerous points to cross the nearby auto-dominant road, allowing the pedestrian zone to extend outward in a symmetrical fashion. The presence of the street grid allows this zone to extend outward in a good direction, resulting in the only TOD area in this research study that has PCA and IPCA scores above 0.60. In terms of internal street connectivity, the intersection surface map shows a broad area of decent connectivity that covers most of the area within the half-mile concentric circle.

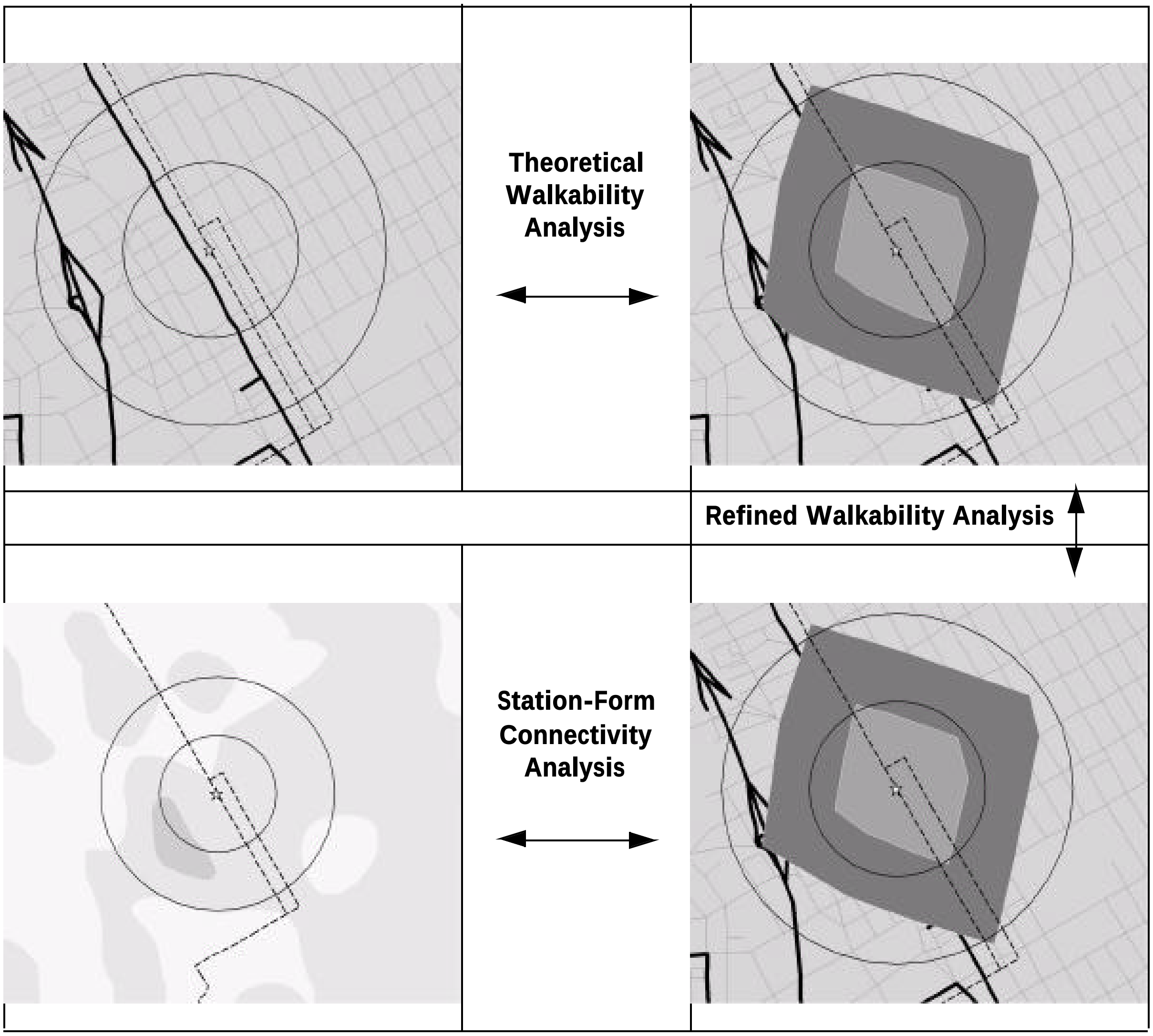


Figure 52 Walkability Schema, Japantown/Ayer, 2000

Table 72 Walkability Statistics, Japantown/Ayer, 2000

	Japantown/Ayer	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	4.4	16.5
Major Roads (miles)	0.5	2.3
Intersection Density (per sq. mi.)	157.8	164.2
Dead-End Density (per sq. mi.)	10.2	8.9
Impedance Based Intersection Density (per sq. mi.)	127.3	122.2
Impedance Based Dead-End Density (per sq. mi)	20.4	17.8
Pedestrian Catchment Area (ratio)	0.61	0.65
Impeded Pedestrian Catchment Area (ratio)	0.61	0.64

Walkability Schema Bonaventura (Silicon Valley)

In sharp contrast to the Japantown/Ayer TOD area, the Bonaventura TOD area is characterized by a poor walkability environment (see Figure 53 and Table 73). There are few streets within a quarter- or half-mile of the transit stop, with two major impedance roads in close proximity to the stop. The initial zone of potential walkability is fair and somewhat symmetrical, but once walking along a major auto-dominant road is eliminated from consideration, the likely pedestrian access zone (the impeded pedestrian catchment area (IPCA)) is reduced almost to nil. The intersection surface map further reflects the poor walking environment, showing no areas where the mobility infrastructure would support pedestrianism as a transportation mode choice.

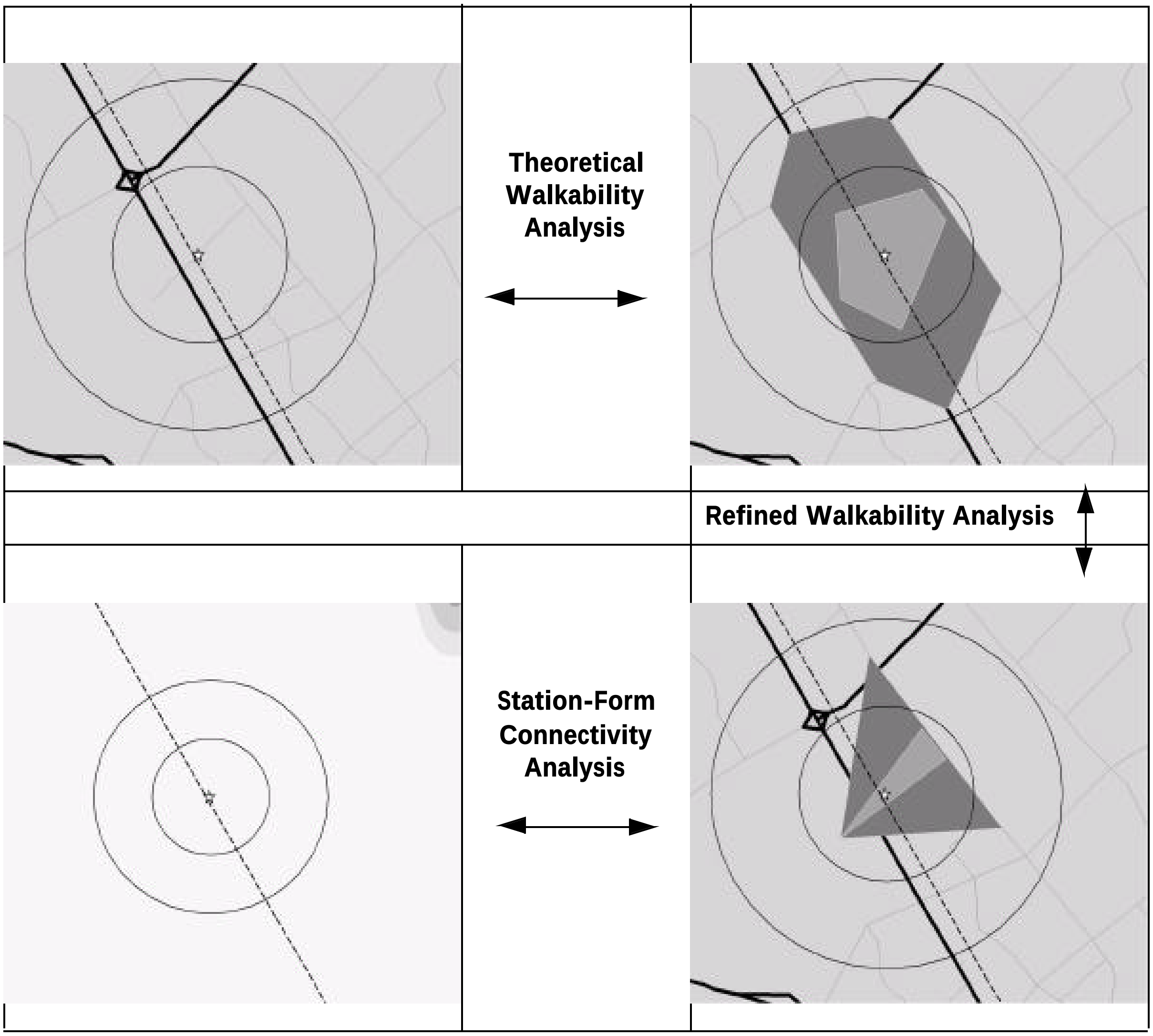


Figure 53 Walkability Schema, Bonaventura, 2000

Table 73 Walkability Statistics, Bonaventura 2000

	Bonaventura	
Distance from Transit Stop	**0.00-0.25**	**0.00-0.50**
Minor Roads (miles)	0.8	3.3
Major Roads (miles)	0.5	1.6
Intersection Density (per sq. mi.)	10.2	19.1
Dead-End Density (per sq. mi.)	5.1	1.3
Impedance Based Intersection Density (per sq. mi.)	5.1	7.6
Impedance Based Dead-End Density (per sq. mi)	5.1	6.4
Pedestrian Catchment Area (ratio)	0.42	0.4
Impeded Pedestrian Catchment Area (ratio)	0.11	0.15

SURFACE MAP COMPARISONS

One other potential form of analysis using small multiples of visual spatial representation of TOD areas is to look at a single variable across all eight case study zones. Perhaps the most instructive of these variables is the intersection surface maps, which show the spatial relationship between a TOD transit stop and the surrounding walkable infrastructure. Such a comparison across TOD areas is especially helpful when a consistent spatial extent and data characterization are used–thereby allowing for a comparison across sites using the same measures. In theory, the transit stop would be located directly at the heart of the area of highest walkability. Looking at Figure 53 (Intersection Map Comparisons), one can quickly see that many of the areas of good internal intersection connectivity (e.g. places with good walkability potential) are close to the transit stop, but not directly overlaying the transit stop. Moreover, the images illustrate the non-uniformity in the development of the local mobility infrastructure surrounding the transit stops. In no case is a transit stop completely surrounded by a zone of good connectivity. Some TOD areas are clearly better than others; some perform much better at the quarter-mile distance, while other are better between a quarter- and half-mile.

The main point, however, is that spatially explicit and spatially consistent measures such as the intersection surface maps can be used to compare and contrast TOD areas in a way that more easily allows researchers, practitioners, and a general public to better understand how the notions of TOD theory are presently translated into practice. Repeating such analyses over time, as development within the TOD areas continues to morph and change, will allow us to see how policy interventions, such as TOD, affect the urban form and pattern of sub-areas within our metropolitan regions.

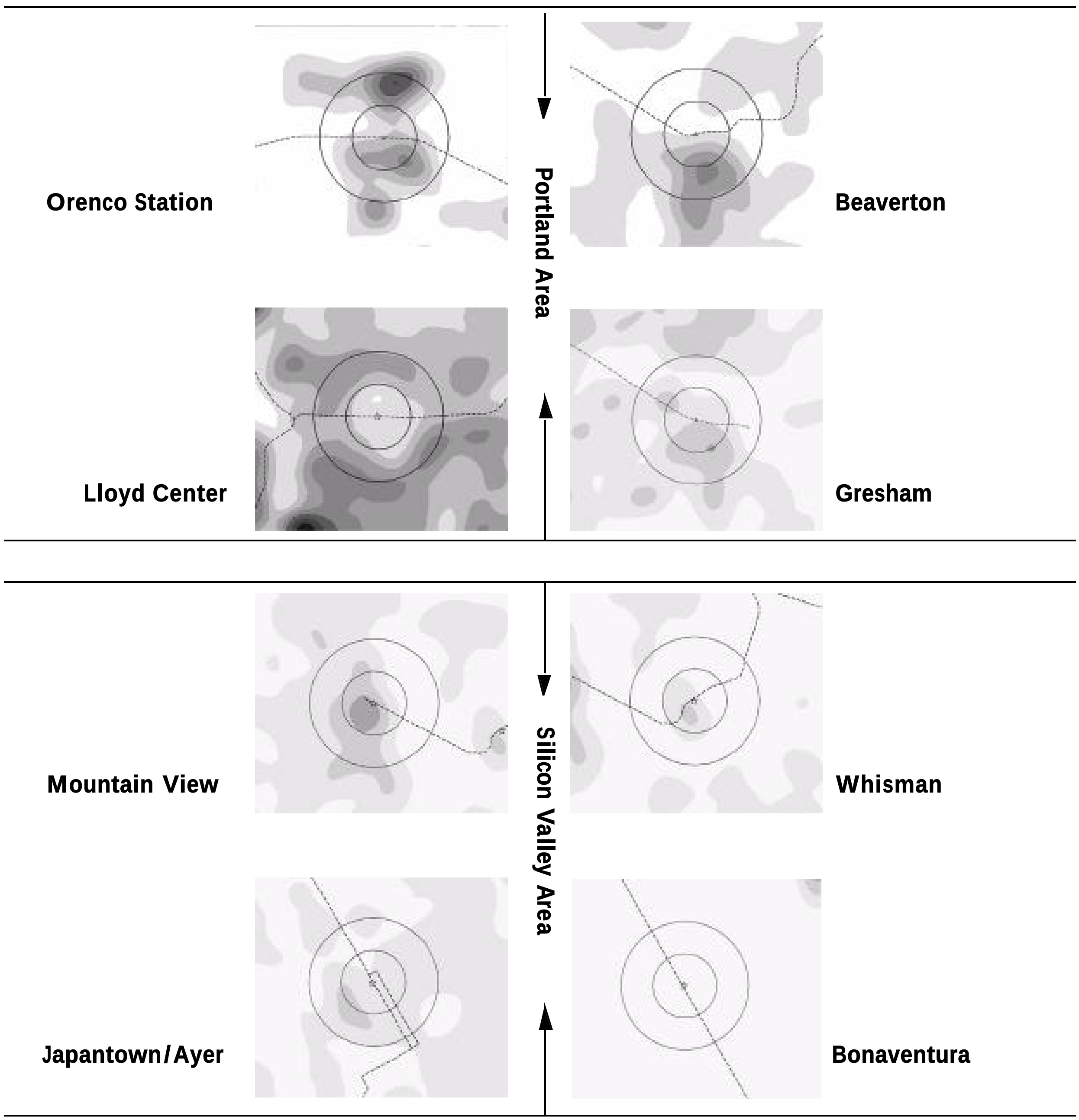


Figure 54 Intersection Map Comparisons

RE-THINKING TOD THEORY

The spatial-visual analysis of walkability indicators raises some serious questions regarding TOD theory in terms of how it is represented and measured. The typical conception of TOD areas is of a transit stop surrounded by concentric circles of quarter-mile increments with the focus of higher-density mixed-land uses occurring in the circles closest to the transit stop. This research challenges the theoretical spatial extent of TOD areas in the following ways:

1. Road types impact walkable service areas. Utilizing the street network for walkability analysis without making some distinctions in street type and use limits the capacity of the analysis to reflect reality. Road type does impact one's conception of a walkable space; therefore, some distinction or classification of street type is necessary if one wants to properly measure and characterize the walkability of a localized place.

2. PCAs and IPCAs are dramatically smaller than theoretical areas, with irregular coverage patterns. Thinking of the transit-oriented zone as a perfect circle undercuts the reality of many places. As was seen in the walkability indicators presented above, the walkable zone from a transit stop never reaches the theoretical "as the crow flies" circle, but is more often an irregular shaped polygon because one's reach is limited by what pathways are available to travel. Moreover, if the types of streets are considered, thereby identifying which paths a pedestrian is likely to travel along or cross, the reachable area from a transit stop becomes even more limited.

3. Major roads present spatial barriers between areas of high connectivity and stations. Not only does the presence of automobile-oriented roads impact the area that one is likely to reach by walking, but such roads may create spatial barriers or impediments between rail stations and areas of high walkability, measured by a high degree of internal street connectivity. Transit riders are almost by definition also pedestrians because when one exits a train, walking is usually the mobility option used. For TOD areas, this transit-pedestrian connection is more explicit. Therefore, areas in which major pedestrian impedances exist between the transit stop and urban space of good walkability are areas inconsistent with TOD theory.

4. Areas of high connectivity are often spatially separate from transit stops (islands and holes). A surface map of connectivity also reveals that transit stops are often spatially separate from areas of high connectivity, even without the spatial barriers of auto-oriented roads considered. In the examples above, areas of high internal street connectivity are not often within a quarter-

mile distance of the transit stop and in some cases are closer to a half-mile from the transit stop. If we are to rely on past research indicating that most transit users will not walk a half-mile to reach transit, then it is possible to conclude that the placement of stops a half-mile away from areas with walkable urban infrastructure patterns will result in an underutilization of the transit service. That is, if transit users are pedestrians when they get to or from the train, then the environment immediately surrounding the train stops should be highly walkable. This research shows that transit stops are often located in "connectivity holes"–places that lack good internal connectivity–at significant distances from "connectivity islands"–places of high connectivity.

CHANGE OVER TIME

One element that was introduced in this research was the use of longitudinal data to track a variety of variables within the TOD areas. Socio-demographic and transit use variables have at times been used in this temporal way in other research. There are two key conclusions from this particular research in terms of linking TOD theory to practice. First, most of the TOD areas are developing over time in ways consistent with TOD theory. These areas are becoming more dense in terms of both population and households as the development policy interventions take hold. Second, and perhaps more significantly, the broader patterns of development within Portland and Silicon Valley are different. In the Portland area, the entire area in close proximity to the light rail lines are developing much more densely than the region as a whole. In contrast, the opposite is true in Silicon Valley: areas further from the light rail line are becoming more dense than those areas in close proximity to the rail line. Clearly there is a difference in approach between the two regions; in Portland there is an emphasis on both areas surrounding transit stops and the corridor that borders the line in general. In Silicon Valley, there is much more emphasis on individual TOD areas, rather than on development along the light rail corridor in general.

Connecting these variables with the change in urban form over time represents an added element in change-over-time analyses. Policy interventions such as TODs, nodal development overlay zones, or smart growth policies, take time to be translated from policy to practice. That is, deeming a set of parcels as mixed-use, high-density does not make those parcels automatically change. Land-use change takes time to occur as does, in this research, the pattern and location of the local street (or other path) network. Incorporating a change-over-time element in urban form analysis can help planners understand how small changes in street location or street type can impact the pedestrian-friendliness of an area. Most urban areas have base spatial data from 1990, which allows a spatial-temporal analysis of urban form at a fine grain to be increasingly incorporated into this type of research.

SUMMARY, CAVEATS AND FUTURE RESEARCH

One of the clear limitations of the analyses above is that they rely on three primary assumptions: 1) local streets are the same thing as local sidewalks; 2) minor roads are walkable and arterials are hostile to walking; and 3) all intersections are the same. Clearly, there are instances when these assumptions hold true, and there are times when they do not. So, while the analyses presented above add a refinement to current street network analyses by adding the concept of the impedance road to the mix, future research on walkable environments can build on these concepts in the following ways:

- **Sidewalk modeling**: developing accurate data sets of sidewalks would enhance the walkability analysis by using actual walking paths as a primary data set, rather than using the street network as a proxy. The development of such layers, however, is not without difficulty. For example, sidewalk layers often do not cross streets, making it difficult to model distance traveled along the network. Informal paths (e.g. a dirt path across a vacant lot) or pseudo-paths (pedestrian walkway through a huge parking lot) present difficult subjective decisions on how a pedestrian path is defined. A positive about the analyses used above is that they are based on street network data that are available for easy and free download for every county in the United States and thus can be used by planners, policy makers, and others relatively easily.

- **Street reclassification**: Streetscape design can have a significant impact on how pedestrian-friendly one given route is compared to another. Physical features such as road and sidewalk width, psychological factors such as perception of crime, physiological factors such as the volume and speed of automobile traffic, and urban form variables such as the streetscape all contribute to the quality of a given pedestrian path. Moreover, the presence or absence of barriers between pedestrian and automobile movement may contribute to walkable friendliness or hostility. Examples of these buffers may include: guard rails, street trees, a green strip, or a parking lane, among many others. Bulb-outs at corners may reduce crossing distances and create a more inviting opportunity to cross an otherwise unfriendly street as well. Further work can be done to refine and re-classify the road network to reflect these ideas. In fact, a complete re-classification of the street network using a pedestrian orientation, in contrast to the current classification based on automobile volume, may be in order as future planning once again pays attention to the mobility, accessibility, and social needs of pedestrians.

- **Intersection weighting**: Not all intersections are the same, and refined classification can help in terms of modeling walking distances. For example, does an ill-designed eighty foot wide road really feel more like 150 feet to a pedestrian? Or does a nicely designed intersection actually feel more like forty feet? Are intersections with crosswalks more conducive to longer walking trips compared to intersections without them? Weighting each intersection using a variety of variables can help reflect actual walking behavior given a certain set of environments.

Future research could include the incorporation of non-work trips and the use of more sophisticated spatial statistics. Both of these additions would add breadth and depth of understanding in terms of how the mobility infrastructure affects transportation choices.

Access, connectivity, and choice are key elements in understanding the pedestrian environment, and all can be derived using various elements of the street network. Intersections, paths, and walkable zones (known in GIS as points, lines, and polygons) can all be derived from the basic urban skeleton of the street network in order to ascertain and evaluate the pedestrian compatibility of certain environments. In terms of TOD areas, the various methods described above can be particularly useful for understanding the key link in the transit-land use connection that TOD areas help to facilitate: the possibility of walking between the transit stop and key locations in close proximity to the transit stop.

Clearly not all TOD areas are the same in terms of the pedestrian environment. Even within a single urban area (i.e. Portland), there can be great variability in terms of the pedestrian infrastructure. Utilizing the analysis methods and a comparative framework can help policy makers, planners, and the public at large understand and evaluate how the network infrastructure relates to the location of the transit stop. Ideally, such analysis can be conducted prior to the placement of transit stops so that the locations can be selected based on an appropriate surrounding pedestrian environment. Alternatively, a post-construction analysis of TOD locations can help planners and policy makers identify key connectivity barriers and opportunities so that TOD theories of walkability can be translated into practice.

It is clear that walkable environments are important to transportation choices and the spatial visualization of urban form can provide insight into the presence or absence of good, walkable urban form. Moreover, the road network can be used to provide key insight into these walkability domains. Quantitative analysis of walkable environments can provide another means by which we can evaluate transit-supportive urban form. Thus, a combination of a visual, spatially-based analysis along with a quantification of the underlying urban form in terms of walkability, can help planners and policy makers understand the condition and performance of existing or potential TOD areas.

APPENDIX A: METHODOLOGICAL CLARIFICATIONS

Below are some technical notes on various aspects of data and the research methods used in this report.

1993 Portland Street File

The 1993 Portland street file contained three categories of streets that were deleted for analysis purposes:

- Some streets were named "?????," which represented anticipated future streets, but not currently existing ones
- Some streets were named "****," which represented anticipated future streets, but not currently existing ones
- Some streets were named "MAX" and represented the path of the light rail line, not walkable streets.

Portland Street Files

In the data set analyzed for this study, the base data for the street network has been custom coded as to street type (arterial, freeway, minor road, etc.) by a regional GIS processor for the Portland region, although standard TIGER files contain a CFCC variable that can be used to easily segregate neighborhood roads from major thoroughfares. See Table 74 for a listing of the street network classifications.

Table 74 Classifying Portland Streets

Classification	Feature	Classification Range	Type	Type Definition
Impedance Arcs	Freeway	1110-1120	1110	Freeway
				Ramps, interchanges & feeders
	Arterials	1121-1450	1120	On-ramp (only)
			1122	Off-ramp (only)
			1123	On- and off-ramp (combination)
			1200	Highway
			1300	Primary arterial
			1400	Secondary arterial
			1450	Other arterial
Accessibility Arcs	Minor	1451-5600	1500	Minor streets
			1700	Private named road, private right-of-way exists
			1750	Private named road, no private right-of-way exists
			1800	Unnamed driveway, private driveway exists
			5101	Freeway with rapid transit
			5201	Highway with rapid transit
			5301	Primary arterial with rapid transit
			5401	Secondary with rapid transit
			5500	Minor with railroad
			5501	Minor with rapid transit

San Jose Street Classification

Streets in Santa Clara County have been segregated using the CFCC variable that comes with TIGER line files. The following CFCC categories were used to designate major/impedance roads:

- A11
- A15
- A21
- A31
- A45
- A48
- A63
- A71
- A74

San Jose Street Shift

The 1992 and the 2002 TIGER files for Santa Clara County (CA) did not line up spatially, making the change over time comparisons difficult because the walkability calculations are very spatially explicit. The goal of these analyses is to see if a change in street pattern and form over time coincided with the investment in light rail and TODs; therefore, it is important that roads that remain the same over time also occupy the same space within the GIS in both data point years.

A manual shift of the spatial data was conducted to line up the two data sets. 1992 data was shifted to align with 2002 data. Because the overall street file for the whole county is quite large and cumbersome to manipulate, a subset of roads within one mile of the case study sites was selected. Using a heads-up digitizing approach, the 1990 streets were spatially moved to line up with the 2000 data. Random checks of different street segments indicated that the entire 1990 data set was uniformly displaced as compared to 2000; in other words, the shifting of the streets did not result in any additional, unforeseen spatial error.

Visualizing Street Change Over Time

In this report, maps for 1992 data were not shown, although quantitative figures for change-over-time were presented. Figure 55 below shows how a visualization of street infrastructure change over time can be quite instructive. The figure shows Orenco Station, which had significant road infrastructure construction between 1993 and 2002 as the site for Orenco Station transformed from open space to a specifically planned TOD area. This TOD-oriented growth is reflected in the significant increase of minor streets (and the slight decrease in auto-centric roads). Minor roads increased by 300 percent within a quarter-mile and 200 percent within a half-mile of the transit stop. Such increases of total roads are expected, of course, as the area was transformed from open space to a mixed-use development, but the simultaneous increase of minor roads without a similar increase in major roads reflects the pedestrian-oriented goals of the area.

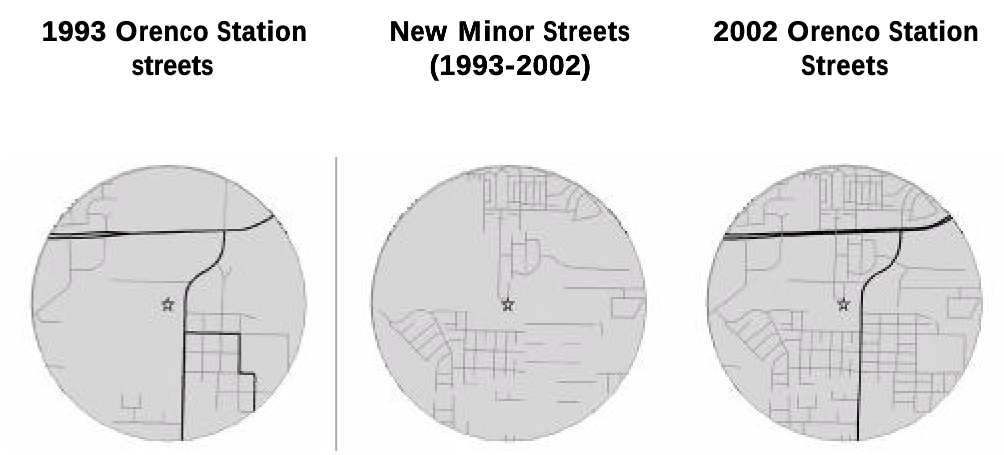


Figure 55 Street Infrastructure Change Over Time, Orenco Station, 1993-2002

One danger in using change-over-time data is the re-classifying of data sets that can happen over time. Because the street files that were used for this research were not created with walkability measures in mind, no single set of accepted street classifications existed between the two data points. Figure 56 below shows how some of these reclassifications affected the area around the Lloyd Center in Portland.

At the Lloyd Center, changes occurred between the years 1993 and 2002 that negatively impact the road hierarchy in terms of walkable places. Specifically, three key segments of arterial roads were re-classified from minor roads to arterials within a half-mile of the Lloyd Center transit stop (see the middle image below for the new arterial additions):

- Horizontal road on the northern edge: split from a single two-way arterial to two one-way arterials.
- Diagonal road near the transit stop: re-classified from a minor road to an arterial.
- Vertical road toward the south: reclassified from minor road to arterial.

1993 Lloyd Major Streets	New Major Streets (1993-2002)	2002 Lloyd Major Streets

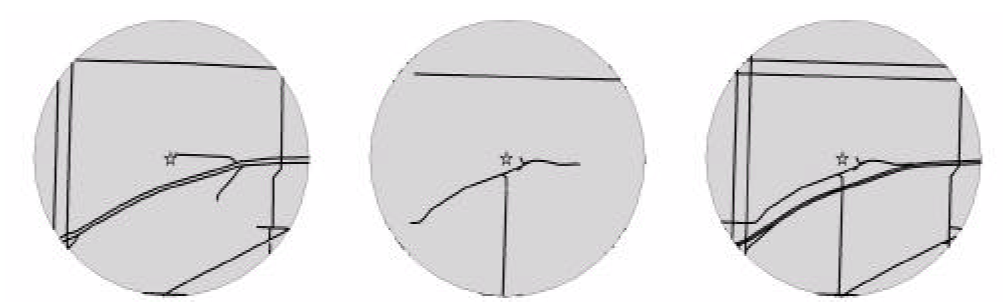
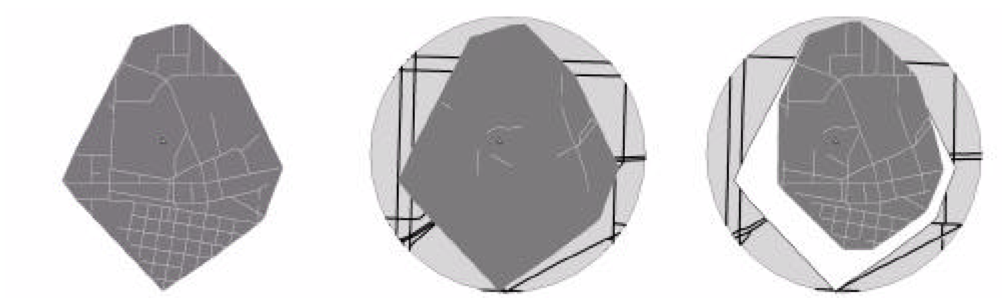


Figure 56 Street Re-Classifications, Lloyd Center, 1993-2002

PCA Calculation (1993-2002)

The proximity of the transit stop to the nearest road impacts the PCA calculations in counter-intuitive ways. For example, in Beaverton, the 2002 PCA is smaller than the 1993 PCA. Between 1993 and 2002, however, new roads were built connecting existing roads to the new LRT stop. With increased connectivity (now that in 2002 streets go much closer to the LRT stop than in 1993), one expects the size of the PCA to be at least the same as in 1993. Due to limitations in the spatial computations, however, the opposite has resulted. In 1993, the network PCA calculations were based on a starting place along the nearest road segment to the LRT stop (or theoretical stop since no stop actually existed in 1993). In 2002, that starting point was much closer to the LRT stop due to the new access roads. The result is a truncated PCA service area because the beginning point for walking distance was actually much closer to the actual LRT stop.

1993 Beaverton PCA (0.50 miles)	New streets (1993-2002)	Smaller 2002 PCA (0.50 miles)



Walkability starting place is artificially moved to the closest road segment (to the right)	**New roads leading to the LRT stop were built**	**Walkability starting place now starts closer to actual LRT stop, resulting in a smaller overall zone.**

Figure 57 Effect of New Streets on Pedestrian Catchment Areas, Beaverton 1993-2002

Means to Work–Workers 16+

These are the following sub-categories for “Means of Travel to Work for those aged 16 and older”:

Total

- **Car**
  - Alone
  - Carpool
- **Public**
  - Bus
  - Streetcar
  - Subway
  - Railroad
  - Ferry
  - Taxi
- Motorcycle
- Bicycle
- Walked
- Other
- Work at Home

For the purposes of this study, these categories have been concentrated into the following five:

1. Car 2. Bus 3. Train 4. Bike/Ped 5. Other

The “Train” category includes all data from the sub-categories of “Streetcar,” “Subway,” and “Railroad.” These categories have been consolidated because they all refer to rail travel, and in the Portland TODs, the only rail option is via the MAX light rail line. The raw data does show responses in each type of rail category, but that is most likely due to a misunderstanding of what type of rail transit the MAX constitutes.

A category called “Bike/Ped” is made up of the combined data from the “Bicycle” and “Walked” categories.

The “Other” category includes “Ferry,” “Taxi,” “Motorcycle,” “Other,” and “Work at Home.”

ENDNOTES

1. P. Calthorpe and S. Poticha, *The Next American Metropolis: Ecology, Communities and the American Dream* (New York: Princeton Architectural Press, 1993); R. Ewing, "Measuring Transportation Performance," *Transportation Quarterly* 49 v 1 (1995): 91; Parsons Brinckerhoff Quade and Douglas, United States Federal Transit Administration, Transit Development Research Council, *Transit and Urban Form* (Washington, D.C.: National Academy Press, 1996); M. Bernick. and R. Cervero, *Transit Villages in the 21st Century* (New York: McGraw-Hill, 1997); R. Cervero, C. Ferrell, et al. *Transit-Oriented Development and Joint Development in the United States: a Literature Review* (Washington, D.C.: Transportation Research Board National Research Council, 2002).

2. R. Cervero and K. Kockelman, "Travel Demand and the 3Ds: Density, Diversity, and Design," *Transportation Research Part D-Transport and Environment* 2 v 3 (1997): 199-219.

3. VTPI, *Online Transportation Demand Management Encyclopedia* (2002), The Victoria Transport Policy Institute, 2003, http://www.vtpi.org/tdm/ (accessed June 18, 2004).

4. Bernick and Cervero

5. S. Handy and University of California (System) Transportation Center, *Regional Versus Local Accessibility: Neo-Traditional Development and its Implications for Non-Work Travel* (Berkeley: University of California Transportation Center, 1995): 253-267.

6. City of Portland Office of Transportation, *Pedestrian Access to Transit: Planning and Design* (Portland, OR: City of Portland, 1998): 1.

7. Bernick and Cervero

8. Calthorpe and Poticha; R.H. Ewing and Florida Department of Community Affairs, *Transportation & Land Use Innovations: When you can't*

pave your way out of congestion (American Planning Association, 1997): 91-104.

9. M. Southworth and E. Ben-Joseph, *Streets and the Shaping of Towns and Citites* (McGraw-Hill, 1997).

10. Calthorpe and Poticha

11. E. Talen, "Measurement Issues in Smart Growth Research," Smart Growth and New Urbanism Conference, University of Maryland, 2002: 1361-1379.

12. Ewing and Florida Department of Community Affairs.

13. R.H. Ewing, R. Pendall, et al., *Measuring Sprawl and Its Impact* (Washington, D.C.: Smart Growth America, 2002).

14. A.B. Jacobs, *Great Streets* (Cambridge, MA:MIT Press, 1993).

15. K.J. Krizek, "Residential Relocation and Changes in Urban Travel: Does Neighborhood-Scale Urban Form Matter?" *Journal of the American Planning Association* 69 v 3 (2003): 265-281.

16. S.L. Handy, M.G. Boarnet, et al., "How the built environment affects physical activity–Views from urban planning," *American Journal of Preventative Medicine* 23 v 2 (2002): 64-73; L. Frank, *Health and Community Design: The Impact of the Built Environment on Physical Activity* (Washington, D.C.: Island Press, 2003).

17. J. Dill, "Measuring Network Connectivity for Bicycling and Walking," ACSP-AESOP, Leuven, Belgium, July 9, 2003, http://web.pdx.edu/~jdill/Dill_ACSP_paper_2003.pdf (accessed June 18 , 2004).

18. Krizek

19. K. Lynch, *The Image of the City* (M.I.T. Press, 1964).

20. Jacobs

21. Southworth and Ben-Joseph

22. E.G. Bossard, *Envisioning Neighborhoods with Transit-Oriented Development Potential* (San Jose, CA: Mineta Transportation Institute, 2002).

23. TIGER stands for Topologically Integrated Geographic Encoding and Referencing and is the system that the United States census uses for creating the base maps for use with census data.

24. In Portland, the pre-construction street data came from a local 1993 revision of the 1992 TIGER files. The local revision added refinements based on local knowledge of local conditions, including the designation of all roads into different categories of type and use.

25. Cervero and Ferrell

26. Talen

27. Local transit ridership data were only available in the Portland area. While full boarding data by years were not available from the Valley Transit Authority (VTA), we were able to obtain boarding data for typical days, which have been used as a rough proxy for the more complete data.

28. In 1990, the census variable was P049, while in 2000, the census variable was P030.

29. Calthorpe

30. In the Portland data set analyzed for this study, the base data for the street network has been custom coded as to street type (arterial, freeway, minor road, etc.) by a regional GIS processor for the Portland region. For Silicon Valley, standard TIGER street files were used that contain a CFCC variable that can be used to easily segregate neighborhood roads from major

thoroughfares.

31. Congress for New Urbanism, *Transportation Tech Sheets: Ped Sheds* (San Francisco, CA: Congress for New Urbanism: 2, 1998), http://www.cnu.org/cnu_reports/CNU_Ped_Sheds.pdf (accessed November 29, 2003).

32. Ibid.

33. G.B. Arrington and Tri-County Metropolitan Transportation District of Oregon, *At Work in the Field of Dreams: Light Rail and Smart Growth in Portland* (Portland, OR: Tri-Met, 1998).

34. Dyett & Bhatia Urban and Regional Planners, ECO Northwest Ltd. et al. *Seattle station area planning: case studies of transit-oriented development* (Seattle: Dyett & Bhatia, 1998).

35. Tri Met, "Facts About Tri-Met," http://www.trimet.org/news/pdf/factsheet.pdf (accessed November 29, 2003).

36. Portland data is derived from a 2002 street file data set enhanced by staff within the Portland metropolitan government. Silicon Valley data is derived from the 2002 TIGER street files.

37. Census data on "Journey to Work" only records the primary mode of transport. It is possible that there may have been an increase in biking or walking as secondary modes of transport, especially relating to the use of the transit stops.

38. The 2002 PCA and IPCA analysis for Mountain View was slightly altered due to a significant omission in the standard TIGER street file for the area. Since TIGER data only represents roadways, the short path connecting the transit station to the adjacent road is not included in the data. Therefore, this short path was added to the data to better reflect the accessibility of the Mountain View transit stop with the district to the south of the station. Without this modification, the analysis method employed would have located the transit stop closer to Central Expressway and begun

the walking zones from there, thereby cutting off access to much of the southern area–the primary area this transit stop serves.

39. Household numbers were derived from census block groups that intersected space within a quarter-mile of the transit stop, thus the total area of the TOD areas differs for each site.

40. Congress for a New Urbanism

41. Earl G. Bossard, *Envisioning Neighborhoods* (Redlands, CA: ESRI Press, in press).

42. As another reminder, since 2002, the tax lots just south of the transit stop have undergone aggressive development, including the creation of a tight internal street network much like the developments to the north of the Orenco Station transit stop and direct access from the transit stop to the south. When conducting a follow up analysis of the Orenco Station area to see change over time, it is likely that the pedestrian accessibility measures will improve dramatically.

ABBREVIATIONS AND ACRONYMS

CFCC	Census Feature Class Codes
Euclidean Distance	The straight line distance between two points. In a plane with p 1 at (x 1, y 1) and p 2 at (x 2, y 2), it is ((x 1- x 2)2+ (y 1- y 2)2)
GIS	Geographic Information System
IPCA	Impeded Pedestrian Catchment Area
Network Distance	The distance between two points based on traveling along an existing line network.
PCA	Pedestrian Catchment Area
STF	Summary Tape File
SF	Summary File
TOD	Transit-Oriented Development
TIGER	The **T**opologically **I**ntegrated **G**eographic **E**ncoding and **R**eferencing system is the system that the United States Census Bureau uses for creating the base maps for use with census data.
TSAP	Transit Station Area Planning
UGB	Urban Growth Boundary
VTA	Valley Transit Authority (Santa Clara Valley)

BIBLIOGRAPHY

Arrington, G. B. and Tri-County Metropolitan Transportation District of Oregon. *At work in the field of dreams: Light rail and smart growth in Portland*. Portland OR: Tri-Met, 1998.

Bernick, M. and R. Cervero. *Transit Villages in the 21st Century*. New York: McGraw-Hill, 1997.

Bossard, E. G. (in press). *Envisioning Neighborhoods*. Redlands, CA: ESRI Press.

Bossard, E. G. *Envisioning Neighborhoods with Transit-Oriented Development Potential*. San Jose, CA: Mineta Transportation Institute, 2002.

Calthorpe, P. "The Urban Network: A Radical Proposal–Peter Calthorpe makes the case for a new suburban transportation network." *Planning* 68 v 5 (2000).

Calthorpe, P. and S. Poticha (1993). *The Next American Metropolis: Ecology, Communities, and the American Dream*. New York: Princeton Architectural Press, 1993.

Cervero, R., C. Ferrell, et al. *Transit-Oriented Development and Joint Development in the United States: A Literature Review*. Washington, D.C.: Transportation Research Board National Research Council, 2002.

Cervero, R. and K. Kockelman. "Travel demand and the 3Ds: Density, diversity, and design." *Transportation Research Part D-Transport and Environment* 2 v 3 (1997).

City of Portland Office of Transportation. *Pedestrian Access to Transit: Planning and Design*. Portland, OR: City of Portland, 1998.

Congress for New Urbanism. *Transportation Tech Sheets: Ped Sheds*. San Francisco, CA., Congress for New Urbanism: 2, 1998. http://www.cnu.org/cnu_reports/CNU_Ped_Sheds.pdf (accessed November 29, 2003).

Dill, J. *Measuring Network Connectivity for Bicycling and Walking.* ACSP-AESOP, Leuven, Belgium. July 9, 2003. http://web.pdx.edu/~jdill/Dill_ACSP_paper_2003.pdf (accessed June 18, 2004).

Dyett & Bhatia Urban and Regional Planners, ECO Northwest Ltd., et al. *Seattle Station Area Planning: Case Studies of Transit-Oriented Development.* Seattle: Dyett & Bhatia, 1998.

Ewing, R. "Measuring Transportation Performance." T*ransportation Quarterly* 49 v 1 (1995).

Ewing, R. H. and Florida Department of Community Affairs. *Transportation & Land Use Innovations: When you can't pave your way out of congestion*. American Planning Association, 1997.

Ewing, R. H., R. Pendall, et al. *Measuring Sprawl and its Impact*. Washington, D.C.: Smart Growth America, 2002.

Frank, L. Health and Community Design: *The Impact of the Built Environment on Physical Activity*. Washington, D.C.: Island Press, 2003.

Handy, S. and University of California (System) Transportation Center. *Regional Versus Local Accessibility: Neo-Traditional Development and its Implications for Non-Work travel*. Berkeley: University of California Transportation Center, 1995.

Handy, S. L., M. G. Boarnet, et al. "How the built environment affects physical activity–Views from urban planning." *American Journal of Preventive Medicine* 23 v2 (2002).

Jacobs, A. B. *Great Streets*. Cambridge, MA: MIT Press, 1993.

Krizek, K. J. (2003). "Residential Relocation and Changes in Urban Travel: Does Neighborhood-Scale Urban Form Matter?" *Journal of the American Planning Association* 69 v 3(2003).

Lynch, K. *The Image of the City*. The M.I.T. Press, 1964.

Parsons Brinckerhoff Quade and Douglas, United States Federal Transit Administration, Transit Development Corporation and National Research Council. *Transit and Urban Form*. Washington, D.C.: Transit Cooperative Research Program, National Research Council, H-1 Project (1996).

Southworth, M. and E. Ben-Joseph. *Streets and the Shaping of Towns and Cities*. McGraw-Hill, 1997.

Southworth, M., E. Ben-Joseph, et al. "Streets and the Shaping of Towns and Cities." *The Town Planning Review* 69 v 1 (1998).

Talen, E. "Sense of Community and Neighbourhood Form: An Assessment of the Social Doctrine of New Urbanism." *Urban Studies* 36 v 8 (1999).

Talen, E. *Measurement Issues in Smart Growth Research*. Smart Growth and New Urbanism Conference, University of Maryland, 2002. http://www.smartgrowth.umd.edu/events/pdf/talenpaper.pdf (accessed June 18, 2004).

Tri-Met (2003). "Facts About Tri-Met, Tri-Met." http://www.trimet.org/news/pdf/factsheet.pdf (accessed November 29, 2003).

VTPI. *Online Transportation Demand Management Encyclopedia*. The Victoria Transport Policy Institute, 2003. http://www.vtpi.org/tdm/ (accessed June 18, 2004).

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