Assessing Transit-Orientation and Development in Freeway Corridor Light Rail Station Walksheds

Gabriel Leon

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Committee:

Marina Alberti

Tzu-Hsin Karen Chen

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Abstract

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Gabriel Leon

Chair of the supervisory committee:

Marina Alberti

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This thesis examines freeway-corridor light rail stations across five transit systems in the western United States to assess the measurable effects of freeway routing and three station design characteristics: adjacency to the freeway right-of-way, placement within or along the right-of-way, and pedestrian access across the freeway. It compares freeway-corridor stations with non-freeway stations using four primary metrics: pedestrian accessibility, measured through walkshed area; development potential, measured through zoning; development outcomes, measured through transit-oriented redevelopment; and ridership.

Walkshed area was calculated in GIS using OpenStreetMap and right-of-way data. Development potential was assessed using zoning data, while redevelopment was estimated through remote sensing methods. Boarding datasets were obtained from transit agencies. The thesis also evaluates whether adjacency, placement, and cross-freeway pedestrian access are associated with differences in station performance.

The results indicate a statistically significant 23% reduction in walkshed area for freeway - corridor stations compared with non-freeway stations. Pedestrian access was the most influential design characteristic. Stations without an ADA-accessible cross-freeway connection had walkshed areas 39% smaller than comparable non-freeway stations. Findings for transit-oriented development were mixed. Freeway-corridor stations produced, on average, 0.8 acres more transit-oriented redevelopment, a 33% increase; however, at the statistical level, redevelopment around freeway-corridor stations was lower than in the combined control group ($p = .0267$). Ridership results were also mixed. Freeway-corridor stations had higher average ridership but generated less than half the ridership per capita of the traditional control group, a statistically significant difference ($p < .0001$).

These findings suggest that freeway-corridor light rail stations impose measurable accessibility costs, but that these costs vary depending on station design, especially the presence or absence of ADA-accessible cross-freeway pedestrian connections. The results also complicate the assumption that freeway -corridor stations necessarily underperform in redevelopment or total ridership. Important limitations include potential false negatives in the redevelopment analysis due to roofing materials, lack of controls for station age, edge cases in classifying station design characteristics, possible zoning data inaccuracies, and the coarse resolution of remote sensing data. Despite these limitations, the thesis provides a quantitative basis for evaluating the tradeoffs of freeway-corridor light rail alignments during the planning process.

Table of Contents

Introduction

The utilization of freeway corridors for rail transportation stretches back to when the roles were reversed: rail corridors were used for the first freeways (National Archives 2022). Railroads had acquired broad swathes of land through agreements with the United States government, which in turn created ideal pathways for siting massive highway projects after the enactment of the Interstate Highway Act in 1956. But the freeway, being less efficient than the railroad, required duplication, width expansion, and geographic dispersion in a way that rail did not. This led freeways to carve new paths into farmlands, wilderness, urbanized city blocks, and rural towns. In urban areas in particular, this lack of spatial efficiency contributed to an expansion in the scale of metropolitan development, and a reduction in the density of housing and commercial activity as development followed new corridors and ring highways. Coordinating transit service in this burgeoning suburban landscape outstripped the ability of beleaguered and poorly maintained streetcar and interurban systems that had long ago stopped expanding as the personal automobile gained supremacy. The Western states suffered a nearly complete wipeout of rail transit, with only San Francisco's system surviving to the end of the 1970s. As the highway continued to come into full force as the driver of transportation policy and urban form throughout the United States, urban transit systems were also recalibrated to follow the new arteries written onto the metropolitan landscape. In the place of former interurban rail lines, express bus services were started from these newly minted suburbs to central business districts across the country, as no rail was being laid along these new tendrils of development (Kershner and HistoryLink 2019). These services had mixed results. Several of these services fell victim to the same declining transit usage that entombed the streetcars that preceded them, while others proved popular enough for discussions to begin on whether they should be converted into rail in an effort to get suburban residents out of cars to reduce highway congestion and relieve overcrowded buses (Freemark 2024). In the Eastern United States, Chicago had re-constructed the Blue Line of the L metro system in the freeway right- of-way of I-290 before Los Angeles had even heard the last ding of the legendary red cars (Freemark 2024). It would be a full twenty years later before Los Angeles, which previously had the world's most expansive transit network, would embark on a freeway corridor rail project that would lead to the origin of this thesis: The I-105 light rail project, now known as the C Line. Conceived of as a concession to the community as part of a consent decree in order to build the controversial freeway, it was the second light rail line to open in Los Angeles, following the Blue Line that tied Downtown Los Angeles to Long Beach (Hestermann et al. 1993). Situated in the median of the I-105 with roaring traffic on both sides of the platforms, missing multiple sidewalk connections, and adjacent to sprawling onramps that ate substantial chunks of the walkshed, The C Line would go on to develop a poor reputation (Mieger and Chu 2007). This legacy impacted light rail projects across the United States, filtering into the public perception of freeway corridor rail projects, and spooking transit agencies into avoiding them (Walker 2016).

However, the death of the freeway corridor rail project has been greatly exaggerated. In fact, some of the most important upcoming transit projects across the country are utilizing freeway corridors for several key reasons. The two most substantial driving factors for a transit agency to pursue a freeway corridor project are their lower cost and general political expediency, which have become key in deciding if and how to build a transit project. In addition to freeway corridors being seen as the path of least resistance, they are increasingly at the center of job hubs (Fragkias and Geoghegan 2009). Finally, they are often faster than street running light rail projects, as grade separation is easier and cheaper to achieve within a freeway corridor, allowing trains to avoid stoplights and speed limits. These four factors have collectively kept new freeway corridor light rail projects on life support, even as cities that rely most heavily on them, such as Denver and San Jose, struggle with ridership. Several cities are actively constructing freeway corridor light rail projects, including Seattle, Minneapolis, and a large number of international cities. In addition to projects in active construction, many cities are debating how to build these corridors for all or part of a proposed project. Phoenix, Seattle, Los Angeles, Sacramento, and Portland in the Western United States all find themselves embroiled in public fights related to whether or how to use the freeway right-of-way to host light rail infrastructure. Some notable vignettes include in the Seattle area, where the mayor of Issaquah is arguing for the placement of the Issaquah station in the median of the I-90 to save money (Packer 2026). In Phoenix the city council recently scrapped the I-10 corridor project entirely and redirected the funding for an arterial project in the same area (Valley Metro 2026). Sacramento has wavered on whether the median of the I-5 would be more feasible than the current plan to use an adjacent arterial (Alvarez 2025). Cities are also pouring money into trying to tamp down some of the perceived weaknesses of freeway corridor stations, including closing offramp infrastructure near stations (WSDOT 2026), building new cross-freeway connections (VTA 2026), and re-orienting ingress and egress points.

Disagreements over the strengths and weaknesses of freeway corridors for rail point to the lack of quantification on the viability of freeway corridor light rail projects. While there is a general understanding that freeway corridor light rail projects are inferior to other projects that don’t follow a freeway corridor, there has been little to no study into how strong this negative impact is across metrics such as ridership and development. There has been even less research on how specific design characteristics, such as placement along the right-of-way and pedestrian connectivity across the freeway, affect ridership and development outcomes. As a result, broader assumptions about the impacts of freeway-corridor light rail stations have often been shaped by a handful of case studies rather than by a systematic comparison with arterial or other non-freeway stations. This thesis attempts to quantify some of these factors, determine whether there is a significant difference between freeway stations and non-freeway stations, and measure the repercussions of siting a light rail station in a freeway corridor so that this information can be used as a planning tool. There are four variables that will be explored: 1. Walkshed, or the area that can be reached within a half mile walk from the station, 2. the percentage of the walkshed that has been zoned for transit-oriented development, 3. The amount of land within the walkshed that has been redeveloped as transit-oriented-development, and 4. Station ridership and the ridership per capita within the station walkshed.

Literature Review

Station Area Size and Formation

Light rail stations vary widely in form, from flagged stop points in Pittsburgh and San Francisco to impressive pieces of infrastructure in and of themselves (such as the majority of Link stations in Seattle). The walksheds of these stations vary according to the urban environment, climate, time of year, and demographics (Access Magazine 2018), but are generally assumed to average to around ½ a mile in North America (O'Sullivan and Morrall 1996). This has been the case in several key studies (Cervero 2001), (Kuby, Barranda, and Upchurch 2004). However, this assumption is not universally accepted, with some research defining light rail walksheds as closer to the ¼ mile assumed for bus stops, while other research suggests the distance transit riders will walk to reach light rail stations can be upwards of a mile and half. The size of the walkshed for a station is important, as the area around the light rail station sees increased rates of walking among residents and fewer car trips throughout the day (Huang et al. 2017). Most studies that look into the impact of transit on the urban landscape use Euclidean distance, but the method has serious shortcomings (Access Magazine 2018). Particularly when observing urban fabric that is entwined with freeway infrastructure where there are numerous disruptions into the street grid and pedestrian desire paths, it can lead to false conceptions of accessibility, which has been noted by multiple authors. The quantified impact of a freeway station is a lightly touched subject, but a frequently cited example is on the Chicago Blue Line's Racine station, which had 27.5 acres of land taken up by freeway infrastructure (Freemark 2024).The alternative method of analyzing the walkshed of a station is by measuring pedestrian walking distance, in what is known as an isochrone. This method uses the pedestrian network of sidewalks and multi-use paths to calculate the actual area accessible within a given amount of time or within a specified distance. To the author's knowledge, this has never been done within the context of a multi-city comparison.

Transportation and Development, Interlinked.

All of the motivational factors associated with the investment of public funds to build a light rail line tie back to one central point: intervening in the land use-transportation feedback loop with a transportation investment, understanding that land use and commute habits will follow. The Gordian knot of problems associated with car dependence: congestion, inefficient land use, social dissolution, and various forms of pollution all tie back to the need to increase transit usage and reshape the urban form around them. It is in this circular pattern between transit usage, land use, and accessibility that fundamentally drive light rail expansion (Higgins, Ferguson, and Kanaroglou 2014).

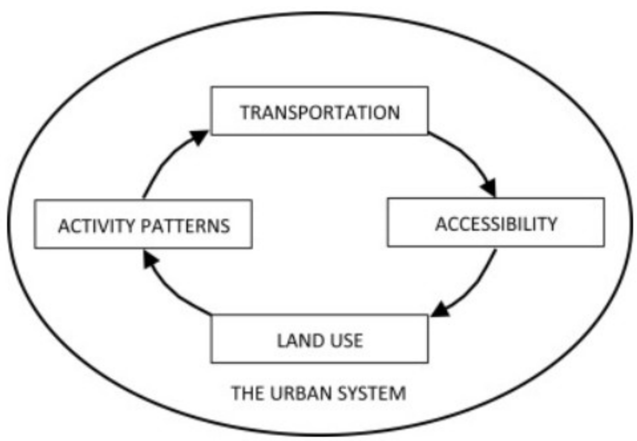

Figure 1. Transportation- land use feedback loop diagram (Higgins 2014)

Density is directly correlated with the percentage of people around a station that walk to transit (Chen, Gong, and Paaswell 2007). This has also been confirmed in international settings (Qiang, Zhang, and Huang 2022). As density increases, a positive feedback loop of mode shift ensues, as described by both Higgins and Chen. This factor is vital to encourage modal shift, as parking availability impacts car ownership (Guo 2012) and car ownership is the biggest factor in determining whether someone utilizes transit (Blumenberg 2020). There are several typologies of urban locations that are favored for TOD development. One is former mall sites due to their large land area, and the potential for the creation of new town centers rather than 1-off developments (Blanco and Wikstrom 2018) . Light rail is often chosen not only because it is a catalyst for development, but the existing developments around multi-modal communities and transit-friendly infrastructure often see a drop in VMT through the multiplier effect after construction, essentially becoming TOD themselves (Ewing and Hamidi 2014). These changes are particularly important in growing cities, such as those of the American West, which were built mostly after the automobile was widely available.

TOD vs. TAD

Not all development that happens within the proximity of a light rail station is going to inherently be TOD; it therefore has to be delineated from non-transit-oriented development, known as transit adjacent development (TAD). Existing research on the differentiation between TAD and TOD tends to follow two lines of inquiry: the driving factors of success or failure in making a TOD, and how to score or judge a TOD site. The first, judging TOD success or failure, often orients around the most literal factor, which is actual transit usage to and from the TOD site in question (Thomas and Bertolini 2015). A second line of inquiry within this topic is how to score developments. Others provide more specific benchmarks for transit and sustainable modes, such as if at least half of trips are made with a sustainable mode such as transit, walking, or cycling (Hale 2012). Other studies support a broader set of criteria, such an Urban Institute study that had nine criteria including building quality, mixed-use, affordability, public access and mode shift of the residents or workers in the building (Freemark, Su, and Lo 2026) . The geographic scale of studies varies from a building or set of buildings to the usage of the station itself, but there are no studies that the author is aware of that extend to the entire community around the station holistically. Both methods conduct much more intense scrutiny than this paper will examine, as a qualitative analysis almost always involves interviewing or observing residents and customers within specific developments to determine their transportation habits. There are a few of these highly atomized studies, with Fruitvale Station along the BART system being the most frequently examined (Goggin 2018). The most helpful for the suburban context of the Anglosphere is Singh et. al. that establishes eight "rules" for TOD that determine whether a site meets the benchmarks to be considered "true" TOD (Singh et al. 2017). The assessment metrics fall into a mix of qualitative and quantitative methods, with some stemming from network analysis tools on GIS platforms to measure intersection density, to public life investigations to assess "user-friendliness of the transit system". Almost universally, TOD analysis involves the creation of an "index" to discern TOD from TAD. Other papers similarly used eight rules but differed in what these rules were. In particular contention is the concept of "adequate parking" for vehicles (cars and/or bikes). There is back and forth over whether parking should be minimized, carefully calibrated, or non-existent. Every paper that established a set of rules considered parking as one of them, and critiqued other researchers for their understanding of parking within TOD. The rift seems to be between papers that are focused on urban settings and papers focused on more suburban settings. The remaining conflict points tend to be over the weights assigned to certain metrics, although nearly all of them seem to lack the concept of quality of development and cohesiveness of the neighborhood, which this thesis deems critical.

Challenges Related to TOD

The challenges relating to constructing and assessing TOD are substantial, starting with getting them off paper and onto the ground. Historically, there have been serious challenges coordinating between transit agencies, local governments, and developers to line up zoning, incentives, access, and interconnectedness between transit stations and mixed-use developments (Knowles 2012). There have also been a slew of other issues related to development, including getting banks to loan to projects that don't include parking (Oliver 2022), and the difficulty in making mixed-use development pencil out due to a consistent mismatch in the interest for housing and commercial elements within TOD developments, with housing demand outpacing brick and mortar (Knowles 2012). This has resulted in a lack of development in areas zoned for it, and often requires government assistance or direct investment to get them to develop (Curtis 2012). When they are built, they have a tendency to leave TOD projects feeling sterile or empty, as a result of extended vacancies on commercial ground floors (Knowles 2012). Other issues including the coarse grain of development and the actual transit usage within those developments as was discussed previously. TOD is also sensitive to other factors. A newer concern related to TOD has been displacement and gentrification. While nearly all studies have been inconclusive (Padeiro, Louro, and Da Costa 2019), there is a broad political feeling that transit projects cause local residents to be displaced, and that neighborhoods become whiter as a result of transit investment and the development that follows (Zukin 2016). While this has dubious merit, it has integrated into the mainstream consciousness. It is also hard to parse whether TOD actually changes mode share of neighborhood residents, or if self-selection bias is occurring, where people move to an area because it is served by rail transit, essentially just re-shuffling the population within a city (Cervero 2007). However, this notion is contradicted by data that the latent desire to walk is prevented from being actualized by the auto-oriented form of neighborhoods (and safety issues). This desire to walk builds onto two factors already discussed, the multiplier effect of a light rail line that decreases VMT, and the increased rates of walking as a result of a station being built to suggest that car-oriented neighborhoods become more transit-oriented in practice once transit infrastructure is extended to the neighborhood. This was outlined by DeVos in 2012 with the concept of spatial dissonance, although it cuts across to affect those who would rather walk in a more suburban environment as well (De Vos et al. 2011).

Challenges & Benefits of Freeway Corridors

Freeway corridors present a double-edged sword for transit capital projects. On one hand, they tend to encounter significantly less political opposition and a higher general level of support among the public (Carroll et al. 2011). This is due to a variety of reasons, from reduced eminent domain needs and the lower level of political capital held by residents nearby. The costs of building a transit project in a freeway corridor are significantly lower than other grade-separated options as well (Carroll et al. 2011), meaning more miles of fast transit can be built compared to projects that avoid freeway corridors. There seems to be an inherent tradeoff between ridership potential and distance covered when a freeway corridor is considered. Lower land acquisition costs, lower construction cost, and fewer delays transpire when rail projects are built in freeway ROW (Evazzadeh, Kheirkhah, and Shakeri 2021). An additional benefit is the average speed of freeway corridor transit is much higher compared to street-running light rail. On the other hand, they have a reputation for having access issues which reduce the walkshed of the stations (Loukaitou-Sideris et al. 2013). This has a known negative impact on user perceptions, and reduces the potential for transit-oriented development, although this has never been quantified in existing literature, as mentioned previously. Additionally, they are recognized for being generally an unpleasant user experience, feeling uncomfortable due to noise and the known health risks associated with freeways from air pollution, with residents near freeways being exposed to 175% more particulate matter and 134% more decibels of sound pollution (Houston et al. 2016). However, there are contradictory factors at play. While noise and air pollution have negative impacts on the health for the users, increased walking as discussed earlier leads to lower rates of obesity and lower BMI (MacDonald et al. 2010). There are also challenging design aspects of a freeway corridor light rail including difficulty of cross freeway connections, ingress/egress, and onramp/offramp infrastructure adjacent to stations (Loukaitou-Sideris et al. 2013).

Remote Sensing: Spectral Endmember Analysis

Remote sensing has long been used to determine land use. This long-standing application of the science has been used in vastly different parts of the field, from assessing crop distribution in America, to determining urban expansion in the Global South. Typically, they rely on broad spectrum open-source satellites such as Landsat and Sentinel, which are coarse multispectral data. The use of Landsat for collecting data on urbanization is well established in particular (T.-H. K. Chen et al. 2020). For the land use component of this thesis, a different methodology known as a spectral endmember analysis was used. The key challenge of this thesis was assessing how to detect redevelopment that increases density and transit-orientation, while decreasing automotive orientation. Detailed land use analysis such as differentiating asphalt and buildings is at the cutting edge of remote sensing research. Existing research related to differentiation uses advanced endmember analysis techniques including the CHRIPS methodology, which creates 13 spectral classes through analyzing hyperspectral imagery in a supervised classification scheme (Alakian and Achard 2020). However, as applicable as CHRIPS is, it is a rigorous process which includes extensive processing and random forest modelling. CHRIPS and other methodologies almost universally rely on using hyperspectral data from commercial satellites, and are focused on one point in time, which is where nearly all high resolution satellite imagery comes from (Veganzones and Graña 2008). There is very little research from where spectral unmixing is used in combination with multispectral open source remote sensing data such as Landsat and Sentinel. Specifically related to the built environment, one problem highlighted is the cluttering of mismatched materials on the landscape. One example from literature is the reflectance from vehicles giving off the spectral signatures associated with plastic and metal, often skewing the data or leading to a false cell value for asphalt (De Luca et al. 2025). This research has also been used to differentiate building materials in the urban form, and has applications outside of the urban planning realm in material detection for warfare, which is where the funding stream for this research largely originates. These methods are usually performed at very high resolution, significantly more so than what is available with the datasets used in this project. However, there is precedent for using Landsat data to analyze differences in the urban form using spectral unmixing (Michelson 2019). The precedent of achieving differentiation of endmembers between asphalt and buildings is present in these examples. These endmembers are defined very differently according to various methodologies and vary broadly. As alluded to above, spectral unmixing from lower resolution satellites is somewhat clunky, but can be done. This precedent for sensing redevelopment with Landsat has been established by a few key studies, including one in Beijing (Liu et al. 2025). Most of the existing research regarding the ability to distinguish and identify change in composition of urban materials has been related to assessing damage or material mix for the purposes of infrastructure maintenance (Schnebe et al. 2015), (Mei et al. 2014). This shows up in research about asphalt, as there are compositional differences in asphalt components depending on the climate and purpose of the asphalt, which would mean we should expect slightly different signatures for asphalt in hot cities in Southern California than we would expect to find in cities farther north, such as Portland. It also has implications for differences between asphalt typologies within our study areas, such as the differences between asphalt on runways, those in freeways, and those on conventional arterial roads. Another key research topic includes the difficulties of defining asphalt, as the composition and reflectance of asphalt changes over time, as bitumen wears away (Pan et al. 2017). Development is expected in places where asphalt is significantly older, such as aging strip malls and former mall sites. This “graying” can result in false positives for buildings, and if calibrated for, could potentially result in false negatives for asphalt. Thankfully, mixed-use redevelopment tended to have higher surface reflectance, reducing this conflict. The twelve-year window of observation in the study cities also made this possibility less likely than it would have if it was over a longer period of time, but still has potential implications to watch out for.

Methodology

Dependent Variables

There are four dependent variables that will be examined in this thesis.

1. Size of walkshed (measure of the pedestrian-accessible area around each station)
2. Percentage of land in the walkshed where transit-oriented development is allowed according to zoning codes
3. Amount of land redeveloped as transit-oriented development within the walkshed
4. Ridership (boardings at each station), and ridership per capita (boardings divided by the population living within the walkshed)

Independent Variables

Freeway Corridor Station:

The foremost independent variable is whether a light rail line follows within 100 feet of a freeway for the majority (50%) of its length. All stations must be no more than half of a mile from the edge of the freeway to be considered a freeway corridor station. A light rail line was considered if it exists in a shared corridor also containing an access road, green space, or freight rail, but the line cannot be more than 500 feet away unless it falls within 100 feet of the freeway at a previous point. A light rail line was determined to still be in-corridor but on a deviation as long as the line returned to the corridor without running in the median or alongside an arterial road oriented parallel to the freeway. Therefore, a deviation from the freeway must be bookended by freeway running portions of the line. For example, a light rail in the median of an arterial that paralleled the freeway 800 feet away was not considered to be in a freeway corridor unless the tracks left the freeway to deviate onto said arterial, and then returned to the freeway corridor before the following station. The control group was split into two sections. The first was the parallel control group. These stations were on light rail lines that followed the general path of a freeway corridor, but did so along arterial roads, where the freeway would have been an alternative routing option to connect the two end points of the rail line. The second was the traditional control group, which was composed of rail lines that operated at least a mile from the freeway on unique corridors.

Design Characteristics

1. **Freeway adjacency.** This attribute was to assess whether orientation of the station relative to the freeway right-of-way had any impact on the dependent variables.

   Median- The light rail station platform(s) was located within the freeway right-of-way, with access requiring riders to move above or below the ROW. This also includes cases where the station was directly adjacent to the freeway on one side and freight rail tracks on the other.

   Shoulder- The light rail platform(s) was located less than 100 feet from the edge of the freeway.

   Small deviation- The light rail platform(s) was located adjacent to the freeway, but was between 100 feet and 500 feet away from the freeway edge, including ramps connecting the freeway to other roads.

Large deviation- The station was a notable distance of at least 500 feet from the edge of the freeway, including onramp/offramp infrastructure. These stations were controlled for when observing the variable of cross-freeway pedestrian access.

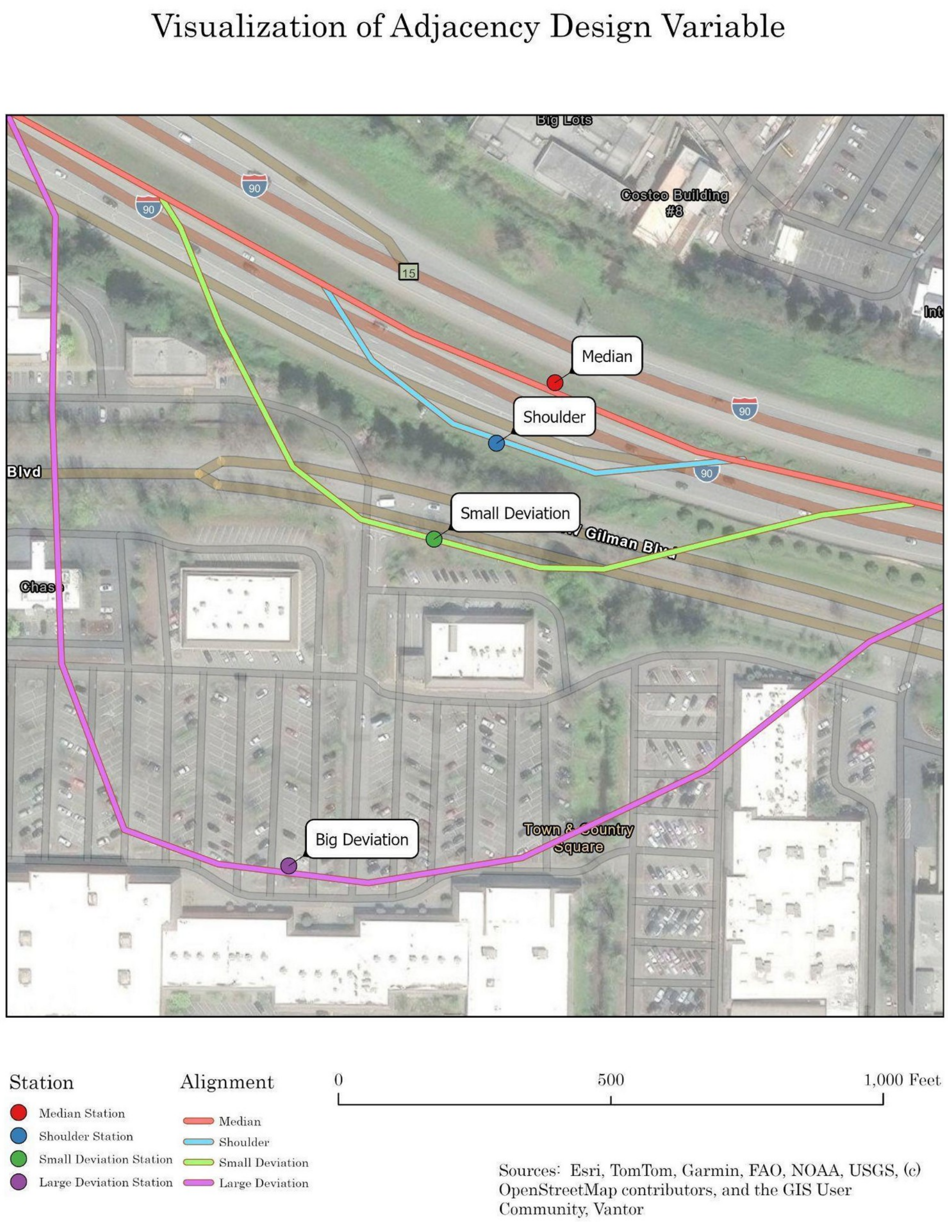

Figure 2. Visualization of adjacency design characteristic

2. **Access: cross-freeway pedestrian connection.** This variable measured the availability and quality of pedestrian and micromobility movement across the freeway corridor. Connections with a "large deviation" under the adjacency variable were controlled and analyzed separately, as cross-freeway access became convoluted and harder to determine due to large distances involved.

   high quality- There was a high-quality pedestrian and bicycle access across the freeway from the station that included full ADA access and at least 12 feet in width with a buffer. Cross-freeway connections with a 16-foot width without a buffer were also counted in this attribute category.

   sufficient- There was substantial access across the corridor, including full ADA access. For a surface level station, this meant at least 8 feet of sidewalk width and substantial ADA treatments including flashing beacons and high visibility sidewalks at any at-grade off-ramp crossing. This was the highest an underpass could score.

   insufficient- There was at least some access across the freeway. This typology usually involved a narrow foot-only path involving stairs lacking ADA access. It existed but was of poor quality. Also included flat at-grade connections that subjected pedestrians to uncontrolled slip lanes and other hostile interactions with vehicles.

   deficient- There was no access to the opposite side of the freeway without substantially deviating onto side paths and parallel roads to reach a pedestrian crossing point. This also applied when a median station lacked an access point at the far end of the station platform.

3. **Placement along ROW.** This variable qualified the placement of stations *along* the light rail line as it related to the hierarchy of perpendicular road infrastructure. If multiple hierarchies were present across multiple station entrances, ADA accessibility was used to decide which was the primary entrance. If further specificity was needed, whichever entrance was associated with more connecting infrastructure (bus, park and ride lot, etc.) was used to assign the value of this variable.

   Local/pedestrianized- The light rail station was accessible via a local street, or not connected with a street at all, and had an independent access point to the area around the station. These stations were located either in fully pedestrianized spaces such as college campuses, or in quiet neighborhoods and office parks on side streets.

   Collector- the light rail station was accessed via a collector street. A collector street is defined as having one lane in each direction, is directionally delineated, and is fed by multiple local streets.

   Arterial- the light rail station is connected to an arterial road, defined as having four lanes or more, but does not have freeway access near the station.

   Freeway- the light rail station was connected to a road that serves as an access point for the freeway, or had station access infrastructure that was bisected or disrupted by freeway onramps/offramps.

Geography of Consideration

Five metropolitan areas were studied. The search parameters were limited to light rail systems in the Western United States that contained both arterial- and freeway- running segments of substantial length to offer a fair test group and control group within the same metro area. The lack of extensive freeway corridor light rail segments resulted in the exclusion of Sacramento and San Francisco. Midwest and East coast systems were excluded due to the complexities of East coast light rail systems, and the unfamiliarity of the author with these cities and their context. Systems in the Intermountain West were not included because of the three major light rail networks (Salt Lake City, Phoenix, and Denver), only Denver contained freeway corridor stations, and unfortunately the Denver metro area lacked a regional zoning dataset. This lack of a regional zoning dataset would have made the process of filtering development down to potential TOD overly tedious due to the number of municipalities and the lack of consistency in zoning codes. Thus, these were the five light rail systems that were analyzed: Portland, Seattle, San Jose, San Diego, and Los Angeles. Stations within city centers were excluded. This was done in order to hone in on the central question, which was whether there was a difference between freeway corridors and non-freeway corridors in converting urban sprawl to transit-oriented development. By removing city centers from the analysis, some of the shortcomings of the remote sensing methods relating to assessing material composition and grain size were also avoided. Stations within parks and at airports were excluded, as TOD redevelopment in these locations would not be desirable. Stations placed alongside grade-separated arterials were not included to avoid confusion. In practice, this only removed stations on the Orange Line in Portland, as the line runs along a state highway with a mix of intersections and full grade-separation.

Data Collection

Vector data was collected from government agencies and Open Street Map (OSM). Station data was acquired from various transit agencies via GIS data portals. In some cases, the locations were refined in GIS to match the topological network, to make sure the walkshed polygons were calculated correctly later in the process. For example, the point layer for San Jose stations was simplified from two per station (the platform for either direction was digitized separately by the VTA) into one in order to develop consistent service area polygons to match the rest of the stations being analyzed. Historical imagery and current imagery were both accessed from Google Earth. Ridership data was derived from the five transit agencies whose systems were part of this study. Zoning data was collected from the county, state, or MPO of the respective metropolitan area. Raster data was used to conduct the TOD redevelopment analysis, which was change over time. The raster data was derived from Landsat 8, and was accessed through Google Earth Engine. Despite being older and coarser than other sources of satellite data, Landsat was chosen to broaden the window of time that the analysis could cover by six years. This expanded observation window allowed development that occurred during the post-recession boom to be captured rather than relying on exclusively post-pandemic data. Lower resolution data also helped to control for false positive development detections stemming from sidewalk construction and other municipal improvements that were common during test runs with Sentinel data, which uses a ten meter resolution. Before processing in ArcGIS, several adjustments were made in Google Earth Engine. Cloud masking was applied to images, and the median pixel was selected from a period over several months. The pixels were sharpened using the Brovey Pan Sharpening method, and elevation was controlled by using a USGS digital elevation model. Bi-directional Reflectance Distribution Function (BDRF) was corrected for, which in test runs had caused errors in development detection across all five metropolitan areas in the same pattern. These earlier test runs had returned false positives for development in the east, and false negatives in the west before the error was fixed. The raster data used an endmember analysis, where the urban environment was divided into six elements: forest, shrubs, water, buildings, roofing tiles, and asphalt. This was done in order to identify any redevelopment of the urban form where car-oriented land uses such as large surface parking lots or single-family homes were replaced with more compact and potentially walkable development inside the zones where TOD was permitted. Each pixel contained fractions of the landscape that each reflectance value imbued. From there, spectral unmixing was used to create a “building index” in which the composition of each pixel’s value associated with what proportion of each pixel contains the spectral information associated with buildings and roofing tiles. This was done ten times, once in 2013 and another in 2025 for each of the five metro areas. The date range for the median pixel selection was from June 1st to August 31st in Seattle and Portland and was both shifted forward and broadened to the window of August 15 to December 30th for the California cities. The date range was adjusted in order to control for persistent wildfire smoke and regional effects.

GIS Processing

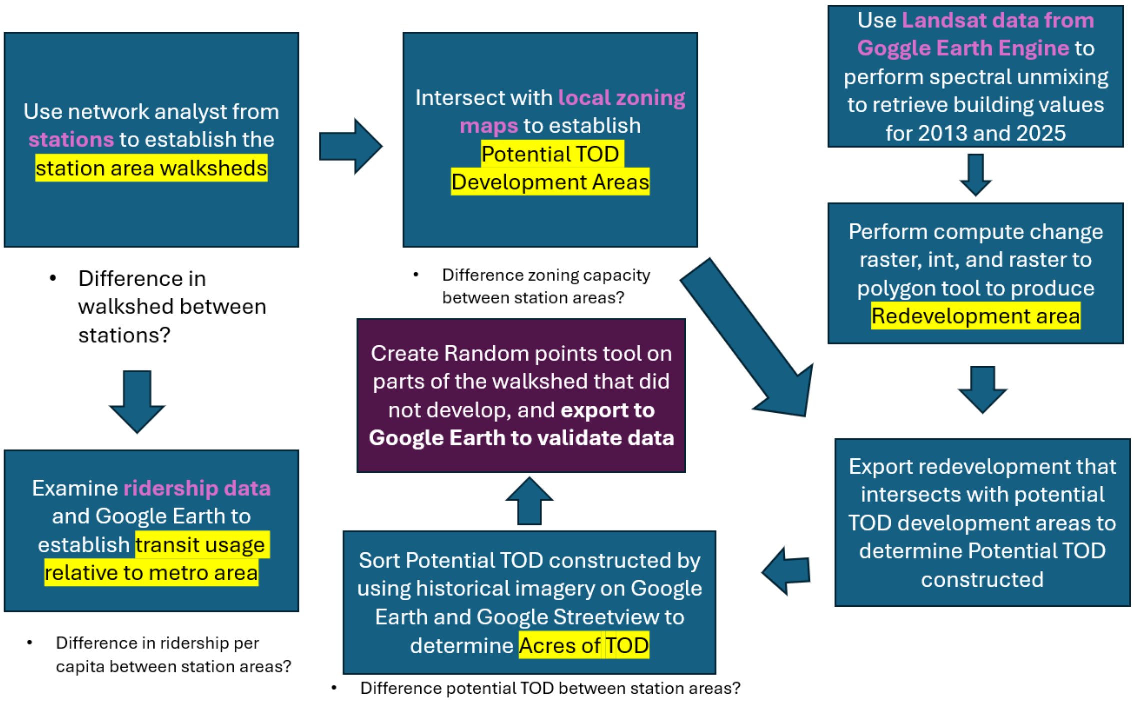

Figure 3. Workflow visualization

1. Station Area Walksheds

To calculate the walksheds of each station, the point layer for each system's light rail stations was brought into QGIS, cleaned for duplicates and outdated information such as closed and relocated stations, and then projected into UTM Zone 10N. The ORS toolset was then used to create isochrones, set to 804 meters (½ a mile) for the shapefile layer containing the refined light rail stations, with the ID field set to the name of the station and the travel mode set to "foot, walking". It should be noted that ORS tools use the Open Street Map (OSM) platform to calculate walkshed, and the ESRI network analyst extension uses a different methodology and network database to produce the isochrones. The tool also produced a population field, which utilized data from the 2020 census. From there, the walksheds were imported into ArcGIS, where water and road rights-of-way were removed from the walkshed using the erase tool.

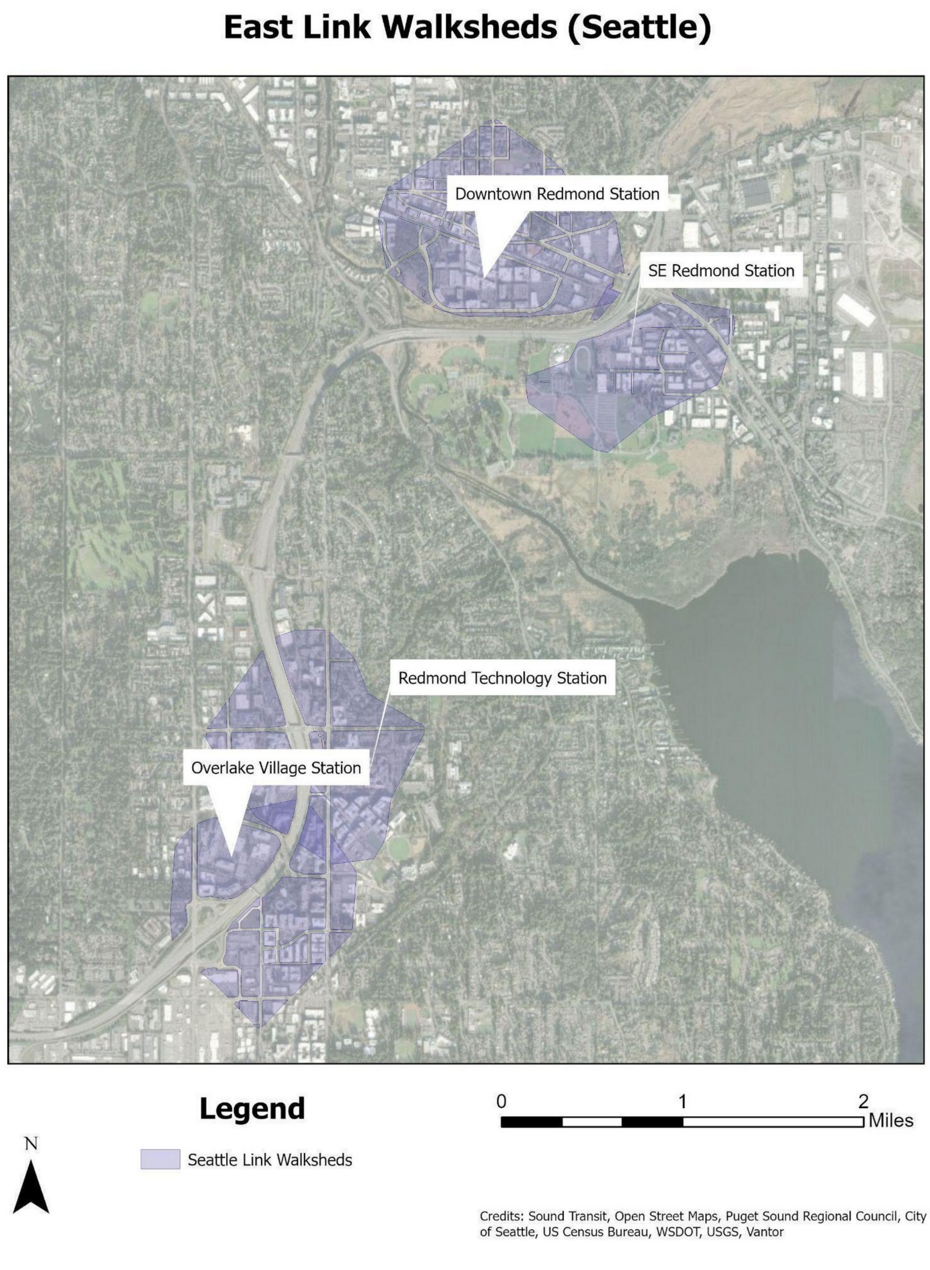

Figure 4. Example of walksheds after processing

2. Zoning that could support TOD

Land use datasets were acquired from the State of California and metropolitan planning organizations (PSRC for the Seattle metropolitan region, and METRO for the Portland metropolitan region). They were then filtered down to mixed-use zoning, multi-family zoning, and high intensity commercial zoning. This was done in order to parse non-TOD building development from the results as much as possible. The California dataset was further refined and filtered, as it excluded many key locations where TOD is actually allowed, while including vast swaths of R-1 single family zoning in the “urban residential” category. Several zoning categories such as C-3, C-4, C-5, and downtown zoning categories were added to the mix, while several R-1 and R-1.5 were removed. This was not a perfect process and will be addressed further in the limitations section. Once filtered, these zoning categories were exported and made into a new shapefile. In order to streamline this dataset, a dissolve tool was used to simplify the area into a single polygon. A “summarize within” tool was then performed to determine the area within each station area walkshed was a potential development zone for TOD. This number was then divided by the area of the station area walkshed itself to achieve a ratio between the area of the walkshed and the area within it that was zoned for TOD.

Figure 5. Map of walkshed with zoning underlaid

3. TOD Identification

From Google Earth Engine, after completing the refinement and retrieval process described earlier, the 2013 and 2025 raster datasets for each metro area were imported into the ArcGIS desktop environment. The compute change tool was used to determine the change in building fraction in each pixel between the two years, with 2013 being "from" and 2025 being "to". The "extract by attribute tool" was then used to select raster cells where the building fraction rose by .25, or a 25% increase. The goal was to cancel out as much of the noise in the urban environment as possible without missing developments that contained solar panels, rooftop gardens, or unique materials. The "Int" tool was then used to convert the raster cells to integer values, which enabled the penultimate step, which was for the potential TOD area to be rasterized using the "raster to polygon" tool. The final step was a qualitative sorting process for the potential TOD layer into TOD redevelopment (mixed-use buildings, missing middle apartments, well-integrated office buildings) and false positive detections (car-oriented uses and roof replacements). This process was completed using historical imagery on Google Earth, comparing late 2012 to present day. Historical imagery on Google Earth was used first to determine if building development had occurred, which was followed with a secondary investigation on Google Streetview. If the land use change was observed to have met the following criteria, it was counted as TOD:

1. Demonstrated a progressive increase in intensity of use
2. Either had no effect on the walking environment or improved it
3. Addressed the street directly without parking as an intermediary

Inevitably, this broad net caught a number of buildings that were not actually generating transit ridership. However, the best way to actually delineate TOD from TAD is by assessing mode share and trip generation from developments, which was impractical for this thesis. It will be discussed at length in the limitations section.

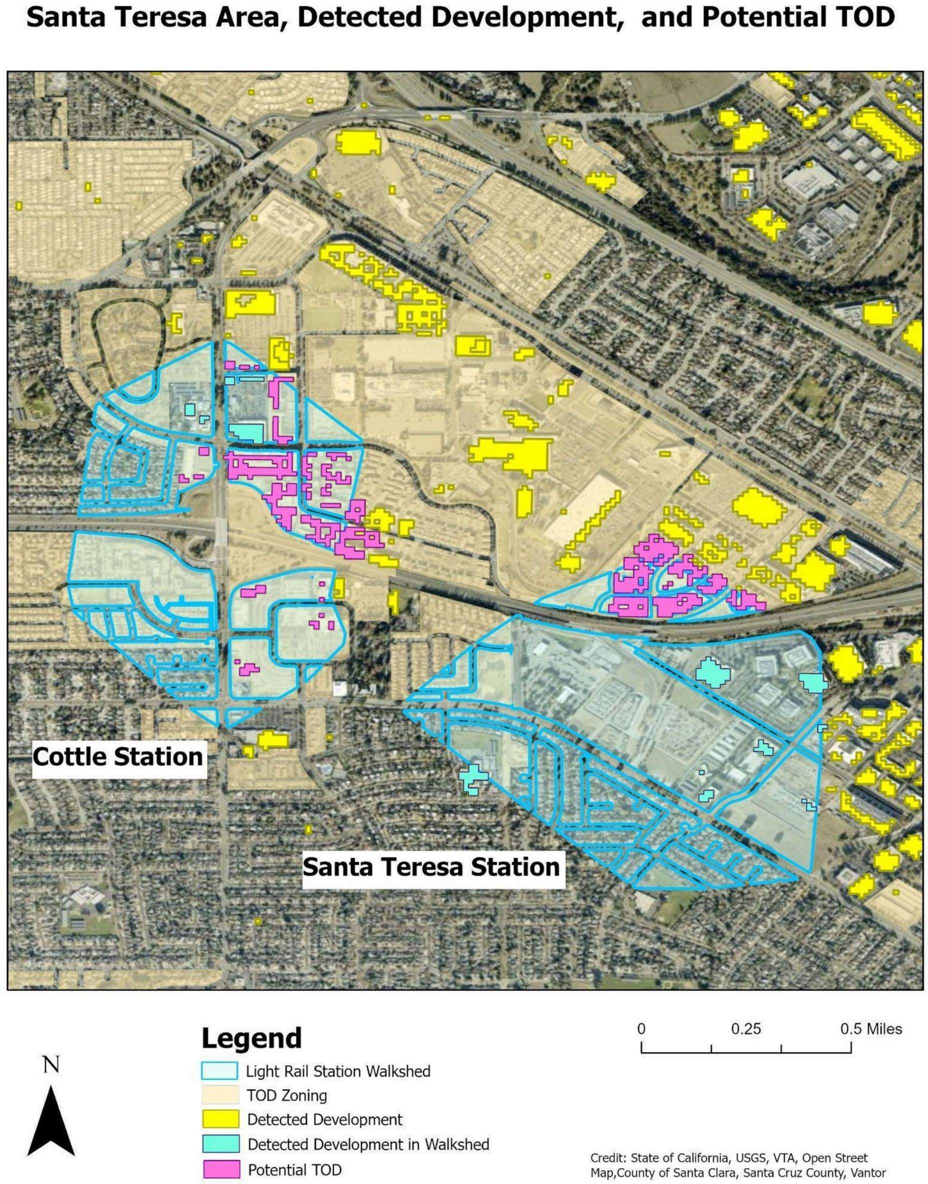

Figure 6. TOD redevelopment layer overlaid and sorted based on zoning

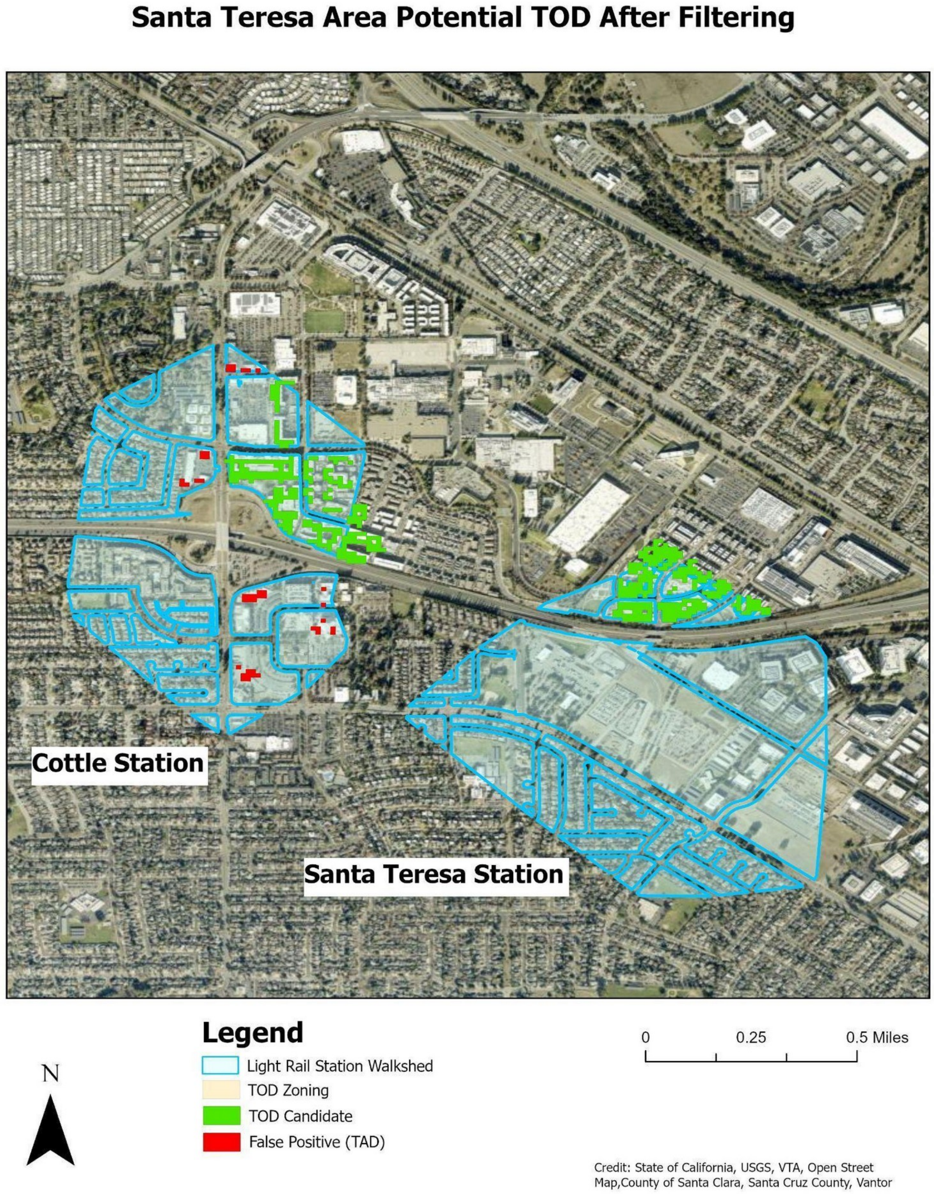

Figure 7. TOD redevelopment layer after qualitative sorting to eliminate non-TOD

4. Ridership

Data for average daily boardings by station was collected from the five transit agencies that operate light rail lines within the study area. This included the Valley Transportation Authority (VTA) in San Jose, the Metropolitan Transit System (MTS) in San Diego, Sound Transit in

Seattle, Metro in Portland, and the Los Angeles County Metropolitan Transit Agency (LACMTA) in Los Angeles. Ridership data was from the previous six months. San Diego, Los Angeles, and Seattle were collected from March of 2026, and San Diego and Portland were collected in October of 2025. This difference was due to data availability, station closures, and avoiding significantly lower boarding numbers during the winter months. This data was then entered manually into each of the five ArcGIS shapefiles for their respective walkshed. Boarding data was taken and divided by the population of each walkshed to determine the ridership per capita. When analyzed later, it should be acknowledged that stations with less than two hundred residents were removed from the analysis to avoid skewing the data.

G. Data Validation

To examine the reliability of the analysis, data validation was performed. First, the “erase” tool was run, subtracting potential TOD detections from the walkshed of each station, since these were already assessed and filtered earlier in the process. This formed a “No detection” layer from which a sample of locations would be tested for missed TOD redevelopment. The “Create Random Sampling Tool” was then used to create 50 validation points for each metropolitan area. Fifty points were chosen as this aligned with existing literature on remote sensing validation (Olofsson et al. 2014). These points that were generated in ArcGIS were then exported as a KML file and imported into Google Earth. These points were then examined using historical imagery to determine if any TOD redevelopment was missed in a 200-foot radius around each point. The results for each metro area are shown in the table below.

Accuracy in Geographic Area	**TOD redevelopment detected (false negative)**	**No TOD redevelopment detected (true negative)**
All Study Regions (98.8%)	**3**	**247**
Seattle (98%)	**1**	**48**
Portland (96%)	**2**	**48**
San Jose (100%)	**0**	**50**
Los Angeles (100%)	**0**	**50**
San Diego (100%)	**0**	**50**

Table 1. Results of validation

Exploring Statistical Relationships

Once the calculations were run, the tables for the GIS shapefiles of all five metro areas were exported as excel files and merged into one spreadsheet. From this point, pivot tables were utilized to examine variables in depth and sift through patterns in the data. The variables were then measured in a comparative case study model. Kruskal Wallis testing followed by Dunn testing were used to explore statistical relationships in the data.

Results

Size of Station Area Walksheds

The difference in the average size of walksheds between freeway corridor stations and the control groups was statistically significant (p=<.0001). The average walkshed of freeway stations was 23% smaller than those in the standard control group, averaging 165.3 acres compared to the control group's 214.7 acres. This difference of 49 acres was over 50% more than what was observed as the impact of freeway infrastructure along the Blue Line in Chicago, where Racine station had 27.5 acres eaten by freeway infrastructure (Freemark 2024). It should be noted however, that when establishing the acreage of land in the walkshed taken by freeway infrastructure, there is an important nuance. While a freeway corridor station walkshed was shown to be statically smaller in size, the vast majority of the difference in walkshed acreage can be attributed to impinging design characteristics that will be explored later in this thesis (cross-freeway pedestrian access, placement along the right-of-way, and adjacency), rather than the freeway infrastructure itself. While the actual freeway infrastructure does have a measurable impact on walkshed size, it only correlated to a reduction of an additional 2.3 acres of the walkshed on average when compared to the traditional control group. In fact, freeway corridor stations had an 0.7-acre advantage over the parallel control group. The limited nature of this difference is almost certainly due to discrepancies in parcel size. Freeway-adjacent parcels tended to be larger, as they are typically rezoned industrial and commercial areas consisting of large lots. These large commercial and industrial lots are characterized by private road infrastructure for internal access, which are not public right-of-way. As a result, parcels near freeway corridors tended to contribute more developable acreage to walksheds than parcels in the control groups.

	Average Walkshed including ROW	*Average Walkshed excluding ROW*	*Average ROW penalty*
Traditional Control Group	287.1	214.7	72.3
Parallel Control Group	267.0	193.1	73.9
Freeway Corridor Stations	239.9	165.3	74.6
Grand Average	**268.3**	**194.9**	**73.4**

Table 2. Walkshed areas of freeway corridor stations and the control groups, in acres.

Regardless, the large divergence in walkshed size was driven mostly by the large number of light rail stations included in the study from Portland and San Diego, which had the biggest difference between the walkshed size of freeway corridor stations and walkshed size of the control group. The smallest average walkshed for freeway corridor stations was San Diego, with just 161.8 acres compared to ~213 acres for both Los Angeles and Seattle, which had the largest average walkshed amongst freeway corridor stations. Seattle was found to have had the smallest ratio between its freeway corridor stations and the control group, with freeway corridor walksheds being only 14.8% smaller on average. This negative impact on walkshed size is much smaller when compared to the parallel control group rather than the traditional control group, due to parallel corridors often being impacted by the freeway on the edge of their walksheds. The comparison between freeway corridor walksheds and the parallel control group is also less universal, with San Jose and Los Angeles not following the pattern exhibited by the other three metro areas. This smaller difference is still statistically significant however, with p=.0321.

City	*Freeway Corridor walkshed (acres)*	*Traditional walkshed (acres)*	*Parallel walkshed (acres)*	*Freeway Penalty (acres)*	*Freeway Penalty (%)*
Los Angeles	166.6	212.5	208.5	45.8	*21.6%*
Portland	165.5	236.4	170.0	70.8	*30.0%*
San Diego	156.3	191.9	161.8	35.6	*18.5%*
San Jose	161.5	204.3	212.1	42.8	*21.0%*
Seattle	182.0	213.5	189.6	31.5	*14.8%*

Table 3. Difference in average walkshed area between freeway corridor stations and control groups broken out by metropolitan area, in acres.

Turning the analysis toward examining the difference within freeway corridor stations based on different design characteristics, we find that the effect of adjacency was largely noise. The hypothesis was that the effect of the adjacency variable would unfold in a sequential order, with median stations being the most affected by the negative influence of the freeway on walkshed size, while stations with large deviations from the freeway would be the least impacted. The actual results of this variable once measured revealed that large deviations did in fact perform the strongest, with walksheds containing only 7% less area than the traditional control group on average and only 1.4% less than the parallel control group. Median stations actually performed better than shoulder stations and small deviations, with median stations losing only 24% of the walkshed area of the control group. Surprisingly, the average walksheds of shoulder stations (0-100 feet from the edge of the freeway) and small deviation stations (100-500 feet from the edge of the freeway) were smaller, with 27% and 35% less area compared to the traditional control group respectively. This was despite being seemingly less exposed to the freeway's walkshed-limiting effects by having only one side of the station facing towards freeway infrastructure and its associated barrier effects. This result was largely due to two factors. The first is that a strong cross freeway pedestrian connection was less prioritized on freeway shoulder running light rail projects, while even value-engineered median stations typically had a cross-freeway pedestrian connection to access both sides of the freeway corridor. This resulted in median stations having a smaller walkshed than the control group on average, but not a cleaved one in the way many stations immediately adjacent to the freeway and those slightly removed from the right-of-way do. The second reason is that freeway stations located on the shoulder tend to have worse background urban form factors. Freeways tended to be much wider at locations where shoulder stations were located, which resulted in cross-freeway connections failing to provide a substantial walkshed on the opposite side of the freeway from where the station was located. This could be observed with Northgate Station in Seattle. Another component of this reason was geographic location. Many of the shoulder stations included in this thesis were adjacent to industrial facilities or were relegated to become primarily park and ride facilities for suburban areas, such as the case with Star Lake in Seattle and Sunset Transit Center in Portland.

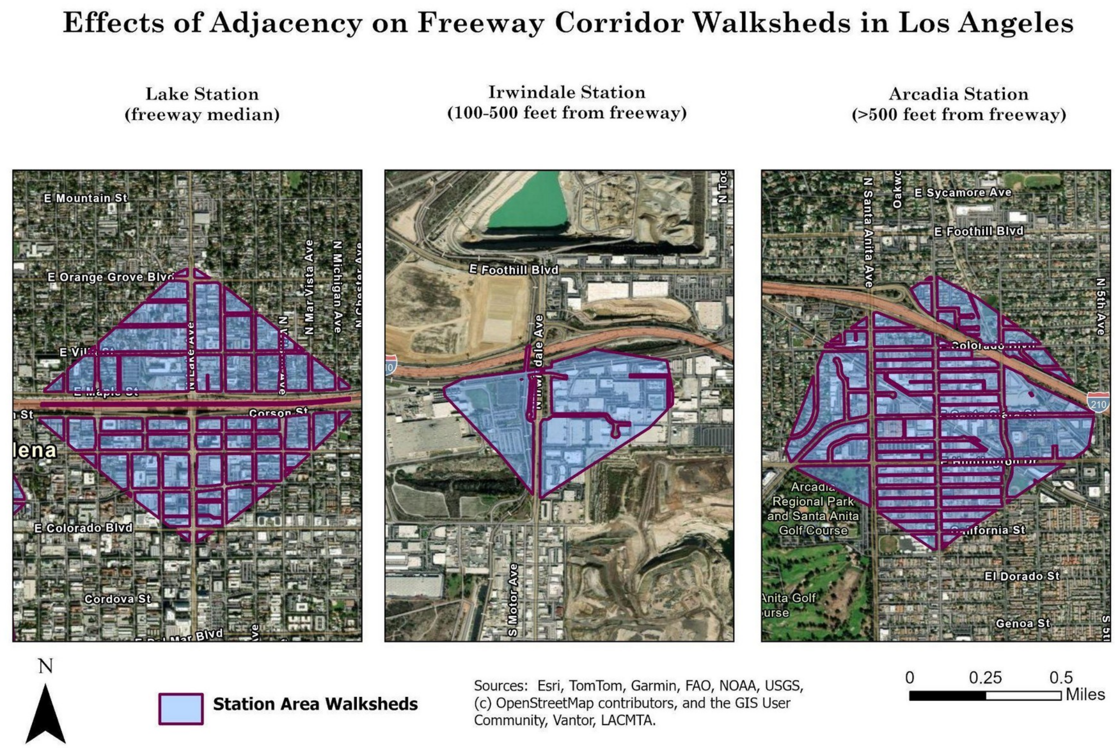

Figure 8. Example of the effects of adjacency on walksheds

The design characteristic of adjacency had a discernible impact on walkshed size among freeway corridor stations. Walkshed averages ranged from 141 acres to 199 acres among freeway corridor stations depending on their adjacency to the freeway corridor. This 58-acre difference is traced back mostly to the proximity of the freeway, with large deviations escaping most of the freeway impact, while small deviations often lacked the cross-freeway pedestrian connections that median and shoulder stations had, and were buffeted by the full impinging force of freeway infrastructure on one flank.

Cross-freeway connections also had no statistically significant impact on the walkshed. However, there was a clear and logical progression in the impact of the variable. The less rigorous cross-freeway pedestrian access was, the smaller the walkshed ended up being. If a station was deficient (missing a pedestrian connection) in the cross-freeway connection attribute, it was on average 39% smaller than the traditional control group, a reduction of 83 acres. If a station had insufficient access (some combination of narrow sidewalks, non-ADA accessible entrances, and long detours) it resulted in the walkshed being 26% smaller than the traditional control group. Stations in the “sufficient” and “high-quality” access categories trailed behind the average walkshed size of the traditional control group by 14% and 16% respectively. Stations with a large deviation were only 7% (16 acres) smaller than the traditional control group. The parallel control group performed roughly in line with freeway corridor stations with large deviations from the freeway. This result makes intuitive sense, with 193 acres on average for the parallel control group compared to 199 acres for the large deviation group. This indicates that while not statistically significant, creating a strong cross-freeway connection is still essential to minimizing the negative impact of freeway siting on light rail station walksheds.

Finally, where the station was placed along the right-of-way did not yield any meaningful results. Stations with access via local streets or pedestrianized spaces came the closest to the control groups, but still lagged behind the parallel control group by 26 acres in average walkshed size. The marginal differences between the remaining groups, such as stations located on arterials having larger walksheds than stations located on collector streets, can be traced back to the other design characteristics, most frequently the presence and quality of cross-freeway pedestrian access.

Zoning Analysis

A preface to discussing the results of the zoning analysis is that only Portland and Seattle had completely reliable zoning data. California’s data had two substantial problems: one, it had just been dramatically rewritten at the statewide level, and two, the common description category that was used to sort TOD constructability was inaccurate. The first problem was the zoning dataset itself did not reflect statewide legal changes that occurred in 2024 (California State Legislature 2025). Because our window of analysis only extended until 2025, this resulted in more land within station area walksheds being zoned for TOD without adequate time for that zoning to actually produce TOD. This recent change in code also created inconsistencies between municipalities, as some had updated their zoning codes to reflect the change in law, while others had not. Secondly, the description category that was originally used to filter zoning did not match the actual zoning categorization. “High density residential” included many R-1 and R-1.5 zones. While this was filtered where possible, the author lacked highly local knowledge to distinguish between many of the included areas.

	Average of Percent of Walkshed Zoned for TOD
Traditional Control Group	44.78%
Parallel Control Group	49.12%
Freeway Corridor Stations	54.36%
Grand Average	**48.65%**

Table 4. Comparison between freeway corridor stations and control groups of the percentage of walksheds zoned for TOD.

The difference in the average percentage of the walkshed that was zoned for TOD between freeway stations and the control groups was low overall. Freeway stations averaged 54.4% zoned for TOD, while the traditional control group averaged 44.8%, and the parallel control group averaged 49.1%. While freeway stations contained a slightly higher percentage of their walksheds zoned for TOD, these results were not statistically significant. It was still an unexpected finding that freeway stations did not have a lower percentage of their walksheds zoned for TOD than the control group considering their automobile-oriented land uses (industrial, low density commercial). The phenomenon of freeway stations having a greater percentage of their walksheds zoned for TOD weakens when broken down by metro area and cross-freeway pedestrian access. Once filtered by urban area, we see that the advantage for freeway stations is due to only two of the five cities. Seattle and San Diego had much larger percentages of their freeway corridor station walksheds zoned for TOD, 58% and 69.5% respectively. Those numbers were notably larger than the 55% and 45% found in the traditional control group for the two cities respectively. The other three metro areas, by contrast, showed the traditional control group having an additional 0-2% of station walksheds zoned for TOD than the freeway corridor group. Of the various design characteristics, none were statistically significant, but there were two points of interest. The first was that a high-quality pedestrian connection across the freeway was associated with a greater proportion of TOD zoning compared to non-TOD zoning. In all five metro areas, a high-quality connection is correlated with a larger proportion of the walkshed zoned for TOD compared to the traditional control group (69% to 45%). This is a logical finding, given the extra infrastructural investment a large bridging structure represents. This investment would naturally align with areas where governments would want to incentivize a large amount of TOD redevelopment. The additional infrastructure also acts as an incentive in and of itself for more encompassing rezoning, in order to recuperate the cost of the connection via increased property tax receipts. The second design characteristic of interest was adjacency. Having a large deviation from the freeway right-of-way was also correlated with a higher percentage of walkshed zoned for TOD (67% compared to 45% for the traditional control group). This trend was consistent across all five metro areas.

TOD Development Analysis

Freeway corridor stations produced an average of 3.3 acres of new TOD, compared to 2.5 acres on average for the traditional control group, and 1.9 acres for the parallel control group. This 0.8 acre advantage is surprising but was not statistically significant. In fact, there was a statistically significant advantage for the combined control group ($p=.0267$). Driven by infill development in San Diego and Seattle, a total of 287 acres were detected to have been developed between the 86 freeway station walksheds, compared with 336 acres for the 134 traditional control group stations, and 110 acres across the 57 parallel control group stations. Of the five metropolitan areas, Seattle and San Diego exhibited strong overperformances by their freeway corridor stations in terms of TOD redevelopment that drove the higher average across the variable overall. Portland exhibited a strong trend in the opposite direction (the control group outperformed the freeway corridor group), while Los Angeles and San Jose both exhibited modest advantages for the traditional control group. The parallel control group did not demonstrate a consistent trend among the five cities when compared to the freeway corridor group, but underperformed the traditional control group in all cities but Seattle.

	Average Acres of TOD		**Average Acres of TOD**		**Average Acres of TOD**
Traditional Control Group	**2.5**	**Parallel Control Group**	**1.9**	**Freeway Corridor**	**3.3**
Los Angeles	2.7	Los Angeles	2.4	Los Angeles	2.3
Portland	2.2	Portland	1.9	Portland	0.9
San Diego	1.5	San Diego	0.2	San Diego	5.0
San Jose	3.0	San Jose	1.6	San Jose	2.2
Seattle	2.6	Seattle	4.1	Seattle	4.5

Table 5. TOD redevelopment in freeway corridor stations and the control groups.

The biggest contributor to freeway corridor stations’ higher average in TOD redevelopment is Stadium Station in San Diego, which produced 42.2 acres. This was due to a large-scale redevelopment of a football parking lot into a mixed-use village centered directly north of the station. While the amount of TOD redevelopment around Stadium Station is clearly an outlier, other San Diego and Seattle stations delivered a substantial amount of TOD over the past dozen years that has pushed the average above the control groups. Other freeway stations of note include Fashion Valley, where several mixed-use developments now wrap around a mall which is undergoing redevelopment, and Downtown Redmond Station in the Seattle region, where a large portion of the walkshed that was previously a collection of low-slung commercial buildings have been replaced by 5-over-1 and 6-over-1 mixed-use developments. The biggest contributor for the combined control group is Milpitas Station in San Jose, where vacant lots and strip malls have been replaced with an endless sea of apartments. It should be noted that the reason Milpitas is a standout for TOD redevelopment is almost certainly due to the new BART station at the same location, rather than the VTA light rail station. Other bright spots among the control group include Downtown Long Beach in the Los Angeles region, former park and ride lots in San Jose, and stations both north and south of Downtown Seattle.

Rank	Station	Freeway Corridor or Traditional Control Group	City	TOD acres
1	**Stadium Station**	**freeway**	San Diego	**42.2**
2	**Milpitas Station**	**traditional**	San Jose	**22.7**
3	**Fashion Valley Station**	**freeway**	San Diego	**15.9**
4	**1st Street Station**	**traditional**	Los Angeles	**12.7**
5	**Great Mall Station**	**traditional**	San Jose	**12.7**
6	**Mission Valley Center Station**	**freeway**	San Diego	**12.6**
7	**Downtown Long Beach**	**traditional**	Los Angeles	**12.5**
8	**Downtown Redmond Station**	**freeway**	Seattle	**12.4**
9	**Overlake Village Station**	**freeway**	Seattle	**12.3**
10	**Pacific Ave Station**	**traditional**	Los Angeles	**12.1**

Table 6. Ten light rail station walksheds with the most TOD redevelopment

The worst performers for TOD redevelopment on the other hand were the 84 stations with no TOD development identified in the analysis. These stations stretched across all five metropolitan areas examined in this thesis, mostly in industrial areas (Irwindale in Los Angeles, Gillespie Field in San Diego) and in single-family residential areas (Hillsboro Airport in Portland, South Bellevue Station in Seattle). However, that isn't to say they didn't see development at all; the industrial stations in particular saw a boom in both new construction and building modernization. Several of the stations that saw no TOD development, including Washington Park and Artesia in Los Angeles, saw some of the most drastic redevelopment across all stations, but it was transit-adjacent development, rather than TOD.

Stations Without TOD Redevelopment	**Freeway Corridor or Control Group**	**City**
Delta Park/Vanport	parallel	Portland
SODO Station	traditional	Seattle
COMPONENT STATION	traditional	San Jose
University of Washington Station	traditional	Seattle
32nd & Commercial St Station	traditional	San Diego
GREAT AMERICA STATION (1)	parallel	San Jose
Massachusetts Ave Station	traditional	San Diego
Highland Park Station	parallel	Los Angeles
Southwest Museum Station	parallel	Los Angeles
Clairemont Drive Station	freeway	San Diego
Wardlow Station	traditional	Los Angeles
Arnele Avenue Station	freeway	San Diego
Long Beach Blvd Station	freeway	Los Angeles
Firestone Station	traditional	Los Angeles
Slauson Station	traditional	Los Angeles
Amaya Drive Station	parallel	San Diego

Vernon Station	traditional	Los Angeles
Lakewood Blvd Station	freeway	Los Angeles
San Pedro Street Station	traditional	Los Angeles
Florence Station	traditional	Los Angeles
Morena/Linda Vista Station	freeway	San Diego
103rd Street / Watts Towers Station	traditional	Los Angeles
South Bellevue Station	parallel	Seattle
70th Street Station	freeway	San Diego
Atlantic Station	parallel	Los Angeles
Clackamas Town Center TC	freeway	Portland
Hazard Center Station	freeway	San Diego
Washington Station	traditional	Los Angeles
Sunset TC	freeway	Portland
OLD IRONSIDES STATION	parallel	San Jose
Grossmont Transit Center	parallel	San Diego
Washington Street Station	freeway	San Diego
Barrio Logan Station	parallel	San Diego
Crenshaw C-Line Station	freeway	Los Angeles
Palm Avenue Station	parallel	San Diego
APU / Citrus College Station	traditional	Los Angeles
Albina/Mississippi	parallel	Portland
Harborside Station	parallel	San Diego
South 272nd Street Station	freeway	Seattle
Hillsboro Airport/Fairgrounds	traditional	Portland
Iris Avenue Station	parallel	San Diego
H Street Station	freeway	San Diego

Millikan Way	traditional	Portland
ALDER STATION	traditional	San Jose
Douglas Station	traditional	Los Angeles
Aviation / Century Station	traditional	Los Angeles
Redondo Beach Station	traditional	Los Angeles
Palomar Street Station	parallel	San Diego
Hawthorn Farm	traditional	Portland
Pomona North	traditional	Los Angeles
Parkrose/Sumner TC	freeway	Portland
SE Main St	freeway	Portland
Norwalk Station	freeway	Los Angeles
Pacific Fleet Station	parallel	San Diego
CAPITOL STATION	freeway	San Jose
Beaverton Creek	traditional	Portland
SE Powell Blvd	freeway	Portland
OHLONE-CHYNOWETH STATION	freeway	San Jose
CROSSMAN STATION	parallel	San Jose
BAYPOINTE STATION	traditional	San Jose
Gillespie Field Station	traditional	San Diego
SE Flavel St	freeway	Portland
WINCHESTER STATION	traditional	San Jose
Old Town Station	freeway	San Diego
SNELL STATION	freeway	San Jose
BLOSSOM HILL STATION	freeway	San Jose
REAMWOOD STATION	parallel	San Jose
BRANHAM STATION	freeway	San Jose

San Ysidro Station	parallel	San Diego
VIENNA STATION	parallel	San Jose
CROPLEY STATION	traditional	San Jose
HOSTETTER STATION	traditional	San Jose
Del Amo Station	traditional	Los Angeles
VIRGINIA STATION	freeway	San Jose
Mariposa Station	traditional	Los Angeles
ALUM ROCK STATION	traditional	San Jose
Artesia Station	traditional	Los Angeles
El Segundo Station	traditional	Los Angeles
Irwindale Station	freeway	Los Angeles
Cascades	traditional	Portland
Mt Hood Ave	traditional	Portland
BAYSHORE NASA STATION	parallel	San Jose
BONAVENTURA STATION	traditional	San Jose
MOFFETT PARK STATION	parallel	San Jose
ORCHARD STATION	traditional	San Jose

Table 7. Stations without TOD redevelopment 2013-2025.

The impact of design characteristics on TOD redevelopment around freeway corridor stations showed some noteworthy results. Looking first at adjacency, freeway corridor stations with big deviations from the right-of-way performed incredibly well at attracting TOD development. Stations with large deviations demonstrated a substantial advantage over the control groups, with an average of 7.8 acres redeveloped as TOD, compared to 2.5 acres for the traditional control group, and 1.9 acres for the parallel control group. However, it should be noted that this difference is not statistically significant. Stations with big deviations drove the higher average seen for freeway corridor stations as a whole. Median, shoulder, and small deviation stations trailed the traditional control group in TOD redevelopment. The only adjacency typology that fell behind the parallel control group were median stations, which averaged only 1.5 acres of TOD redevelopment. This result falls in line with existing research that underlines the development challenges surrounding median stations. Both the shoulder stations (2.1 acres) and the small deviation stations (2.3 acres) outperformed the parallel control group, although by an amount that is statistically noise.

Design Characteristics	**Average Acres of TOD**
Traditional Control Group	**2.5**
Parallel Control Group	**1.9**
Freeway Corridor	**3.3**
Shoulder	2.1
Median	1.5
Small Deviation	2.3
Big Deviation	7.8
Grand Average	**2.6**

Table 8. TOD redevelopment broken out by adjacency

Placement along the freeway right-of-way was statistically a wash. Light rail stations whose primary access points were along collector or arterial streets performed marginally better than the traditional control group, and made up the vast majority of the freeway corridor stations included in this thesis. Freeway corridor stations with access points on local streets or in pedestrianized spaces perform remarkably well (12.7 acres of redevelopment on average), but its success as a design characteristic is statistically limited by relying on a cluster of strong performing stations along San Diego's Green Line in the Mission Valley, and the far northern end of the Blue Line near the University of California San Diego. Outside of San Diego, access on local and pedestrianized streets is constrained to two stations in Portland, which produced an average amount of TOD. Stations that were placed in the immediate proximity of freeway exits resulted in a worse performance than either control group, with the majority of stations seeing no TOD developed, or just traces of development that bled over from a neighboring station. Stations with freeway exits would perform even worse without a few strong performing stations such as Cottle in San Jose (10.7 acres) and Northgate in Seattle (2.4 acres).

	Average Acres of TOD
Traditional Control Group	**2.5**
Parallel Control Group	**1.9**
Freeway Corridor Stations	**3.3**
arterial	2.8
freeway exits	1.3
collector	3.5
local or pedestrianized	12.7

Table 9. TOD redevelopment broken out by placement along ROW

Access (cross-freeway pedestrian connections) also showed no statistically significant results, but pointed in an instructive direction for planning agencies. High quality cross-freeway pedestrian connections outperformed both control groups in TOD development, with 6 acres of TOD redevelopment on average compared to 2.5 acres for the traditional control group, and 1.9

acres for the parallel control group. All freeway corridor light rail stations with a lower quality cross-freeway connection performed worse than the control group, including those that had a connection that contained cost cutting elements (sufficient, insufficient). Seattle is central to the advantage behind the high-quality connection attribute (Redmond Technology, Overlake Village, Northgate, Judkins Park, and Marymoor Village), but San Diego and Los Angeles also have stations that contribute to the TOD redevelopment advantage for stations with a high-quality connection. The results suggest that non-appealing and non-existent cross-freeway pedestrian connections may contribute to the TOD development challenges often associated with freeway stations. More importantly, it demonstrates that this TOD generation issue might be moderated, or even reversed, with high quality cross-freeway pedestrian infrastructure, as has been demonstrated in Seattle. It should be noted that pulling the freeway out of the right-of-way by more than 500 feet still resulted in more TOD generation than having a high-quality cross-freeway pedestrian connection. Another aspect of this variable worth future exploration is whether development is still more likely to occur on the station side of the freeway than on the side made accessible by a high-quality cross-freeway pedestrian connection.

	Average Acres of TOD
Traditional Control Group	**2.5**
Parallel Control Group	**1.9**
Freeway Corridor	**3.3**
(Large Deviation)	7.8
High Quality	6.0
Sufficient	1.1
Insufficient	0.3
Deficient	2.2

Table 10. TOD redevelopment broken out by cross-freeway pedestrian connection.

Ridership

The average ridership for freeway corridor stations is actually much higher than the traditional control group, with 1504 riders per day and 1218 riders per day respectively. Terminal stations and major transfer points were both very key to the ridership advantage held by freeway corridor stations, which matches existing literature. For ridership per capita, the advantage that freeway stations had in terms of overall ridership dissolves. The ridership per capita of freeway corridor stations is less than half that of the traditional control group, and less than two-thirds that of the parallel control group. Therefore, despite the fact that freeway corridor stations might be situated in highly populated locations, it is clear that those residents are riding transit significantly less.

	Average Daily Ridership	Average Ridership per Capita
Traditional Control Group	1218	3.7
Parallel Control Group	1384	2.9
Freeway Corridor	1504	1.8

Table 11. Ridership and ridership per capita.

Of the ten stations that achieved the highest ridership per capita, all but one of them is located in Los Angeles, with the majority located on the East L.A. segment of the E Line. The only non-Los Angeles station was University of Washington Station, a major employment destination. Every station in the top ten for ridership per capita also happens to be in one of the control groups. The top ten stations for overall ridership is populated with a mix of freeway corridor stations and the control group in Seattle’s Rainier Valley, San Diego’s Blue Line, and various stations across Los Angeles. The stations with the both the lowest ridership and the lowest ridership per capita are mostly located throughout San Jose, and industrial parks in Los Angeles.

Station	***Ridership per Capita***	***Freeway Corridor or Control Group***
5th Street Station	40.6	traditional
1st Street Station	38.9	traditional
Fairview Heights Station	19.5	traditional
University of Washington Station	18.8	traditional
Leimert Park Station	18.8	traditional
Maravilla Station	16.8	parallel
Pacific Ave Station	16.8	traditional
Mariachi Plaza / Boyle Heights Station	16.5	traditional
Hyde Park Station	15.0	traditional
East LA Civic Center Station	13.2	parallel

Table 12. Top 10 stations by ridership per capita

Discussion

Interpretation of Mixed Results

Freeway corridor light rail stations were found to have serious but nuanced limitations, underperforming the control groups. As an overarching rule, Freeway corridor stations had a 23% smaller walkshed and only half the ridership per capita as stations in the traditional control group, while having higher overall average ridership. While statistically, freeway corridor stations generated less TOD than the traditional control group, the average freeway corridor station generated 0.8 acres more TOD than its average counterpart in the traditional control group. The downsides of freeway corridor stations are well known: the stations are louder, dirtier, less accessible, and have a more dangerous pedestrian environment around them. More importantly, freeway corridor stations have less land to actually develop on since the freeway and associated car infrastructure eat up so much of the walkshed compared to the control group. With these structural advantages for arterial-running or otherwise grade-separated stations not following the freeway ROW carry into any comparison, why is their advantage over freeway stations nuanced? There are a few potential roads of inquiry, which could potentially explain some of the advantageous findings for freeway stations:

1. It might be cheaper and easier to build near freeway corridors.
2. Poverty is pushing transit-dependent riders farther out along rail lines.
3. Speed offers a unique advantage to freeway corridor light rail.
4. Car access is desirable, and COVID made freeway corridors uniquely appealing.
5. Some of the negative impact of freeway routing is being masked.

1. It might be cheaper and easier to build near freeway corridors.

The first potential explanation is that building development along the freeway is generally cheaper. This explanation in particular addresses some of the stations in San Diego and Seattle that powered the higher average TOD redevelopment acreage for freeway corridor stations. Data has shown there's roughly a 10% reduction in land value within ¼ to of the freeway (Cervero, Kang, and Shively 2009), although it depends on the grade of the freeway (Lewis et al. 1997). Building in a freeway corridor also generates less resistance to development than other parts of the city. There are typically less politically connected neighbors to contend with, and the area is often already presumed undesirable due to freeway infrastructure (Ramirez et al. 2024). This can make getting construction approval easier, acquiring zoning variances acquired if they are needed, and constructing at a higher density (Whittemore and BenDor 2019). It may also be easier to assemble parcels of land to build larger buildings, although this further raises the specter of transit adjacent development. Additional building size is often to account for parking facilities either due to demand, regulations, requirements to receive loans, or a combination of these factors.

2. Poverty is pushing transit-dependent riders farther out along rail lines.

The second possibility is that poverty has changed where transit-reliant populations live. Displacement has been a major issue within the discussion around mass transit expansion, with concerns being raised that new projects would push poor populations into the urban fringes and away from the city core (Manville et al. 2024). However, there are other, more concrete causes of gentrification within urban cores than transit expansion, and the displacement that follows could therefore be pushing transit users away from city centers, and toward the less desirable locations along the light rail system. These locations fit the geographic circumstances of most freeway corridor stations, as they are typically on the outer portions of the system and situated in less desirable locations. However, the data doesn't seem to match this line of inquiry. For example, in San Diego, where some of the strongest results were for freeway corridor stations, the poorest populations don't align with the highest ridership per capita stations or the most substantial pools of transit-oriented development (County of San Diego, Health and Human Services Agency 2022). There are some overlaps in El Cajon and the eastern part of Mission Valley near SDSU, but these are modest correlations and do not form a cohesive pattern. Other metro areas also coincide with this incongruency, with some of the highest income areas of the Seattle area showing some of the most substantial TOD gains and biggest ridership numbers, while poorer areas have mixed results.

3. Speed offers a unique advantage to freeway corridor light rail.

Freeway corridor rail lines offer a speed advantage that has been noted by both literature, and renowned professionals (Walker 2016). While there has been no research focused on the average speed advantage provided by aligning urban rail with a freeway right-of-way, individual systems that make extensive use of freeway corridors, including Transperth Rail in Perth, Australia, have. Perth offers a key example of the impressive speed and reliability bonuses that freeways can offer transit, attributes that street-running light rail systems are usually in short supply of (McIntosh, Newman, and Glazebrook 2013). The average speed of transit can be hard to compare given the diversity in stop spacing and design characteristics between systems, but there are notable differences in transit speeds between freeway-running light rail lines, and those that run mostly on arterial roads in mixed-separation environments. Using transit timetables and google maps, it can be observed that the transit speeds are consistently faster on freeway-running segments (see Table 13 below). In Portland, freeway corridor light rail saw only a small speed improvement over the control group (likely due to grade crossings), while San Jose, San Diego, Seattle and Los Angeles saw more substantial improvements of between 8 and 16 miles per hour. This potential explanation holds up to scrutiny, but would have to be researched in its own right to determine its connection to ridership and development.

City	Speed Bonus for Freeway Corridor Light Rail	Name of Light Rail Line Analyzed	Speed of	Control	Control speed
San Diego	**9** mph	Blue Line	31 mph	Orange Line	21.5 mph
Los Angeles	**16** mph	C Line	34 mph	K Line	18 mph
San Jose	**8** mph	Blue Line (Santa Teresa to Children's Museum)	27.5 mph	Orange Line	19.5 mph
Portland	**4** mph	Green Line	23 mph	Blue Line	19 mph
Seattle	**13.5** mph	1 Line (Lynwood Link)	35.5 mph	1 Line (Rainier Valley)	22 mph

Table 13. Speed comparison between freeway and non-freeway corridor light rail lines based on timetables

4. Car access is desirable, and COVID made freeway corridors uniquely appealing

Car access is another potential factor that could have generated nuance in the results. Nearly all of the freeway corridor stations include an increased amount of parking and general car-orientation compared to the control groups. Existing scholarship has shown that parking is a statistically significant variable to control for when assessing ridership, but it was impossible to do so in the context of studying freeway corridor stations while still retaining a pool of stations to analyze. In fact, it would have left less than a dozen stations total among the five light rail systems looked at in this thesis. It was therefore quite possible that the ridership numbers in deeply suburban stations were simply drafting off the ridership bonus provided by park and rides. Parking alone cannot explain away all aspects of the strong performance by light rail corridor stations, as the TOD outcome was also stronger than either control group. One potential explanation for the prevalence of TOD development around freeway corridor stations is the interest in car-light lifestyles, or the desire to use transit for occasional entertainment and commute purposes but relying on the automobile for most transportation needs. This thesis was conducted post-COVID while transit ridership was still down across the United States, and return to work policies had yet to come into full force on the Pacific Coast. COVID-19 created a set of conditions in the early 2020s where housing demand fell in the urban cores, and grew dramatically in the suburbs, known as the “donut effect” (Ramani and Bloom 2021). The donut effect created an artificial set of conditions that potentially caused areas like Mission Valley in San Diego and freeway corridors in places like San Jose to seem more desirable that they will be in future scenarios where a five-day back to office order is in place. In the future, long commute times (regardless of mode) may rejuvenate ridership and development in inner-city neighborhoods and deflate demand in the suburbs where freeway corridor stations tend to be located. In fact, data is already trending in this direction (Andrews 2024).

5. Some of the negative impact of freeway routing is being masked.

The simplest explanation is that nuances in data are just noise, and freeway corridor stations actually carry a more significant cost to TOD development. One aspect of this explanation has already been examined in the data; by excluding large deviations from the dataset, freeway corridor stations fall behind both control groups. A second aspect of this explanation is that the bonus for freeway corridors in this thesis might be unnatural, resulting from overcorrection by transit agency involvement. Many freeway corridor light rail stations with very poor ridership saw large increases in TOD redevelopment, such as Cottle and Santa Teresa Stations in San Jose. The VTA in San Jose operates a portfolio of development partnerships and allocates 1% of their budget to TOD, which has resulted in new TOD developments along the Blue Line (VTA 2026). However, the agency overcorrection hypothesis quickly falls apart. The VTA was involved in more development along the Orange Line (in the traditional control group) than along the freeway corridor Blue Line, meaning agency involvement actually benefitted the control group rather than freeway stations. Sound Transit in Seattle has also taken a very proactive approach with TOD, with more than a dozen large projects completed (Sound Transit 2026). Sound Transit's particularly muscular TOD program has substantially added to station areas across the network, although it should be noted that there is far more TOD development not connected to the transit agency than development that was. Portland, San Diego, and Los Angeles all have more modest programs, but still resulted in boosted TOD numbers around freeway stations. Most of the redevelopment by transit agencies occurred on excess lands including parking and ride lots owned by transit agencies.

Centrality of High-quality Pedestrian Connections

Pedestrian accessibility across the freeway emerged as the most important observed design characteristic in this analysis. The impact of cross-freeway pedestrian infrastructure is apparent across walkshed size, TOD redevelopment, and ridership per capita. Specifically, high-quality pedestrian connections across the freeway, with 16 feet for non-motorized users (or 12 feet with an adequate buffer zone) ended up creating a clear advantage for freeway corridor light rail stations, exceeding both the other adjacency categories, as well as both control groups.

The strength of high-quality cross-freeway pedestrian connections can first be seen in walkshed areas, where stations with this kind of infrastructure avoided the truncation effects created by the freeway. This allowed the walksheds for median stations, with their poor reputation, to end up performing better than shoulder stations and stations with only a small deviation from the freeway, due to being more likely to have received the investment of a high-quality connection. While a high-quality pedestrian connection expands the walkshed, it should be noted that much of that additional walkshed area is eaten up by freeway infrastructure. The amount of the walkshed consumed by road and freeway right-of-way was higher for high-quality connected stations. The number of acres consumed by right-of-way within the freeway corridor walksheds was statistically significant compared to deficient connections ($p=0.0341$), insufficient connections ($p=0.0339$), and both traditional ($p=0.0389$) and parallel ($p=0.0205$) control groups.

High quality pedestrian connections across the freeway also resulted in 140% more transit-oriented redevelopment than the traditional control group, averaging six acres of TOD redevelopment as compared to just 2.5 for the traditional control group. While not statistically significant, they were clearly correlated with having a high-quality connection. Most of the TOD development that occurred around these stations was still highly clustered on the side of the freeway that hosts the station; development on the opposite side is usually limited. However, the mobility benefit provided by enhanced pedestrian access is seen as influential in attracting development, both office and residential (Rodriguez and Leinburger 2023). Having a high-quality pedestrian connection also facilitates and encourages residents and workers on the opposite side of the freeway to patronize businesses within new TOD development, making businesses more viable.

The transit-orientation of stations with a high-quality connection was also higher than less robust pedestrian connections, as well as stations in the control groups. Stations with a high-quality connection had higher ridership per capita, outperforming stations with deficient connections ($p=0.0055$), insufficient connections ($p=0.0015$), and even sufficient connections ($p=0.0005$). Stations with a high-quality connection also outperformed both control groups; traditional ($p=0.0064$), and parallel ($p=0.0003$). These results suggest that high-quality cross-freeway access is associated with larger walksheds, more transit-oriented redevelopment, and higher ridership per capita.

Limitations

There were an abundance of limitations. Trying to sort them into buckets for closer analysis was challenging, but they generally fell into four categories: the limitation of spectral endmember analysis, temporal limitations, edge cases, and the zoning database of California.

Limitations of Spectral Endmember Analysis

The most substantial limitation of this project was dealing with the technical limitations of a spectral endmember analysis. While the method was highly successful in identifying mixed use buildings with white, highly reflective roofs, it was less effective at correctly distinguishing between road asphalt and asphalt roofing tiles. Similar to what literature suggested, there was also confusion introduced by other rooftop materials including solar panels and green roofs, which lessened the building fraction of new buildings with sustainable features. This resulted in many new buildings being discounted in the analysis, with either parts of the roof not showing up as development, or the development being missed entirely. This issue of roofing materials being read as asphalt or vegetation muddled the results and potentially impacted the distribution of the results across the urban landscape. This issue largely traces back to the decision not to use hyperspectral data. More powerful satellites can handle a large number of endmembers, but the limitations of Landsat (or Sentinel for that matter) made having multiple material categories as endmembers nearly impossible. The issue of false negatives was disappointing because much of the fine-grained infill development that occurred across the study area were largely roofed with asphalt tiling, since it is a more appropriate material for gabled roofs. This resulted in the lack of inclusion of most small units including fourplexes, ADUs, and townhouses in this thesis. There were several key locations where this resulted in missed development. One location of note was the U District neighborhood in Seattle, where there were multiple examples of missed development the author was familiar with. While a substantial amount of TOD redevelopment was correctly detected in this neighborhood, both the asphalt roofing and solar panels resulted in over an acre of missed development. One example of a missed development in U District is visualized in figures 9 and 10 below.

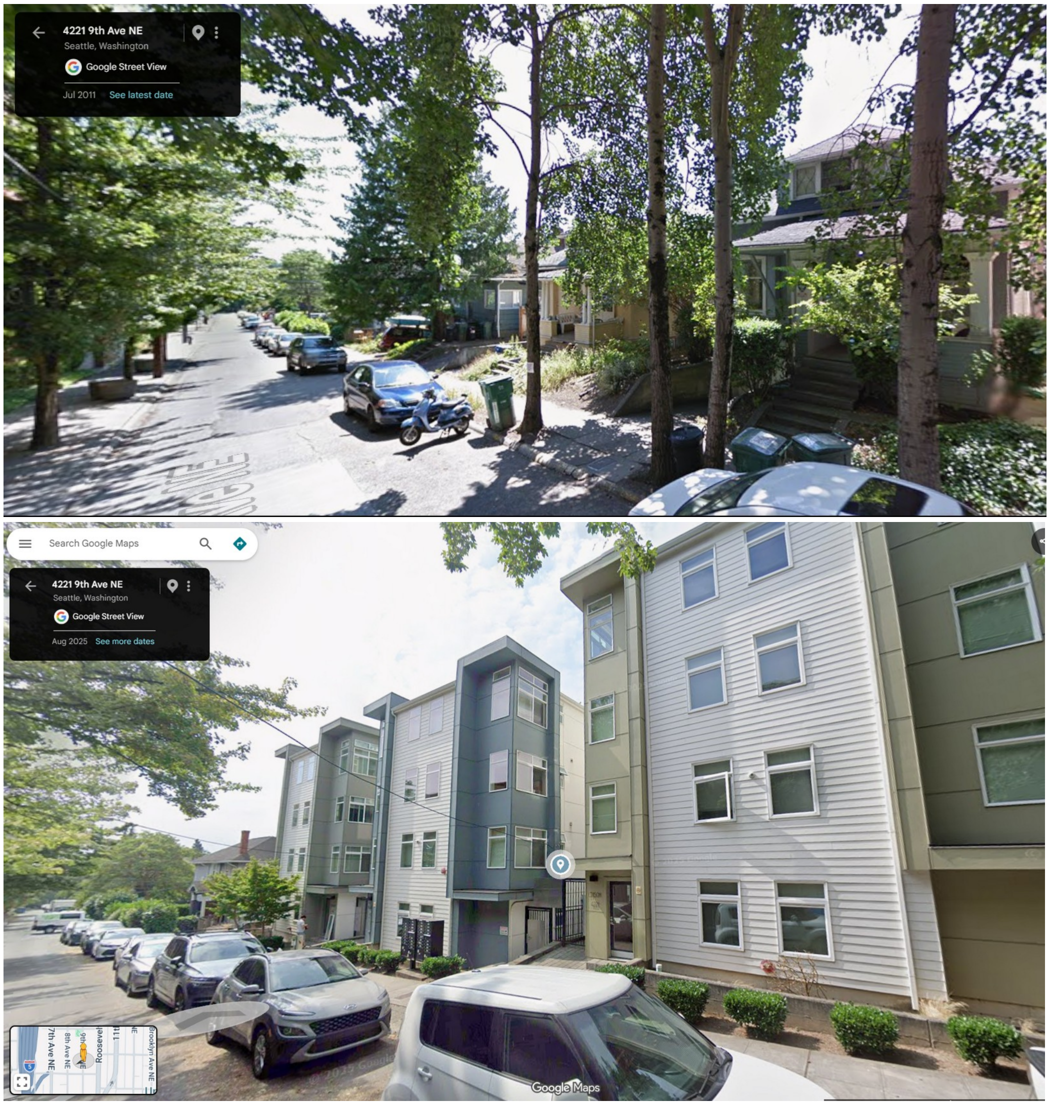

Figure 9. Street view of missed infill in the U District

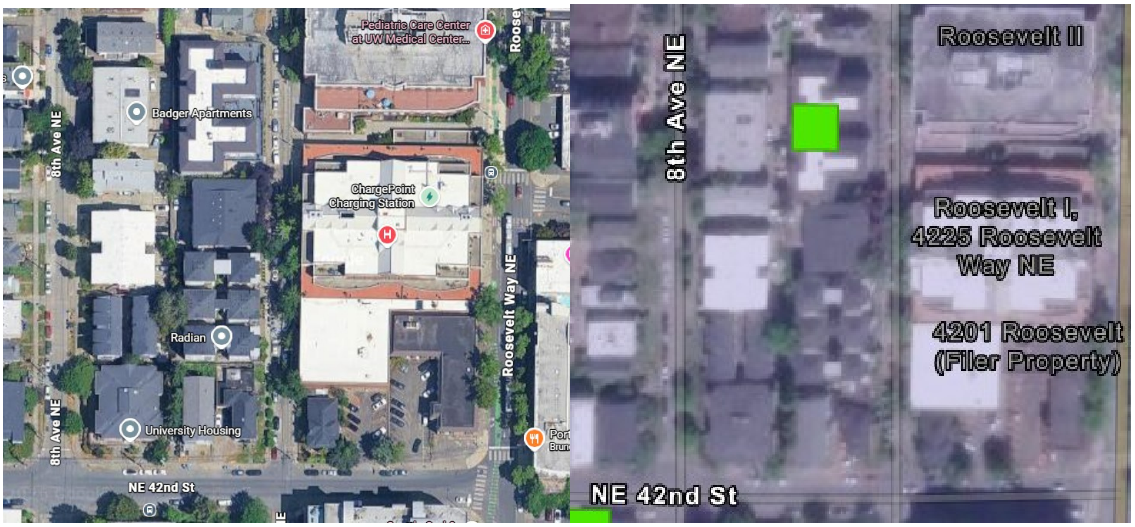

Figure 10. Aerial view of missed infill in the U District

Temporal Limitations

The second limitation is the temporal aspect of development. This can be broken down into two points; the starting point of the urban fabric and length of time the station has been influencing the urban fabric of its respective walkshed. The biggest temporal limitation was the pre-existing urban form of a walkshed. While freeway corridors are typically composed overwhelmingly of transit-hostile urban environments such as single-family residential monocultures, power centers, office parks, and expansive parking craters prior to the introduction of light rail, there are notable exceptions. These exceptions are places where a freeway cut through the heart of historic streetcar suburbs and satellite cities that were built before the automobile era. In these locations, light rail introduced to the freeway corridor had a built-in advantage. Some examples of pre-existing transit-orientation fully or partially in the walkshed of freeway corridor stations include Pasadena in Los Angeles, Old Town in San Diego, Willow Street in San Jose, Hollywood in Portland, and Judkins Park in Seattle. In these cases, redevelopment is often a more nuanced prospect and isn't desirable in all parts of the walkshed. These places have historic buildings that tend to be more pedestrian oriented, while newer mixed-use buildings tend to be cluttered with garage access points and have a bigger bulk than historic buildings (Renne and Listokin 2019). Potential yardsticks for measuring the starting value for transit-orientation, such as intersection density, were not accounted for in this thesis.

A second temporal limitation was that this thesis only accounts for the period from 2013 to 2025. While that timeframe provides a relatively complete picture of the post-recession building boom, it does not account for any development that occurred directly after the original light rail lines launched in the 1980s and 1990s, nor does it account for the early years of urban renaissance in the late 2000s and early 2010s. There are several notable examples of early TOD that were thus not counted, such as the Rio Vista development in San Diego (Inam 2012). There was never going to be a clean process to control for time, due to changing economic conditions, and the staggered opening dates of light rail systems and various extensions. If the period of time after opening was accounted for, stations opening in an economic boom would see more development in their first several years than those which opened during recessions. Additionally, metro areas which take a proactive approach to mixed-use zoning inevitably see TOD before a transit station is open, particularly with the inevitable delays that have followed most modern light rail projects. This phenomenon can be observed in the substantial TOD developed along the East Link in Seattle.

Edge Cases

Edge cases were prolific throughout this project. There were two major types of edge cases: which design characteristic category each station belonged in, and delineating TOD from TAD.

The process for differentiation between design characteristics was pockmarked with edge cases that only narrowly missed being moved to a different categorization. For adjacency, there were many cases where stations were within 10 feet of being in a different category. Lynnwood City Center is one example, where measuring from the south end of the platform would result in it shifting from large deviation to small deviation. Relatedly, “large deviation” should have been split in two given some of the literature, as it was potentially too broad. The adjacency category in general often clashed with the parallel control group, blurring the lines between the two based on often a hundred feet or less, which would have resulted in a large deviation freeway corridor station flipping to the control group. Placement along the right-of-way suffered from not being a great measure in general, due to stations having multiple entrances. The methods refer to the “primary” entrance or the point which was most ADA accessible, or if all entrances are accessible, relying on point of contact with other modal facilities, such as bus transfers. This proved challenging for locations with equivalent access. Additionally, the definition of arterial and collector used in this thesis does not match what all cities use. There are examples where a station with multiple entrances exists, one located on an arterial, and another located on a calmer street. Blossom Hill Station in San Jose embodies this problem, where the park and ride is located on an arterial with freeway access, and the other is located on a quiet local street. Cross-freeway connections were the least impacted by this limitation. However, the difference between "sufficient" and “insufficient” was largely determined by the presence of freeway exits, due to the lack of crossing improvements to assist pedestrians navigating onramp and offramp infrastructure. This differentiation was somewhat of an afterthought, as analyzing the presence and quality of cross-freeway bridges was the original intention of this variable. Similarly, while the difference between “sufficient” access and “high quality” is less complicated, it came with its own flaws, with “sufficient” containing a mix of wide sidewalks alongside arterial roads and low-quality pedestrian bridges, while high quality connections were almost entirely grandiose and inviting structures. The setup of this variable might have also generally introduced error by mixing sidewalk projects that go under the freeway with bridging structures that go over the freeway. In hindsight, they should have been separated rather than housed under the same attribute, as they are distinct approaches that appear to potentially have different influences on the built environment.

Another edge case scenario was determining what counted toward transit-oriented development and what did not. Literature largely points to actual travel behavior of residents and employees as the best barometer to delineate what is TOD from what is simply development close to transit. However, this was beyond the scope of the project and would have required interviews and observations that could not be done at the scale of this project. Instead, qualitative filtering eliminated car-oriented uses such as storage units, data centers, gas stations, and new construction that did not meet basic criteria (such as buildings with their entrance facing a parking lot). Much of what remained was clearly mixed-mode mixed-use complexes. These projects were not graded or filtered based on parking or mode share, which means even projects that generated minimal transit usage were counted as TOD. The thesis included a substantial number of newly constructed apartment units and office blocks that clearly contained extensive parking and blank walls addressing the street. The specter of transit adjacent development is not unique to freeway corridor stations, as some of the most egregious examples of potential TAD were located in the control groups. The difficulty in delineating or “rating” developments to add a weighted “TODness” metric without having access to information on the mode share of each development led to that part of the thesis methodology being excised early in the process.

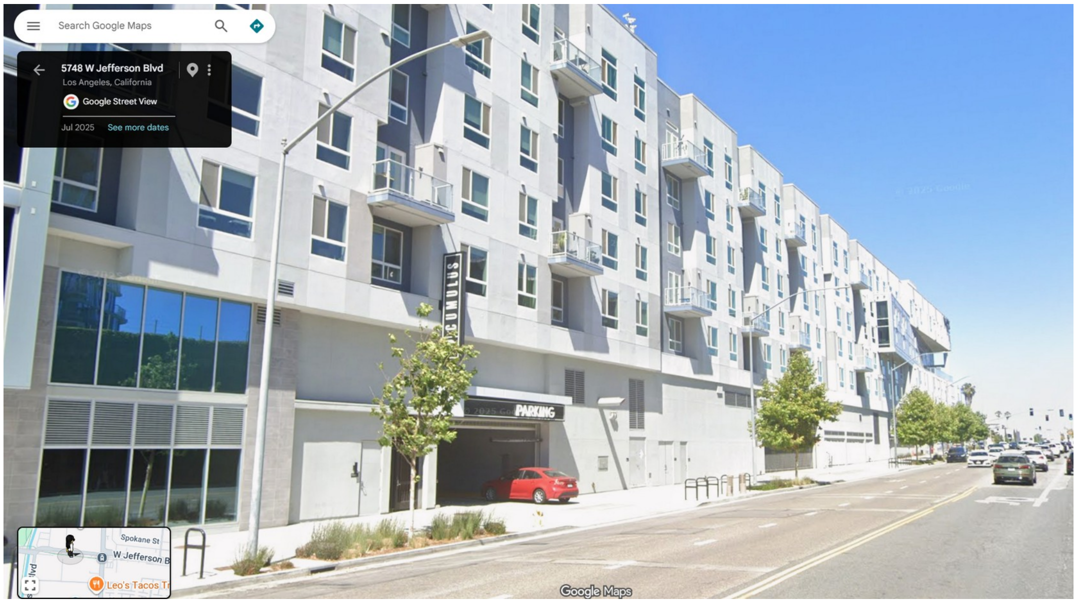

Figure 11. Example of a TOD/TAD edge case in the La Cienega/ Jefferson Station walkshed in Los Angeles

Zoning Data Issues

Filtering zoning was a key element in this project, as it was not only an analyzed variable, but it also had a determinative effect on where TOD could be located under the methodology. This process relied on categorization provided by regional planning bodies and the state of California. While Metro and PSRC had reliable categorized zoning data, California did not. The State of California produces a statewide zoning database, which regional planning authorities direct to on their websites and open GIS portals. Under this zoning database “Description” was used to filter for potential locations of TOD. This attribute is littered with mistakes and inconsistencies that made zoning as a filter challenging. Downtown Los Angeles and Downtown San Diego were mislabeled as low intensity commercial zoning, along with dense mixed-use neighborhoods such as Hillcrest and Pasadena. Fixing this error was challenging due to the systematic nature of the problem, and the scope of the affected study area (three metro areas). Other points of error existed within the data such as inconsistent attributes ascribed to commercial mixed-use districts in the heart of Los Angeles, and low density residential being included with areas that were actually zoned for fourplexes. Part of the problem also stems from California being in the midst of rezoning required from state law, with a mismatch from municipalities, some of which have updated their zoning codes to comply with the law, and others which have not. This had to be painstakingly sifted through to attain a rational set of lands to assess potential development from and is almost certain to have created some residual errors in its wake.

Future Research

There were multiple avenues that should be explored in future research, and there were five that stood out, all having to do with refining our understanding of TOD development

1. Repeat this analysis using hyperspectral imagery

One of the key problems with this research is the limitations imposed by relying on publicly available data with limited capacity for extensive endmembers. While using Landsat data eliminated the noise of sidewalk improvements, tree removals, and the likes of backyard gazebos that plagued Sentinel data (10m resolution), using hyperspectral imagery with the capacity to analyze a few dozen endmembers would be worth the trade-off. Using hyperspectral data would allow for a more robust analysis involving dozens of materials present in the urban landscape, particularly roofing materials. This would help catch more fine-grained development, such as the addition of ADUs and fourplexes, as well as more effectively pull apart asphalt roofing tiles from roads. This would not only catch missed smaller buildings, but it could also be used to expand the analysis to cover sustainability, by measuring green roofs and solar panels.

2. Analysis of the impact of incentives and public-private partnership on overall TOD development

One of the lingering questions was what role different development mechanisms had in development. It is unclear if and where development incentives such as height bonuses and transit-induced zoning changes have had impacts on the urban environment. From publicly available documents, it is clear that most large-scale TOD projects exist somewhere on the public-private partnership spectrum and researching which mechanisms and aspects of partnership were most effective could be helpful in understanding how to generate more TOD in stubborn low-development walksheds.

3. Factoring in distance decay

Looking at more specific distance bands from the stations could yield more nuanced results about where TOD is developing, particularly for freeway corridor stations. Analyzing if TOD is being generated in a narrower walkshed or if development is happening farther than half a mile out from the station could be insightful for how proximity to the freeway is or is not impacting development. From visual analysis, it is clear that modern redevelopment projects related to or oriented toward the stations tended toward the outskirts of the ½ mile walkshed, rather than at the heart of it. This may be project developers and future residents avoiding the known negative health impacts of the freeway.

4. Looking at ridership and mode share to assess transit-orientation.

Ridership over time was not analyzed over time due to the hangover from the COVID-19 pandemic and its downstream effects. In an ideal research scenario, ridership and ridership per capita in a walkshed would be measured before and after development, to determine how development impacted the number of people riding trains relative to the population change that occurred. Even more effective would be analyzing actual trips from developments at stations to determine if there is any difference in mode share between TOD generated by freeway corridor stations and TOD generated by stations in the control group.

Conclusion

This thesis confirmed that freeway -corridor light rail stations have statistically significant drawbacks, broadly consistent with existing research. However, it also identified important nuances that complicate the conventional understanding of freeway corridor transit. Most notably, the results highlight the importance of pedestrian access across the freeway in shaping station performance. Freeway-corridor stations had walksheds that were, on average, 23% smaller than those of non-freeway stations, with the largest accessibility penalties observed for stations with small deviations from the freeway (28%). Freeway-corridor stations also exhibited substantially lower ridership per capita, with residents generating only about half as many transit boardings as those living near control stations.

At the same time, the study found more complex patterns for total ridership and transit-oriented development. Although freeway-corridor stations generated higher average boardings, much of this advantage was attributable to major transfer stations and termini, while ridership per capita remained substantially lower. Similarly, freeway-corridor stations produced, on average, 0.8 acres more transit-oriented redevelopment, yet the statistical comparison favored the combined control group. These contrasting results suggest considerable variation among freeway-corridor stations and indicate that average performance alone does not fully capture their overall effectiveness.

This study has important limitations that warrant further investigation. In particular, the contradictory findings for redevelopment may reflect factors that were not explicitly measured, including lower development costs in freeway corridors, the attractiveness of combining high-quality transit with convenient automobile access, and the travel time advantages provided by grade-separated alignments. Additional research is needed to evaluate the relative contribution of these mechanisms.

Despite these limitations, the findings suggest practical design strategies that may help mitigate some of the known disadvantages of freeway-corridor rail projects. Stations with high-quality pedestrian connections across the freeway generally exhibited larger walksheds, higher ridership per capita, and greater transit-oriented redevelopment than stations with poorer pedestrian access. Similarly, locating stations away from the freeway at key redevelopment locations appears to reduce many of the accessibility constraints associated with freeway corridors. These findings suggest that freeway alignments can potentially combine the cost and speed advantages of freeway rights-of-way with stronger station performance, provided that pedestrian connectivity and station placement receive sufficient attention during planning and design.

Ultimately, freeway corridors offer important opportunities for rapid transit expansion, but they also present substantial risks. While they provide benefits in terms of right-of-way availability, construction efficiency, and operating speed, value engineering that compromises pedestrian accessibility or station integration may undermine ridership and transit-oriented development in the long term. The results of this thesis provide a quantitative basis for evaluating these tradeoffs and underscore the importance of station design in determining whether freeway-corridor light rail projects succeed or fall short of their potential.

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