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Land Use Development Transit Ridership Calculator – Phase 1: Blueprint

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Land Use Development Transit Ridership Calculator – Phase 1: Blueprint

A National Center for Sustainable Transportation Research Report

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Table of Contents

Executive Summary.....	i
Literature Review.....	i
Interviews	ii
Calculator Blueprint	ii
Introduction	1
Methods.....	3
Literature Review.....	3
Subject Matter Expert Interviews	4
Calculator Blueprint	6
Results.....	7
Literature Review.....	7
Interviews	26
Calculator Blueprint.....	40
Calculator inputs	40
Calculator implementation	47
Using the TOD Calculator for policy decisions	51
References	53
Data Summary.....	63
Appendix A: Interview Script	64
Introduction	64
Section 1 – Conceptualization and Implementation of TOD	64
Section 2 – Decision making and Community Integration	65
Section 3 – Ridership Estimation and Data Analysis	65
Section 4 – Engagement and Future Considerations.....	65

List of Tables

Table 1. Representation of Interviewees.	5
Table 2. Interviewee Descriptions.....	6
Table 3. Project Characteristics Calculator Inputs.....	40
Table 4. Location Characteristics Calculator Inputs.	43
Table 5. Transit Service Characteristics Calculator Inputs.	44
Table 6. Access Calculator Inputs.	45
Table 7. Existing Land Use Inputs.	46

List of Figures

Figure 1. Quantitative analysis of relationships between the built environment and transit ridership.	10
Figure 2. Relationships between transit service characteristics and ridership.	15
Figure 3. Relationship between sociodemographics and ridership.....	20
Figure 4 Conceptual model of inputs, models, and data flow	48

Executive Summary

This project presents a blueprint for the development and implementation of a calculator to estimate expected ridership resulting from land use development projects around transit, with a focus on transit-oriented development (TOD) construction in California. We draw on a thorough review of the literature related to projects around transit, TOD, and built environment impacts on transit ridership as well as practitioner subject matter expert interviews to inform the calculator design recommendations presented here.

Literature Review

The literature review was conducted in Scopus, Web of Science, and the Transportation Research Board (TRB) Transport Research International Documentation (TRID) literature database. It was based on the following search terms in order to ensure we included relevant papers that addressed the built environment more generally as well as TOD more specifically:

- “transit oriented development”, “TOD”, “station area development”, “TOD investment”, “mixed-use development”, “urban form”, or “density”; and
- “transit” or “public transportation”; and
- “ridership”, “mode choice”, “mode split”, or “public transport use”; and not
- “fare”, “route”, or “automat*”

This process produced 1,531 possible results after removing duplicates. Of those, we included 144 total, 96 with a model are included in the quantitative analysis presented below. We also retained an additional 48 papers that provide background information. The outcomes of the literature review provide evidence supporting which variables should be included in the calculator. This includes, but is not limited to the following:

1. Population and employment density were the most frequently reported built environment variables most frequently observed as significant predictors of ridership, though there was some variation in the direction of impact – largely due to what other modes are competing with transit for mode share (walk versus auto).
2. Among transit service variables, frequency of service, service reliability and access to the station were the most commonly reported significant predictors of ridership. Both are typically reported to have a positive relationship with ridership.
3. Household income and vehicle ownership are the top two variables reported in the literature reviewed here, as significant predictors of ridership. With both typically having a negative relationship with ridership.

Additional variables found to be significant in several of the papers reviewed here include travel times, access metrics, parking and park and ride availability, and station locations, as well as several additional built environment and transit service characteristics.

Interviews

We completed 16 interviews over the months of March to May in the spring of 2026. Interviewees included city planning departments, transit planners, and county transportation authorities. The interview questions focused more explicitly on TOD, though participants were encouraged to discuss related topics, such as projects around transit more broadly, and policies and other factors that affect the implementation of TOD. Each interview was approximately 30 to 40 minutes and included questions related to: the conceptualization of TOD and expected benefits; challenges and barriers related to TOD, impact estimation, what successful TOD looks like, and what features would be valuable in the planned calculator. The key themes that emerged from the interviews along with example quotes are as follows:

1. Expected outcomes and benefits from TOD: “...assumed benefit is housing... more ridership, just providing opportunities where people don't need to use their car.”
2. Challenges surrounding TOD: “...butting up against what the community thinks is pushing them beyond what is the nature of their community.”
3. TOD Planning in practice: “Almost everywhere can be considered TOD,” and on the other hand, one interviewee told us, “...we don't really have TOD...”
4. Ridership estimation and data analysis: “we haven't really done anything that's like, hey, if you put TOD in here, what would be the implications on ridership?”
5. Considerations for a TOD calculator: “if there were more, there was more information to, to say, look, yes, this type of build and this type of, um, you know, mix, um, currently, or, you know, would result in, these types of inhabitants, meaning, right, like I said, they're more prone to be mass transit users...”

Relevant policies including Senate Bill 79 and the California Environmental Quality Act (CEQA) were also mentioned in several cases, and generally seen as facilitating efforts to implement TOD and land use development projects to reduce transportation pollutants. Many interviewees discussed the need for integrated planning between the local government and transit operators, as well as ongoing financial and ridership recovery needs stemming from the COVID-19 pandemic.

Calculator Blueprint

Based on the results of the literature review and practitioner interviews, we have the following recommendations for the calculator.

The calculator will require the user to input variables that provide the details of the planned TOD and some other development projects around transit, including the mix of units,

square footage, and any additional changes to transportation infrastructure, transit service, or land use that will coincide with the TOD construction. In the background, we recommend the calculator also incorporate data related to surrounding land uses, transit service, access metrics, and what is currently located on the project site. The calculator formulae will be developed in Phase 2 of this project, but will involve a series of models that estimate ridership including: 1. residential model that predicts the transit ridership of residents of new projects around transit including TODs, 2. commercial model to predict the transit ridership attracted by commercial portions of TODs, 3. existing land use model that predicts ridership loss due to loss of existing land use and 4. park-and-ride model: predicts ridership gain or loss due to removal or addition of park-and-ride spaces.

Introduction

Land use development projects around transit may take on many forms, thereby having various effects on transit use in the project vicinity. One approach, Transit-Oriented Development (TOD) is the creation of compact, walkable, pedestrian-oriented, mixed-use communities centered around stations along transit priority corridors (rail, bus rapid transit). These developments have the potential to increase transit use among residents, employees, and other individuals who visit the residential and commercial units constructed as part of TODs. Increased transit use in these areas and among users is expected to improve bicycle use and walking and to reduce auto-dependence and vehicle miles traveled (VMT). To that end, the State of California has established several policies to support TOD, as have local jurisdictions and the Federal Transit Administration (FTA). Some of these policies include grant opportunities that require applicants to evaluate the expected ridership (and other) changes that will result from projects. Agencies and municipalities applying for grants such as Transit and Intercity Rail Capital Program (TIRCP) and the Affordable Housing and Sustainable Communities Program (AHSC) provide estimates of ridership impacts and new development catalyzed by the project, but producing well-supported, reliable numbers in their applications remains a challenge. Some regions have regional ridership models they use in service planning and environmental review documentation, but these models are generally not designed to forecast changes associated with a single building or neighborhood. Other regions do not have ridership models at all and must rely on ad-hoc approaches to estimate ridership impacts. There is also a need to provide consistent, transparent transit ridership estimates so that more-resourced agencies applying for grants do not out-compete less-resourced agencies that don't have their own regional ridership models. Different local or regional transit ridership model methodologies may not be transparent to audiences, including grant application evaluators. This study addresses these challenges by conducting the first steps in the development of a TOD and transit ridership calculator for the state of California.

The calculator will level the playing field between agencies by providing an easy-to-use tool for estimating the ridership impacts of TOD and some other land use development projects, similar to the Induced Travel calculator that already exists and is in wide use in planning in California (<https://travelcalculator.ncst.ucdavis.edu/>). Through this tool, ridership estimates for applicants seeking funding or zoning variances for TOD and some other projects will be able to document how the projects will impact ridership. These estimates will be comparable across projects thanks to using a standardized methodology. This project lays the groundwork for creating such a calculator, by reviewing the existing literature on the topic and identifying an actionable plan and concrete model structure to implement the calculator.

This report details the work completed in this Phase 1 study and presents a blueprint for the implementation of a Land Use Development Transit Ridership Calculator. The blueprint

presented here draws on the existing body of literature on the impacts of various factors (fares, gas prices, service levels, Transportation Network Companies (TNCs), etc.) and the impacts of land use generally (employment/population density, land use types) on transit ridership. TOD impacts on ridership, however, are not well researched to date because data on TODs and the residents that move into them is not available at a consistent level.

We also conducted a series of interviews with local government planners, and transit agencies to inform the design and future implementation of the Land Use Development Transit Ridership Calculator. This report is organized as follows: the next section, Methods describes our approach to the literature review and the interviews. The Results section details the outcomes of these two aspects of the project. Next, we present the calculator Blueprint, followed the final section where we present Conclusions and Next Steps.

Methods

Literature Review

Though other types of projects are relevant, our literature review is centered on TOD, but we also incorporate broader built environment terms into our search. The linkage between TOD and ridership has a number of important sub-research questions. We did not identify many studies that explicitly look at TOD impacts on transit use or ridership numbers. For this reason, the literature review covers studies on a number of different processes through which TOD affects ridership.

Firstly, the only way TOD policies can affect ridership is through the built environment. Thus, one important part of the literature review was to identify work that describes how different types of TOD policies, in different economic and geographic contexts, do (or do not) spur development.

In the U.S., transit ridership is highly correlated with demographics, so who lives in projects spurred by TOD policies is very important for understanding ridership impacts. The second thread of the literature review covers research on residential location choice, to better understand who is likely to move into units created by TOD programs.

Specific aspects of individual projects may affect both who moves into the projects and how likely they are to use transit. Location along with availability and cost of parking is a prominent example, but aspects such as unit mix, income-restricted units, surrounding land uses, and so on are relevant as well. The literature review also examines the relationships between these aspects of the developments themselves and ridership outcomes.

We initially expected that there would be relatively few studies that mentioned both TOD policies and ridership, given that TOD is a relatively new concept. We did not find this to be the case, however, once we began our searches. As ridership is the outcome predicted by the calculator, we systematically identified papers that examined TOD with ridership as an outcome variable. We conducted searches across Scopus, Web of Science, and the Transportation Research Board (TRB) Transport Research International Documentation (TRID) literature database. The search terms used to identify potentially relevant papers are as follows:

- “transit oriented development”, “TOD”, “station area development”, “TOD investment”, “mixed-use development”, “urban form”, or “density”; and
- “transit” or “public transportation”; and
- “ridership”, “mode choice”, “mode split”, or “public transport use”; and not
- “fare”, “route”, or “automat*”

Focusing on ridership as an outcome was necessary to keep the number of papers manageable for the systematic portion of the literature review. However, it does run the risk of missing some papers that are relevant to the likelihood of development or the demographics of TOD residents that don't also provide a direct discussion of ridership. Thus, we conducted informal ancillary searches through Google Scholar to fill in any gaps in this area.

We restricted the included literature to papers published since 2005, and which evaluated projects in the U.S., Canada, Australia, or New Zealand. While there are many studies in other parts of the world, they exhibit very different urban form than the U.S., and thus have limited relevance. I.e., the impacts of development on ridership in other parts of the world are likely to differ substantially from those in the U.S.

Targeted Policy and User Background

Additional background material was reviewed to expand the scope of this project and ensure we assessed policies aimed at supporting transit-oriented development as well as the impacts of these and the developments themselves on who ultimately become the residents and end-users (e.g., employees of commercial aspects) of TOD.

This review was performed in a more targeted process, with searches on Google Scholar and TRID including general terms of "TOD and policy", or "TOD policy". The aims of this targeted search were to identify key features of TOD policy, differences in policies by transit service types, and the impacts of these policies on the construction of TOD, as well as how they are integrated into or create new development areas.

Subject Matter Expert Interviews

We completed 16 interviews over the months of March to May in the spring of 2026. Interviewees included city planning departments, transit planners, and county transportation authorities. We developed a list of potential contacts based on outreach and engagement for past projects. The sample may be characterized as a convenience sample, however, there is a high degree of variation in terms of size, past TOD implementation, and approaches to ridership estimation within the sample. In some cases, we expanded our list based on recommendations from those we initially contacted and/or interviewed.

We contacted potential interview participants by email and followed up with those we did not hear back from, with a second email. In some cases, the research team made follow-up phone calls. We aimed to have 10 to 15 interviews; when we reached approximately this number we stopped recruiting new interviewees. For each interview we scheduled a one-hour block of time though in practice they were completed in approximately 30 to 40 minutes. Interviews were recorded via Zoom and were later transcribed. The research team also prepared memos based on the key points covered in each interview.

Sample

To maintain the confidentiality of the interview participants and the agencies they represent, neither the identities of our participants, nor their agency are connected to the interview comments. However, to provide the reader with an idea of the kinds of local governments and transit agencies who participated, Table 1 shows a list of agencies including those that participated in our project interviews, and a subset of other agencies representing similar sized or geographically located agencies.

Table 1. Representation of Interviewees.

Transit Agencies and County Transportation Authorities	Local Governments
Sacramento Regional Transit	City of Arcata
OmniTrans	City of Ukiah
Santa Clara County	City of Long Beach
Napa Valley Transportation Authority	City of Beverley Hills
Soltrans	City of Fresno
Samtrans	City of Sacramento
Yolo County Transportation Authority	City of San Jose
Victor Valley Transit Authority	City of Santa Ana
Los Angeles County Metropolitan Transportation Authority	City of Chino
Fresno County Rural Transit Agency	City of Santa Monica
Valley Transit Authority	City of San Francisco
Monterey Salinas Transit	City of Walnut Creek
Livermore Amador Valley Transit Authority	City of Pleasanton
Palo Verde Valley Transit Agency	Santa Clara County
Santa Cruz Metro	Solano County
Needles Area Transit	Marin County

Note: the agencies listed in this table include those who participated in interviews and additional agencies who did not, to protect the confidentiality of our participants.

We assigned each interviewee an identification (ID) number and these are used below in the presentation of comments and quotes from the interviews. Here we give a brief description of each interviewee, matched to their ID number – in order to help put the comments in context, while maintaining the confidentiality of each participant.

Table 2. Interviewee Descriptions.

Interviewee ID numbers	Description of Locality or Area Served (for transit)
01, 09, 15, 11	Rural area or town
08, 13, 14	Suburban city or town
04, 12	Medium or large city
02, 03, 05, 06, 07, 10, 16	Large metropolitan region (within)

Interview Content

The interview content included questions about these topics:

1. How agencies conceptualize TOD and what benefits are expected with the implementation of TOD
2. What challenges and barriers exist for the implementation of TOD,
3. How the impacts of TOD are estimated before it is constructed,
4. What would be considered a successful implementation of TOD
5. What would be valuable in terms of features of a calculator or tool to help estimate ridership.
6. The inputs that would be most relevant in a calculator or tool, including considerations about the context of the TOD such as surrounding land uses and transportation infrastructure.

The full interview script is included in Appendix A: Interview Script.

Calculator Blueprint

Based on the literature review and interviews with subject matter experts, the research team developed a plan for the development and implementation of the ridership calculator, including the necessary inputs and existing data sources that would be incorporated in the background. In addition, we have identified areas where additional data collection and/or analysis would improve the potential calculator estimates by supporting the evaluation of the relationship between, for example, using the residential mix of the TOD to determine the expected characteristics of residents and their transit use.

Results

Literature Review

There is a large amount of literature on the relationship between various TOD characteristics and transit ridership. We systematically identified articles on the relationship between ridership and the built environment, and between ridership and TOD specifically. The bulk of this section covers the results of this search—looking first at characteristics of the built environment, then transit service, then sociodemographics, and then discussing articles that looked specifically at TODs. Most of the articles cited in this section result from the search, though we did include some additional references based on the authors’ experience or ancillary searches to provide additional context.

There are two mathematical issues that can cloud interpretation of the literature reviewed. First of all, most of the reviewed articles use some form of regression to model ridership. The relationships estimated by a regression model, known as *coefficients*, are conditional on all other variables in the model. For instance, even using the same data, the estimated relationship between population density and ridership could vary based on whether transit service frequency is included in the model. In extreme cases, this can even cause the direction of the effect to reverse. Thus, when interpreting literature, it is important to be careful to consider whether other important variables are included in or excluded from models. For example, including population density but not service frequency might lead to an incorrect estimated relationship between density and ridership, because high-density areas also tend to have frequent transit service, so the model attributes some of the effect of frequent transit service to density.

The second issue is the ecological fallacy: attributing the characteristics of a group to all members of that group. For instance, it is common to use Census averages of demographic variables in the region around transit stops when predicting ridership. While this can be highly predictive, it can also be misleading when trying to translate these results to individual outcomes. For instance, some studies find that higher median incomes in an area are associated with higher ridership. While higher-income people may ride transit more in unusual contexts, it is also possible that transit ridership is high in locations where high-income people live, but the high-income people are not the people riding transit—perhaps these locations have other attractions (such as employment), or expensive parking that pushes lower-income individuals living there to be especially likely to use transit.

These and other research quality considerations were considered in our review of the body of research related to TOD and ridership. In some places, we do discuss the reasons for differences in outcomes, and where these might be attributed to research quality issues. However, this review generally includes studies in which we consider the estimates of the relevant relationships to be reliable, unless otherwise noted.

Relationship between the built environment and ridership

The primary way TODs can influence ridership is through the built environment (there are others, such as free transit passes, or bike-share access, or parking cash-out policies, but the built environment is the most universal factor). TODs affect ridership through the built environment in two ways. First, they directly modify the built environment by increasing population and employment density around transit stops. Second, they influence the distribution of people in the built environment by allowing more people to live in denser (and typically more walkable) areas near transit. Had TODs not been built, the residents of TODs might have otherwise had to live in less transit-supportive environments. For these reasons, the relationship between the built environment and ridership is arguably the most important measure of the effectiveness of TODs, and thus the primary focus of our literature review efforts.

We conducted a systematic literature search across three databases, in addition to including a small number of papers that were known to the authors. Keywords and details of the search process are described above in “Methods.” This process produced 1,531 possible results after removing duplicates. After an initial review, 136 met our inclusion criteria. Of those, 81 include a model from which we can assess the relationships between key variables of interest and ridership and are therefore included in the quantitative analysis presented below. We also reviewed an additional 55 papers that provide background information.

For those studies modeling ridership outcomes, we identified a number of broad categories of predictors of ridership (e.g. population density or income) and identified which of these categories were found to be predictive in each study. Many of these map onto the “D variables” traditionally used in describing urban development impacts on travel behavior—i.e. density, diversity, and design (Cervero and Kockelman 1997).

Due to the variation in ridership outcomes (e.g. absolute ridership, ridership change, mode share, etc.), we were not able to directly compare effect sizes. Instead, we classified each significant predictor in each paper as having either a positive or a negative effect (or, in some more complex studies, both depending on context).

Categories related to the built environment are shown in Figure 1. The x axis reports the number of studies that found a statistically significant relationship between a variable in that category and ridership; positive relationships are shown to the right in green and negative to the left in red.¹ It is possible for one study to find both positive and negative relationships, in which case it will be reported on both sides; this can arise through multiple models in a single paper, multiple variables in a single model (e.g. population density at both the block and tract level), or nonlinear relationships or interactions.

¹ For the very small number of papers not reporting statistical significance, relationships were determined based on researcher judgement.

The majority of studies find results in the theoretically expected direction. However, for many categories, a significant minority of studies find results opposite to the theoretically expected direction. These often represent unique contextual factors of individual studies; we address these in the sections below.

The number of studies finding a statistically significant relationship between a category of predictor and ridership is a function both of the strength of the relationship but also the frequency with which it is tested. So, for example, the small number of studies finding a relationship between educational employment and ridership may mean that the relationship is relatively weak, but it may also represent that few authors tested this relationship. In the most extreme cases, a variable that truly has no relationship with ridership but that is tested very frequently will show statistically significant results occasionally, simply by chance.

Unfortunately, we cannot reliably assess how often a particular variable was tested. It is unfortunately a widespread practice in the transport literature to only report on statistically-significant coefficients, rather than on all relationships tested (Bhagat-Conway et al. 2022). Furthermore, publication bias can lead statistically significant and thus more “interesting” results to be more likely to be published, further exacerbating the situation (Ioannidis 2005). This can lead to spurious findings being amplified while true findings of no relationship are hidden. All hope is not lost, however; there are strong theoretical reasons to believe the factors listed in Figure 1 are relevant to transit ridership, making it likely that statistically significant results reflect a true relationship rather than spurious findings.

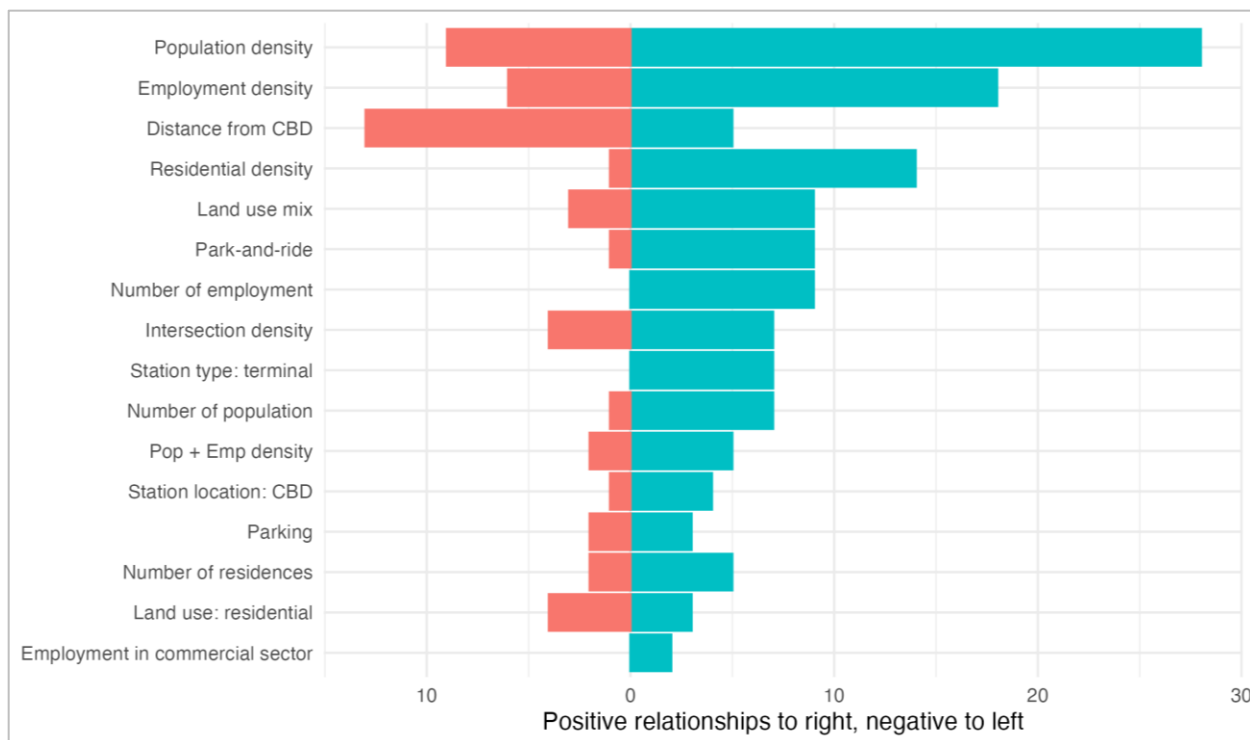


Figure 1. Quantitative analysis of relationships between the built environment and transit ridership.

Population and residential density

Population density is widely recognized as a key predictor of transit ridership in urban contexts, as dense city centers typically generate high levels of transit use, and is used in most transit ridership forecasting going back decades (Chan and Miranda-Moreno 2013; Ewing and Cervero 2010; S. Li et al. 2019; Pushkarev and Zupan 1977; Aston, Currie, Delbosc, et al. 2021). Others have argued that population density itself is not the most important factor, but rather the lowered costs of transit and other non-auto modes and the increased hassle of driving in high-density areas that promote transit use and discourage driving (Salon 2009). Nevertheless, density is a powerful predictor of transit ridership.

Population density is also a critical factor in determining where to build transit, with transit being considered most cost-effective in the highest-density areas (Guerra and Cervero 2011). This can, however, introduce bias, as places with high population density tend to experience greater transit demand, which in turn supports higher service frequency and better network coverage, which also contributes to demand. For example, since rail tends to service higher-population-density areas than buses, it is possible for models to conflate the inherent attractiveness of rail with population density (Aston, Currie, Kamruzzaman, Delbosc, Fournier, et al. 2020).

While most studies find a positive relationship between population density and ridership, in certain contexts the relationship is not uniform—generally when the competition for

transit is not driving. Several studies found a negative relationship with certain modes, which tend to serve lower density areas, and in higher density areas are outcompeted by rail (De Gruyter et al. 2020; Bento et al. 2005). Li and Rodriguez (2024) found a similar negative relationship, but many of the influential stations in their sample were in extremely dense areas, so transit may have been competing primarily with walking rather than driving. This suggests a non-linear relationship/diminishing returns of ridership from density in contexts where walking competes with transit. Though walk trips should also be viewed as a policy success.

Like population density, residential density is also recognized as a key determinant of transit ridership in TOD and built environment research. Although the two concepts are closely related and generally highly correlated, they differ in their definitions. Population density refers to the number of people per unit of total land area (e.g., persons per square kilometer or square mile). In contrast, residential density measures the number of dwelling units per unit of land area. Empirical studies consistently demonstrate that dense residential development promotes transit mode choice and reduces reliance on private vehicles (Nasri and Zhang 2019; Zhang et al. 2013). Like population density, the effect is nonlinear and flattens at high density (Sajjad Abdollahpour et al. 2024). Overall, higher residential density and concentration of households are associated with increased transit ridership, particularly when supported by appropriate transit services and complementary built environment features.

Density is a highly relevant predictor that shows almost all research on the relationship between the built environment and transit ridership and thus should be a part of the calculator. Fortunately, data on density is easily obtained from the Census or American Community Survey. Both population and residential density are readily available. They are usually highly correlated, so there is little reason to prefer one over the other—and indeed it is often inadvisable to include two such highly correlated variables in a model.

Employment and employment density

A large body of literature suggests that higher employment densities, together with residential density at both trip origins and destinations within TOD areas, increase the likelihood of choosing transit (Nasri and Zhang 2019; Aston, Currie, Delbosc, et al. 2021; Ewing and Cervero 2010). While population density is a consistent predictor of transit ridership, some scholars suggest that employment density at destinations or workplaces may be an even stronger determinant of transit use than residential density around origins (Chen et al. 2008).

While employment density across all sectors is generally associated with higher transit ridership, certain employment sectors appear to have a stronger influence than overall employment density. In particular, employment in educational and commercial sectors tends to produce stronger effect on ridership than total employment (Gutiérrez et al. 2011). One explanation is that commercial and educational employment generates both employee and non-employee trips by attracting shoppers, students, and visitors

throughout the day. Consequently, areas with higher concentrations of commercial and educational employment are likely to support higher levels of transit ridership than areas dominated by other employment sectors.

One of the benefits of living in a TOD area is that many opportunities can be accessed using non-motorized transport. Once people get accustomed to that lifestyle, they follow it in some other places too. This normalization of travel behavior is reflected through walking to work from TOD stations. Therefore, the number of jobs within walking distance of a transit station could be a good predictor of transit ridership (Wu et al. 2023). Because of such transformations in travel behavior, researchers often suggest pro-affordable housing policies, and neighborhood-scale commercial development near the destination station to increase the residential and employment density, which will eventually increase ridership (J. Cao et al. 2015).

Data on current employment density is also relatively easy to come by from the U.S. Census Bureau Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics dataset (LEHD LODES), which provides Census-block-level employment estimates for the entire U.S. This dataset is heavily used in transportation analysis, particularly accessibility analyses (e.g., Owen and Levinson 2014; Conway and Stewart 2019). The advantage of this dataset is its block-level granularity, and its basis on unemployment insurance programs (which should be akin to an employment census) rather than a survey sample. However, it is not without limitations for neighborhood-scale work, as multi-site employers do not always report work locations accurately, and to preserve privacy the dataset is ultimately based on a synthetic population (Spear 2011). That said, we still recommend it as an input for the calculator, but with the option to override with better data when it exists (for example, a local employment survey, or planned commercial development being built concurrently with a development being reviewed).

Neighborhood design characteristics

In addition to density, there are a number of neighborhood design characteristics that can influence transit use. These include intersection density, land use mix, and proximity to the central business district (CBD). They influence transit use by improving accessibility, increasing street connectivity, shortening walking distances, and bringing residences, jobs, and services closer together. Well-designed neighborhood environments can make transit more convenient and attractive, encouraging greater ridership and enhancing the effectiveness of transit-oriented development.

Intersection density measures the number of intersections per square mile or kilometer. It is widely recognized as a proxy for street network connectivity and pedestrian accessibility. The literature suggests a positive relationship between intersection density and transit ridership (Ewing and Cervero 2010; Gruyter et al. 2020). High intersection density reduces detour burdens for pedestrians. The vast majority of transit users walk to or from transit,

particularly in TODs. A dense grid of streets facilitates more direct pedestrian networks to the station and therefore supports increased ridership.

Station-area land use is also a strong predictor of transit ridership; this is the central tenet of the push towards TOD. However, the magnitude of this contribution varies depending on the type and intensity of development. A higher concentration of residential land use within TOD areas increases the number of potential transit users located within station catchment areas and is generally associated with higher transit ridership, although the strength of this relationship differs across transit modes and urban contexts (Aston, Currie, Kamruzzaman, et al. 2021). Mixed land use near transit stations, particularly when combined with neighborhood-scale commercial activities, increases activity density and supports a wider range of travel purposes. By placing residential, commercial, and service functions in close proximity, mixed-use development enables many daily activities to be completed within TOD areas, thereby reducing the need for longer automobile trips and lowering overall travel time. Consequently, mixed land use can decrease automobile dependency and encourage greater transit use (Ding et al. 2019; Gutiérrez et al. 2011; J. Cao et al. 2015), as well as encourage off-peak travel (Cervero 2007). Meta-analyses further confirm that land-use diversity is an important determinant of walking and transit use (Ewing and Cervero 2010; Aston, Currie, Delbosc, et al. 2021).

Moreover, the influence of land-use mix on ridership varies across transit modes. Rail-based transit systems are typically developed in dense urban centers characterized by a strong mix of residential, commercial, and institutional land uses. In contrast, conventional bus services often function as feeder or local neighborhood routes in suburban and peripheral areas where single-use, automobile-oriented zoning patterns are more prevalent. So, the association between land-use mix and ridership is stronger for rail than for bus services (De Gruyter et al. 2020). However, this finding should be interpreted with caution because of the aforesaid differences. Whether introducing more mixed-use development around bus corridors would generate comparable ridership gains remains an open question.

Literature consistently shows that stations located within or near a CBD experience higher ridership than stations situated farther away. Because of high land prices, CBD locations experience dense development and activity concentration (Alonso 1964), with many commercial offices, retail, and services are located in small areas. As a result, CBD locations attract many commuter and non-commuter multi-purpose trips during both peak and off-peak hours of the day (Cervero 2006; Brown et al. 2014). Consequently, transit stations located in or near CBDs benefit from their proximity to major trip destinations and activity centers. Although travel patterns have changed since the COVID-19 pandemic, recent evidence suggests that the importance of central locations has remained largely intact. CBDs continue to serve as major anchors of transit demand and ridership despite reductions in traditional commuting trips (Chapman et al. 2025).

Including neighborhood characteristics in the calculator is somewhat more challenging than density, because there is wide variety of types of characteristics and definitions of them; furthermore, they can be difficult to measure. Intersection density measurement is complicated, for example by miscounting of complex junctions or junctions with footpaths as multiple intersections, though there has been some recent progress in methods to address these challenges (Boeing 2025). Furthermore, the pedestrian environment within the TOD can have significant impacts on connectivity, which is the underlying concept intersection density measures, even without there being a sizable change in intersection density. Indeed, there are automated tools available to find ways to maximize connectivity in developments with minimal changes to the network (Bhagat-Conway et al. 2025)—a tool that is very useful for building well-connected developments, but whose impact might not show up in simple metrics. Neighborhood design metrics are very important, but how exactly to incorporate them into the calculator will require further research and conversations with calculator users.

Land use mix is also difficult to measure. A common measurement is entropy, which measures how evenly mixed different categories of land use are, but it is sensitive to the exact categories chosen. We suggest simpler measures, such as an interaction between population and employment density, as a better measure for the calculator.

Central business districts are likewise somewhat difficult to define, particularly in California where many urban regions are polycentric (Manduca 2020). For the purposes of the calculator, we believe nonlinear functions of employment density are a better way to represent CBD-like functions than a binary CBD indicator, and accessibility metrics (see below) are a better way to represent distance to employment centers.

Transit service characteristics

The built environment generates the potential for transit demand by gathering people and activities around stations. However, this potential can only be translated into actual ridership when supported by adequate transit services, including frequent service, competitive travel times, accessible station catchment areas, and convenient network connectivity. The various transit service variables quantitatively assessed are shown in Figure 2. As before, the number of studies that found a statistically-significant negative effect is shown to the left, and the number that found a positive effect is shown to the right; it is possible for one study to be in both categories if it had multiple models, measures of the sociodemographic variable in question, or nonlinear relationships.

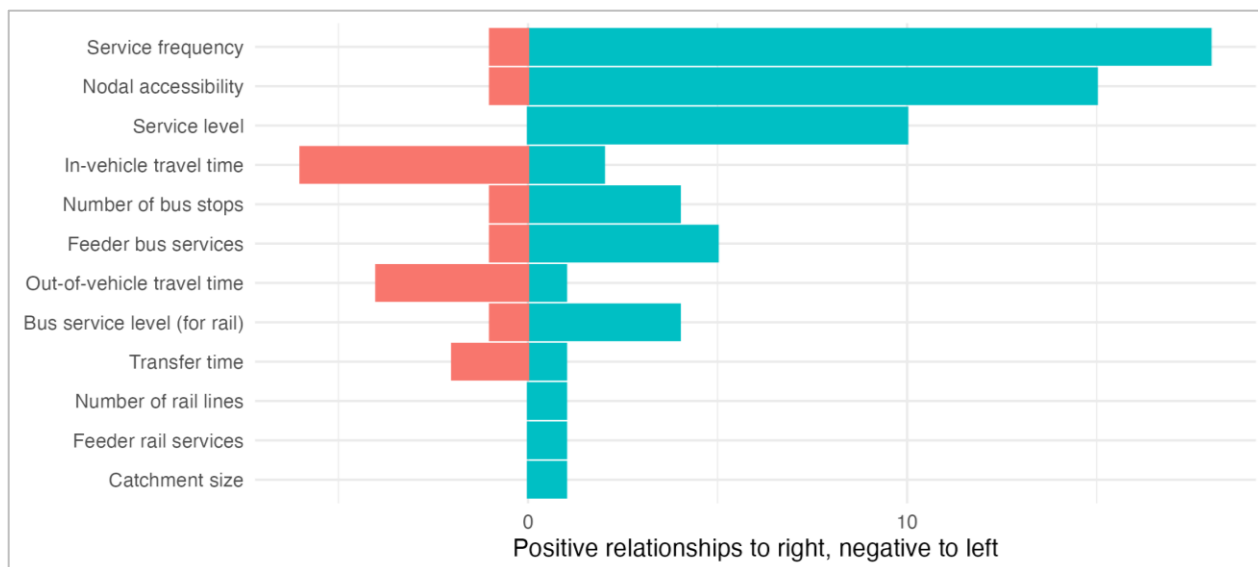


Figure 2. Relationships between transit service characteristics and ridership.

Transit service frequency is the most significant determinant of TOD ridership among transit service characteristics. Empirical evidence and common sense suggest that transit service frequency is positively associated with station-level ridership (e.g., Kashfi et al. 2015; Chakour and Eluru 2016; Shantz et al. 2022; Cervero 2006); a common refrain among transit planners is “frequency is freedom” (Walker 2024). Frequent service is often valued by passengers as highly as, or even more than, other service attributes such as reliability and travel time because it reduces waiting times and minimizes scheduling constraints.

Previous studies further indicate that travelers are willing to cover longer access distances to use high-frequency transit services. Accordingly, Akbari et al. (2018) suggest that increased commuter rail service frequency, when integrated with feeder bus connections, can further enhance ridership by improving overall network accessibility. This is underscored by recent experience in California; after Caltrain electrification, which improved frequencies and travel times significantly, ridership increased by over 70%.²

Reliability is another strong predictor of ridership. We found relatively few papers including it as a predictor, perhaps because of data limitations, but Mucci and Erhardt (2018) found that more reliable services see higher ridership. Knowing future reliability of a transit service near a TOD is difficult, but infrastructure characteristics such as dedicated lanes or signal priority can suggest that service will be more reliable and thus attract more riders in the future. It is also reasonable to expect future reliability to be similar to current levels, unless the development involves improvements such as these.

² Author analysis of 2022–April 2026 National Transit Database (NTD) ridership data, using difference-in-difference specifications using either Bay Area Rapid Transit (BART) or all other commuter rail operators in the U.S. as a control group.

Transit ridership is sensitive to both overall travel time and travel time ratios—the ratio of transit travel time to automobile travel time. Kashfi et al. (2015) found transit usage declines as travel time ratio increases, while Salon (2009) recommended that one strategy to reduce auto dependence would simply be to allow congestion to occur and thus increase auto travel times. Brown et al. (2014) and Thompson et al. (2012) found that bus ridership is highly elastic with respect to total travel time, and suggested that direct connections to reduce travel time and easier transfers to access destinations could make transit use attractive to all users. Collectively, these findings highlight the importance of providing fast, direct, and convenient transit services to maintain and increase ridership. Transit priority infrastructure such as bus lanes or signal priority can also help improve the travel time ratio.

Proximity to stops and stations plays an important role in facilitating ridership; most riders walk to transit and need stops nearby to be able to do so. Traditional studies often use fixed-radius buffers to identify catchment areas. But recent studies suggest that there is wide variability in willingness to walk to transit, and station catchment areas should not be represented by a single fixed-radius buffer, and that people walk further to higher-quality service (van Soest et al. 2020). Guerra et al. (2012) found that the exact catchment used did not make much difference for ridership estimation, though may make a difference when planning locations of TODs. Many studies of ridership generated by TODs compare buildings very close to the station with those located slightly further away (e.g., Barajas et al. 2020; Lund et al. 2004), but this binary assumption of near transit vs. not near transit simplifies a phenomenon that is truly continuous. The comfort and “niceness” (e.g., the presence of shade trees) of the walk to access the station may also be important – a concern that was highlighted by one of the interviewees in this study.

Transit mode is another aspect of nearby transit that may have an impact on TOD, though it is not always clear whether differences in modal outcomes are due to the modes themselves or due to the non-random assignment of modes to locations (Aston, Currie, Kamruzzaman, Delbosc, Fournier, et al. 2020). For example, Brown et al.’s (2014) findings suggested that rail users tend to travel to dense employment and business centers, whereas bus users are more likely to travel to dispersed employment locations, but this may also be an artifact of the types of locations typically served by buses. Abdollahpour and Buehler (2024) found that built-environment variables have a larger impact on rail than BRT ridership. However, others have argued that service attributes such as dedicated right of way and high frequency are more relevant to users than the vehicle technology (Walker 2024). Most TODs in the U.S. to date have centered on rail, and bus-based TOD is an active topic of research, as evidenced by a recent Transit Cooperative Research Program call on the topic.

Characteristics of nearby transit service are important inputs to the calculator. While many aspects of transit service are captured by accessibility, discussed in the next section, we believe there is sufficient evidence for an independent effect of transit service characteristics. Frequency (and span of service) are very important to enabling a lifestyle

built on transit use, rather than built around transit use, and most people will not walk a long distance to transit. Whether to include transit mode as a predictor, though, is both a theoretical and a policy question. From a theoretical standpoint, there are reasonable arguments that mode is simply a convenient proxy for reliability, frequency, and other attributes typically associated with rail service, but there are also arguments that people view rail service as fundamentally preferable. From a policy standpoint, including rail access as a variable in the calculator will likely lead to higher ridership estimates for projects near rail—whether due to the rail itself or other attributes it proxies for. This could in turn lead to a preference for rail-based TODs, favoring the regions of the state where rail service exists and is practical.

Data on existing transit service characteristics is easy to come by, thanks to the widespread adoption of General Transit Feed Specification (GTFS) schedule data (and, for assessing reliability, GTFS-realtime data). The California Integrated Travel Project (Cal-ITP) curates GTFS data for agencies across California, and is the ideal place to source transit service data. Many TODs are built in advance of new transit service, however (Atkinson-Palombo and Kuby 2011), so it will be important to allow existing conditions to be modified with transit projects that are forecast to open in the future when relevant for evaluating a particular project. Knowing existing and planned service features will help evaluate the impacts of TOD in the calculator.

Access metrics

All of the built environment characteristics listed above represent some aspect of making a transit-oriented lifestyle easier, but none of them are sufficient on their own. Access metrics combine all of these attributes into a single metric indicating how much opportunity the transit system in combination with regional land use provide. First introduced by Hansen (1959), they have gained popularity for transportation planning in the last few decades (E. J. Miller 2018; Committee of the Transport Access Manual 2020). While there are many different formulations of access (Geurs and van Wee 2004), the cumulative-opportunities metric is the arguably the most widely used and understandable. A cumulative opportunities metric is something akin to “from this location, you can reach 200,000 jobs in 45 minutes by transit,” where the type of destination (jobs in this case), travel time, and mode can all be varied. In much of the literature, access metrics are referred to as “accessibility;” we do not use this terminology here to avoid confusion with accessibility for people with disabilities.

Access metrics are, unsurprisingly, strong predictors of transit usage (Wu et al. 2019; Owen and Levinson 2015; Chakraborty and Mishra 2013). Authors have also argued that population density alone is not sufficient to promote transit access unless combined with accessibility (Merlin et al. 2021; Concas and DeSalvo 2014). Access metrics are also extremely flexible, and can incorporate other modes, such as auto (e.g., Owen and Murphy 2020), or aspects of trip planning such as social costs (Cui and Levinson 2018) and transit fares (Conway and Stewart 2019).

While access metrics have most often been conceptualized at the trip level, it is also possible to conceptualize them at the tour level. Hägerstrand (1970) proposed the “time-space prism” which is the area a person can access during their day, accounting for constraints in time and space (for example, arriving at work by 8 or picking children up from school at 3:30). This can be extended to access metrics by using the time-space prism to evaluate potential activities that could fit around the constraints in one’s day (H. J. Miller 1991, 1999; Farber et al. 2013), though this is relatively rare in the applied access literature. Time-space based metrics allow accounting for trip chaining as well. This is a key reason many may not take transit, and something TODs can address by placing many things someone might need on a tour in close proximity (Concas and DeSalvo 2014).

We believe access metrics are highly relevant predictors for the calculator. Access metrics are relatively easy to calculate, and moreover are provided nationwide for existing conditions by the Access Across America project (Levinson 2013), making their inclusion in the calculator straightforward. Like both built environment and transit service characteristics, however, it will be important to be able to re-calculate them with projected future conditions when a TOD includes both residences and destinations, or when changes to transit service are planned. For transit accessibility metrics, re-calculation needs only transit network data (curated by Cal-ITP, with any modifications needed for a particular project) and street network data (often OpenStreetMap). Open-source software for calculating accessibility metrics is also readily available, e.g. r5r (Pereira et al. 2021).

Auto-based access metrics are also important, because they demonstrate the relative ease of using transit as opposed to an auto. These are more difficult to recalculate due to the need to account for congestion; congestion data are not always readily available. Since auto access is not heavily affected by local changes to land use, we propose simply using existing auto access metrics from Access Across America wherever auto access metrics are needed in the calculator.

Parking

Parking is an important variable when considering the relationship between TOD and ridership. Parking in transit-oriented developments and around stations takes essentially two forms: parking for the station itself, and parking for other land uses near the station. Park-and-ride spaces for the station itself tend to have a positive effect on ridership (Kuby et al. 2004; Durning and Townsend 2015; Pogodzinski and Niles 2021). Aston et al. (2020) found that car parking at railway stations was a significant predictor for both bus and train, whereas train ridership was more associated with bicycle and pedestrian connectivity. However, the author suggested that the observed significance of railway-station parking may be partly due to the higher ridership at bus stops located near train-station interchanges, rather than the parking alone.

On the other hand, increases in parking for TOD-area residences and businesses are generally associated with lower ridership. The economic argument is clear: supplying parking, particularly free parking, lowers the cost of driving and thus encourages people to

drive (Shoup 2011). An expert panel recruited by Moudon et al. (2005) felt that parking supply, particularly at grade, strongly discouraged transit usage. Chatman (2013) found that parking availability was one of the strongest predictors of auto ownership (and, by extrapolation, use), regardless of transit availability.

Several authors have directly considered the tradeoff between park-and-ride and TOD. Pogodzinski and Niles (2021) acknowledge that park-and-ride has significant positive ridership impacts, and may be the most effective way for agencies to reach riders beyond the reach of the existing fixed route system. However, they also argue that partnering with housing developers for dense and walkable development in station areas is a viable option, can encourage systematic growth in ridership, and may be more lucrative for transit agencies if they are selling off land they own. Duncan (2010) simulated development around Bay Area Rapid Transit (BART) stations and found that the development densities needed to maintain ridership if park-and-ride was replaced by TOD were much higher than is generally seen outside urban cores, particularly for residential development. Duncan proposes combination of TOD and continued park-and-ride spaces may be the most appropriate, as was done in the Fruitvale BART TOD (Sandoval 2018), though Duncan argues that 1:1 replacement of park-and-ride spaces is excessive—something that FTA agrees with and allows even when park-and-rides were originally FTA-funded (Raine et al. 2021). Akbari et al. (2018) also stressed that better walkability would reduce dependence on parking and increase ridership. This is an important policy consideration for regional VMT however, if some previous park and riders shift to driving the whole way, even if they are replaced as riders by those who move into the new TOD.

Parking requirements should also be carefully considered. While TODs do not always have parking demands lower than other developments (Cervero et al. 2010), it is reasonable to expect that in at least some cases they would—for example, a case study by Thigpen (2018) found that there was significant oversupply of parking in a walk- and bike-friendly apartment complex, even without an explicit TOD orientation. Parking policies matter; even in relatively auto-oriented areas, removing parking requirements can result in a significant reduction in parking supply (Bealke 2026).

Parking is critical to TOD ridership outcomes. Unfortunately, data on parking can be somewhat difficult to come by. For the purposes of the calculator, details of parking proposed should be provided for any project under consideration, along with whether any spaces are dedicated to park-and-ride use. Ideally, data on other nearby parking would also be included, but this is more difficult to acquire. Flexibility to provide parking off-site can furthermore make projects in complex or constrained urban environment more possible (Manville 2013). If the TOD plans to directly use off-site parking, however, then it should be included in calculations. The evolving policy landscape related to parking in California is important to consider in the calculator – perhaps most notably, whether or not Assembly Bill 2097 applies to, and prohibits parking minimum requirements at or around the station or parcel in question.

Sociodemographics

While not directly related to the built environment of TODs, many socio-demographic variables such as gender, age, car ownership, household income, white population, worker population, and ethnicity have effects on transit ridership. While some authors have found that built-environment variables explain ridership well without need for sociodemographics (Durning and Townsend 2015), sociodemographics are widely found to be important to ridership prediction. It is thus very important for the calculator to have at least basic information not only on what will be built, but some sense of who might live in it. Relationships between sociodemographics and ridership found in the literature are shown in Figure 3; as before, the number of studies that found a statistically-significant negative effect is shown to the left, and the number that found a positive effect is shown to the right; it is possible for one study to be in both categories if it had multiple models, measures of the sociodemographic variable in question, or nonlinear relationships.

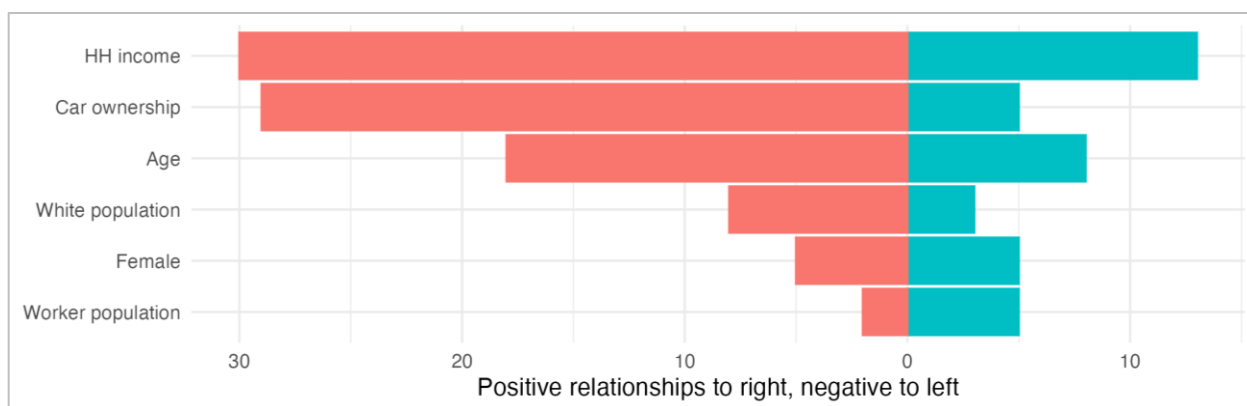


Figure 3. Relationship between sociodemographics and ridership.

Income is perhaps the single most important demographic predictor of transit ridership. Fortunately, it is also the demographic variable likely to be best known when the calculator is applied to a development. Very early on in the development process, developers estimate likely rents and whether any units will be designated as affordable. This gives some idea of the incomes of those who might live in the development. Most studies find that income has a negative relationship with ridership (e.g., Parker 2024; Zamir et al. 2014; Mucci and Erhardt 2018; Pogodzinski and Niles 2021; Bento et al. 2005).

However, the relationship between income and transit ridership is not completely unidirectional. Lachapelle (2018) showed high income workers are more likely than lower income workers to use transit when offered a transit pass by their employer. Ding, Cao, and Liu (2019) found a nonlinear association between income and ridership, which was positive for lower income households, negative for middle income households, and positive for the highest-income households. However, their study used median income rather than individual household income—which is a common practice, but represents the ecological fallacy discussed above and could mean the relationship is driven by housing

values and thus where high income people live, rather than by high income people actually riding.

Like income, car ownership tends to be negatively associated with transit ridership (e.g., De Gruyter et al. 2020; Cervero 2006; Dill and McNeil 2023)—though car ownership may also be necessitated by not using transit, rather than a cause of not using transit. In limited instances, however, car ownership may be positively associated with ridership, notably for commuter/regional rail (Brown et al. 2014; Shantz et al. 2022). Car ownership is also closely correlated with parking, which is discussed above. Driver status is another related variable; Yang (2025) showed that non-driver adults use transit more than driver adults.

While our systematic literature review found relatively few articles discussing family structure and presence of children—perhaps because our search terms focused on the built environment—this is also an important sociodemographic characteristic. Traveling with children, or making household serving trips among households with children, tends to lead to more complex trip chains, which transit is often less suited for, particularly outside the highest-density areas (Hensher and Reyes 2000). That said, this is true regardless of where families live, so TODs may help them take at least some trips via transit. Developers indirectly choose the family structure of tenants based on the unit mix—e.g. one vs. two vs. three-bedroom units. This should be accounted for in the calculator, but care should be taken to avoid structuring the calculator to penalize developers for building family-sized units. Furthermore, people who experience transit as children or young adults are more likely to ride transit later in life, amplifying the impact of TODs for families (Smart and Klein 2018).

There are a host of other demographic variables that have associations with ridership, but they are of limited usefulness for building a calculator. It is unlikely that a developer would know, for example, the immigrant status or gender of likely residents (beyond neighborhood or regional averages). For completeness, though, we note that immigrant status has heterogeneous relationships with transit ridership. Schouten et al (2024) found Hispanic immigrants are more likely to use transit than U.S.-born Hispanics, while the opposite is true of Asians. Relationships between gender and ridership are likewise complex. Yousefzadeh Barri et al. (2025) found that in car-owning households with less than one vehicle per driver, males tended to have car access while females relied on transit.

For the purposes of the calculator, the demographics of TOD residents are the primary relevant demographic inputs. Thus, typical demographic data source (Census and American Community Survey) will not be helpful. Instead, we propose that a minimal set of demographics—income, car ownership, total number of residents, and possibly family structure—be estimated based on proposed rents and affordability, proposed parking, and unit mix.

Relationship between TOD and ridership

While most papers we reviewed examined the built environment generally rather than explicitly looking at TODs, a small number of papers directly examined the link between transit-oriented development and ridership. Caltrans supported surveys of residents of TOD projects across California in the early 1990s and early 2000s (Cervero 1993; Lund et al. 2004). Several of these TODs in the Bay Area were surveyed again in the late 2010s by Barajas et al. (2020). All three studies found that TOD residents use transit at higher rates than non-TOD control groups, suggesting that TOD investment can indeed spur ridership.

Dill (2008) and Dill and McNeil (2023) surveyed residents of transit-oriented developments in Portland, Oregon, about their transportation habits. They found that residents of transit-oriented development make more commute trips by transit than the citywide average and are also relatively frequent non-work transit users. Transit was more likely to be used for commuting than non-commute trips. Demographic and built-environment variables further moderated transit use, even within TODs. Older and wealthier respondents rode transit less for non-work purposes. People with fewer vehicles rode more—suggesting parking pricing may be a viable policy lever to encourage transit use in new TODs.

Income is one of the strongest predictors of transit usage. Lund et al. (2004) noted that residential units in TODs “tend to be smaller and less expensive than their surrounding region,” potentially leading to lower-income households already predisposed to transit use choosing to live there. This may have changed in the intervening two decades, however. Home prices in TODs have been growing faster than prices of other homes near transit, though this may be offset by lowered transportation costs (Renne et al. 2016). There is evidence that lower-income individuals prefer transit rich environments even when housing costs are higher (Glaeser et al. 2008). There is some concern that TOD can induce gentrification, though findings are mixed (Padeiro, Louro, and da Costa 2019). This finding should also be contextualized by noting that the concept of TOD is relatively new, and unsubsidized new housing is typically occupied by higher income households, and filters down to lower income households over time (Rosenthal 2014), though this finding is less consistent in high-cost West Coast metros (Spader 2025). Furthermore, California TOD plans often do not include explicit affordability requirements (Garde et al. 2024). Though this is true, there are other California policies (discussed above) that do provide developers benefits when including affordable housing in high quality transit areas. The relevance of these policies for a particular site may shape the development and the affordability of the residential units.

Whether TODs include affordable housing is a housing policy question out of scope for the TOD calculator, but it is still highly relevant to ridership forecasts. Barajas et al. (2020) separated out affordable and market-rate TODs and found that TOD had a larger impact on travel behavior for residents of market-rate units; residents of affordable TOD units used rail at a lower rate than market-rate residents, though both TOD and non-TOD residents of affordable units used the bus at fairly high rates. This is opposite the normal relationship between income and ridership—generally, lower income individuals ride transit more than

higher income individuals—but it still demonstrates the importance of accounting for income and affordability. In part, the unexpected directionality may be a contextual factor—Barajas et al. studied areas around BART stations, and BART has the highest per-trip fare of any heavy rail metro system in the U.S.³ It may also be that those who moved into the TOD areas were already transit users, and so did not change behavior as a result – rather they self-selected into these environments.

There were various methods of defining control groups. Some studies (Cervero 1993; Lund et al. 2004; Dill 2008; Dill and McNeil 2023) use the transit ridership levels of the surrounding cities as controls. The challenge with this approach is that municipality boundaries vary significantly in how much suburban and exurban area they include, and as relatively static entities cannot capture changes in the concentration of residents over time (Sancton 2008). When looking at workers, both Cervero (1993) and Lund et al. (2004) use metropolitan statistical areas as a control group. While this accurately reflects the labor market of the region, it does not allow comparison between TODs and alternative developments that may not be TOD but are still located in central parts of the region. On the other hand, it may also understate the TOD benefits. In a region where much existing development is centralized, a suburban TOD might be a success even if it results in transit ridership below the MSA-level average.

Another approach is to compare TOD residents with those slightly further away from transit, which is used by both Lund et al. (2004) and Barajas et al. (2020). Looking only at commute mode, Lund et al. found that TOD residents used transit at rates almost four times higher than those living slightly further away. Barajas et al. found a slightly more nuanced story, with TOD residents using rail at higher rates than non-TOD residents. However, TOD residents used buses at relatively low rates, and those living in affordable units in non-TOD developments were actually more likely to use the bus than those living in affordable units in TOD developments (though the difference was not statistically significant).

While most studies focus on the travel behavior of TOD residents, many TOD projects allow mixed use and include office or retail components. To accurately model the impact of TOD on transit ridership, it is important to also account for trips to destinations within TODs. Both Cervero (1993) and Lund et al. (2004) survey workers in TOD areas, in addition to residents, though this is somewhat rare in the literature. They found that office workers in TODs were roughly three times more likely to commute by transit than other workers in the same metropolitan areas.

³ Author analysis of 2024 National Transit Database (NTD) data; BART received an average of \$3.89 in fare revenue per passenger trip; the next most expensive system, the New Jersey-New York Port Authority Trans-Hudson (PATH) system, received an average of \$2.44. BART's fares are more similar to commuter rail systems, falling just above the fare for the median U.S. commuter rail system.

Many of the papers reviewed survey the areas around major transit stations, sometimes referring to them as TODs, but do not focus on purpose-built TODs. These papers are included in the analyses in previous sections, but are not included here. Station areas may share many characteristics with purpose-built TODs. However, the purpose of the calculator is to forecast ridership from new development, and as noted above the residents of new TODs may be different from other residents of station areas.

Who lives in TODs?

There is some concern that transit improvements along with TODs, because there are municipal economic considerations and because developers are for profit entities, will contribute to displacement of lower income residents, and to gentrification (Padeiro, Louro, and Da Costa 2019). The processes through which displacement and gentrification occur are expected to differ, but both raise a related question about who ultimately lives in TODs. Do previous residents stay, and benefit from the amenities ushered in by the new TOD? Do housing, service, and other costs go up in the area as more higher income residents move into any market rate housing constructed as part of the TOD?

In a review of empirical studies evaluating the occurrence of gentrification along transit lines and within cities, Padeiro and co-authors find that among the 35 studies reviewed in their paper there is a high degree of variability in the findings related to gentrification as an outcome of transit expansion and/or TOD (Padeiro, Louro, and Da Costa 2019). They note that: “...high variability in findings and the relevance of local contexts might suggest that gentrification is more closely associated with existing local dynamics, built environment attributes, and accompanying policies. (p. 749)”

Another key concern when assessing the efficacy of TODs is residential self-selection. People choose their residential locations based on their preferences, and thus it is likely that TOD residents have a higher propensity to ride transit than the average citizen. That said, extensive research suggests that there is at least some impact of the built environment over and above the impact of self-selection—that is, transit supportive environments can be expected to lead to more transit usage (X. J. Cao et al. 2009). This is underscored by studies of TOD residents, which find that many residents switched to transit after moving to TOD (Cervero 1993). Furthermore, even if TODs do attract people predisposed to taking transit, that does not mean they were taking transit in their previous residential location. There are far more Americans interested in car-free living than there are who actually are car-free (Corcoran et al. 2026). Or can be car-free!

How do TOD policies impact development?

Most development in the U.S. is financed and executed by private developers, possibly with some government subsidies. This includes most development spurred by TOD policies. For TOD policies to be effective, then, they must create an environment where it is not only legal to build TODs, but also profitable to do so.

The typical way developers assess the feasibility of a project is through a *pro forma*, a document balancing the different costs and potential income streams of a development (Miles et al. 2015). The costs include land, construction, permitting fees, taxes and interest during the development period, and so on. The income is primarily from rent or sales, but may also include revenue from other uses (e.g. parking or cell towers), or from subsidies such as the federal Low Income Housing Tax Credit (LIHTC). Providing incentives for TOD and disincentives for other development may be important factors. This can include policies that impose requirements on developers (i.e., a minimum number of affordable housing units) or provide things like density bonuses as incentives (K. Yang and Pojani 2017).

To understand the impacts of development policies, the most common approach is to build simulated pro formas for various types of developments that would be permitted under the policy, and see if they “pencil”—i.e. turn sufficient profit that investors will invest in them. The University of California, Berkeley’s Turner Center produces a regular report detailing pro formas for various buildings in different regions in California; the most recent report finds that medium size multifamily developments are unlikely to pencil in most parts of the state, but that policy changes such as reductions to parking minima or reductions in impact fees could help (Garcia et al. 2023). This approach has been applied in modeling as well, understanding what parcels are likely to redevelop if land-use policies were changed (Conway 2021; Johnson et al. 2018; Stiphany and Wegmann 2020; Waddell 2013).

The relevance of this to the TOD calculator depends on the desired use of the calculator. If there is a desire to use it for assessing the districtwide impacts of general policies, it is highly relevant to understand how those policies will actually affect the built environment, and the calculator should include a pro-forma simulation step. If instead it is used later in the process to assess the impacts of individual developments, where any decisions based on the tool are contingent on the building being constructed, it is less relevant to understand all of the contributors to whether a development will occur.

Pandemic impacts

Much of the research discussed above was published pre-pandemic, and even more was likely based on data collected pre-pandemic. Transit was heavily affected by the pandemic, with precipitous ridership drops and slow recovery. While it is still fairly early to make conclusive claims about how the pandemic affected TOD and transit ridership, it is likely that there will be at least some effect (Salon et al. 2021). There is some evidence that predictors of transit ridership may be changing post-pandemic; for instance, employment density may be less important than it previously was, and fares and frequencies more so (Chapman et al. 2025). For auto travel, demand is less heavily peaked than it was in the past (Bhagat-Conway and Zhang 2023); the peak is a time that transit historically served heavily. All of these findings are consistent with a shift from work travel to more household serving, care trips, and discretionary travel as people work from home more.

At this point, post-pandemic ridership recovery is still somewhat fluid, and there certainly has not been enough time for a sizable body of post-pandemic research on transit ridership to develop. Thus, our recommendation for the calculator is to develop relationships based on pre-pandemic data for the many relationships where post-pandemic data are not available, while keeping in mind how shifts to working from home might affect these relationships. In a future update to the calculator, it may be possible to focus exclusively on post-pandemic data.

Interviews

Below, we summarize the primary themes that came up in the interviews. Though the interviews generally followed the interview script, we allowed for free form responses which often touched on multiple questions even if we asked something specific. The themes included in this section represent topics that were discussed by many of the interviewees, or topics that related directly to the development of the calculator. The interviews centered on the current state of the practice related to TOD in the areas relevant to our interviewees. Outcomes that will directly inform the calculator include those related to the current estimation methods and how planning for TOD is integrated with other planning and how this impacts ridership estimation. Further, the interviews asked about what factors are important in the development of the calculator and what functionality would be most useful. For some topics, such as current estimation practice, many participants reported that their methods are limited and in some cases, “back-of the envelope”. Interviewees also talked about a number of topics that are not directly tied to the calculator, but are relevant to policy and practical outcomes. These are also included below as they are important outcomes of the interviews. Where possible, the interview participant ID is included for reference.

Theme 1: Expected Outcomes and Benefits from TOD

The expected outcomes of TOD generally included improved economic activity and increases in the use of transit and other active modes, while also making transportation more affordable. These benefits were described by the large majority of the interviewees. Some additional benefits included safety improvements, further densification, and more livable communities. Others noted that bringing people closer together and closer to transit would help encourage behavioral change.

TOD is seen as an effective means to improve sustainability at the city level. One suburban city also noted VMT reduction as the first benefit of implementing TOD. It was also noted that it can’t be done by transportation alone. TOD needs to be combined with the right mix of land uses to support densification. Other related comments include:

“But then the second goal is to achieve sustainability by reaching carbon neutrality by 2030, as well as reducing the drive-alone share in the city from 80% today to 40% by 2040. TOD is one of the most effective ways to achieve that goal.”

“...assumed benefit is housing”, and “...more ridership, just providing opportunities where people don't need to use their car.” (13).

“TOD now gives us a chance to kind of reintegrate that, try to build a more like, kind of downtown-esque environment where you have mixed use of housing and retail that's close to transit.” And “...integrate more, you know, denser, walkable, usable downtown-type environments with these transit stations that were designed to be directly the opposite.” (08)

“If you can get to something in a more direct way because the street network is rich enough it just encourages people to use transit and walk rather than drive point to point.” (07).

One comment, “And if [] did it well, then they would see that these kinds of places are actually livable and offer a lot. And so the view was that it would subsequently affect decisions in the surrounding community.” (16), suggests that a potential benefit of TOD is in fact more TOD, or denser development.

Though they also talked about their possibly unique views on TOD;

“So TOD in some ways is just an excuse to finally actually zone for and create policies for the kind of place that people and the market clearly demand more than we have supplied it. So it's great that it's at transit, but it being at transit is simply an excuse to create some policies that deliver mixed use, that deliver densities, that deliver walkability, that deliver the kinds of access to services that people want, even without the transit.” (16).

Comments related to economic vitality noted improved tax revenue as well as relieving economic downturns and alleviating financial instability:

“Even the influx of dollars that comes with transit development, that could boost the economy in certain areas of this town” (011).

“Economic development is a big driver for at least TOD that tends to spur off of these BRT lines. And that's kind of a huge motivator for cities in our service area for getting BRT builds, you know, the TOD that comes with it usually has some, you know, improved tax revenue and that kind of thing that really helps them fund infrastructure.” (10).

Relatedly, one transit agency saw TOD as an opportunity to alleviate a “food desert”, by including a grocery store as part of the development (15). And one suburban city described TOD as a potential win even if it doesn't increase ridership a lot – if it provides a revenue stream for the transit provider and allows them to maintain or even potentially expand service.

Safety was not a major theme in the interviews, but one rural transit operator mentioned how it could be a benefit: “We want there to be, you know, livelihood and thriving because the more people in an area, the less likely for, you know, small incidents to occur.” (15).

The two central takeaways from this theme are economic activity and the increased use of transit and active modes resulting from TOD.

Theme 2: Challenges Surrounding TOD

Our interviews covered the challenges surrounding the planning and implementation of TOD. One important topic that was discussed by many of the interviewees was how to encourage behavior change; the chicken and egg metaphor was popular:

“if people don’t choose to take transit, and drive?” (07).

“And the way that I've looked at it is that, you know, there's, there's sort of like this chicken and egg when it comes to public transit in, in a rural jurisdiction, where if transit isn't convenient, people won't ride it.” (01).

“We don't have short headways, for instance. I think our best is 45 or 60-minute headways on most of our routes. So, you got these two things that are mutually fighting each other for one to happen first.” (03).

“...geared towards luxury buyers. So then though you'd have folks that are near transit, I don't know if they would be the ones utilizing it only because the acquisition of land is so high.” (14).

Some of this can be impacted during the design stage;

“Like one of the things I have issues with the particulars like pedestrian connectivity that doesn't get that often doesn't get thought about a lot, even in like the most well-meaning developments that are supposedly, you know, high density doesn't always mean transit oriented. So, you've got to think about it like that.” (10).

One challenge that came up for some interviewees is community opposition. While it can be understood as a means for people to protect their communities and investments, it can also reflect a resistance to change because they like the city how it is and they are afraid of what this could open it up to.

“...think particularly among like residents, there's not necessarily an understanding of the potential that TOD and transit service can provide.” (10)

“...butting up against what the community thinks is pushing them beyond what is the nature of their community.” (16).

“there's not necessarily an understanding of the potential that TOD and transit service can provide. ... I hear often like the buses are like half empty. Why are they taking a full lane? Like, I think there's an assumption that cars should be priority.” (15)

In one case there was a lawsuit trying to prevent rail transit from extending into the community that eventually lost, but not without impacting the progress of integrated planning:

“Because of that I think the community kind of lost a little bit of time that they could have used for planning for the uses around the transit stations.” (02).

Local government support, or the lack thereof, is also an important factor for transit agency-led implementation of TOD:

“The experience that we have had with the local jurisdiction is the mayor's on our board. She seemed really excited about the project. ...within our city council, um, is excited about it as well and wanting to work with us and wanting to see what they can do to help us.” (15).

“... they prioritized places where the community were— was a willing partner. So legislation made it possible without a willing partner, but it's always better to have a willing partner. So they prioritized a lot of the places where the community was, was more interested in partnering...” (16).

“...would see that there's the affordable housing sustainable communities program that the state offers that basically requires affordable housing developers if you want to get enough points right to team up with the transit agency and the jurisdiction, um, in order to compete well so we have done that. Six times. We have applied six times. Yeah, we have been successful one time.” (09)

“...us as the transit agency have the most potential to develop TOD. I can give you some history on that, but essentially lots of like things with the city have just never led to full, full fruition.”

“...they want to have the control to negotiate with some of these developers. And a lot of these developers come in trying to look for a deal, trying to look for a way to cut corners. And the first corner they cut is always transit” (11).

“So they built, you know, the BRT [Bus Rapid Transit] line in []. And the first development that went in next to one of the stations was an automated car wash. ... And so the kind of disconnect that happens with that in terms of, hey, we put in this transit line and the first thing you do is you put in a car wash.” (10).

“...depending on the group that's proposing the development, we could be wheeled in to help with conditions or the project just happens and then we deal with the ramifications of not putting conditions in.” (11).

“...then they went ahead and just put in sidewalks on one side of the street, right? Not on the second. So it makes it very hard to serve it because you can only serve it going one direction, right?” (09).

In the above case the city put in a new pharmacy but did not include any transit improvements. So, transit users were forced to line up outside and inside the store; eventually the transit agency acquired funding to put in a bus stop.

Or it can be the scale of the project, with one rural agency telling us, “We're a really small agency, um, so we're trying to navigate how to even begin.” (15).

Developers are another important actor, whose interests are more aligned with financial outcomes; developers are in the private sector and consider things like risk, money, and community receptiveness, along with other local requirements:

“I'll jump straight to it: money, right?” (06).

“You know, it's almost like we don't have nothing cohesive. Certain areas of town were cohesive, like there's cutouts and there's bus stops, but overall, it's just a patchwork of like things that we've had to go behind a development and put in instead of being purpose driven for transit” (11).

“So mostly the concerns right now are interest rates, construction costs, and the fact that there's not really a lot of projects that are feasible on the market conditions.” (12).

“But it's like pulling teeth to try and convince a developer to develop a project that has fewer than at least like 1.25 parking spaces per, you know, per unit, even though there's no requirement for it.”

“So just by sheer fact of it being a rural area and not having those urban services does limit development, even when you have a station, you're like, oh, you could kind of do something here, like a little rural village core. Not having a sanitary district or not fully having water supply is limiting because then you have to come up with private systems.” (14).

Though the challenges discussed in the interviews don't necessarily have implications for the structure of the calculator, the coordination of transit planning and land use planning is important in the ability to implement TOD. This coordination should also include developers. Similarly, community support is necessary for TOD implementation.

Theme 3: TOD Planning in Practice

Many of the interviews covered topics related to how TOD planning plays out in practice. These ranged from positive outcomes to elaboration on some of the challenges noted in Theme 2.

“So, all of these laws are taking a perspective that they want to concentrate housing near transit. ...It is helping I think developers to like see all these things... they can layer all the benefits from the different laws and make it pencil more, especially in [] where the land cost is so high”.

This was also pointed out by a smaller city within a large metropolitan area. Others have embraced the ideas of the state laws and done away with parking minimums for housing on their own, and implemented some of the recent regulations that were passed, before they were passed, by incorporating them into their most recent general plan.

“A lot of the state housing laws have sort of helped us work on enhancing housing and densifying housing. And we try to be strategic about where that's at so that it's closer to those transit routes.”

There were also discussions around state policies, both with favorable views and unfavorable views. One transit agency talked about, “whatever law comes out of Sacramento is not necessarily going to change that. Like, okay, you can force cities to put in TOD, but I think even then if...” they went on to talk about project management and ensuring partnership with the transit agency to make sure there are ridership gains that result from the TOD projects. They also pointed out that “I think it's some of those things where it's the political aspect. that I think just can't necessarily be regulated, that is one of those challenges in TOD. At least that's my sense for our area and kind of maybe our specific example where we could put TOD.” (09)

A number of interviewees also covered relevant policies including California Environmental Quality Act (CEQA) and other land use policies that intersect with CEQA review or discretionary approval. One municipality noted, when discussing some of the recent changes to CEQA and zoning including Senate Bill (SB) 79, that

“The state is really taking away a lot of our local discretionary review processes. So that will help, I think, once people do decide to actually develop.”

Another interviewee spoke about how CEQA is great because it has forecasting requirements and evaluates environmental impacts, but the models are somewhat conservative, and this means outcomes might not be what planners are hoping for. The long-term vision is that people are going to use other modes of transportation as opposed to just driving. However, under CEQA, they are still required to project a conservative estimation of what if things don't go well. In some cases this leads to high parking and vehicle travel estimates that are not desirable and may lead to challenging a project.

The extent to which TOD is seen as an available opportunity varied:

“Almost everywhere can be considered TOD,” (07).

“...we don’t really have TOD...” (10).

“...the most comprehensive planning that we’ve done along transit corridors was to create the Mixed-Use Overlay Zone.” (06)

“...in downtown, like around my office in this whole area, we have a zoning district called the Transit zoning code that is meant to allow a lot of sort of densification and sort of road diets and sort of enhancements for mobility around the train station, which serves [] and [], the commuter rail.” (06)

“And so we are in this weird subset where we don't have a carve out for being rural and we're not one of the big cities where we don't have a carve out for being rural and we're not one of the big five cities.” (09).

“what I might think of as some TOD, but they are primarily city led than us led. And then there's a little bit of TOD in []. Again, we don't own the transit center there. We provide a lot of bus service there.” (02).

“...[SB 79] covers the ¼ mile radius around the transit station but it covers single family properties, and we want to preserve some of those single-family neighborhoods, so we are trying to move some of the density that is allowed on those single family parcels to our mixed use areas. We’ll see if this can make a big difference and encourage and incentivize development in the mixed-use area, especially around transit.”

“You need to get familiar with SB 79 because it is probably the most significant piece of legislation in the last, I don't know, decade or more, in my opinion. And this basically allows transit agencies to basically have their own zoning and do their own TOD projects without pretty much talking too much with the cities, although we typically try to work in coordination with cities and be partners. But really SB 79 liberates the work, perhaps.” (12).

One large city noted they have approximately 50 locations that could be considered transit hubs and they are interested in building TOD in all of them. When a station is identified for development, the city works through a master planning process and if there is interest from the property owner they are usually brought to the table to help ensure that the planning effort is realistic and meets the needs of those who actually own the land.

Turning to land ownership, another city noted that they are fortunate because the transit agency actually owns a lot of the land around their stations (05). This is not typical though, but it does allow the city to work closely with the agency to plan sites near the TOD areas

and apply the same principles to the rest of the station area. A transit agency in a large metropolitan area emphasized that,

“...when the transit operator owns land around their stations, they are able to plan development, and seek input from the city on the general plan and zoning relevant to the project location.” (10)

In some cases, the local government works closely with the transit operators to ensure coordination.

“we're conscious of that when developments happen along routes. We make sure the bus stops are enhanced.” And, because they don't have their own transit operation, they noted, “we coordinate with them with their needs, and we also express concerns from our constituents to them. So we take that all into consideration as we look at developments when they come in.”

“... that development includes extending that existing line as a spur into the development itself again to both include a stop that's closer to the future housing but also to allow that line to work more efficiently by providing turnarounds...” (07).

However, in some cases, even when the final plan is integrated, the timing of each stage matters, for example if improvements like ticket kiosks are not required until the final phase even though residents might be already living in the first phase of a project, potentially causing a lag in transit uptake;

“I guess the lessons from there are one, it needs to be part of the initial development, right? Because it needs to be you move there and you get used to this. It can't be the last thing.” (09).

One interviewee from a large metropolitan area noted that an approved development that would add approximately 5,000 additional units and therefore (as in other examples in this city) would also expand the light-rail transit infrastructure. In this same interview we heard a lot about how future expansions, updates, and other improvements to transit (such as dedicated right-of-way) were also considered when approving developments and similarly when a large-scale rezoning of much of the city was approved. Even though the projections about ridership change and service needs were great, the planning horizon for transit and land development occur in tandem and don't necessitate (nor would it make sense to implement) piecemeal improvements to the transit networks or services for each particular development or rezone that the city considers. (07).

In a mid-sized city within a large metropolitan area they described discussion in the community about how one station will likely revitalize the area surrounding the station, and the potential to provide an opportunity to “place-make” (02).

In a smaller rural city with a medium university, they noted that they think about “development-oriented transit”, as a means to describe the pattern of aligning transit routes to the university and other areas where they know there will be ridership. They went on to talk about how they came to understand the importance of transportation in planning for land use,

“they convinced me that, you know, the tie between circulation and mobility and all of these other, you know, principles, kind of like a TOD mindset, were intertwined in such a way that they were inextricable. And so, you know, after several conversations, I, you know, reluctantly at first, but then, you know, ultimately embraced the ideas.” (01).

Finally, in one interview, tradeoffs between different types of development were discussed:

“if we reach this metric of housing, you know, this is where transit would increase. So maybe we keep it here and we add a grocery store and a library. Or if we just double the housing, then, you know, we can't even maintain the transit needs. So then does that behoove us to even explore going full into the housing portion and kind of balancing the retail and access and community parts?” (15)

Building on theme 2, there is some variation in how planning is carried out, but it is linked to whether the transit operator owns the land that can be developed, and the coordination of transit and land use planning, including the timing of transit improvements and the different phases of construction. Land ownership has important implications for how easy it is to see TOD move forward, what it might look like and this has implications for ridership even if it upstream from the calculator perspective.

Theme 4: Ridership Estimation and Data Analysis

Though there was limited estimation of ridership outcomes related specifically to TOD, a few ridership estimation methods were mentioned.

“I do projections. And maybe I use some land use patterns and trends of development around the stations to understand that. But that is not really— the focus is not TOD.” (13).

A few participants discussed the use of various demand models, and alignment with the CEQA process. One interviewee noted that using the CEQA process can help, but the models may not make realistic predictions if they are “off-the-shelf”. They also discussed the regional travel demand model, from which their transit agency uses part of it for their service area, and the city also uses their area themselves. They have added refinements to include more detail relevant to these different scales. They described it as a digital twin of the city and explained how it is used for travel demand forecasting.

One participant from a large city also noted that capacity impacts might be centered on one peak hour or one corridor and pinpointing that can help address any concerns about

crowding. And that travel demand models are the main tool used to evaluate impacts, and that the environmental planners are largely undertaking this effort, but it is integrated with other project level requirements including travel demand management (TDM). TOD is viewed as an effective means to reduce the mode share of single occupant vehicles.

“Just using the modeling system that we use, which is actually from []. Yes. Which uses, you know, an approximation of what transit services are nearby, what type of development it is, and housing and other services that they already modeled based on land use data that's available. So I presume that would go down there. But there's other things in the county, funny enough, that just related to VMT, not necessarily to TOD, that have had developments go through that have lowered VMT.” (14)

“And then we do everything in-house and we use a system called [] at the county level to input all of our data so then the county and Caltrans and [] can look at trends. Most of the rural operators, so our closest neighbors like [] in that community, and then even our [] partners that are right across the river from us, they all do the same type of type of estimation, but they have different ways that they handle transit developments” (11).

Some had rules of thumb for determining how many transit trips would result from a project:

“And then when it comes to development, we base it on the number of employees or potential customers that they wish to development comes in with. So when they make their first preliminary presentation to the city or to the county, they say this development will have, let's just say, 50 employees or 100 employees. So based on the type of business, right, whether it's industry, retail, whatever the business is. Typically retail, more public facing ones, we do about a third, those 33% of that. So we know about 33 more people will be using that stop on a weekly basis. So that's how we estimate the ridership when it comes to developments” (11).

“What I would probably do now is...I would say, hey, okay, this is my radius. This is within my quarter mile. My population is currently whatever, 2000, right? People within there. And because of this TOD development, I'm going to get up to 2,000... ...So say it's 2% right of that. ...I would probably add some type of premium, you know, if it's super close to transit and it's a well-served area.” (09).

Several participants do not do any specific estimations for TOD, though they estimate ridership impacts for other service changes, etc.

“we haven't really done anything that's like, hey, if you put TOD in here, what would be the implications on ridership?”

For others, observing the outcomes of constructed TOD is relevant;

“now that it's been built, you know, we see really high demand for those residences and for those shops. So, you know, we can measure success that way. Ridership.” (08)

“... the affordable housing project that we gave transit passes to. You know, certainly the concentrating students in, you know, the dorms off campus created an opportunity for increased ridership, and we did see that.”

The limited estimation of ridership resulting from TOD, and the ad hoc methods described by some interviewees suggest that the calculator would fill a need among transit agencies and local government planners alike.

Theme 5: Considerations for a TOD Calculator

We asked about what would be useful in a calculator, and what underlying or contextual factors are important in determining the success of TOD. For example, what existing surrounding land uses, demographics, and other factors are expected to impact how much the TOD changes ridership. Our interviewees were generally enthusiastic about the idea of the calculator and had ideas about what to include – in most cases that aligned well with what we found in our review of the literature.

“I was talking with our director and he was like, yeah, if there was some kind of calculator for TOD, you know, I'm sure there's lots of factors and things to consider. But having something that's not too, too crazy to like try and, you know, you need all these.... factors, variables, kind of what to put in to get it. But if kind of, hey, this many units, this many people, I'm sure you'd need some like travel demand. ... calculators or whatever, but I think having something like that would be helpful. I think it's also just we're not a huge agency. So we're not.... I don't think we'd have the capacity to do massive kinds of like projections and what would be the implications. Like that tends to fall more with like [] or a little bit maybe with the county transportation authority.”

One interviewee noted how it would be helpful to know what land uses are the most symbiotic with transit. Would retail, housing, office space, restaurants, etc. generate the most ridership and vice versa. Similarly, others pointed out that considering who is moving in is important;

“if there were more, there was more information to, to say, look, yes, this type of build and this type of, um, you know, mix, um, currently, or, you know, would result in, these types of inhabitants, meaning, right, like I said, they're more prone to be mass transit users...” (06).

“something that would that would kind of like measure for the amount of square footage and type of business, tell us kind of how much we could potentially get from that development. A tool like that would work for us, you know, in a rural community. I know other places are more involved, but here, you know, we don't see a lot of development. But at the same time, having a tool that's like an industry standard would really help us” (11).

“... then maybe some assumptions where, hey, it's not saying universally if you add 200 people, this is how many people would ride, but you'd want to make some assumption about, okay, well, it's households that are this size, that are of this income or that have this number of vehicles, and then you could add a premium to that, I guess, be the first thought.” (09).

“I'm definitely looking into like mixed, different, maybe market rate, low income, and even some affordable. So we weren't looking for just one mode of housing just because of statistics show that, you know, having different socioeconomic income groups in a community, all the groups thrive in a preferable light. So that's what we're looking for.” (15).

“we think that a lot of these development projects are underparked until we start to actually see the folks that are moving in that are now, you know, younger, professional, you know, they don't have, you know, six people in their family needing three cars. It's, you know, two folks moving in and they have maybe one car or sometimes zero cars.” (06).

“Is it all just housing very general, you know, in order to get state density bonuses and other concessions, there will usually be some percentage that is considered affordable, like 10%, 15%, but this is generally market rate housing. Now, that said, this is still denser, higher unit multifamily market rate housing, which when you have a lot of that going up has, you know, an overall downward effect on prices, especially in areas that were built out to be more single-family suburban.” (08).

Existing and/or surrounding land uses, including planned development:

“Incorporating other agencies, local developments, you know, their land use plans so that you're not necessarily coordinating just within your own agency. You're seeing sort of the whole regional picture. And so maybe I could see that being helpful to guide decision making, make sure that we're not just making a decision for [] but for the whole region” (03).

“The park-and-ride lot that you're replacing, which was filled with people that were just using transit, was more valuable to transit than the heavily overparked condos that you put in. That was not necessarily for people that cared about transit. It was just kind of an extra convenience. Whereas if you deliver some of the places that these policies were clearly calling for, which is very low parking, mixed-use spaces.

You know, it, it was, it was clearly more beneficial from a ridership perspective to have the families adjacent to transit, fully oriented around transit, than the couple of car spaces that you replaced with that unit”. (16).

“I think then it being more accessible and, and more like lively, safe space, then we would bring the people from the neighborhood. There's a huge neighborhood that lives in that surrounding area that maybe then now the transit system would be more accessible for them and it would be something that they would use.” (15).

“that station, uh, there is businesses there that could be revitalized. Some storefronts have been closed for many years, but the thing there is they—there isn't really a critical density of people in general because just outside of that core, which is only a few blocks, are actually agricultural lands that are being, you know, properly cultivated.”

One small rural city (01) mentioned how their population dynamics shift over time due to the university students leaving town in the summer. While another trend that was identified in the interviews was the affect of the TOD on planning and development in the area,

“So we kind of have to look long-term for that. It's only been up for like 4 or 5 years. ...we're working on, um, kind of connecting it better, um, so that there's more continuity between downtown and between the station area TOD.” (08).

One interview provided more general recommendations about how to structure the calculator and what factors should be included;

“...very careful about this because when you're trying to do a correlation between ridership and TOD, it's not necessarily a direct correlation. The proximity to the station does not create a causality for ridership, if you are following me. You cannot make a strong case. I mean, you're gonna have to do a very sophisticated algorithm or an equation.” (13).

“You have to model the ridership within half mile of the stations. Not a quarter mile, probably half mile. Why is that? Because the principle of TOD is that the ridership that you can effectively capture for a transit station is within half mile. That doesn't mean that somebody doesn't drive from...” (13).

These comments confirm the importance of the land use mix, when planners and transit operators are thinking about the impacts of TOD.

Other Considerations

Funding was also an issue brought up by several interviewees. One city mentioned some programs they might like to support including transit subsidies and bikeshare but they do not have the funding sources for these programs. Another key concern mentioned by interviewees, surrounding transit in California and other parts of the U.S. is the need for

operations funding. One interviewee noted that ridership in their area was still depressed due to the pandemic and lasting changes in where people live and work and how people are getting around. This creates challenges with TOD planning as it might mean that existing capacity is not sufficient and cannot be expanded, or that existing service is not as strong as it could be. Another discussed the challenge of meeting the Innovative Clean Transit transition to zero-emission buses:

“And now we're taking on zero emissions, we're taking on all these big things. And what about, it has to be at the expense of the rider because there's no other, it's not like we have another pot of money or another place to dip from. It has to be from operations and we can't do that.” (11).

One interviewee brought up the importance of bandwidth or capacity and how learning about TOD has been important in “knowing what questions to ask”. We later spoke about how Cal-ITP has provided support around GTFS and open-loop payments in ways that it would also be helpful to have support in the context of TOD, such as a “TOD liaison” housed within Caltrans, but as a point of contact for agencies developing TOD plans and projects, someone who could help provide information, connect agencies to relevant sources of information, and to other agencies whose experiences and projects might be most relevant to, for example, this particular interviewee (15). This relates to recent work highlighting capacity development needs, even in the context of open-loop payments (Pike et al. forthcoming). They noted that

“But when it's something like Cal-ITP and they have built form relationships all around California, it's helpful because sometimes they'll tap in somebody and they'll make those relationships and they'll help you like meet somebody's acquaintance.” (15).

Another interview mentioned was how transit-oriented policies and transit funding bounce off each other. Agencies use funding as an incentive to encourage cities to adopt land-use policies that support transit, because transit investments tend to perform better in places that are already planning for density and growth around stations (14).

This relates to the comments above and planned development; when to include it and when not to... same for the fluctuations in ridership due to seasonality of things like schools and universities being in session. This can affect ridership, though it is likely already accounted for in the areas, and along the routes where it is most important.

Taken together, the interviews provide valuable insights into how TOD is envisioned, carried out or delayed and the importance of coordination among transit providers, city planners, and developers. We also found a fairly limited use of any methods to estimate ridership changes resulting from TOD, though many interviewees were eager to share recommendations about what factors are important to include in the calculator.

Calculator Blueprint

In this section we present an overview of our design recommendations for the calculator. Because ridership is so highly dependent on the demographics of residents, we propose that the calculator be a semi-aggregate model, modeling behavior of residents within TODs and other land use development around transit. Residents of affordable units travel very differently than market rate units, for example, and parking provision also plays a strong role. By modeling the behavior of individual classes of residents, such as residents of market-rate units with low parking provision, we can more accurately capture the likely variations in ridership resulting from demographic differences among residents of different development types. Forecasting of ridership associated with commercial uses will be somewhat more aggregate, based on commercial floor area differentiated by the type of commercial use (e.g. office, retail, food service).

Calculator inputs

Procedurally, the calculator will require some inputs from the user, but will also employ lookup tables and default values, wherever possible, and algorithms incorporating the relevant factors. To allow accounting for other planned developments or transit service changes, the user will have the option to override most values from the lookup tables. The variables we recommend for inclusion in the calculator are summarized in Table 3 through Table 7. These variables were chosen based on the literature review and the interviews. Reasons for choosing each are described in the preceding portions of this report. The next sections describe how we expect these to be input into the calculator formulae to produce ridership change estimates.

Project characteristics

Table 3. Project Characteristics Calculator Inputs.

Input	Description	Source
Project location	Street address or latitude/longitude of project, used for looking up other relevant variables.	User
Residential units	Number of residential units in the project, summarized by affordability and size of unit	User
Commercial space	Square footage of commercial space, by use (retail/office/foodservice/drive-through/etc.)	User
Parking	Number of parking spaces proposed	User
Park-and-ride	Number of park-and-ride spaces proposed	User

The primary inputs from the user of the calculator will be information about the project itself. The most important of these is the location, as most of the lookup tables are keyed on the project location. We recommend the location be a specific address or latitude/longitude for the most accurate results. In Phase 2 we will consider opportunities for the use of the parcel or polygon as the location, but this will require more steps in the estimation process.

The next attribute of the project the user will need to specify is the number of residential units, along with some description of the units. Specifically, the calculator will need to know the unit mix—studio, one bedroom, two bedroom, etc. This will be used to determine the likely household size and composition of future tenants or owners. It will also need to know which if any units will be designated affordable, and ideally at what level of affordability. Income is a very strong predictor of transit usage, so knowing if any units are designated affordable will help understand the likely transit usage of the residents.

Not all development projects, nor TODs are only or even primarily residential, and retail and office space can generate significant transit demand. The next attribute the user will specify is the amount of commercial space, ideally subdivided into restaurant, retail, and office, as these generate different levels of travel. The square footage of these spaces will also help predict the numbers of employees, customers, and other users of these non-residential uses.

The final project attribute the user will need to specify about the project will be parking characteristics—the number of spaces, and how many (if any) are designated park-and-ride. Park-and-ride spaces have a strong positive effect on ridership, while other spaces suppress ridership, so this information is crucial to a valid calculation. There are several additional inputs the user needs to specify, described in the following sections.

Location characteristics

Most location characteristics will be derived from other datasets based on the location, and do not require user input, with the exception of pedestrian and bicycle infrastructure variables. The location characteristics inputs are listed in Table 4. All location characteristics can be overridden by the user if significant changes to those characteristics are forecast due to other planned development, or the user is able to provide more detailed information.

Population and employment density are important attributes that the literature has found highly predictive of ridership. They will be derived from data from the U.S. Census, and looked up by location. One open question for Phase 2 is the appropriate geography—should population density in the Census block group, tract, blocks within a buffer, etc., around the project be used? As a general rule, we recommend using the finest geographic resolution that provides a reasonable balance with levels of error, and aggregating multiple units around a project when necessary, to avoid edge effects from being close to the edge of a large geographic unit.

Intersection density is a representation of pedestrian connectivity. We propose deriving it from OpenStreetMap data which provides some level of statewide consistency (though mapping practices may vary). Because intersection density figures derived directly from transportation network data can be misleading due to dual carriageways, separately-mapped sidewalks, and so on, we will use the technique of Boeing (2025). This data can be precomputed statewide and looked up for any project very quickly. Like density, the appropriate geography remains to be seen.

Land use mix around the project or TOD is critical for modeling local trip capture and thus the likelihood of a transit-first lifestyle. Unfortunately, we are not aware of a standardized statewide land use database, so this may need to be sourced from individual municipalities or a commercial provider. There are a number of ways to include land use mix in ridership models (e.g. percentages, entropy); we will test several when developing the calculator.

Interviewees identified the pedestrian and cycling environment around the project or TOD as being critical to success. In part, the quality of the environment for active travel is determined by vehicle speeds, which can be sourced through a lookup to one of several commercial speed data providers. Other important variables are presence of sidewalks, lighting, and high-quality cycling facilities around the project and along the path to the nearby transit stops. As we are not aware of any statewide database of bicycle and pedestrian infrastructure or lighting, we expect these will need to be provided by the user (possibly with a reasonable default value or simple algorithm when they are not available). We encourage and eagerly await the development of reliable large-scale data sources on the pedestrian and active travel environment that could increase the fidelity of the calculator in a future revision.

Table 4. Location Characteristics Calculator Inputs. (all can be overridden to account for other planned projects)

Input	Description	Source
Population or residential density	Population or residential density around the project; exact area of influence (e.g. Census block group or tract) to be determined through sensitivity testing in Phase 2	U.S. Decennial Census or American Community Survey
Employment density	Density of jobs, by sector of employment	U.S. Census Bureau LEHD LODES
Intersection density	Density of intersections, representing pedestrian connectivity	TBD, possibly OpenStreetMap with corrections defined in Boeing (2025)
Land use mix	Presence of different types of land use; e.g. residential, retail, office, educational, recreational	TBD, possibly local parcel data or purchased data
Pedestrian environment	Lighting, presence of sidewalks in area around project or TOD, and on path between project or TOD and nearby transit, possible walkability score or similar	User (or walkability score database)
Cycling environment	Presence of LTS 1 or 2 bike facilities near project and on path between project and nearby transit	User
Traffic speeds	Vehicular speeds around project and on path between project or TOD and nearby transit	TBD, possibly purchased big data or use Caltrans supported license for Replica data

Transit service characteristics

Most transit service characteristics, listed in Table 5, will be derived from GTFS data, sourced from Cal-ITP. Specifically, we will extract frequency and span of service for nearby routes, distance to nearby stops, and transit modes from GTFS data. Frequency and distance to transit using the pedestrian network will be extracted for each nearby route. We will test several possible ways to combine frequency and distance information across routes (for instance, medians or sums). We will also explore the use of existing state metrics related to high quality transit (i.e., in SB 79, AB 2097, and others) as a way to represent the quality of transit service. Transit mode has been shown to be related to

ridership, but it may also be proxying for other built environment characteristics, and we seek feedback from Caltrans on whether it is desirable to include transit mode as a variable. One possible downside of including it is potentially favoring areas with established rail systems over those without.

Reliability is extremely important to riders, but difficult to quantify and even more difficult to forecast. Thus, rather than directly incorporating reliability the calculator will incorporate features that tend to make transit more reliable—namely exclusive right of way and signal priority. Phase 2 will test whether it is best to include these only when they exist near the project, or also when they are further afield but on routes that serve the TOD or other project. We are not aware of any datasets containing statewide information on transit priority, so this will likely need to be input by the user. However, this should not be a large burden as these interventions are not extremely numerous, and can be left off entirely in cases where they do not exist. Related to reliability is the availability of real time information; this has been linked to some ridership improvements and the availability of real time information may be included in the calculator.

Table 5. Transit Service Characteristics Calculator Inputs. (can be overridden to account for other planned projects)

Input	Description	Source
Frequency	How often vehicles arrive on nearby routes. Several forms will be tested, with different definitions of nearby and different ways to aggregate across routes (e.g. sum, median)	GTFS curated by Cal-ITP
Distance to transit	Distance to nearest transit stop using the pedestrian network. If frequencies are very different at nearby stops, may also include distance to nearest high-frequency stop.	GTFS curated by Cal-ITP, OpenStreetMap or local pedestrian network data
Mode	Light rail, heavy rail, commuter rail, bus, BRT, etc. May or may not be included, see discussion in literature review.	GTFS curated by Cal-ITP
Transit priority infrastructure	Presence of bus lanes, dedicated right-of-way transit, or transit signal priority near the project. Definition of “near” to be calibrated in Phase 2, may be distance based or based on which routes serve the proposed project.	User <i>(optional)</i>

Access metrics

Access metrics (e.g. number of jobs accessible by transit in 45 minutes) are highly predictive of transit system usefulness. As shown in Table 6, we propose to measure access to jobs, population, and points of interest by transit and auto from the project or TOD location. Job access is a nearly ubiquitous measure at this point. The reason for measuring access to population (e.g. the number of people within a 45-minute transit ride) is because commercial uses in TODs or otherwise, need a large number of people in reasonable travel distance to patronize these establishments. The reason to measure access to POIs is because successful TODs support transit use for trips beyond the commute. By including both auto and transit access, we are indirectly measuring the ratio of auto and transit travel time, which our literature review found to be important in addition to absolute transit travel time.

Transit metrics will be precomputed for the state using GTFS from Cal-ITP and OpenStreetMap data and software such as r5r (Pereira et al. 2021). Auto access is more difficult to calculate, because it requires congestion information. Furthermore, auto access is less likely to be affected by a single project, so we propose to use the precalculated auto access to jobs values provided by Access Across America (Owen and Murphy 2020). This only provides information on access to jobs; whether and how to source access to population and points of interest for autos remains an open question for Phase 2.

Unlike the other characteristics, the user will not be able to directly override access metrics but will be able to override their input data to recompute the metrics with proposed transit service, land use, or street network improvements.

Table 6. Access Calculator Inputs. (input data can be overridden to account for other projects)

Input	Description	Source
Access to jobs via transit	Number of jobs within a travel time threshold, peak and off-peak; threshold to be calibrated in Phase 2	GTFS curated by Cal-ITP, OpenStreetMap street networks, LEHD LODES job locations
Access to population via transit	Number of people within a travel time threshold, peak and off-peak; threshold to be calibrated in Phase 2	GTFS curated by Cal-ITP, OpenStreetMap street networks, Decennial Census or American Community Survey

Input	Description	Source
Access to points of interest via transit	Number of points of interest within a travel time threshold, peak and off-peak; threshold to be calibrated in Phase 2	GTFS curated by Cal-ITP, OpenStreetMap street networks, POIs purchased or from OpenStreetMap
Access to jobs via auto	Number of jobs within a travel time threshold, peak and off-peak; threshold to be calibrated in Phase 2	Access Across America
Access to population via auto	Number of people within a travel time threshold, peak and off-peak; threshold to be calibrated in Phase 2	TBD; may not be available
Access to points of interest via auto	Number of points of interest within a travel time threshold, peak and off-peak; threshold to be calibrated in Phase 2	TBD; may not be available

Existing land use

While some development projects and TODs may be in greenfields or on unused land, most often they will be replacing some other development on the site. To avoid overstating impacts, it is important to account for net rather than gross ridership. We propose including existing land uses and ridership information, listed in Table 7, as a baseline from which ridership changes will be estimated.

Table 7. Existing Land Use Inputs (for net ridership calculation).

Input	Description	Source
Existing land use	Current use of land being redeveloped	User
Existing ridership	Existing agency ridership, ideally at stop level but could be at route or agency level	Transit agencies or National Transit Database
Park and ride occupancy	Daily peak occupancy of existing park and ride spaces	Transit agencies

One land use that requires special consideration is park-and-ride. Park-and-ride land uses tend to be associated with a large number of station boardings based on our literature review, even though they are essentially an auto-oriented land use. Some projects and TODs address this by replacing unstructured with structured parking, but this is costly and care must be taken to avoid making the station environment unpleasant for pedestrians. For situations where park-and-ride occupancy studies are available, we recommend using

these to estimate the number of trips generated by park-and-ride, with an assumed ridership of slightly more than two trips per day per occupied space (one round trip for a single driver, plus additional trips for HOVs and for spaces that turn over more than once a day). For certain park-and-rides, for instance those often used as satellite parking for sporting events, the average trip generation per space may be higher. Ideally, a survey of park-and-ride vehicle occupancy would be conducted to calibrate this figure.

It is common for TOD projects to provide some park-and-ride spaces; if the proposed project does so, the estimated positive ridership impact of these spaces will be included in the final projection. If an existing park-and-ride is underutilized, it may be possible to provide enough spaces to meet current demand within the TOD project—though it should also be noted that a small amount of excess capacity is necessary to avoid deterring drivers concerned they may not find a space.

The other way ridership estimates could fail to account for ridership declines caused by the project is through self-selection. If the people moving into new projects or TODs were already using transit in their previous residential locations, ridership generated by the development is not new but relocated. We do not recommend accounting for this in the calculator, for several reasons. First, pragmatically, it is very difficult to quantify how many of the new residents were previous transit users, and if they were how much they might increase their transit use in the new project or TOD. Second, research suggests that movers to TODs do tend to increase their transit usage—so while self-selection is a concern, it generally would not completely undermine ridership benefits. Third, the calculator will likely be used to compare projects to one another, and self-selection will likely be present in all projects under consideration, so any bias is likely to be somewhat uniform (though there could still be different amounts of self-selection in different parts of the state). Lastly, there is significantly more interest in car-free living than there are people who live car-free (Corcoran et al. 2026), suggesting that there are ample people who would like to move to a TOD and change their travel behavior.

Calculator implementation

We envision the calculator being a system of four models that predict different aspects of ridership and whose outputs are summed. We recommend a process of developing, validating, and refining the proposed models based on available data from existing TOD and other land use development projects in order to reduce the uncertainty in calculator estimates to the greatest extent possible. Therefore, the descriptions below incorporate a model estimation step to inform the coefficients that will be present in the final calculator.

Specifically, the models we anticipate are:

- Residential model: predicts the transit ridership of residents of new TODs or other projects
- Commercial model: predicts the transit ridership attracted by commercial portions of TODs and other projects
- Existing land use model: predicts ridership loss due to loss of existing land use
- Park-and-ride model: predicts ridership gain or loss due to removal or addition of park-and-ride spaces

The models are detailed in the following sections. Figure 4 shows how categories of inputs (described in detail above) feed into each model, how the outputs are post-processed, and how they combine to form a single net annual transit demand forecast.

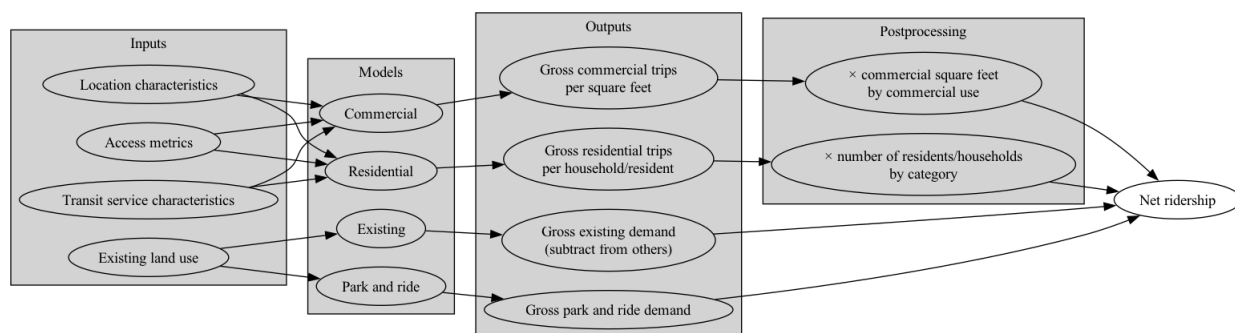


Figure 4. Conceptual model of inputs, models, and data flow

This model system falls into the category of “direct-demand” ridership models, which directly model a ridership outcome using regression or similar techniques, rather than the traditional travel demand modeling approach of simulating origins and destinations for individual trips or tours. Direct-demand models are often used for transit ridership outcomes (e.g., Cervero 2006; Mucci and Erhardt 2018; Kuby et al. 2004). They have a number of advantages over traditional travel demand models for the calculator—most notably their ability to respond to highly-local conditions and their relatively lower data needs. Traditional travel demand models are regional and often use large analysis zones, and as such are not at the right scale for assessing impacts of a single project. Furthermore, they often require extensive travel diary surveys, which have high respondent burden and are expensive to collect.

The other approach that is commonly used to estimate relationships between built environment characteristics and travel outcomes is meta-analysis, combining the findings of many papers (e.g., Ewing and Cervero 2010; Aston, Currie, Delbosc, et al. 2021) to produce an average (or range of) estimates. We have relied heavily on these meta-analyses to architect the calculator, and may use them to inform coefficient values we are unable to estimate (see below). Meta-analysis is not our primary methodological tool, however, because meta-analysis in built environment research generally estimates uncontrolled

relationships, rather than relationships with specific controls (or, more accurately, many studies the meta-analyses are based on do have controls, but they are not consistent between analyses). By estimating a model from scratch we can choose what to control for.

Residential and commercial models

The residential model predicts ridership for residents of TODs and other projects, based on estimated demographics and the variety of neighborhood and transit service variables described above. The commercial model will predict annual transit trips attracted per square foot of commercial space, based on a similar set of variables. The residential model will predict annual trips produced per household or per resident, pending the design of the survey; the unit of analysis of the models will match that of the survey. These will be scaled to produce gross annual trips per development.

As the core models, we plan to include all of the variables listed in the tables above in these models. We anticipate these will be logarithmic linear models. This model form has several advantages. First and foremost, it is simple and understandable; relationships are expressed as elasticities (percent change in ridership associated with a percent change in another variable) or semi-elasticities (percent change in ridership associated with a one-unit change in another variable). This helps with validation, as it is easy to see whether the estimated relationships have reasonable signs and magnitudes. It also makes model output predictable; if a developer finds that their development is forecast to have unsatisfactory transit ridership, it is clear to see what aspects of the development they could change to improve the ridership outlook.

Given the relatively large number of variables proposed for inclusion in the calculator, it is possible that collinearity (many variables being similar to one another) will stymie estimation of this model. In this situation, it is common practice to remove variables to make estimation possible. We recommend that this *not* be done in the case of the calculator. All of the variables selected for inclusion have strong theoretical basis for affecting travel demand, and improving any one of them should have an impact on forecast outcomes. Instead, if estimation is an issue, we recommend using LASSO regression (James et al. 2013), a modification of traditional regression that avoids the estimation issues described above. We also advise not removing variables based on insignificant p-values or high variance inflation factors, as these can bias other relationships in the model (O'Brien 2007; Bhagat-Conway et al. 2022). These suggestions will be evaluated in Phase 2 of this project as part of the final calculator development.

While we strive to estimate as many of the relationships discussed above as possible, we may not be able to collect sufficient data to reliably estimate some of them. Since the relationships estimated in a logarithmic linear model are elasticities or semi-elasticities, it is possible to “assert” or assume these relationships based on values in the literature, rather than having to remove them from the calculator entirely. We will do this sparingly if at all, for several reasons. When asserting coefficients, we are not able to account for how elasticities should be affected by the other variables in the model (see discussion of

omitted variable bias at the start of the literature review section). Furthermore, elasticities will need to be carefully sourced as differences in unit of analysis, geographic location, or vintage may lead to substantially different elasticities. That said, asserting elasticities is preferable to not being able to include these variables at all. Using a logarithmic linear model is a more defensible model form for coefficient assertion than the discrete-choice models often used in travel demand modeling, where coefficient assertion is nevertheless still a common practice (Bhagat-Conway 2025). Since the tool will produce ranges of outcomes accounting for uncertainty, it is important that these ranges also reflect uncertainty in asserted elasticities, for instance through asserting a range of elasticity values and calculating outcomes with a sample of values in that range.

Machine learning techniques (such as random forests or XGBoost) are increasingly gaining traction in transportation. Their main advantages are higher predictive power and better handling of nonlinearities. However, this comes at a cost: their outputs are not very interpretable, which is a critical aspect of the calculator. Instead of using a machine learning model, we plan to account for nonlinearities in a more traditional way: through nonlinear variable transformations in the context of a linear model.

To gather data for the residential model, we propose a survey of the residents of TOD projects, similar to previous studies in California (Lund et al. 2004; Cervero 1993; Barajas et al. 2020). This will allow us to directly estimate the ridership of TOD residents based on the variables identified above. We plan to resurvey some of the same TODs to extend the longitudinal nature of the dataset, but will also design the sample to get good coverage of the independent variables in the model. Survey recruitment is increasingly challenging, but we feel a combination of a short and targeted survey with a recruitment strategy including paper invitations is very likely to produce a sufficient sample size for the calculator.

For the commercial model, we propose using existing travel survey data, for instance the California add-on to the NHTS or regional household travel survey data collected by Metropolitan Planning Organizations (MPOs) throughout the state. Due to sample size limitations for transit trips in many of these datasets, we will perforce have to use fairly broad categories of commercial use.

Existing conditions model

While the calculator is explicitly designed to calculate parcel-level ridership, it is neither easy nor advisable to use exactly the same model form to represent existing ridership. It is not easy because it would require the same inputs—parking, rent, unit mix, etc.—about the existing land use, which may not be available. It is not advisable because it ignores a critical piece of information that we have about existing land use, which is that we know the total ridership at the stop, route, or agency level. Instead, for most land uses, we recommend an allocation model that allocates observed existing ridership based on land use and distance to transit. The exact model will depend on the resolution of the ridership data. For agencies that have stop- or route-level ridership, we can disaggregate ridership to

nearby parcels based on land use. The main coefficients that will need to be established will be related to distance decay (i.e., how quickly does ridership drop off as you move away from the transit line) and land use (how much ridership should be allocated to commercial, residential, etc.), and demographics (e.g., car ownership, income, and racial composition). In the common situation where only unlinked passenger trip data are available, boardings at transfer points should be reduced to account for ridership that is not originating from the local area.

For agencies that only have agency-level ridership, disaggregation will be more complicated. Most models in the literature do not model parcel-level ridership. We propose an approach that uses model forms drawn from the literature to estimate zonal ridership, and then similar distance and land-use-based methods to disaggregate further to the parcel level.

It is also important to recognize that the buildings being replaced by TOD are more likely than average to be vacant or underutilized. In these cases, it is prudent to reduce the estimate for the number of transit trips produced by the existing land use that is being replaced.

Park-and-ride model

The goal of the park-and-ride model is to estimate ridership resulting from park-and-ride spaces, whether they are being added or removed. We conceptualize park-and-ride ridership resulting from a single space as being the product of two quantities: the probability a space is occupied multiplied by the number of occupants of the vehicle (further multiplied by two for a round trip, or possibly slightly more to account for trip chaining). For park-and-rides being removed, the first variable should be known based on utilization of the existing park-and-ride. When evaluating removal, it is important though to consider non-linearities; removing 25% of spaces from a lot that is 50% full at peak will not appreciably reduce ridership, but rather will increase the probability the space is occupied. We expect that proposed park-and-rides will usually be replacing existing park-and-rides, so this variable can be drawn from the lot being replaced; in rare instances where this is not the case, other park-and-rides for the same agency can be used.

We expect that there is relatively little variation in vehicle occupancy at park-and-rides (except those used heavily for sporting events). We propose an in-person or video-based observational survey to estimate vehicle occupancy at a number of park-and-rides across the state to see how many people are usually in vehicles being parked at the park-and-ride.

Using the Calculator for policy decisions

There are several aspects of the calculator that will need to be considered when applying it to policy. First, as with any model, there will be uncertainty in the estimates. Rather than present an artificially precise number, the calculator should present this uncertainty as a key part of the output of the tool. How uncertainty is incorporated into uses of the tool,

such as project prioritization, is a key discussion that should be had at an early stage. This will also feed discussion about how to best present uncertainty in a policy-relevant way—for instance, through confidence intervals or likelihoods of ridership exceeding a particular target.

Second, models are useful for many tasks beyond prediction (Epstein 2008). The calculator should be used not only to provide forecasts for fully-designed projects, but also to understand how changing the characteristics of a project changes the forecast. This will promote understanding of the model itself and its sensitivities, but moreover will help demonstrate real-world relationships between project attributes and transit ridership.

Third, ridership numbers alone are not necessarily directly comparable across projects. A 30% transit mode share might be a resounding success in a suburban location, and a disappointing outcome in downtown San Francisco or Los Angeles. Since mode shares translate directly into ridership, simply prioritizing projects that produce the largest ridership outcomes is likely to favor projects in areas that are already transit-rich, where any new development is likely to have high transit mode share, rather than guiding development to be more transit-supportive in places where this might not happen naturally.

This report presents a blueprint plan for a land use development around transit ridership calculator. This blueprint was developed through a systematic literature review and input from interviews with practitioners. We present an overview of the models and formulae that will underly the calculator and include recommendations for additional data collection. The proposed models should also be estimated and validated wherever possible, to ensure the accuracy of coefficient values and reduce uncertainty to the greatest extent possible. Where that is not possible, calculator formulae should be based on the literature. The additional data collection, analysis, and model estimation will be conducted in Phase 2 of this project in which the calculator will be implemented.

References

- Akbari, Saidal, Ehab Diab, Amer Shalaby, and Khandker Nurul Habib. 2018. “A Study on the Mode Choices of Commuters Living Near Regional Commuter Train Stations in the Greater Toronto and Hamilton Area.” 6p. 01659985.
<https://trid.trb.org/view/1496694>.
- Alonso, William. 1964. *Location and Land Use*. Harvard University Press.
- Aston, Laura, Graham Currie, Alexa Delbosc, Md. Kamruzzaman, and David Teller. 2021. “Exploring Built Environment Impacts on Transit Use – an Updated Meta-Analysis.” *Transport Reviews* 41 (1): 73–96. <https://doi.org/10.1080/01441647.2020.1806941>.
- Aston, Laura, Graham Currie, Md. Kamruzzaman, et al. 2021. “Multi-City Exploration of Built Environment and Transit Mode Use: Comparison of Melbourne, Amsterdam and Boston.” *Journal of Transport Geography* 95. Scopus.
<https://doi.org/10.1016/j.jtrangeo.2021.103136>.
- Aston, Laura, Graham Currie, Md. Kamruzzaman, Alexa Delbosc, Nicholas Fournier, and David Teller. 2020. “Addressing Transit Mode Location Bias in Built Environment-Transit Mode Use Research.” *Journal of Transport Geography* 87 (July): 102786.
<https://doi.org/10.1016/j.jtrangeo.2020.102786>.
- Aston, Laura, Graham Currie, Md. Kamruzzaman, Alexa Delbosc, and David Teller. 2020. “Study Design Impacts on Built Environment and Transit Use Research.” *Journal of Transport Geography* 82. Scopus. <https://doi.org/10.1016/j.jtrangeo.2019.102625>.
- Atkinson-Palombo, Carol, and Michael J. Kuby. 2011. “The Geography of Advance Transit-Oriented Development in Metropolitan Phoenix, Arizona, 2000–2007.” *Journal of Transport Geography* 19 (2): 189–99.
<https://doi.org/10.1016/j.jtrangeo.2010.03.014>.
- Barajas, Jesus M., Karen Trapenberg Frick, and Robert Cervero. 2020. *Travel of TOD Residents in the San Francisco Bay Area: Examining the Impact of Affordable Housing*. <https://escholarship.org/uc/item/1r20w0tv>.
- Bealke, Logan. 2026. “From Minimums to Maximums: Evaluating the Impact of Raleigh’s Parking Reform on Residential Parking Supply.” Master’s project, University of North Carolina. <https://doi.org/https://doi.org/10.17615/8bfm-k835>.
- Bento, Antonio M., Maureen L. Cropper, Ahmed Mushfiq Mobarak, and Katja Vinha. 2005. “The Effects of Urban Spatial Structure on Travel Demand in the United States.” *Review of Economics and Statistics* 87 (3): 466–78.
- Bhagat-Conway, Matthew Wigginton. 2025. “Asserting Coefficients and Parameter Scaling.” Indicatrix, February 26. <https://indicatrix.org/post/parameter-scaling-and-assertions/>.

- Bhagat-Conway, Matthew Wigginton, Audrey Compiano, and E. Irene Ivie. 2025. "So Close, yet so Far: A New Method for Identification of High-Impact Missing Links in Pedestrian Networks." *Computers, Environment and Urban Systems* 120 (September): 102290. <https://doi.org/10.1016/j.compenvurbsys.2025.102290>.
- Bhagat-Conway, Matthew Wigginton, Laura Mirtich, Deborah Salon, Nathan Harness, Alexis Consalvo, and Shuyao Hong. 2022. "Subjective Variables in Travel Behavior Models: A Critical Review and Standardized Transport Attitude Measurement Protocol (STAMP)." *Transportation*, ahead of print, September 29. <https://doi.org/10.1007/s11116-022-10323-7>.
- Bhagat-Conway, Matthew Wigginton, and Sam Zhang. 2023. "Rush Hour-and-a-Half: Traffic Is Spreading out Post-Lockdown." *PLOS ONE* 18 (9): e0290534. <https://doi.org/10.1371/journal.pone.0290534>.
- Boeing, Geoff. 2025. "Topological Graph Simplification Solutions to the Street Intersection Miscount Problem." *Transactions in GIS* 29 (3): e70037. <https://doi.org/10.1111/tgis.70037>.
- Brown, Jeffrey, Gregory Thompson, Torscha Bhattacharya, and Michal Jaroszynski. 2014. "Understanding Transit Ridership Demand for the Multidestination, Multimodal Transit Network in Atlanta, Georgia: Lessons for Increasing Rail Transit Choice Ridership While Maintaining Transit Dependent Bus Ridership." *Urban Studies* 51 (5): 938–58. <https://doi.org/10.1177/0042098013493021>.
- Cao, Jason, Yingling Fan, Andrew Guthrie, and Yi Zhang. 2015. *Exploring Strategies for Promoting Modal Shifts to Transitways*. Digital/Other MN/RC 2015-49. Final Report. Center for Transportation Studies, University of Minnesota. 01599769. <https://hdl.handle.net/20.500.14153/mndot.3040>.
- Cao, Xinyu Jason, Patricia L. Mokhtarian, and S. L. Handy. 2009. "Examining the Impacts of Residential Self-Selection on Travel Behaviour: A Focus on Empirical Findings." *Transport Reviews* 29 (3): 359–95. Scopus. <https://doi.org/10.1080/01441640802539195>.
- Cervero, Robert. 1993. *Ridership Impacts of Transit-Focused Development in California*. UC Berkeley. <https://escholarship.org/uc/item/8sr9d86r>.
- Cervero, Robert. 2006. "Alternative Approaches to Modeling the Travel-Demand Impacts of Smart Growth." *Journal of the American Planning Association* 72 (3): 285–95. <https://doi.org/10.1080/01944360608976751>.
- Cervero, Robert. 2007. "Transit-Oriented Development's Ridership Bonus: A Product of Self-Selection and Public Policies." *Environment and Planning A: Economy and Space* 39 (9): 2068–85. <https://doi.org/10.1068/a38377>.
- Cervero, Robert, Arlie Adkins, and Cathleen Sullivan. 2010. "Are Suburban TODs Over-Parked?" *Journal of Public Transportation* 13 (2): 47–70. <https://doi.org/10.5038/2375-0901.13.2.3>.

- Cervero, Robert, and Kara Kockelman. 1997. "Travel Demand and the 3Ds: Density, Diversity, and Design." *Transportation Research Part D: Transport and Environment* 2 (3): 199–219. [https://doi.org/10.1016/s1361-9209\(97\)00009-6](https://doi.org/10.1016/s1361-9209(97)00009-6).
- Chakour, Vincent, and Naveen Eluru. 2016. "Examining the Influence of Stop Level Infrastructure and Built Environment on Bus Ridership in Montreal." *Journal of Transport Geography* 51 (February): 205–17. <https://doi.org/10.1016/j.jtrangeo.2016.01.007>.
- Chakraborty, Arnab, and Sabyasachee Mishra. 2013. "Land Use and Transit Ridership Connections: Implications for State-Level Planning Agencies." *Land Use Policy* 30 (1): 458–69. <https://doi.org/10.1016/j.landusepol.2012.04.017>.
- Chan, S., and L. Miranda-Moreno. 2013. "A Station-Level Ridership Model for the Metro Network in Montreal, Quebec." *Canadian Journal of Civil Engineering* 40 (3): 254–62. Scopus. <https://doi.org/10.1139/cjce-2011-0432>.
- Chapman, Janna, Hiroyuki Iseki, Victor Irekponor, et al. 2025. "Changes in the Determinants of Travel Demand for the Washington DC Metrorail System after COVID-19: Evidence from a Replication Study." *Case Studies on Transport Policy* 20 (June): 101394. <https://doi.org/10.1016/j.cstp.2025.101394>.
- Chatman, Daniel G. 2013. "Does TOD Need the T?" *Journal of the American Planning Association* 79 (1): 17–31. <https://doi.org/10.1080/01944363.2013.791008>.
- Chen, C., H. Gong, and R. Paaswell. 2008. "Role of the Built Environment on Mode Choice Decisions: Additional Evidence on the Impact of Density." *Transportation* 35 (3): 285–99. Scopus. <https://doi.org/10.1007/s11116-007-9153-5>.
- Committee of the Transport Access Manual. 2020. *Transport Access Manual: A Guide for Measuring Connection between People and Places*. January 1. <https://ses.library.usyd.edu.au/handle/2123/23733>.
- Concas, S., and JS DeSalvo. 2014. "The Effect of Density and Trip-Chaining on the Interaction between Urban Form and Transit Demand." *JOURNAL OF PUBLIC TRANSPORTATION* 17 (3): 16–38. WOS:000343158300002. <https://doi.org/10.5038/2375-0901.17.3.2>.
- Conway, Matthew Wigginton. 2021. "If You Zone It, Who Will Come, and How Will They Travel? The Effects of Relaxed Zoning Regulations on Travel Behavior." Doctoral dissertation, Arizona State University. <https://hdl.handle.net/2286/R.2.N.161665>.
- Conway, Matthew Wigginton, and Anson F. Stewart. 2019. "Getting Charlie off the MTA: A Multiobjective Optimization Method to Account for Cost Constraints in Public Transit Accessibility Metrics." *International Journal of Geographical Information Science* 33 (9): 1759–87. <https://doi.org/10.1080/13658816.2019.1605075>.

- Corcoran, Nicole, D. Salon, H. T. Jamme, R. Saadaoui, and J. Hitzeman. 2026. "Who Is Interested in Car-Free Living in the US? Findings from a Nationwide Survey." *Transportation Research Part A: Policy and Practice* 204 (February): 104756. <https://doi.org/10.1016/j.tra.2025.104756>.
- Cui, Mengying, and David Levinson. 2018. "Full Cost Accessibility." *Journal of Transport and Land Use* 11 (1): 661–79. <https://doi.org/10.5198/jtlu.2018.1042>.
- De Gruyter, Chris, Liang Ma, Tayebbeh Saghapour, and Jago Dodson. 2020. "How Does the Built Environment Affect Transit Use by Train, Tram and Bus?" *Journal of Transport and Land Use* 13 (1): 625–50.
- Dill, Jennifer. 2008. "Transit Use at Transit-Oriented Developments in Portland, Oregon, Area." *Transportation Research Record* 2063 (January): 159–67. <https://doi.org/10.3141/2063-19>.
- Dill, Jennifer, and Nathan McNeil. 2023. "Transit and Active Transportation Use for Non-Commute Travel Among Portland Transit-Oriented Development Residents." *Transportation Research Record: Journal of the Transportation Research Board* 2677 (1): pp 151-168. 01848435. <https://doi.org/10.1177/03611981221098391>.
- Ding, Chuan, Xinyu Cao, and Chao Liu. 2019. "How Does the Station-Area Built Environment Influence Metrorail Ridership? Using Gradient Boosting Decision Trees to Identify Non-Linear Thresholds." *Journal of Transport Geography* 77 (May): 70–78. <https://doi.org/10.1016/j.jtrangeo.2019.04.011>.
- Duncan, Michael. 2010. "To Park or To Develop: Trade-Off in Rail Transit Passenger Demand." *Journal of Planning Education and Research* 30 (2): 162–81. <https://doi.org/10.1177/0739456X10385935>.
- Durning, Matthew, and Craig Townsend. 2015. "Direct Ridership Model of Rail Rapid Transit Systems in Canada." *Transportation Research Record* 2537 (1): 96–102. <https://doi.org/10.3141/2537-11>.
- Epstein, J. M. 2008. "Why Model?" *Journal of Artificial Societies and Social ...*, January 1. <http://jasss.soc.surrey.ac.uk/11/4/12.html>.
- Ewing, Reid, and Robert Cervero. 2010. "Travel and the Built Environment: A Meta-Analysis." *Journal of the American Planning Association* 76 (3): pp 265-294. 01219924.
- Farber, Steven, Tijs Neutens, Harvey J. Miller, and Xiao Li. 2013. *The Social Interaction Potential of Metropolitan Regions: A Time-Geographic Measurement Approach Using Joint Accessibility*. 103 (3): 483–504.
- Garcia, David, Ian Carlton, Lacy Patterson, and Jacob Strawn. 2023. *Making It Pencil: The Math Behind Housing Development (2023 Update)*. Turner Center for Housing Innovation.

- Garde, Ajay, Huê-Tâm Jamme, Benjamin Toney, Deepak Bahl, and Tridib Banerjee. 2024. "Can TODs Include Affordable Housing?: The Southern California Experience." *Journal of the American Planning Association* 90 (2): 303–17. <https://doi.org/10.1080/01944363.2023.2236586>.
- Geurs, Karst T., and Bert van Wee. 2004. "Accessibility Evaluation of Land-Use and Transport Strategies: Review and Research Directions." *Journal of Transport Geography* 12 (2): 127–40. <https://doi.org/10.1016/j.jtrangeo.2003.10.005>.
- Glaeser, Edward L., Matthew E. Kahn, and Jordan Rappaport. 2008. "Why Do the Poor Live in Cities? The Role of Public Transportation." *Journal of Urban Economics* 63 (1): 1–24. <https://doi.org/10.1016/j.jue.2006.12.004>.
- Gruyter, Chris De, Tayebbeh Saghapour, Liang Ma, and Jago Dodson. 2020. "How Does the Built Environment Affect Transit Use by Train, Tram and Bus?" *Journal of Transport and Land Use* 13 (1): 625–50. <https://doi.org/10.5198/jtlu.2020.1739>.
- Guerra, Erick, and Robert Cervero. 2011. *Mass Transit & Mass: Densities Needed to Make Transit Investments Pay Off*. UCTC Policy Brief 2011-02. University of California Transportation Center.
- Guerra, Erick, Robert Cervero, and Daniel Tischler. 2012. "Half-Mile Circle: Does It Best Represent Transit Station Catchments?" *Transportation Research Record* 2276 (1): 101–9. <https://doi.org/10.3141/2276-12>.
- Gutiérrez, Javier, Osvaldo Daniel Cardozo, and Juan Carlos García-Palomares. 2011. "Transit Ridership Forecasting at Station Level: An Approach Based on Distance-Decay Weighted Regression." *Journal of Transport Geography*, Special section on Alternative Travel futures, vol. 19 (6): 1081–92. <https://doi.org/10.1016/j.jtrangeo.2011.05.004>.
- Hägerstrand, Torsten. 1970. "What about People in Regional Science?" *Papers in Regional Science* 24 (1): 6–21. <https://doi.org/10.1007/BF01936872>.
- Hansen, Walter G. 1959. "How Accessibility Shapes Land Use." *Journal of the American Institute of Planners* 25 (2): 73–76. <https://doi.org/10.1080/01944365908978307>.
- Hensher, David A., and April J. Reyes. 2000. "Trip Chaining as a Barrier to the Propensity to Use Public Transport." *Transportation* 27 (4): 341–61. <https://doi.org/10.1023/A:1005246916731>.
- Ioannidis, John P. A. 2005. "Why Most Published Research Findings Are False." *PLoS Medicine* 2 (8): e124-6. <https://doi.org/10.1371/journal.pmed.0020124>.
- James, Gareth, Daniela Witten, Trevor Hastie, and Robert Tibshirani. 2013. *An Introduction to Statistical Learning, with Applications in R*. Springer.
- Johnson, Jerry, Jeff Frkonja, Maribeth Todd, and Dennis Yee. 2018. "Additional Detail in Aggregate Integrated Land-Use Models via Simulating Developer pro Forma Thinking." *Journal of Transport and Land Use* 11 (1): 1–14. <https://doi.org/10.5198/jtlu.2018.1189>.

- Kashfi, Syeed Anta, Jonathan M. Bunker, and Tan Yigitcanlar. 2015. "Effects of Transit Quality of Service Characteristics on Daily Bus Ridership." *Transportation Research Record: Journal of the Transportation Research Board* 2535 (1): 55–64. <https://doi.org/10.3141/2535-06>.
- Kuby, Michael, Anthony Barranda, and Christopher Upchurch. 2004. "Factors Influencing Light-Rail Station Boardings in the United States." *Transportation Research Part A: Policy and Practice* 38 (3): 223–47. <https://doi.org/10.1016/j.tra.2003.10.006>.
- Lachapelle, U. 2018. "Employer Subsidized Public Transit Pass: Assessing Disparities in Access, Use, and Latent Demand." *CASE STUDIES ON TRANSPORT POLICY* 6 (3): 353–63. WOS:000441947400008. <https://doi.org/10.1016/j.cstp.2017.08.006>.
- Levinson, David M. 2013. *Access Across America*. CTS 13-20. Center for Transportation Studies, University of Minnesota. <https://hdl.handle.net/11299/199892>.
- Li, Meiqing, and Daniel A. Rodriguez. 2024. "Marked Crosswalks, Station Area Built Environments, and Transit Ridership: Associations between Changes in 877 US TOD Stations, 2010–2018." *Transportation Research Part A: Policy and Practice* 179 (January): 103926. <https://doi.org/10.1016/j.tra.2023.103926>.
- Li, Shuailin, Hongtai Yang, Gong Zhang, Ziwen Ling, Yaohua Xiong, and Yanlai Li. 2019. "What Is the Best Catchment Area of a Metro Station? A Study Based on Station Level Ridership Modeling." *2019 5th International Conference on Transportation Information and Safety (ICTIS)*, July, 1239–44. <https://doi.org/10.1109/ICTIS.2019.8883789>.
- Lund, Hollie M., Robert Cervero, and Richard W. Willson. 2004. *Travel Characteristics of Transit-Oriented Development in California*. https://www.bart.gov/sites/default/files/docs/Travel_of_TOD.pdf.
- Manduca, Robert. 2020. "The Spatial Structure of US Metropolitan Employment: New Insights from Administrative Data." *Environment and Planning B: Urban Analytics and City Science*, ahead of print, June 26. Sage UK: London, England. <https://doi.org/10.1177/2399808320934821>.
- Manville, Michael. 2013. "Parking Requirements and Housing Development." *Journal of the American Planning Association* 79 (1): 49–66. <https://doi.org/10.1080/01944363.2013.785346>.
- Merlin, Louis A., Matan Singer, and Jonathan Levine. 2021. "Influences on Transit Ridership and Transit Accessibility in US Urban Areas." *Transportation Research Part A: Policy and Practice* 150 (August): 63–73. <https://doi.org/10.1016/j.tra.2021.04.014>.
- Miles, Mike E., Laurence M. Netherton, and Adrienne Schmitz. 2015. *Real Estate Development: Principles and Process*. Urban Land Institute.
- Miller, Eric J. 2018. "Accessibility: Measurement and Application in Transportation Planning." *Transport Reviews* 38 (5): 551–55. <https://doi.org/10.1080/01441647.2018.1492778>.

- Miller, Harvey J. 1991. "Modelling Accessibility Using Space-Time Prism Concepts within Geographical Information Systems." *International Journal of Geographical Information Systems* 5 (3): 287–301. <https://doi.org/10.1080/02693799108927856>.
- Miller, Harvey J. 1999. "Measuring Space-Time Accessibility Benefits within Transportation Networks: Basic Theory and Computational Procedures." *Geographical Analysis* 31 (1): 187–212. <https://doi.org/10.1111/gean.1999.31.1.187>.
- Moudon, Anne Vernez, D. W. Sohn, Washington State Transportation Center, Washington State Department of Transportation, and Federal Highway Administration. 2005. *Transportation-Efficient Land Use Mapping Index (TELUMI) Phase 3 of Integrating Land Use and Transportation Investment Decision-Making*. Print. Final Research Report. 01011100. <http://www.wsdot.wa.gov/research/reports/fullreports/620.1.pdf>.
- Mucci, Richard A., and Gregory D. Erhardt. 2018. "Evaluating the Ability of Transit Direct Ridership Models to Forecast Medium-Term Ridership Changes: Evidence from San Francisco." *Transportation Research Record: Journal of the Transportation Research Board* 2672 (46): 21–30. <https://doi.org/10.1177/0361198118758632>.
- Nasri, A., and L. Zhang. 2019. "How Urban Form Characteristics at Both Trip Ends Influence Mode Choice: Evidence from TOD vs. Non-TOD Zones of the Washington, D.C. Metropolitan Area." *Sustainability (Switzerland)* 11 (12). Scopus. <https://doi.org/10.3390/SU11123403>.
- O'Brien, Robert M. 2007. "A Caution Regarding Rules of Thumb for Variance Inflation Factors." *Quality & Quantity* 41 (5): 673–90. <https://doi.org/10.1007/s11135-006-9018-6>.
- Owen, Andrew, and David Levinson. 2014. "Access across America: Transit 2014 Methodology." *University of Minnesota*, January 1. <https://pdfs.semanticscholar.org/82ca/8271f5eca0706222c258053a7a94f73a15cd.pdf>.
- Owen, Andrew, and David M. Levinson. 2015. "Modeling the Commute Mode Share of Transit Using Continuous Accessibility to Jobs." *Transportation Research Part A* 74 (C): 110–22. <https://doi.org/10.1016/j.tra.2015.02.002>.
- Owen, Andrew, and Brendan Murphy. 2020. *Access Across America: Auto 2018*. Nos. 20–03. University of Minnesota. <http://cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=3164>.
- Padeiro, Miguel, Ana Louro, and Nuno Marques da Costa. 2019. "Transit-Oriented Development and Gentrification: A Systematic Review." *Transport Reviews* 39 (6): 733–54. <https://doi.org/10.1080/01441647.2019.1649316>.
- Padeiro, Miguel, Ana Louro, and Nuno Marques Da Costa. 2019. "Transit-Oriented Development and Gentrification: A Systematic Review." *Transport Reviews* 39 (6): 733–54. <https://doi.org/10.1080/01441647.2019.1649316>.

- Parker, Madeleine E. G. 2024. “No Longer Seat-Less in Seattle: The Role of Coordinated Transportation and Land Use Planning in Sustaining Transit Ridership through the Pandemic Recovery Period.” *Journal of Planning Education and Research*, September 5, 0739456X241269026. <https://doi.org/10.1177/0739456X241269026>.
- Pereira, Rafael H. M., Marcus Saraiva, Daniel Herszenhut, Carlos Kaue Vieira Braga, and Matthew Wigginton Conway. 2021. “R5r: Rapid Realistic Routing on Multimodal Transport Networks with R5 in R.” *Findings*, 10. <https://doi.org/10.32866/001c.21262>.
- Pogodzinski, Joseph M., and John S. Niles. 2021. “Impact of Park-and-Ride on Public Transit Ridership.” *Transport Problems* 16 (1): 211–21. <https://doi.org/10.21307/tp-2021-018>.
- Pushkarev, Boris S., and Jeffrey M. Zupan. 1977. *Public Transportation and Land Use Policy*. Indiana University Press.
- Raine, Alden S., James Gast, Robert Cervero, et al. 2021. *Guide to Joint Development for Public Transportation Agencies*. Transportation Research Board. <https://doi.org/10.17226/26045>.
- Renne, John L., Tara Tolford, Shima Hamidi, and Reid Ewing. 2016. “The Cost and Affordability Paradox of Transit-Oriented Development: A Comparison of Housing and Transportation Costs Across Transit-Oriented Development, Hybrid and Transit-Adjacent Development Station Typologies.” *Housing Policy Debate* 26 (4–5): 819–34. <https://doi.org/10.1080/10511482.2016.1193038>.
- Rosenthal, Stuart S. 2014. “Are Private Markets and Filtering a Viable Source of Low-Income Housing? Estimates from a ‘Repeat Income’ Model.” *American Economic Review* 104 (2): 687–706. <https://doi.org/10.1257/aer.104.2.687>.
- Sajjad Abdollahpour, Seyed, Ralph Buehler, Huyen T. K. Le, Arefeh Nasri, and Steve Hankey. 2024. “Built Environment’s Nonlinear Effects on Mode Shares around BRT and Rail Stations.” *Transportation Research Part D: Transport and Environment* 129 (April): 104143. <https://doi.org/10.1016/j.trd.2024.104143>.
- Salon, Deborah. 2009. “Neighborhoods, Cars, and Commuting in New York City: A Discrete Choice Approach.” *Transportation Research Part A: Policy and Practice* 43 (2): 180–96. <https://doi.org/10.1016/j.tra.2008.10.002>.
- Salon, Deborah, Matthew Wigginton Conway, Denise Capasso da Silva, et al. 2021. “The Potential Stickiness of Pandemic-Induced Behavior Changes in the United States.” *Proceedings of the National Academy of Sciences* 118 (27): e2106499118. <https://doi.org/10.1073/pnas.2106499118>.
- Sancton, Andrew. 2008. *The Limits of Boundaries: Why City-Regions Cannot Be Self-Governing*. McGill-Queen’s University Press.

- Sandoval, Gerardo Francisco. 2018. "Planning the Barrio: Ethnic Identity and Struggles over Transit-Oriented, Development-Induced Gentrification." *Journal of Planning Education and Research*, ahead of print, January 1. <https://doi.org/10.1177/0739456X18793714>.
- Schouten, Andrew, Evelyn Blumenberg, and Brian D. Taylor. 2024. "Are Immigrants Migrating Away from Transit? Immigrant Transit Use Trends in California." *Travel Behaviour and Society* 36 (July): 100817. <https://doi.org/10.1016/j.tbs.2024.100817>.
- Shantz, Aaron, Jeff Casello, Clarence Woudsma, and Erick Guerra. 2022. "Understanding Factors Associated with Commuter Rail Ridership: A Demand Elasticity Study of the GO Transit Rail Network." *Transportation Research Record* 2676 (8): 131–43. <https://doi.org/10.1177/03611981221082573>.
- Shoup, Donald. 2011. *The High Cost of Free Parking*. American Planning Association Planners Press.
- Smart, Michael J., and Nicholas J. Klein. 2018. "Remembrance of Cars and Buses Past: How Prior Life Experiences Influence Travel." *Journal of Planning Education and Research* 38 (2): 139–51. <https://doi.org/10.1177/0739456X17695774>.
- Soest, Dennis van, Miles R. Tight, and Christopher D. F. Rogers. 2020. "Exploring the Distances People Walk to Access Public Transport." *Transport Reviews* 40 (2): 160–82. <https://doi.org/10.1080/01441647.2019.1575491>.
- Spader, Jonathan. 2025. "Has Housing Filtering Stalled? Heterogeneous Outcomes in the American Housing Survey, 1985–2021." *Housing Policy Debate* 35 (1): 3–25. <https://doi.org/10.1080/10511482.2023.2298256>.
- Spear, Bruce. 2011. *Improving Employment Data for Transportation Planning*. [http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP08-36\(98\)_FR.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP08-36(98)_FR.pdf).
- Stiphany, Kristine, and Jake Wegmann. 2020. "From Owner-Occupant to Senhorio: The Microeconomics of Rentrification in São Paulo." Paper presented at Association of Collegiate Schools of Planning.
- Thigpen, Calvin G. 2018. "Giving Parking the Time of Day: A Case Study of a Novel Parking Occupancy Measure and an Evaluation of Infill Development and Carsharing as Solutions to Parking Oversupply." *Research in Transportation Business & Management*, Special Issue title: [RE]EVALUATING HOW WE VALUE TRANSPORTATION, vol. 29 (December): 108–15. <https://doi.org/10.1016/j.rtbm.2018.03.003>.
- Thompson, Gregory, Jeffrey Brown, and Torsha Bhattacharya. 2012. "What Really Matters for Increasing Transit Ridership: Understanding the Determinants of Transit Ridership Demand in Broward County, Florida." *Urban Studies* 49 (15): 3327–45. <https://doi.org/10.1177/0042098012443864>.

- Waddell, Paul. 2013. *Draft Technical Documentation: San Francisco Bay Area UrbanSim Application*.
http://analytics.mtc.ca.gov/foswiki/pub/Main/Documents/2013_04_01_DRAFT_RELEASE_UrbanSim_Documentation.pdf.
- Walker, Jarrett. 2024. *Human Transit: How Clearer Thinking about Public Transit Can Enrich Our Communities and Our Lives*. Revised edition. Island Press.
- Wu, Hao, Jinwoo (Brian) Lee, and David Levinson. 2023. “The Node-Place Model, Accessibility, and Station Level Transit Ridership.” *Journal of Transport Geography* 113 (December): 103739. <https://doi.org/10.1016/j.jtrangeo.2023.103739>.
- Wu, Hao, David Levinson, and Andrew Owen. 2019. “Commute Mode Share and Access to Jobs across US Metropolitan Areas.” *Environment and Planning B: Urban Analytics and City Science*, November 14, 2399808319887394.
<https://doi.org/10.1177/2399808319887394>.
- Yang, Katie, and Dorina Pojani. 2017. “A Decade of Transit Oriented Development Policies in Brisbane, Australia: Development and Land-Use Impacts.” *Urban Policy and Research* 35 (3): 347–62. <https://doi.org/10.1080/08111146.2017.1294537>.
- Yang, Yong. 2025. “Public Transit Use among American Older Adults: Insights from a Nationally Representative Survey.” *Journal of Transport & Health* 41 (March): 101982. 01945277. <https://doi.org/10.1016/j.jth.2025.101982>.
- Yousefzadeh Barri, E., S. Farber, H. Jahanshahi, I. Tiznado-Aitken, and E. Beyazit. 2025. “Exploring the Joint Impacts of Income, Car Ownership, and Built Environment on Daily Activity Patterns: A Cluster Analysis of Trip Chains.” *Transportmetrica A: Transport Science* 21 (1): 272–302. Scopus.
<https://doi.org/10.1080/23249935.2023.2236235>.
- Zamir, Kiana Roshan, Arefeh Nasri, Babak Baghaei, Subrat Mahapatra, and Lei Zhang. 2014. “Effects of Transit-Oriented Development on Trip Generation, Distribution, and Mode Share in Washington, D.C., and Baltimore, Maryland.” *Transportation Research Record* 2413 (1): 45–53. <https://doi.org/10.3141/2413-05>.
- Zhang, Lei, Arefeh Nasri, and Transportation Research Board. 2013. “Analysis of Transportation-Oriented Development in Washington, DC, and Baltimore Metropolitan Areas.” 18p. 01473482. <https://trid.trb.org/view/1242230>.

Data Summary

Products of Research

The data collected in this study is limited to the content of the interviews with practitioners and planners. The research team also compiled a database of relevant literature.

Data Format and Content

The interview materials consist of transcriptions of the interviews in Word documents. The literature database is in an Excel format.

Data Access and Sharing

The interview transcripts contain confidential information about the interview participants and the agencies they represent. It is not publicly available. Relevant information from the interviews is contained in the body of this report. The literature database is summarized in the report.

Reuse and Redistribution

Not applicable.

Appendix A: Interview Script

Introduction

I'd like to start by thanking you for agreeing to participate in this interview today. This interview is part of research we are conducting at the Institute of Transportation Studies at UC Davis, in partnership with Caltrans. The study focuses on Transit Oriented Development (TOD) implementation, community engagement, and ridership within established TODs in California.

We are interested in learning about your perspective and experience of working on TOD. This can include conceptualization, community input, and design, or expected outcomes such as transit use and ridership changes. We'd also like to learn about any future considerations.

Participation in this interview is entirely voluntary, and you may choose not to answer any of our questions. The use of your responses in any reports, publications, or presentations will be completely anonymous and will not be connected to you personally.

(If not Susie: If you have any questions related to the project or your interview, you may contact project's director, Susan Pike at [email], or [phone number].)

I would like to audio-record our conversation today in order to transcribe the information you share with me. Once the transcription is completed, the audio recording will be deleted. Do you agree to participate in this interview today?

Section 1 – Conceptualization and Implementation of TOD

This section focuses on the definition, goals, and practical execution of Transit Oriented Development projects

1. What does TOD look like in your city? What are the motivations for TOD?
2. When considering a TOD, are there assumed benefits for the community? If so, what are they? Have you seen these benefits play out?
3. What is an example of a successful TOD project that you have worked on? What did that look like (more housing, affordability, accessibility, etc.)?
4. What is the most significant constraint to successfully implementing a TOD project? What is the most significant challenge of implementing a transit service?
5. If there was one thing you could change or improve about TODs, what would that be? What would the ideal TOD look like?

Section 2 – Decision making and Community Integration

Section two questions explore the planning processes and how projects fit into the existing social fabric.

1. How do planners and local governments (city councils) make decisions about proposed TOD projects? What factors are considered? What outcomes are expected/evaluated?
2. What concerns do you usually see come up in the proposal stage? Is there ever a fear that TOD would not fit in with the established surrounding communities?
3. Do you think TOD outcomes are largely shaped by existing conditions? If so, what are some of the effects you observe?
4. How have/would there be an impact due to changes in property values with the TODs? What actions are considered?

Section 3 – Ridership Estimation and Data Analysis

This section centers on the technical side of measuring success through ridership and impact modeling.

1. How are ridership or other changes estimated? Is there a certain threshold level of transit service required before TOD meaningfully increases ridership?
2. What tools would be helpful for decision-making in TOD planning and estimating ridership impacts? Are these tools currently accessible to your department?
3. Do you also consider VMT or other impacts related to private vehicle use? If so, how? Have there been any indicators showing a reduction in VMT?
4. On the topic of ridership, are there design of planning features that impact ridership? Have you observed any features that do or do not increase transit use?

Section 4 – Engagement and Future Considerations

Lastly, section four looks at human interaction with transit and open-ended expert advice

1. What strategies would you implement to increase the engagement of people using the transit services?
2. Is there anything about TODs or ridership estimation that we have not asked about but should be thinking about?