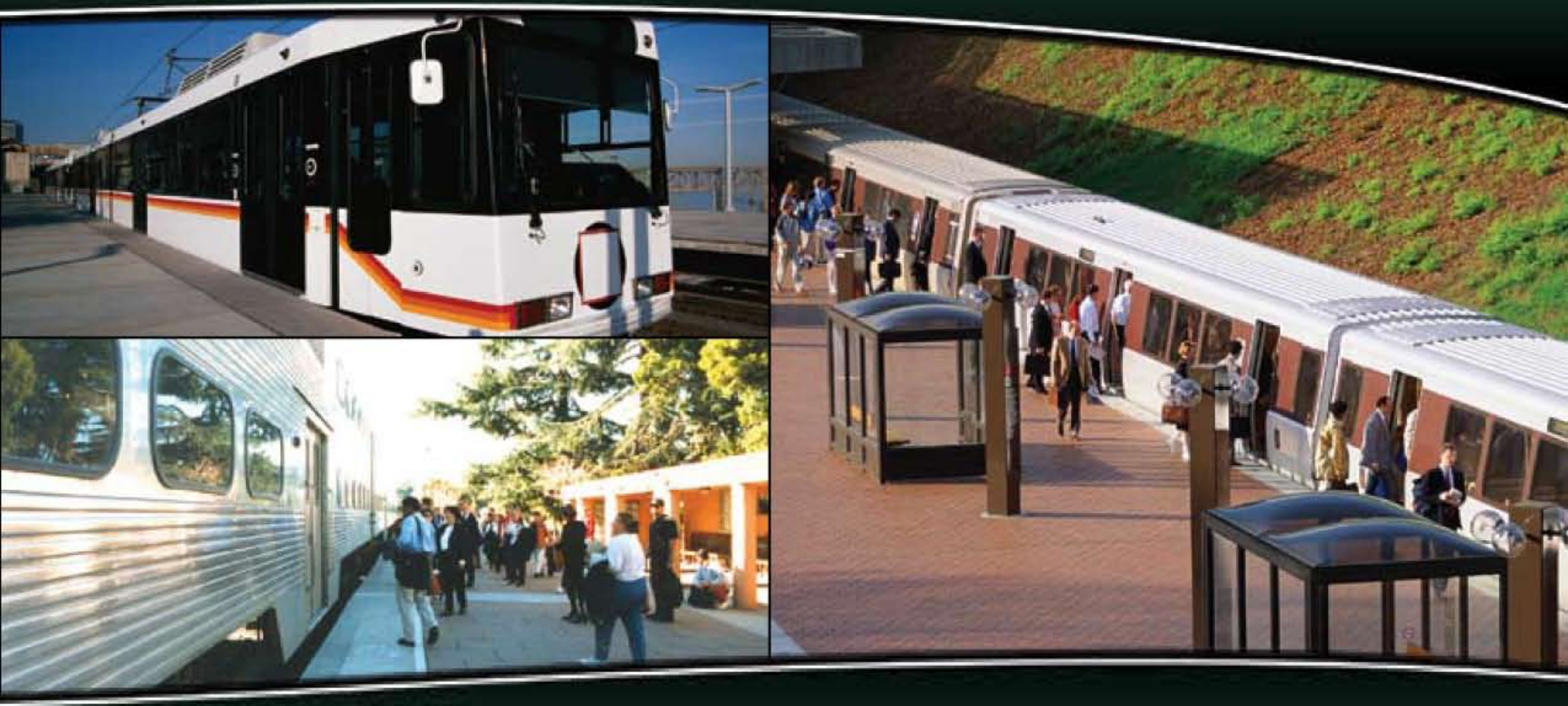
DIRECT RIDERSHIP FORECASTING

Out of the Black Box



- Transit corridor suitability
- Station site selection
- Modal alternatives evaluation
- Rapid rail, commuter rail, LRT
- Effects of TOD
- Effects of parking
- Quick-response
- Local validation

The feasibility – and “fundability” – of a new transit service hinges on ridership projections. Rail ridership is traditionally forecasted with region-wide travel demand models, which often represent transportation networks and land use at an aggregate scale. These models are relatively unresponsive to changes in station-level land use and transit service characteristics. As transit trips often represent a relatively small percentage of regional travel, even minor model imprecision can produce erratic swings in location-specific ridership estimates and unreliable transit forecasts. Large, complex models also require substantial and continuing investments of time and money to develop, maintain, and operate.

Direct Ridership Models represent a precise, quick-response alternative for forecasting transit patronage. They are directly and quantitatively responsive to land use and transit service characteristics within the immediate areas of prospective transit stations, and to comparative regional accessibility offered by transit and auto. Direct Ridership Models use multivariate regression based on empirical local data to determine the station characteristics that most influence rail transit patronage for light rail, commuter rail, and heavy rail. They respond directly to factors such as parking, rail service levels and characteristics, feeder bus levels, and data on station-area households and employment to estimate ridership.

DIRECT RIDERSHIP MODELS - QUICK, RELIABLE EVALUATION OF TRANSIT EFFECTIVENESS

Direct Ridership models have been used to evaluate, compare, and screen transit alternatives in all sizes of urban areas throughout the US. Four examples are described below:

- Bay Area Rapid Transit (BART) – Heavy Rail
- Sacramento Regional Transit (RT) – Light Rail
- Salt Lake City (TRAX) – Light Rail
- Sonoma Marin Area Rail Transit (SMART) – Commuter Rail

While region-wide travel demand models are effective for many uses, detailed forecasts of transit ridership at individual stations can be problematic. For example, the effects of transit-oriented design (TOD) may not be fully represented. By contrast, Direct Ridership Models:

- Are more sensitive than state-of-practice four-step models in capturing effects of localized conditions within communities and transit station areas at a more refined level than traffic zones.
- Provide a predictive method with demonstrated ability to match ridership relationships measures.
- Can be developed at a fraction of the budget and data needed for enhancements of existing four-step models.

The direct models used to forecast rail ridership were derived from statistical analysis of independent variables related to recent boarding and alighting counts at all BART Metro Rail, Caltrain Commuter Rail, and Salt Lake City and Sacramento LRT stations.

GIS-based data was also developed for over 30 prospective independent variables believed to potentially be correlated with station ridership both individually and in combination:

- Population and Income
    - Population within ¼, ½, and 1 mile of station
    - Population density within ¼, ½, and 1 mile of station
    - Population within station catchment area
    - Mean household income within station area
- Employment
    - Employment within ¼, ½, and 1 mile of station
    - Employment density within ¼, ½, and 1 mile of station
- Cost
    - Mean travel time to all other transit stations
    - Mean travel time to all other transit stations weighted by the relative attractiveness of each station
    - Destination-weighted transit fare
- Station Characteristics
    - Number of parking spaces
    - Terminus or freeway-intercept station
    - Station spacing
- Transit Service Characteristics
    - Number of feeder buses
    - Vehicle type
    - System speed
    - Train frequency
- Comparative Auto and Transit Accessibility
    - Destinations-weighted travel time from transit station to all other locations within region
    - Destinations-weighted travel time by auto to all other locations in region

BART and Caltrain Commuter Rail

BART recently explored extending service to central Contra Costa County, eastern Alameda County, and western San Joaquin County via three alignment alternatives. These alternatives included both light and heavy diesel multiple unit (DMU) technology and were comprised of different combinations of twenty station locations.

Fehr & Peers developed direct ridership models for BART, and based them on empirical BART and Caltrain data. This data provided a comparative analysis of new rail service along the different alignments, with different station placements, parking and feeder bus services, and transit frequencies and speeds. The models are also responsive to land use changes within the immediate areas of prospective transit stations, and the entire station catchment area. Given the number of transit alternatives under consideration, the forecasting method was also designed for a quick-response evaluation of alternatives.

The statistical analysis included linear regression and log-log regression analysis of combinations of variables to discover the combination of variables with the strongest statistical correlation with ridership. The formula found to have the highest correlation (R-squared) is able to estimate rail ridership at any station as a direct function of the following system attributes, land use and demographic characteristics:

- Sum of population employment within ½ mile of station
- Population within station catchment area
- Frequency of peak period feeder buses
- Number of station parking spaces
- Number of peak period trains
- Tech = Rail technology: 0 = Commuter (Caltrain) 1 = Heavy (BART)

The R-squared for the direct ridership equation is 0.87, indicating that the formula explains 87% of the variation in ridership among transit stations on the existing BART and Caltrain system. A log-log transformation of the model was also performed to estimate elasticities relating ridership to individual system attributes. These elasticities may be summarized as follows:

Given a 100% increase in:	Expected Ridership Increase:
Population and employment within 1/2 mile of station	23%
Population within catchment of station	2%
Number of peak period trains	48%
Peak period feeder buses	29%
Parking spaces	4%

In other words, doubling the amount of population and employment within a 1/2-mile buffer around a given station increases station ridership by 23%.

Salt Lake City LRT

The Utah Transit Authority (UTA) expressed an interest in developing a quick-response direct ridership model for use in planning possible extensions of UTA's current LRT system. Fehr & Peers worked with UTA and the MPO (the Wasatch Front Regional Council or WFRC) to develop such a tool using data from both agencies. Several useful models were devised. One of the best models (in terms of predictive power) uses the following variables to predict LRT ridership:

- The accessibility of the station area to the rest of the region during peak periods
- Population plus employment within station ½-mile buffer
- Whether or not the station is an end station
- Frequency of peak period feeder buses (6-9 AM)

Accessibility was determined using the WRFC four-step model, and auto and transit accessibility were measured separately. For each mode, accessibility was defined as the sum of all trip ends in the regional model divided by the aggregate peak travel time from the station to all zones in the modeling area.

A log-log transformation of the model was performed, and elasticities were estimated, as summarized below:

Given:	Expected Ridership Change:
A 10% increase in Transit Accessibility throughout region	+272%
A 10% increase in Auto Accessibility throughout region	-50%
A doubling of population & employment within 1/2-mile of station	+19%
A doubling of station bus access frequencies	+40%

The overall model was highly significant statistically. More than three-quarters of the variation of observed ridership at the existing LRT stations was collectively explained by the above variables, with an adjusted R-squared statistic of 0.77.

Sacramento LRT

The Sacramento Area Council of Governments (SACOG) engaged Fehr & Peers to develop a direct ridership forecasting methodology for Sacramento's LRT system to help predict ridership at individual new stations within the LRT system.

Land use, station area characteristics, and transit service variables were combined into over 40 models. The two recommended models have both high correlation (R-squared) with ridership, and include system attributes and land use/demographic characteristics deemed significant in literature on TOD and transit ridership:

- Population within station ½-mile buffer
- Employment within station ¼-mile buffer
- Number of station parking spaces
- Frequency of peak period feeder buses

The R-squared for each of these formulations (adjusted for the sample size) is 0.75, indicating that each of the formulae explains 75% of the variation in ridership among transit stations on the existing LRT system.

As with the BART and Salt Lake City studies, log-log transformations were performed to estimate elasticities relating ridership to individual system attributes. These elasticities may be summarized as follows in the next column:

Given a 100% increase in:	Expected Ridership Increase:
Population within 1/2-mile of station	30%
Employment within 1/4-mile of station	21%
Parking spaces	11%
Peak period feeder buses	47%

SMART Commuter Rail

To forecast Commuter Rail ridership in Petaluma CA, an enhanced version of the Bay Area direct ridership model was used to compute a station-specific transit likelihood index (TLI). The TLI is used in conjunction with the regional Metropolitan Transportation Commission (MTC) four-step model to predict the rail ridership generating potential of three 2025 citywide land use alternatives.

Fehr & Peers adapted a set of equations it had developed for the EPA's Smart Growth INDEX planning model. The equations predict the change in the likelihood of transit choice based on differences in development density in proximity to rail transit stations. The selected equation (one of 66 equations derived from data on BART and Caltrain) includes population and employment within a station ½ mile buffer and catchment area, number of peak period trains, and rail vehicle type.

The equation compares alternative land uses and transit characteristics and computes the relative TLI, or probability of using rail transit. The TLI, used in conjunction with the MTC regional model, estimates the number of person trips converted from automobile to transit. The highest density future alternative had three times the station-area land use density and five percent higher citywide population than the base case, and generated about 40% higher commuter rail ridership.

TRANSIT-SUPPORTIVE LAND USE - HOW MUCH IS ENOUGH?

A substantial body of literature considers the relationship between transit share and station-area land use, including:

- What land use factors contribute to increased transit ridership?
- What specific empirical evidence exists on the percent of people within immediate proximity of transit that use it?
- What other station area characteristics support transit ridership?
- What land use density/intensity thresholds are needed to support transit?

Land Use Factors Affecting Transit Use - Density and other "D"s

At the residential end, the principal land use factors that can promote transit ridership have been summarized as the three Ds: Density, Diversity (land use mixture) and Design (e.g., provision of convenient sidewalks and other pedestrian amenities that encourage walking). A fourth D – accessibility to concentrated regional Destinations (e.g. downtown) is also a key factor in transit use. Of these four D-factors, density in the transit corridor and the intensity of the concentration at the destination end of the corridor are the main quantifiable land use variables. Density near transit increases transit patronage by reducing the time and cost of accessing transit.

Ross and Dunning (1997) report an almost three-fold increase in transit mode share occurs when densities are greater than six units per acre. A Holtzclaw (2002) study finds that a doubling in density results in a 25 percent reduction in vehicle miles traveled. Only a fraction of this reduction is due to more transit use.

Residential Density Thresholds For Supporting Transit

Pusharkev & Zupan (1977) recommend residential densities of at least four dwelling units per acre for minimal (bus) transit service to be viable. However, the supporting studies are over 20 years old and based on data from the New York City region only. USDOT/Snohomish County Transportation Authority (1989) stated that seven to 15 dwelling units per acre can support local bus service.

Mode Shares Near Transit

Using the 2000 Bay Area Travel Survey, Cervero and Duncan (2002) found that 19.6 percent of residents living within 1/2 mile of BART commuted via transit This is slightly higher than the 1990 Census BART mode split for workers within the 1/2-mile radius (17.8 percent).

Cervero (1993) found the following effects of residential proximity to LRT on mode choice in Sacramento: 12 percent of residents' "main trips" were by rail; another 3.2 percent were by bus transit. For employment sites in suburban Sacramento within easy walking distance of LRT stations, he found that 6.3 percent of workers arrived by rail and 5.4 percent by bus.

Effects of Land Use Diversity

With respect to land use mixture, Cervero (1996) found that if retail shops are within 300 feet, transit ridership is encouraged, but if retail is 300 feet to 1 mile away, residents are likely to drive and link a short shop trip onto their journey to work. This study further found that mixed land use encourages non-motorized trips more consistently than residential density.

At suburban employment centers, Cervero (1989) found a 3 percent increase in transit/ridesharing use with every 10 percent increase in retail uses. The ability to accomplish midday errands and shopping without a car influences some commuters to take transit.

Station Area Design Characteristics that Support Transit Ridership

A variety of studies (Cervero 1993, Cervero and Gorham, 1995, Dill 2003) have found that direct walkway access to stations matters for transit access. However, Cervero and Gorham found that density had less than one-half the impact of neighborhood design.

Employment Intensity and Transit Use

Frank and Pivo (1995) found employment densities to be as important or more important than residential densities. Using Seattle-area data, they found that bus transit ridership to employment centers rises to about 10 percent of all work trips when there are about 100 employees/acre, and exceeds 33 percent when employment densities exceed 200/acre.

Dill (2003) found that work sites being within 1/4 mile of a rail station greatly increases the chances of employees using rail. Proximity to a BART station had a much greater effect than proximity to a Caltrain or VTA light rail station.

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For information, please contact:
Jerry Walters, Principal
Fehr & Peers
925-930-7100
j.walters@fehrandpeers.com
www.fehrandpeers.com

References

Cervero, R. *Ridership Impacts of Transit-Focused Development in California*, University of California at Berkeley Institute of Urban and Regional Development, 1993.

Cervero, R. and M. Duncan, *Residential Self-Selection and Rail Commuting: A Nested Logit Analysis*, University of California Transportation Center, Berkeley, California, 2002.

Cervero, R. and R. Ewing, *Travel and the Built Environment-Synthesis*, University of California at Berkeley Institute of Urban and Regional Development, 2002.

Cervero, R. and R. Gorham, *An Evaluation of the Relationship between Transit and Urban Form,* TCRP Research Results Digest, Number 7, Transportation Research Board, 1995.

Dill, Jennifer, "Transit Use and Proximity to Rail: Results from Large Employment Sites in the San Francisco Bay Area", *Transportation Research Board Annual Meeting CD-ROM*, 2003.

Fehr & Peers, *Travel Forecasting Approach for Smart Growth Twin Cities*, 2002.

Fehr & Peers, *4D Application to SACMET Travel Demand Model*, 2003.

Fehr & Peers, *tBART 580/680 Corridor Ridership Forecasting Methodology*, 2003.

Frank, L. and G. Pivo, "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: SOV, Transit and Walking," *Transportation Research Record* 1466, 1995.

Holtzclaw, J. and R. Clear, H. Dittmar, D. Goldstein, and P. Haas. Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use Studies in Chicago, Los Angeles, and San Francisco, *Transportation Planning and Technology*, Vol. 25, 2002, p. 1-27.

Pushkarev, B. and J. Zupan, *Public Transportation and Land Use Policy*, Indiana University Press, 1977.

Ross, C. and A. Dunning, *Land Use Transportation Interaction: An Examination of the 1995 NPTS Data,* 1997.

United States Department of Transportation/Snohomish County Transportation Authority, *A Guide to Land Use and Public Transportation for Snohomish County, Washington*, 1989, pp 3-1:3-9.

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For information, please contact:

Jerry Walters, Principal
Fehr & Peers
925-930-7100
j.walters@fehrandpeers.com
www.fehrandpeers.com