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# Incorporating Rail Potential and Equity Analysis into Market Analyses for Rail Investments: A Case Study of the Link21 Program in Northern California

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**Abstract**

This paper presents an innovative approach for conducting market analyses for major rail investments. The approach considers which locations have the greatest potential to repay investment support and/or benefit specifically from the investment in the form of potential rail riders and the factors that could influence their decision to travel by rail. It is guided by an overarching commitment to equity with an emphasis on identifying potential benefits to communities that have been marginalized. The approach is applied to a case study of the Link21 program, a transformational investment in the Northern California passenger rail network that is focused on a new transbay passenger rail crossing between San Francisco and Oakland. The analysis found there is significant unmet potential for transbay rail ridership across the Northern California megaregion, with the greatest unmet potential found in and around San Francisco and Oakland, specifically in locations with a poor or no rail service. Although much of the potential for new riders centers around transbay travel, the Link21 program could also benefit non-transbay trips and riders. Ultimately, new transbay rail infrastructure and services will create more opportunities for accessible, direct, faster, or less crowded trips across the megaregion. These findings illustrate the value of the innovative market analysis approach as follows: it serves as an objective foundation for developing investment alternatives; and it influences the findings of the analysis and the development of alternatives by emphasizing the importance of serving communities that have been marginalized.

**Keywords**

planning and analysis, decision-making, decision tools, planning methods, project selection, decision analysis and processes, passenger rail, market analysis, equity, unmet rail potential

Major rail investments rely on market analyses to identify areas that would be suitable for a passenger rail service during the early stages of project development. These analyses typically consider where people are currently traveling to and where they want to travel to in the future, but stop short of asking what locations within the project's study area have the greatest potential to support new, additional, or improved passenger rail services.

Amid concerns of unequal access to public resources as well as the long-term impacts of historical underinvestment in communities that have been marginalized, cities and regions are now seeking to incorporate equity into their transportation planning and practices (*1–3*). Because it relates to transportation, equity can be defined as ensuring that residents are able to reach destinations across a city or region in a timely, cost-effective, healthy, and sustainable manner, regardless of their geographic location or socioeconomic status (*4*).

This paper presents a market analysis methodology that goes beyond a conventional analysis of existing and future travel patterns by seeking to understand the potential for attracting new rail riders in a wide geography and in particular markets or corridors. The

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analysis is guided by an overarching commitment to equity with an emphasis on identifying potential benefits to historically disadvantaged and underserved populations.

This methodology is applied to a case study of the Link21 program, a major opportunity for transforming the passenger rail network in the Northern California megaregion, and which is centered around a new transbay passenger rail crossing between Oakland and San Francisco. The Northern California megaregion is comprised of 164 cities, 21 counties, and 4 major regions: the greater San Francisco Bay Area, the Monterey Bay Area, the Sacramento Area, and the Northern San Joaquin Valley.

The paper indicates how unique elements of the methodology can be applied to other market analyses for major transportation investments, and then presents some selected initial findings in relation to unmet rail ridership potential in various markets and corridors across the megaregion.

## Methodology

### Overview of Approach and Application to the Link21 Program

A conventional market analysis for a rail investment examines where people are currently traveling to, and their future travel needs, initially to identify locations that could be served by the investment. This analysis is informed by current population numbers, employment distribution, travel patterns, and preferences, as well as projected population and employment growth.

A conventional analysis does not consider which locations have the greatest potential to repay investment support and/or benefit specifically from investment in the form of potential rail riders and factors that could influence their decision to travel by rail. Both elements are the subject of a rail potential analysis, which can be broken down into three main steps:

1. Identifying high-potential market opportunities: locations and location pairs that may be served by passenger rail services
2. Identifying high-potential corridor opportunities: geographically proximate bundles of markets that may be served by passenger rail services
3. Testing corridor performance under several future scenarios as part of an uncertainty analysis

The findings from the rail potential analysis may subsequently inform the specification and development of investment alternatives without any preconceived ideas or constraints, specifically by identifying communities that are most likely to use passenger rail services. This application of the methodology provides transportation planners and decision-makers with an unbiased perspective on which locations have the greatest need for rail investment and the greatest potential for achieving the investment's goals and objectives.

The remainder of this methodology section presents in detail the innovative rail potential analysis methodology that adds several elements to a conventional market analysis. The market analysis is applied to a case study of the Link21 program, a transformational investment in the Northern California passenger rail network, which is comprised of the San Francisco Bay Area Rapid Transit District (BART) and Regional Rail, the latter of which includes commuter, intercity, and high-speed passenger rail services. It first introduces the overarching theme of equity, which guides the development of the rail potential analysis methodology, and then describes each of the three steps in greater detail. Finally, some key considerations are advanced and limitations of the methodology are discussed.

### The Role of Equity

The Link21 program defines equity as "a state in which an individual's background does not predetermine or predict their opportunity." Promoting equity (along with livability) is identified as one of Link21's goals. It is also a lens through which to analyze the metrics that underpin those goals, including the potential for attracting new rail riders.

A "priority populations" definition was developed to support Link21's efforts to address inequities across the megaregion; all other megaregion areas are referred to as "general populations." The definition combines state-disadvantaged and low-income communities with Equity Priority Communities (previously called Communities of Concern), as defined by the San Francisco Bay area's Metropolitan Transportation Commission, other agencies such as the California Department of Transportation, and local counties.

In the Link21 market analysis, the priority populations definition is used to explore disparities and disadvantages in livability, affordability, and accessibility experienced by priority populations compared with general populations. Specifically in the rail potential analysis, potential trips made by priority populations are double counted, reflecting the importance of serving areas with high-priority populations.

### Step 1: Market Rail Potential Analysis

The rail potential analysis identifies individual neighborhoods or entire municipalities that could generate sufficient ridership potential to support future new or additional passenger rail services. The entire megaregion is covered by hexcells, hexagonal areas that are 0.5 mi in diameter. Clusters, which represent neighborhoods or municipalities and have a hub at the center, are a group of multiple hexcells, and are the main geographic unit of analysis for the rail potential analysis. The analysis identifies clusters and cluster pairs with the greatest unmet potential, with an emphasis on equity in the outputs. Unmet potential is defined as follows:

- **Baseline ridership** represents passenger rail demand and includes land use and projects incorporated into the regional transportation plans (RTPs) adopted by the various metropolitan planning organizations (MPOs) in the megaregion.
- **Good service rail potential** (or total rail potential) represents demand for passenger rail services under an "idealized network," that is, a (potentially unrealistic) good rail service and no crowding between all cluster pairs in the megaregion.
- **Unmet rail potential** is the difference between good service rail potential and baseline ridership. It measures the number of additional riders who could be captured with new or additional/improved passenger rail services, and it explicitly includes latent demand.

Based on the definition of unmet rail potential, outputs may be further analyzed as follows:

- **Equity weighted**: potential trips made by priority populations living in the origin or destination clusters are counted twice, which is consistent with the methodology used by the Federal Transit Administration (FTA) in its Capital Investment Grants (CIG) program. The current use of passenger rail services by priority populations may be particularly detached from overall demand for rail services because of historical underinvestment, which has made rail services harder to access and/or less convenient.
- **Miles-weighted** demand between two clusters is weighted by the rail distance between them, which raises the importance of long-distance trips and their impacts on key program objectives such as environmental stewardship and public health and safety.
- **Transbay trips** associated with a given cluster that cross San Francisco Bay using the Transbay Corridor between Oakland and San Francisco versus total trips to or from that cluster.

*Rail Potential Model Estimation.* Unmet potential is estimated using a regression model that is custom specified to identify conditions that drive and enable high rail ridership in the megaregion. The model estimates passenger rail potential as a function of key factors, including but not limited to the following:

- Socioeconomic data (population and employment at both ends of the cluster pair) collected from the U.S. Census Bureau, MPOs in the megaregion, and other public data sources
- Probability of using rail/transit according to Experian's Mosaic market segmentation, which aims to classify the population into various groups and types depending on demographic and socioeconomic characteristics as well as consumer behavior
- Rail level of service characteristics (journey time, cost, frequency, and transfers), collected from rail operators and public data sources such as Google Maps
- Whether the trip is transbay
- Time period (peak/off-peak) of travel
- Trip distance
- Parking costs at both ends of the cluster pair
- Whether one end of the cluster pair is an end-of-the-line BART station or a railway station that is located a long way from any other; both tend to have large catchment areas and higher market potential

A crowding curve is incorporated, assuming some people choose not to use passenger rail services when there are crowded conditions, particularly during peak travel periods. As a train gets more crowded, the capture rate—defined as the share of a given set of travelers who are willing to use a passenger rail service—decreases, starting just before the load factor hits 100% of seated capacity. This is modeled using a crowding curve, which estimates a multiplier on in-vehicle travel time as a function of load factor. This is estimated using both observed data on cluster pairs with capacity constraints and benchmarking from other peer operators such as Metrolinx (*5*). The full list of passenger rail demand drivers and their estimated impacts (regression coefficients) is presented in Table 1.

*Rail Potential Model Application.* The regression model is applied using a spreadsheet tool to calculate the future year's (2040) good rail service potential and unmet rail potential for all cluster pairs in the megaregion. In estimating future unmet rail potential, the tool also incorporates crowding constraints, as described in the preceding subsection, and future population and employment growth (between the base year 2015 and 2040).

Future year growth includes population and employment growth and takes into account future baseline

**Table 1.** Rail Demand Drivers and Estimated Impacts

| Variable | Coeff. | Notes |
|---|---|---|
| Population/employment | 1.00 | If population/employment increases by 10%, forecast trips should increase broadly by 10% |
| Rail journey time (minutes) | −0.83 | If rail journey time decreases by 10%, forecast trips should increase by 8.3%—this is in line with most benchmarks |
| Rail cost (dollars) | −0.35 | If rail cost decreases by 10%, forecast trips should increase by 3.5%—this is in line with (or slightly more sensitive than) most benchmarks |
| Rail frequency (trains per hour) | 0.23 | If rail frequency increases by 10%, forecast trips should increase broadly by 2.3% |
| Rail transfers (binary indicator of rail–rail transfers) | −0.52 | The impact is a flat −0.52; however, the relative impact varies by trip length and is equivalent to a penalty of approximately 25 min for a 35-mile trip and 50 min for an 85-mile trip |
| Transbay marker | 1.25 | Transbay trips have higher demand |
| Off-peak marker | −0.40 | Off-peak trips have lower demand |
| Long distance marker (⩾ 30 mi) | −0.96 | Long-distance trips have lower demand |
| Longer distance marker (⩾ 90 mi) | −2.40 | Very long-distance trips have lower demand |
| Short distance marker (⩽3 mi) | −1.37 | Short-distance trips have lower demand |
| Shorter distance marker (⩽2 mi) | −1.28 | Very short-distance trips have lower demand |
| Parking cost marker (parking cost exists) | 0.62 | Trips with auto parking costs (e.g., downtown San Francisco) have higher demand |
| BART end-of-line marker | 0.83 | Trips that have an extended park and ride catchment area have higher demand |
| Widely spaced stations (⩾ 5 mi from other stations) | 1.12 | Stations that are situated a long way from other stations have higher demand |
| Constant | −15.36 | No conventional interpretation; estimated only to maintain statistical validity of overall model |
| $R^2$ | 0.51 | The proportion of variance in rail demand that can be explained by the variables listed above (ranges from 0 to 1) |
| Total error (%) | −8.6% | Average deviation of observed values from values estimated using the regression model |

*Note*: Coeff. = coefficient; BART = Bay Area Rapid Transit.

projects from the RTPs adopted by the MPOs. The model responded with a growth in total daily passenger rail potential of 33% and a growth in population and employment of approximately 28%. It is reasonable that passenger rail potential will grow faster because clusters with passenger rail services are expected to grow faster than clusters without them.

Figure 1 illustrates how baseline rail trips in 2040 were developed from baseline rail trips in 2015 across all origin–destination pairs in the megaregion. Crowding first depresses 2015 trips by 7% (i.e., a certain number of potential rail trips are not accommodated because riders are unable or unwilling to board crowded trains). Future population and employment growth and baseline service improvements then combine to account for a 62% increase in trips between 2015 and 2040. This demand in 2040 is subsequently depressed by 9% to account for future levels of crowding.

A good passenger rail service is a theoretical concept of service that is fast, frequent, affordable, direct, and has plenty of available seats (whether plausible or not). The model application provides a consistent basis on which to assess the relative ridership potential across cluster pairs. Assumptions about a good rail service differ by trip duration and the assumed type of rail service (urban or regional) used for each duration:

- Trips less than 30 min: urban rail
- Trips higher than 90 min: regional rail
- Trips between 30 and 90 min: test urban and regional rail and take the maximum unmet rail potential of the two

The definition of good service for urban and regional rail is shown in Table 2.

Figure 2 shows how the impacts of a good rail service are applied to future year conditions (the first column “Future year”—baseline in Figure 2—is the same as the final column in Figure 1). Figure 2 shows that improving travel times to good rail service standards and eliminating transfers had the largest impacts on rail potential at + 22% and + 16%, respectively. The main output from

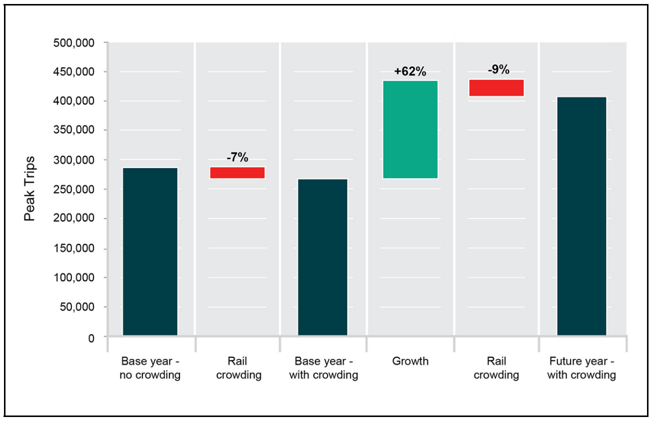


**Figure 1.** Future year (2040) crowding and growth impacts on rail trips.

the rail potential model application is a series of markets with high unmet rail potential. This serves as an input to the next step, the corridor rail potential analysis.

### *Step 2: Corridor Rail Potential Analysis*

Once high-potential individual markets have been identified, the second step is to identify corridors that could be served by passenger rail services. Corridors are defined as geographically proximate and bundled sets of high-potential markets (clusters), and do not consider engineering, operational, or cost factors (at this point). They may consist of multiple segments, which are shorter components of a longer corridor.

Most of the 202 clusters analyzed in the market rail potential analysis, particularly those with high transbay unmet potential, fall naturally into geographically organized corridors. Nine such corridors exist in the East Bay, and three corridors in the West Bay. Parts of the megaregion with very low unmet potential have been excluded from corridors altogether. Additional information about the geographies covered in each corridor is provided in the Corridor Rail Potential Findings subsection later in the paper.

The methodology and dimensions of the corridor rail potential analysis are similar to those of the market rail potential analysis described in the Market Rail Potential Analysis subsection. Unmet rail potential is estimated using the regression model and spreadsheet application tool. It is then weighted by share of priority populations and transbay trips are separated out. The steps taken are as follows:

1. **Split the corridors into segments** at logical break points based on large markets (e.g., Richmond) or infrastructure barriers (e.g., the Carquinez or Benicia–Martinez bridges), which start from one end of the Transbay Corridor in San Francisco or Oakland.
2. For each segment, **identify several potential sub-alternatives** by connecting high-potential, geographically proximate clusters.
3. **Evaluate the transbay equity-weighted unmet potential** of each sub-alternative by connecting it with all clusters representing all existing and planned railway stations on the other side of San Francisco Bay (e.g., an Oakland–Richmond sub-alternative is evaluated by measuring the unmet rail potential from all its clusters according to all existing and planned railway station clusters in San Francisco, San Mateo, and northern Santa Clara counties).

**Table 2.** Good Rail Service Definitions

| Rail service characteristic | Urban rail | Regional rail |
|---|---|---|
| Rail travel time | Whichever is lower:<br>• Rail travel time based on 40 mph average speed<br>• 120% of auto travel time | Whichever is lower:<br>• Rail travel time based on 50 mph average speed<br>• 120% of auto travel time |
| Rail cost | Whichever is lower:<br>• $2 + $ 0.10 per mile (minimum of $2.10)<br>• 150% of auto cost | Whichever is lower:<br>• $ 0.25 per mile<br>• 150% of auto cost |
| Peak rail frequency | Whichever is higher:<br>• 8 trains per hour (tph)<br>• tph with implementation of BART's Core Capacity project | 4 tph |
| Off-peak rail frequency | 5 tph | 2 tph |
| Rail transfers | No transfers | No transfers |
| Rail crowding | No crowding | No crowding |

*Note*: BART = Bay Area Rapid Transit

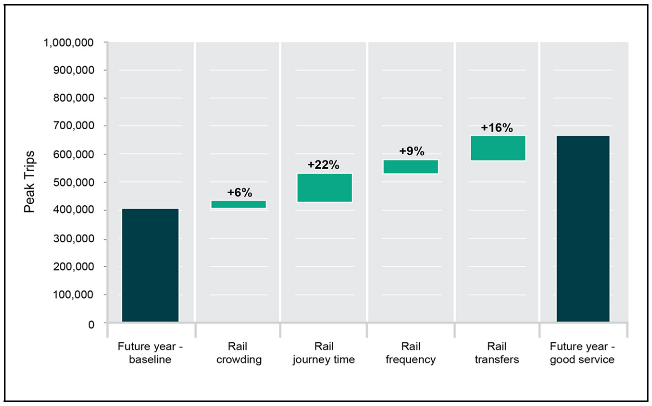


**Figure 2.** Good rail service impacts on rail trips.

4. For each segment, identify the sub-alternative with the **highest transbay equity-weighted unmet potential**.
5. For each corridor, **identify segments (incrementally)** that have the highest combined total transbay equity-weighted unmet potential.

The main output of this step is a list of corridors and segments with high unmet rail potential. These corridors and segments directly inform the development of alternatives, and the information can be used along with other sources such as public studies/plans, public and stakeholder engagement, and engineering and operational considerations, among others.

### *Step 3: Uncertainty Analysis*

The uncertainty analysis enables the prioritization of corridors and segments that perform well under a variety of possible future scenarios. It ensures the analysis can be future proofed by considering how travel demand patterns can change from today's estimates as land use patterns and rail competitiveness evolve. The goal is to compare the **relative** performance of corridors, specifically changes in the ranking of corridors and segments, in each of the several uncertainty scenarios and the baseline corridor analysis.

Within the context of the market analysis, the uncertainty analysis focuses on the following five key parameters. Each is selected based on research and professional judgment, including that of several technical review panels:

1. Housing growth and patterns
2. Job growth and patterns
3. Working patterns, primarily in relation to remote work
4. Travel costs, particularly rail fares
5. Baseline projects: those scheduled to be implemented in the future and included in a baseline or do-nothing scenario

Up to five scenarios are defined for each key parameter, and each set of scenarios is intended to represent a broad range of possible futures with regard to the relevant parameter. Some scenarios correspond to high or low values of a parameter. Others correspond to specific developments such as the implementation of a congestion pricing zone. The full set of scenarios considered is presented in Table 3.

Development of rail potential model inputs for the uncertainty scenarios relies on data from a variety of sources, including MPO and municipal land use forecasts, consumer segmentation data, and research on telecommuting.

Once the scenarios are defined, equity-weighted unmet rail ridership potential for 2040 is estimated for each set of key corridors and segments under each scenario. This is done using the methodology for steps 1 and 2 described in the preceding subsections.

Rankings of this metric across corridors and segments are compared with the corresponding rankings in the baseline scenario. Any changes in rankings are then considered when identifying corridors and segments with high unmet rail potential. The goal is for Link21 not to do the following:

- Overrate alternatives that perform well in the baseline scenario but poorly across several sensitivity scenarios
- Underrate alternatives that perform poorly in the baseline scenario but well across several sensitivity scenarios

### *Other Key Considerations and Limitations*

Below are some other key considerations along with certain limitations of the approach with regard to the three steps described in the preceding subsections.

- The analysis focuses primarily, but not entirely on transbay markets.
- It focuses on trips longer than 3 mi, because shorter-distance trips are not transbay and would likely be better served by other modes in much of the megaregion.
- It includes induced trips but not land use impacts. Induced trips are those that are directly attributable to a new or improved passenger rail service. Land use impacts may include new development or zoning policies attracting large amounts of new

**Table 3.** List of Uncertainty Scenarios

| Parameter | | Scenario |
|---|---|---|
| Housing growth and patterns (HG) | HG1 | High population growth (2x expected growth from plans 2015–2040), increased clustering around railway stations |
| | HG2 | High population growth, no change in clustering around railway stations |
| | HG3 | No population growth, no change in clustering around railway stations |
| | HG4 | No population growth in Bay Area, high population growth in outer MPOs, no change in clustering around railway stations |
| Job growth and patterns (JG) | JG1 | High employment growth (2x expected growth from plans 2015–2040), increased clustering around railway stations |
| | JG2 | High employment growth, no change in clustering around railway stations |
| | JG3 | No employment growth, no change in clustering around railway stations |
| | JG4 | No employment growth in Bay Area, high employment growth in outer MPOs, no change in clustering around railway stations |
| Working patterns (WP) | WP1 | 60% of eligible work above the baseline takes place remotely, no change in nonwork trips |
| | WP2 | 20% of eligible work above the baseline takes place remotely, no change in nonwork trips |
| | WP3 | 60% of eligible work above the baseline takes place remotely, 20% increase in nonwork trips by remote workers |
| | WP4 | 20% of eligible work above the baseline takes place remotely, 20% increase in nonwork trips by remote workers |
| Travel costs (TC) | TC1 | Increased rail fares (50% increase) |
| | TC2 | Reduced rail fares (50% decrease) |
| | TC3 | Reduced rail fares (50% decrease) for cluster pairs with a share of high-priority populations (proxy for means-based fare policy) |
| | TC4 | Reduced rail fares (50% decrease) for trips to/from downtown San Francisco (proxy for auto congestion pricing) |
| | TC5 | Regional rail fares adjusted to use BART fare formula |
| Housing/job growth and patterns (HJG) | HJG1 | Low population growth (0.5x expected growth from plans), high employment growth (2x expected) in San Francisco; no change in expected growth elsewhere |
| Baseline projects (BP) | BP1 | Rail projects scheduled for implementation after 2035 (based on other MPOs' plans adopted by Plan Bay Area 2050) removed |

*Note*: MPOs = metropolitan planning organizations; BART = Bay Area Rapid Transit.

housing construction and, thus, travel demand, to certain areas.

- Trips made by priority populations are double counted when analyzing unmet rail potential to reflect the importance of serving systematically disadvantaged communities.
- Rail potential is one of several criteria for evaluating alternatives. Other criteria are examined and analyzed alongside unmet rail potential when developing and evaluating alternatives.
- Although the market analysis identifies markets with high rail potential, it does not necessarily mean passenger rail is the best transit mode for serving those markets. Other transit modes can serve the market more effectively.

## Key Findings for Link21

The market and corridor rail potential analyses for Link21 resulted in the identification of a series of markets and corridors with a high potential for attracting passenger rail riders. The following subsections present these results and findings in greater detail.

Note that the analyses and their results do not account for changes in travel patterns experienced as a result of the COVID-19 pandemic and future changes in demographic trends and travel patterns that may arise because of the ongoing pandemic. All data and figures represent the pre-pandemic state, because the pandemic may cause significant and unknown (as of yet) future changes in population and employment patterns.

### *Market Rail Potential Findings*

The primary finding is that a new transbay passenger rail crossing could substantially increase transbay rail ridership across the megaregion. Figure 3 illustrates that substantial unmet potential is found in all parts. The area of the circles seen in the figure is proportional to the sum of the unmet equity-weighted rail potential between that

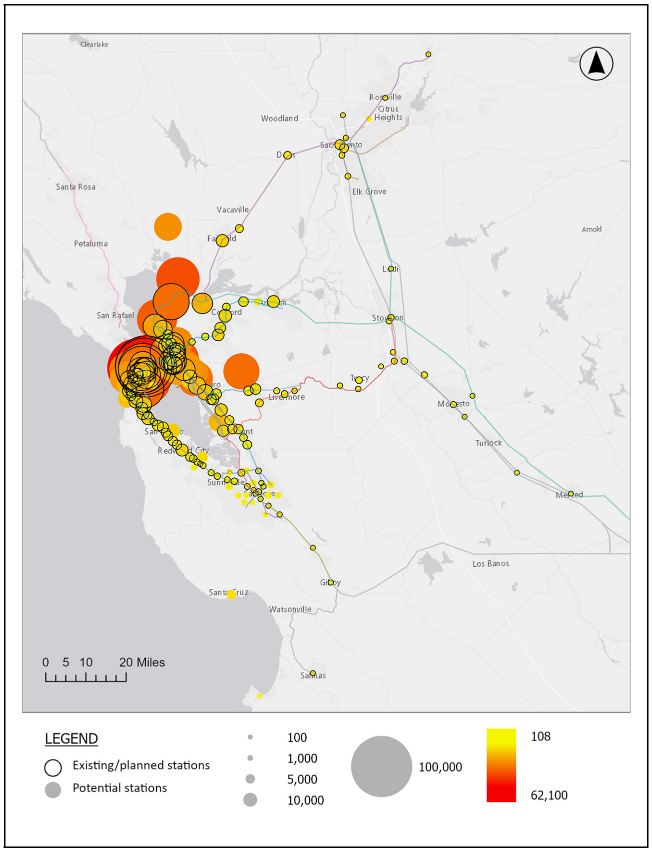


**Figure 3.** Transbay equity-weighted unmet rail potential (number of potential trips), 2040.
*Map background source*: Esri, HERE, NPS, Garmin, USGS, EPA, NPS.

cluster and every other cluster that is transbay from it. Most of this unmet transbay passenger rail potential is concentrated in San Francisco, Alameda, and Contra Costa counties.

Figure 4 illustrates that those markets closer to the Transbay Corridor, on the eastern and western ends, have the greatest unmet transbay passenger rail potential. These high-potential markets cover municipalities such as San Francisco, Oakland, Emeryville, Berkeley, and Alameda. The highest potential markets can be categorized as follows:

- New markets without an existing passenger rail service, such as western San Francisco, Lower Pacific Heights/Japantown in San Francisco, and the Grand Lake District and MacArthur Boulevard corridor in Oakland
- Markets with a poor transbay rail service, such as southeastern San Francisco and Emeryville
- Markets with significant rail crowding, such as the existing BART corridor along Market Street in San Francisco

Other travel markets close to the Transbay Corridor with medium levels of potential include the following:

- San Francisco (0–10 mi from the Transbay Corridor):
  - South of Market
  - South Park
  - Dogpatch neighborhood
  - Mission neighborhood
  - Balboa Park neighborhood
- Oakland (0–10 mi from Transbay Corridor):
  - Downtown
  - Jack London Square
  - Around MacArthur BART
  - San Antonio neighborhood
  - Fruitvale neighborhood
- Other Alameda County (3–5 mi from Transbay Corridor):
  - Eastern Berkeley
  - Central Alameda
  - Western Alameda

Reducing or eliminating transfers is one of many benefits that can emerge from a new transbay passenger rail crossing. For example, a regional rail crossing connecting Emeryville to San Francisco and continuing south along the Peninsula could provide a no-transfer ride from Sacramento or Stockton to San Francisco or San Mateo County.

As shown in Figure 3, although a large share of transbay unmet rail potential is found in the core of the megaregion, other markets further away from the Transbay Corridor could also benefit from a good transbay rail service and/or associated investment. Such investment could unlock a relatively high amount of unmet rail potential in markets without an existing transbay rail service, for example, San Pablo, Hercules, Vallejo, and San Ramon. It could also improve the service to existing riders and offer them additional benefits. Other markets with a medium amount of unmet transbay rail potential include Richmond, Martinez, Napa, and San Mateo County.

On the other hand, in Figure 3, markets located a long distance from the Transbay Corridor, for example, Sacramento, Stockton, Modesto, and Sonoma County, have more limited absolute unmet transbay rail potential. The good rail service potential in these markets is relatively high compared with baseline ridership. However, this large percentage/relative difference is driven mostly by low baseline ridership rather than any significant amount of unmet potential. That said, as mentioned above, investment in a new transbay passenger rail crossing and other infrastructure in the core of the megaregion

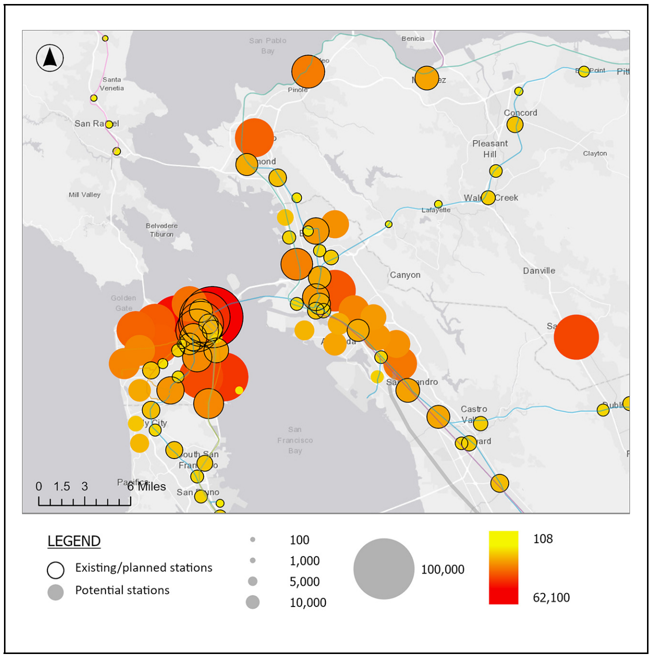


**Figure 4.** Transbay equity-weighted unmet rail potential (number of potential trips, zoomed in), 2040.
*Map background source*: U.S. Bureau of Land Management, Esri, HERE, Garmin, USGS, EPA, NPS.

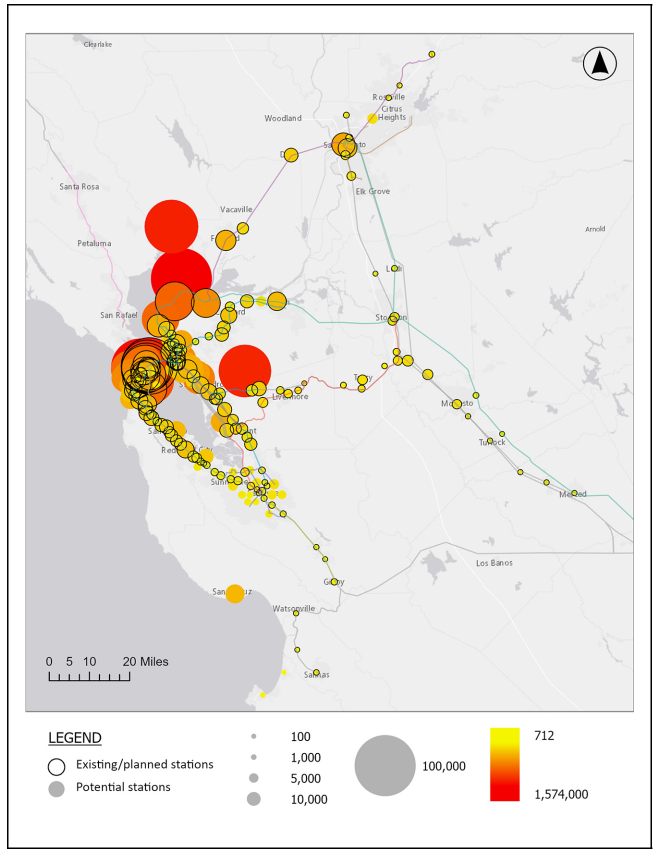


**Figure 5.** Transbay miles- and equity-weighted unmet rail potential (number of potential passenger miles), 2040.
*Map background source*: Esri, HERE, NPS, Garmin, USGS, EPA.

can still deliver travel and other benefits to all parts, including these long-distance markets.

Figure 5 depicts the unmet potential transbay passenger miles by cluster as opposed to potential riders. The impact of these medium- and long-distance markets is amplified because of the higher number of passenger miles traveled. Key markets with increased impacts include Vallejo, San Ramon, Napa, and Sacramento. The higher passenger miles traveled drive greater mileage-related benefits such as travel time savings and a reduction in greenhouse gas emissions.

Finally, although one of the key objectives of Link21 is to improve transbay passenger rail travel, the project could also benefit non-transbay rail travel. Figure 6 illustrates the unmet rail potential for all trips, not just transbay. For all clusters in the megaregion, Figure 6 reveals a substantial amount of unmet rail potential in Santa Clara County in particular, albeit substantially lower than that in San Francisco. This concentration of unmet potential suggests that Santa Clara County could benefit from Link21-related investments that would improve the passenger rail service to either the West or East Bay. For example, a new transbay passenger rail crossing that connects San Francisco to Oakland and extends south to San Jose could attract new non-transbay rail riders between San Jose and Oakland.

## *Corridor Rail Potential Findings*

In total, 12 corridors—9 in the East Bay and 3 in the West Bay—were developed and tested. As Figure 7 illustrates, East Bay corridors originate in Alameda and Oakland, and extend to Sacramento, Stockton, and Modesto. They are approximate linear groupings of markets, both with and without an existing passenger rail service, that are defined by natural geography, existing urbanization, and development patterns.

As Figure 8 illustrates, the West Bay corridors originate in San Francisco and occupy three different segments of the city before converging into a common segment through San Mateo and northern Santa Clara counties and ending in San Jose. Two of the three segments through San Francisco are defined by existing rail corridors: the east corridor approximately follows the Caltrain alignment from downtown San Francisco to Millbrae via the Bayshore District; and the central corridor approximately follows the BART alignment from downtown San Francisco to Millbrae via Daly City. The

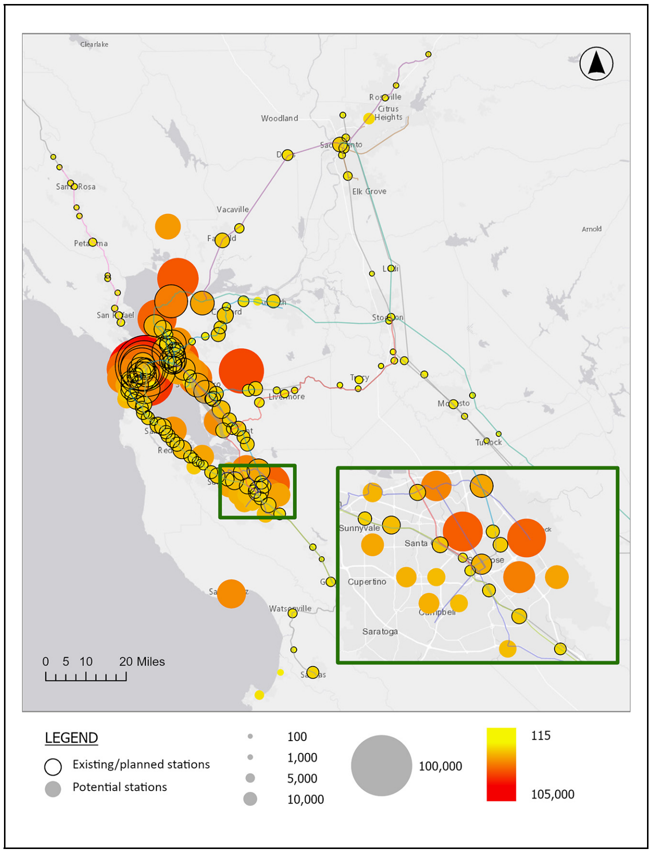


**Figure 6.** Total equity-weighted unmet rail potential (number of potential trips), 2040.
*Map background source*: Esri, HERE, NPS, Garmin, USGS, EPA.

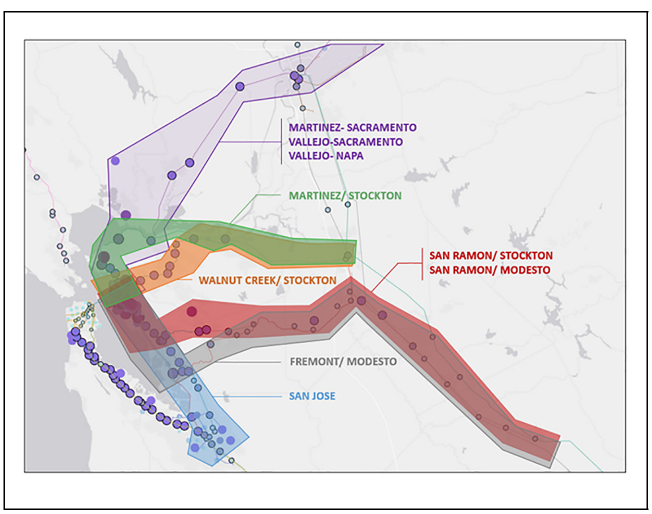


**Figure 7.** East Bay corridor definitions.

west corridor consists of several new markets without an existing passenger rail service. The common segment in San Mateo and northern Santa Clara counties approximately follows the existing Caltrain alignment from Millbrae to San Jose.

For each corridor, the segment immediately adjacent to the Transbay Corridor accounts for over half of the transbay unmet and total potential. This potential is largely driven by the selected alternative that involves new markets without an existing transbay rail service. This is particularly true for markets in the East Bay, such as parts of East Oakland that are outside the existing BART corridor.

For Sacramento-bound corridors (Figure 9) most of the remaining transbay unmet and total potential in the East Bay exists in suburban areas, notably the Richmond–Hercules segment. This segment consists of new markets without an existing transbay service, including San Pablo and Hercules. Unmet potential beyond Hercules is fairly limited apart from Vallejo, which is in the top 10 single markets by unmet potential.

Similarly, among Stockton-bound corridors, an example of which is illustrated in Figure 10, the Richmond–Hercules segment in the Martinez–Stockton corridor has the highest unmet and total potential outside of the more urban and densely populated Oakland–Richmond and Oakland–Bay Fair corridors because of the new markets along that segment.

Of all the nine East Bay corridors, unmet potential in the Modesto- and San Jose-bound corridors, an example of which is illustrated in Figure 11, is most heavily skewed toward the initial Oakland–Bay Fair segment. San Ramon, a single new market east of Bay Fair but separated from the Oakland and Bay Fair areas by a hill range, contributes a more modest amount of unmet potential compared with other segments, but on its own it is in the top five single markets by unmet potential.

By contrast, in the three West Bay corridors, an example of which (east corridor) is illustrated in Figure 12, the high unmet transbay potential in San Francisco can be attributed to new clusters in densely populated western San Francisco (e.g., Lower Pacific Heights/Japantown, Richmond District, and Sunset District), existing clusters with a poor existing transbay rail service (e.g., southeastern San Francisco), and crowded trains on the existing BART transbay rail service through downtown San Francisco. A new passenger rail service serving the latter markets could relieve crowding on existing services and unlock substantial potential demand that is unable or unwilling to use existing services.

Beyond the initial segment in San Francisco, outer segments, particularly Palo Alto–San Jose, have relatively high amounts of non-transbay unmet potential, signifying the potential benefits Link21 can deliver to riders making non-transbay trips within either the South or East Bay or between them.

Figure 13 shows the unmet rail potential by segment for a corridor between Oakland and Stockton via

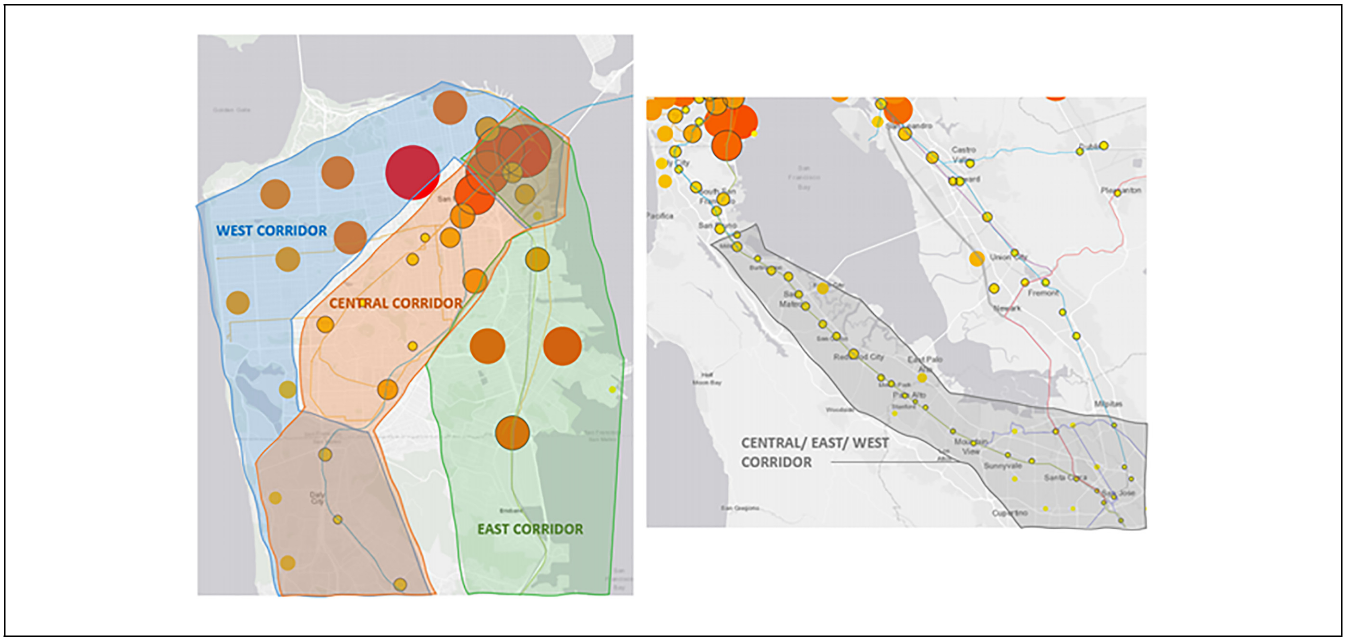


**Figure 8.** West Bay corridor definitions.

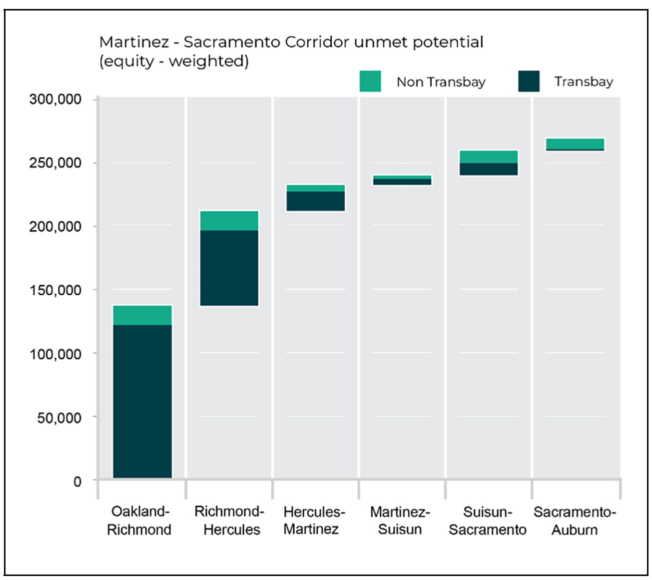


**Figure 9.** Unmet potential by segment on the Martinez–Sacramento corridor (number of potential trips), 2040.

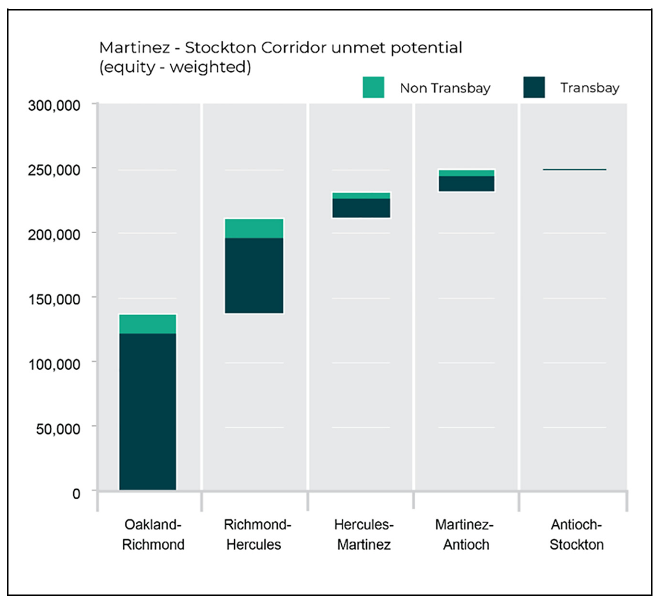


**Figure 10.** Unmet potential by segment on the Martinez–Stockton corridor (number of potential trips), 2040.

Rockridge, Martinez, and Antioch. Like other corridors, most of the transbay unmet potential can be found in the Oakland–Rockridge segment, close to the Transbay Corridor at the core of the megaregion.

However, the total unmet rail potential, both in the entire corridor and particularly in the core Oakland–Rockridge segment, is substantially lower than that of other corridors and core segments. This is because the Oakland–Rockridge segment is already well served by BART. The reason for the unmet rail potential is the crowded conditions on the existing BART service.

Other segments that have an existing transbay BART service, such as the Market Street corridor between downtown San Francisco and Daly City, have higher amounts of unmet rail potential because trains traveling through these segments have higher levels of crowding, which results in many potential riders choosing not to use passenger rail services.

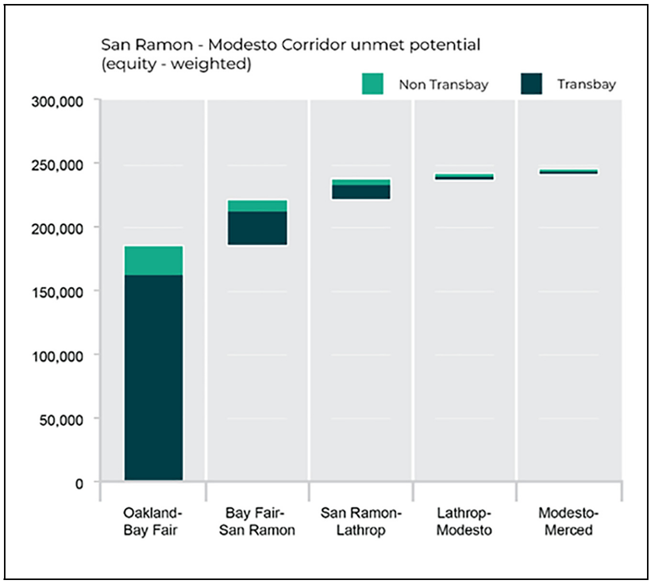


**Figure 11.** Unmet potential by segment on the San Ramon–Modesto corridor (number of potential trips), 2040.

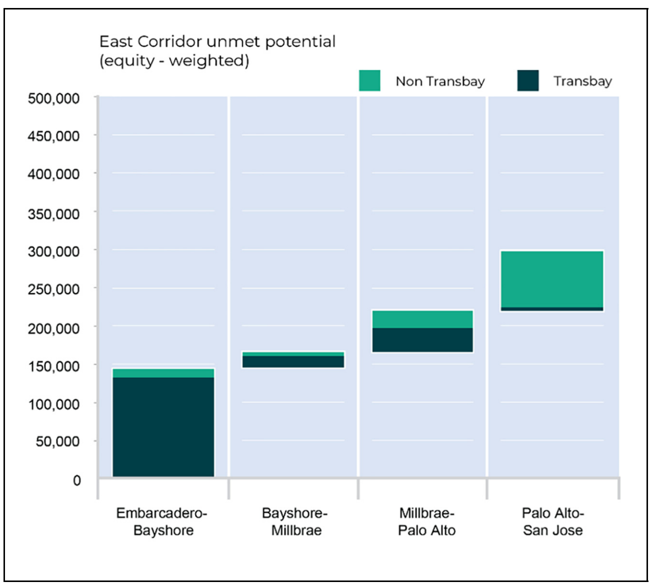


**Figure 12.** Unmet potential by segment on the West Bay (via Bayshore) east corridor (number of potential trips), 2040.

Considering individual segments across all corridors, the top five segments for transbay unmet potential on both sides of San Francisco Bay are directly connected to either end of the Transbay Corridor, as the orange boxes in Figures 14 and 15 show. As such, the extent to which an alternative can serve unmet potential will largely be driven by the markets and segment(s) it serves in the core of the megaregion.

This high amount of unmet potential can be attributed primarily to new markets without an existing transbay passenger rail service in these core areas. This includes areas such as western San Francisco and parts of East Oakland outside the existing BART corridor. Markets with a poor existing transbay rail service include areas such as Emeryville and southeastern San Francisco. Additionally, certain segments, such as Embarcadero–Daly City (central corridor), experience significant crowding. This means many potential riders choose not to use passenger rail services.

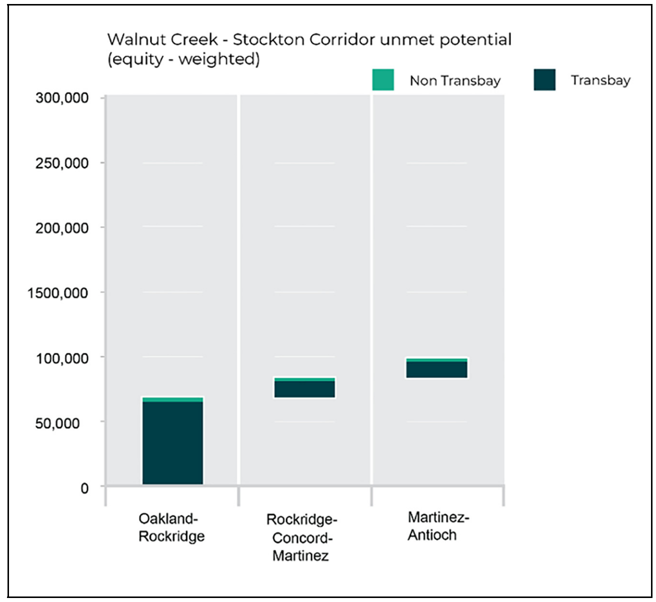


**Figure 13.** Unmet potential by segment on the Walnut Creek–Stockton corridor (number of potential trips), 2040.

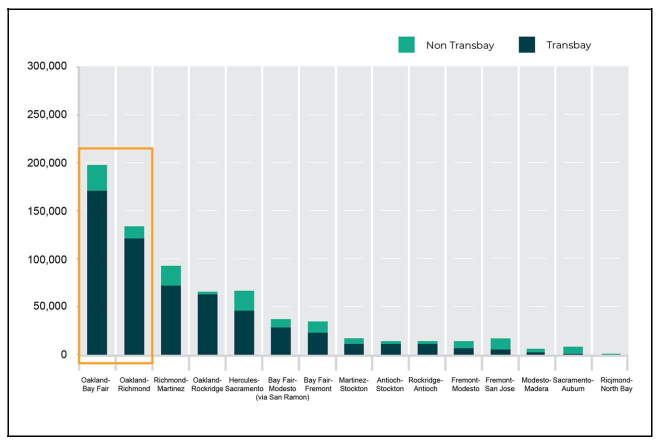


**Figure 14.** Total equity-weighted unmet rail potential (number of potential trips) for segments in East Bay corridors, 2040.

## *Uncertainty Analysis Findings*

The key finding from the Link21 uncertainty analysis is that although the absolute performance of the various

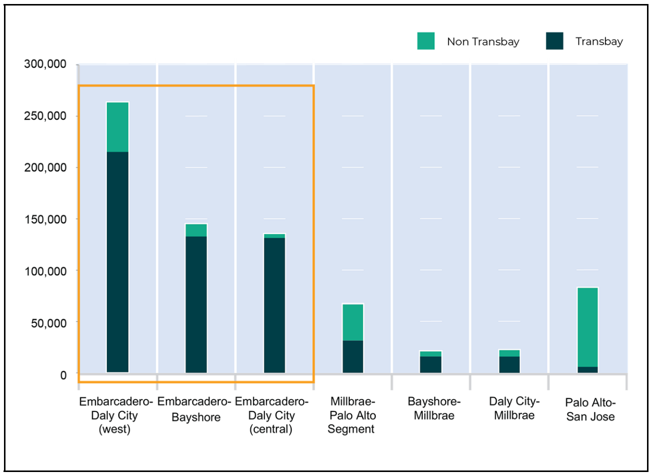


**Figure 15.** Total equity-weighted unmet rail potential (number of potential trips) for segments in West Bay corridors, 2040.

corridors and segments changes considerably under many of the uncertainty scenarios, there are no significant impacts on relative performance.

Across all the uncertainty scenarios, there are only two unique pairs of corridors and one unique pair of segments that saw changes in relative rankings, listed below:

- Oakland–Fremont–San Jose decreased one rank and Oakland–Martinez–Stockton increased one rank in the HG1 (housing growth and patterns), HG2, JG1 (job growth and patterns), JG2, TC2 (travel costs), TC3, and TC4 scenarios.
- Oakland–Martinez–Stockton decreased one rank and Oakland–San Ramon–Modesto increased one rank in the HG4, JG3, and JG4 scenarios.
- Embarcadero–Bay Fair decreased one rank and Embarcadero–Balboa Park increased one rank in the TC3 scenario.

None of the corridors or segments tested increased by more than one rank with regard to equity-weighted unmet rail potential. In all cases in which rankings did change, these were largely a result of two corridors or segments having similar potential in the baseline scenario.

This reinforces the main market analysis findings with regard to identifying corridors and segments with the highest relative equity-weighted unmet rail potential. The uncertainty analysis indicates the findings from the market and corridor rail potential analyses are very robust.

## Conclusions

The Link21 market analysis found that significant unmet potential for transbay rail ridership exists in the megaregion. This unmet potential is greatest at the core of the megaregion closest to the Transbay Corridor, particularly in and around San Francisco and Oakland and to/from locations in inner East Bay cities between Richmond and Oakland. Selected markets further from the Transbay Corridor have relatively high to medium unmet transbay rail potential, particularly those without an existing high-quality transbay service, such as San Pablo, Hercules, Martinez, Vallejo, Napa, Fairfield, San Ramon, and parts of San Mateo County. Other markets have high non-transbay unmet rail potential (particularly in San Mateo and Santa Clara counties). These findings suggest that a new transbay passenger rail crossing and associated investment in the rail network could benefit travelers across the megaregion.

The findings demonstrate how a market analysis methodology for a passenger rail potential analysis with an overarching emphasis on equity can be applied to similar analyses for other passenger rail and transportation investments. Such an application to other investments and areas would require careful consideration of local contextual factors, such as existing rail service provision, demographic and socioeconomic characteristics, and other elements of the local transportation system.

First, beyond existing and future travel patterns across all modes and distributions of population and employment, insights into the potential demand for the mode and service that are being considered for investment provide valuable information that can offer direction with regard to the specification and development of investment alternatives. The rail potential findings presented in this paper provide important input for developing and refining Link21's initial alternatives, but they should be considered alongside other factors such as engineering and operational feasibility, cost, and deliverability. For example, some alternatives were developed primarily to serve areas identified in the market analysis as having high unmet potential, whereas others were based on different sources, but adjusted to serve some high-potential markets.

Second, during such an exploration of potential demand, the importance of serving certain population groups and influencing the outputs and findings accordingly should be emphasized. In the case of Link21, the program team has acknowledged that the current use of passenger rail services by systematically disadvantaged populations may be particularly detached from the overall demand for passenger rail because of historical underinvestment, which has made passenger rail services harder to access and/or less convenient. As such, serving communities that have a high share of such populations and delivering benefits to them is a point of emphasis for Link21, and it has increasingly been the case for cities and regions around the world too. Double counting potential trips made by these priority populations is in line with the methodology used by the FTA in its CIG program. Incorporating this step early in the lifecycle of an investment, as has been done for Link21, can help transportation planners across the country ensure that the travel needs of such populations are a central part of the decision-making process.

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## Author Contributions

The authors confirm contribution to the paper from the following individuals: study conception and design: Laura Vina-Arias, Megan Brock, Mario Scott, Andrew Desautels, Mark Mukherji, Tony Duckenfield; data collection: Laura Vina-Arias, Megan Brock, Mario Scott, Alex Malerba, Hana Shuck, Nikita Benson; analysis and interpretation of results: Laura Vina-Arias, Megan Brock, Mario Scott, Andrew Desautels, Mark Mukherji, Alex Malerba, Hana Shuck, Nikita Benson. All authors reviewed the results and approved the final version of the manuscript.

## Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Andrew Tang is a BART employee with a full-time role on the Link21 project. Elisa Tejedor and Derek Cheah are consultants hired by BART to perform various aspects of the Link21 planning study.

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