APPENDIX B
Model Development Report

FEHR & PEERS
TRANSPORTATION CONSULTANTS

MEMORANDUM

Date: May 5, 2009

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Kenya Wheeler and Val Menotti, BART

From: Jerry Walters, Mark Feldman and Jeff Davis, Fehr & Peers

Subject: BART Demand Management Study (DMS) Direct Ridership Model Development

WC07-2478

INTRODUCTION

This memo describes the development of a Direct Ridership Model for the BART Demand Management Study (DMS). The overall study objectives include assessing the effects of changes to BART fares and parking fees on station ridership at different times of the day.

What is a Direct Ridership Model?

Direct Ridership Models use multivariate regression and other statistical models based on empirical local data to determine the station characteristics that most influence rail transit patronage. They respond directly to factors such as parking, feeder bus levels, station-area households and employment, and the effects of transit-oriented development (TOD). Direct Ridership Models are a more efficient and responsive means of forecasting the effects of individual station activities than conventional transit patronage models. Rail ridership is traditionally forecast with region-wide travel demand models, which often represent transportation networks and land use at an aggregate scale. Such models are relatively unresponsive to changes in station-level land use and transit service characteristics. Direct Ridership Models are directly and quantitatively responsive to land use and transit service characteristics within the immediate vicinity and within the catchment area of existing transit stations.

The Direct Ridership Models developed for this study predict changes in ridership at individual stations for four access and three egress modes during nine different times of the day (as shown in Table 1 below), based on empirical relationships found through statistical analysis of BART system ridership data and the 2008 Passenger Profile Survey. Direct Ridership Models provide a predictive method based on existing rail transit service and with demonstrated ability to match ridership relationships measured on those services. In addition, the models have demonstrated the ability to match total station alightings in most times of the day for a “backcast” year of 2000, based on the station area demographics and transit service characteristics at that time.

Relationship to BART Ridership Model (BRM)

The Direct Ridership Models in this study will integrate with the larger BART Ridership Model (BRM) by providing total boardings and alightings at each station during different time periods. These station totals will then be used to develop station origin-destination (OD) matrices in the larger BART Ridership Model, developed by HDR Consulting. The larger model will also include the ability to adjust for global effects like BART fare and parking fee changes, travel time changes, auto fuel price changes and auto congestion levels. These global effects are not possible to capture in the Direct Ridership Models alone, due to their dependence on combinations of origins and destinations.

MODEL DEVELOPMENT PROCESS

The objective of the BART DMS model development effort was to derive statistically valid models capable of predicting current station-specific ridership, both boardings and alightings, over nine time periods. The models would need to be capable of respond to input changes, and therefore be able to predict future ridership. The time periods modeled are presented in Table 1. The time periods were obtained through analysis of the station profile survey data to determine peak ridership periods and approved in discussions with BART staff.

TABLE 1
TIME PERIODS MODELED

Period	Boardings Time Period	Alightings Time Period
AM Early	3:30 AM – 6:29 AM	3:30 AM – 6:59 AM
AM Pre-Peak Shoulder	6:30 AM – 7:29 AM	7:00 AM – 7:59 AM
AM Peak	7:30 AM – 8:29 AM	8:00 AM – 8:59 AM
AM Post-Peak Shoulder	8:30 AM – 9:29 AM	9:00 AM – 9:59 AM
Midday	9:30 AM – 3:59 PM	10:00 AM – 4:29 PM
PM Pre-Peak Shoulder	4:00 PM – 4:59 PM	4:30 PM – 5:29 PM
PM Peak	5:00 PM – 5:59 PM	5:30 PM – 6:29 PM
PM Post-Peak Shoulder	6:00 PM – 6:59 PM	6:30 PM – 7:29 PM
Evening	7:00 PM – 1:59 AM	7:30 PM – 1:59 AM

Source: Fehr and Peers, 2009.

Boardings models were developed for each time period for four modes of access: Walk/Bike, Transit, Park, and Drop Off. These models were combined to develop the total boardings for each time period. Alightings models followed a similar process, but with only three modes of egress: Walk/Bike, Transit and Drive. The drive alightings models represent both patrons who drive out of the station lots and those who are picked up. It is not necessary to distinguish those on the alightings side in the same way as on the boardings side, because there are no access constraints associated with people leaving the parking lots. Walk and bike models were combined due to small sample sizes; a meaningful bike-only model could not be produced with the amount of data available.

In the case where time periods had too few riders to produce statistically significant models (early AM drive alightings for example), ridership from adjacent time periods were combined and the time periods were modeled together. A factor was then applied to the combined model to produce the best statistical match for the individual time periods relative to the survey data. Typically these combined models represented a single mode of access or egress for the three hour AM or PM peak period.

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The access and egress mode data supplied by BART came from the passenger profile survey conducted during the spring of 2008. The survey responses included the boarding station, the alighting station, and the mode of access and egress to or from each station.

The ridership data, also supplied by BART, came from the same days on which the survey was taken. Average boardings and alightings for each time period were created from the ridership data.

Data was developed for nearly 100 independent variables believed to be potentially predictive of station ridership. These variables roughly break into ten categories:

- Population (1/2 mile and catchment)
- Employment (1/2 mile and catchment)
- Housing
- College Enrollment
- Parking (Automobile and Bicycle)
- Walkability Measures
- Feeder Transit Service
- BART train data (frequency and in-vehicle travel time)
- Impedance Measures (auto vs. transit utility)
- Geographic Location (the two sides of the East Bay Hills)[1]

Station-related population, housing, and employment data within a half-mile radius of the BART station was derived with Travel Analysis Zone (TAZ) data from several regional travel demand models, including the Alameda CMA and Contra Costa Transit Authority (CCTA) models, the San Francisco CHAMP3 model, and the Metropolitan Transportation Commission (MTC) model for San Mateo County data[2]. The versions available of all of these models at the time of the beginning of the study used *ABAG Projections 2005* for their land use data. For each station, a set of demand model TAZs was defined from which to include land uses. For TAZs entirely within a half-mile radius of BART stations, all of the land use was included in the station-related data. In cases where part of the TAZs was within a half-mile radius, aerials and the roadway network were examined to determine appropriate percentages of the residential and non-residential uses within each TAZ to include in the station-related data.

The extensive effort necessary to determine station area land use based on local TAZs made it possible to analyze only one radius length around each station. The half-mile was chosen, as opposed to the quarter-mile or some other distance, because it corresponds roughly to what is considered waling distance for most people, and because it has proven to be explanatory in past BART direct ridership modeling efforts, such as *Access BART* (2006).

The same dataset was also used to develop station catchment area population and employment data[3], as well as full and part-time college enrollment. The local model data was used to more

[1] The side of the East Bay Hills was only a predictor of the arrival distribution in the early AM and AM peak for park-and-ride boardings, with stations to the east of the hills attracting more of these passengers earlier in the AM, because of their greater distance from downtown San Francisco.
[2] San Mateo County does not have a recent travel demand model with greater detail than the MTC TAZ system.
[3] The catchment area refers simply to the most likely service areas for each station. These areas are developed based on the proximity to the station and the ease of access over different transportation modes. Each station catchment has a

accurately measure land use in the stations' immediate vicinities; the MTC model TAZs are usually much larger than the stations' half-mile radii.

Catchment areas were developed from the survey responses to the passenger's home origin. The origins were geocoded by the Santa Clara VTA using ArcGIS, and the geographic data was overlaid on the MTC TAZ system to obtain areas for each origin station. BART staff performed data cleaning and some address research. In cases where TAZs contained a significant number riders accessing more than one station, the catchment population was divided proportionally according to the relative number of riders accessing these stations. TAZs beyond certain geographic points with only the occasional rider (e.g. in most of Santa Clara County) were not included, to prevent terminus stations like Fremont from having artificially large catchment populations. A technical description of how the catchment areas were derived is provided in Appendix D.

On-site parking supply was received directly from BART and contained information on total number and types (free, reserved, paid, carpool, and midday) of spaces. Neighborhood parking supply, defined as unrestricted free on-street parking or private lots costing less than $7 / day, was collected in the field by Fehr and Peers in 2008. Data was gathered at both quarter mile and half mile walk-sheds[4] for similar categories as on-site parking.

Two walkability measures were developed for the study. The first, a neighborhood connectivity measure, was calculated by determining the number of polygons (complete shapes) created by roadways and pedestrian/bike paths within a half mile of the station. Polygons were created using GIS roadways, with additional walking paths added from local knowledge. The polygon method is superior to other simple measures of street connectivity, such as street density, because it differentiates between a grid development pattern and a suburban cul-de-sac pattern.

The second walkability measure was the station design rating. This rating related directly to the permeability and accessibility of the station, as well as its orientation (automobile or pedestrian). The measure combined three categories to form a score from 0-6. The station scored a single point for (1) being underground, (2) not being adjacent to a freeway, and (3) for each direction (out of four) that the station provides direct access to the surrounding neighborhood without having to travel at an angle more than 45 degrees in either direction or having to cross a freeway/expressway, a large parking lot, or an industrial area.

Feeder transit frequency data was received from BART in December, 2008. Data was given in terms of peak hour headways. This variable was used for transit frequency for all time periods in the absence of more specific data. The variable should still be valid across all time periods because, in general, the proportional relationship between peak headways and off-peak headways should be similar across stations.

Two more explanatory transit frequency variables, regular and "premium" transit, were developed to account for the difference in the quality of transit service. "Premium" transit included services that tend to generate higher amounts of riders, for reasons including frequent service, an exclusive right-of-way, or a higher quality in-vehicle experience. Some examples of this are MUNI light rail, Caltrain commuter rail, and shuttle service such as the Oakland Airport Shuttle or shuttles run by large private employers.

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unique area, with no over-lapping. Since many drive access riders come from outside the ½ mile station area, catchment area population and employment data are often more descriptive than half mile variables for parking and transit models.

[4] A walk-shed refers to the actual walking distance along roads or paths as opposed to the straight "air" line distance, which is a linear distance from the station.

BART train frequency at each station for the nine time periods was developed from BART schedules as of 2008. In-vehicle travel times were received from BART in 2008.

Impedance measures, or auto vs. transit utility, compared the travel time and cost between origins and destinations across the BART system to determine which of the two modes was preferable, and by how much. Data from the MTC travel demand model were used for auto travel times, equating time with monetary cost, station area parking costs, fuel and auto operating costs. Actual BART schedules, fares, and station parking fees were used to determine the travel time and cost of BART trips. Once the relative utilities were computed for all origin / destination pairs in all time periods, these utilities were weighted by a measure of destination station attractiveness for use in boardings models, and by a measure of origin station attractiveness for use in alightings models. The attractiveness measures were either ½ mile population, ½ mile employment, or ½ mile (population + employment), depending on the time period being analyzed.

Airport stations (SFO and the future OAC station) were excluded from this study, because of the unique station area land uses and factors which influence ridership at those stations.

DESCRIPTION OF DIRECT RIDERSHIP MODELS

The mathematical form of each model is a linear regression formula, with each incorporating a portion of the variables listed in Tables A-1 and A-2. The final systemwide Direct Ridership Model results for both 2008 and the 2000 "Backcast" described in the following section are presented in Tables 2 and 3. Station-by-station comparison graphs for each of the nine time periods and a daily summation grouped by boardings and alightings are presented in Appendix A. The variables included in each model, along with overall model performance indicators (R-squared) are presented in Appendix B. The R-squared indicator expresses how close the model comes to explaining all of the station-to-station variability in the dependent variable. For example, a perfect R-squared value of 1.0 model indicates the variation in PM ridership among all BART stations is fully described by the model's combination of independent variables (population, employment, etc.) with their respective coefficients and constant term.

BACKCAST

Demonstrating that a regression model can respond accurately to changes over time can lend additional credibility to its overall validity. To this end, Fehr & Peers tested the model on a best estimation of conditions from the year 2000. Values for most of the variables that were components of the models were available for 2000. The variables not available were neighborhood parking supply, bike parking supply, and the neighborhood connectivity and design measures. Bike parking supply from 2005, the earliest year available, was used in the backcasts. In the other two cases, the values from 2008 were used.

The backcasts were developed by applying the models developed and calibrated to 2008 conditions to the variables' 2000 values. Because the 2000 ridership data was available by time of day for exits but not for entries, a direct comparison to the 2008 time of day models was only possible for alightings. Table 2 presents the model's systemwide ridership predictions by time period and compares the predictions to actual ridership for both 2000 and 2008. Table 3 presents the predicted daily access mode shares for 2000 and 2008 and compares them to the actual mode shares from BART's 1998 and 2008 passenger surveys[5]. Appendix C contains the backcast station-by-station comparison graphs for the AM and PM peak hour and daily alightings.

TABLE 2
SYSTEMWIDE ALIGHTINGS BY TIME PERIOD

Time Period	2008			2000		
	Predicted	Actual	Deviation	Predicted	Actual	Deviation
Early AM	19,317	17,424	11%	13,876	19,403	-28%
AM Pre-Peak	32,580	32,047	2%	26,860	33,842	-21%
AM Peak	43,671	42,854	2%	37,684	38,767	-3%
AM Post-Peak	25,983	25,770	1%	20,760	19,947	4%
Mid-Day	94,069	92,903	1%	85,095	79,577	7%
PM Pre-Peak	33,193	33,401	-1%	30,969	31,335	-1%
PM Peak	42,065	42,566	-1%	39,698	36,446	9%
PM Post-Peak	26,588	26,714	0%	26,416	25,493	4%
Evening	41,493	41,285	1%	36,765	36,892	0%
Daily	358,959	354,963	1%	318,122	321,702	-1%

Source: Fehr & Peers, 2009.

TABLE 3
SYSTEMWIDE DAILY ACCESS MODE SHARES

Mode	2008			2000 Ridership Model / 1998 Station Survey		
	Predicted	Actual	Deviation	Predicted	Actual	Deviation
Walk / Bike	55%	56%	-1%	59%	49%	10%
Transit	17%	16%	1%	15%	21%	-6%
Park	20%	20%	0%	20%	22%	-2%
Drop-Off	8%	8%	0%	6%	8%	-2%

Source: Fehr & Peers, 2009.

Table 2 shows that the ridership models come very close to 2008 actual ridership, for all time periods studied and for each access mode. For 2000, the models predict ridership within 10% for most time periods, with the exceptions of the early AM and AM pre-peak (i.e. prior to 8:00 AM). A

[5] There was no survey in 2000, so 1998 access mode shares were used in combination with 2000 ridership as the best available estimate of 2000 ridership by access mode.

comparison of the actual ridership for those two time periods shows that the number of riders actually decreased from 2000 to 2008; this decrease was offset by an increase in riders in the AM peak hour and post-peak hour (8-10 AM). The majority of this shift was manifested in alightings at the four downtown San Francisco stations (Embarcadero through Civic Center). Discussions between Fehr & Peers, Nelson Nygaard and BART staff have revealed several possible explanations for this shift, including:

- Implementation of reserved and paid parking programs providing the opportunity for some BART patrons to arrive at the parking lots later than before
- A 5% decline in catchment employment levels for BART stations in the downtown area since early 2000[6], due to the "dot com bubble"
- Small survey sample sizes at the individual station level at many stations in the early time periods

Independent of external economic trends or parking policy decisions, the model responds well to other shifts in station characteristics to capture overall ridership trends. In addition to the shift from early AM to late AM peak period, Table 3 shows that access modes have shifted towards walking and biking, at the expense primarily of transit, with a slight decrease in drive access as well. The direct ridership model does not completely pick up on this trend. We believe some reasons for this are:

- The lack of available data on neighborhood off-site parking supply[7]
- Changes in the pricing and/or convenience of feeder transit service
- The implementation of parking fares acting as a slight deterrent to drive access
- The lack of available data on the increase in the number and quality of bike parking facilities since 2000

FORECASTING

The Direct Ridership Models will be used in tandem with HDR's updated O/D models to forecast ridership by station in the year 2020 for the purposes of the DMS.

Year 2020 station service characteristics and area demographics will be fed into the models. The 2020 model predictions obtained in this way will be adjusted automatically in the spreadsheet tool provided to BART staff, based on the differences between the 2008 model estimates and actual ridership for each station. This accounts for unique characteristics of each station that the model is unable to capture. This adjustment is done as follows:

[6] Obtained from ABAG *Projections 2005*

[7] Anecdotally, it is believed that many cities have implemented residential permit and/or 2 hour maximum parking on streets in the vicinity of BART stations since 2000, and at least one station – El Cerrito Plaza – did not actively prevent BART patrons from parking in a nearby mall lot in 2000. The model's predictions use the 2008 levels of neighborhood parking supply.

If the predicted values from the models differ from the actual values by more than 50%, either above or below, the following “difference” equation is used:

2020 Forecast Value = 2020 Model Prediction + (2008 Model Prediction – 2008 Actual Value)

If, on the other hand, the predicted values from the models are within 50% of the actual values (which is usually the case), a “blend” method is used instead:

2020 Forecast Value = the average of

2020 Model Prediction + (2008 Actual Value – 2008 Model Prediction) and
2020 Model Prediction * (2008 Actual Value / 2008 Model Prediction)

An example of each of the above forecasting equations is shown in Appendix E.

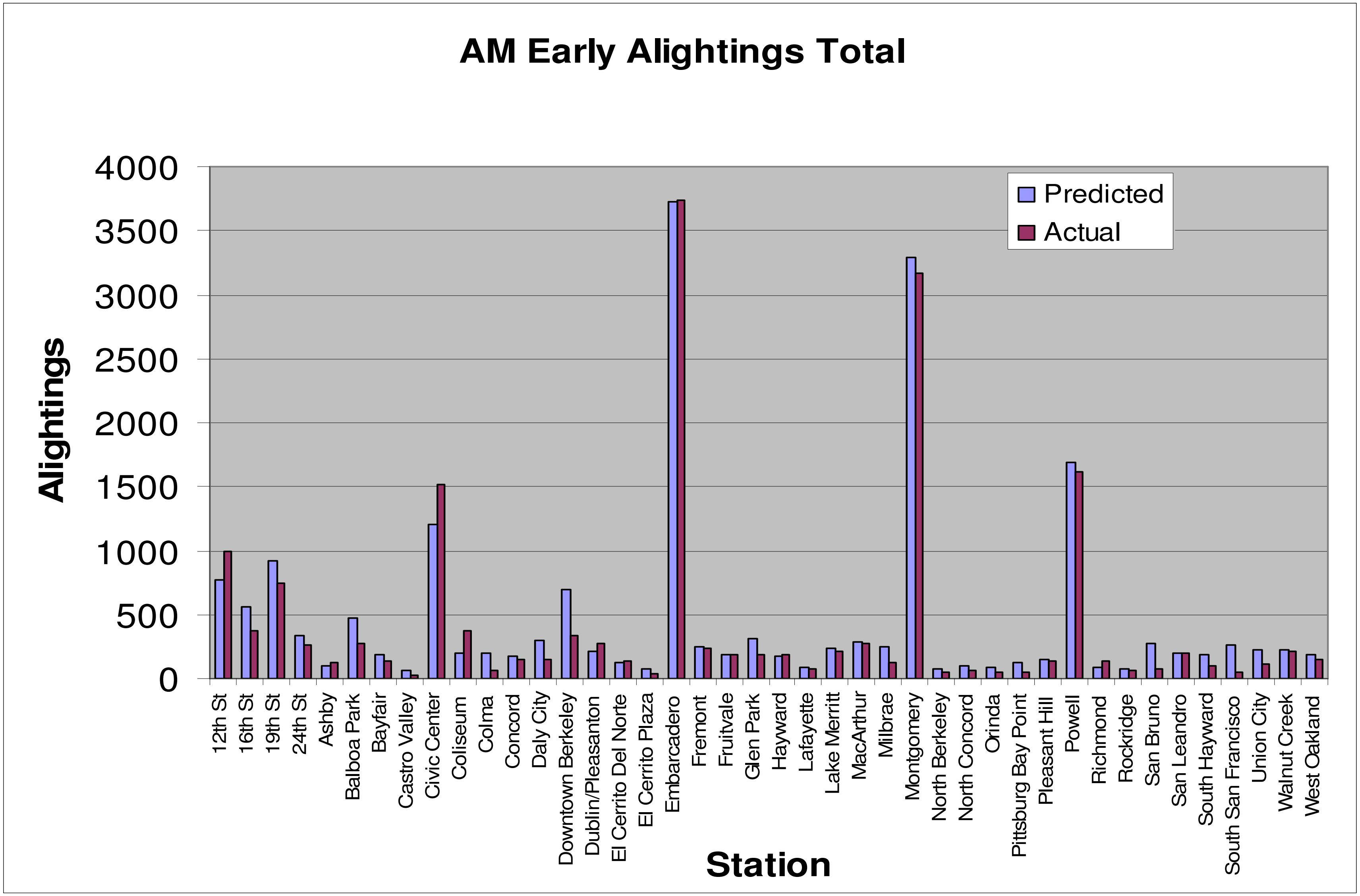
These 2020 Forecast Values for each individual model are combined across access or egress modes to obtain total boardings or alightings at each station for each of the nine time periods. The results will then be fed into the O/D component of the model, developed by HDR, which incorporates BART fare and parking fee elasticities.

The combined models will be delivered as a spreadsheet to BART staff, with the ability to vary station inputs and fare strategies for 2020, as defined within the parameters of the DMS.

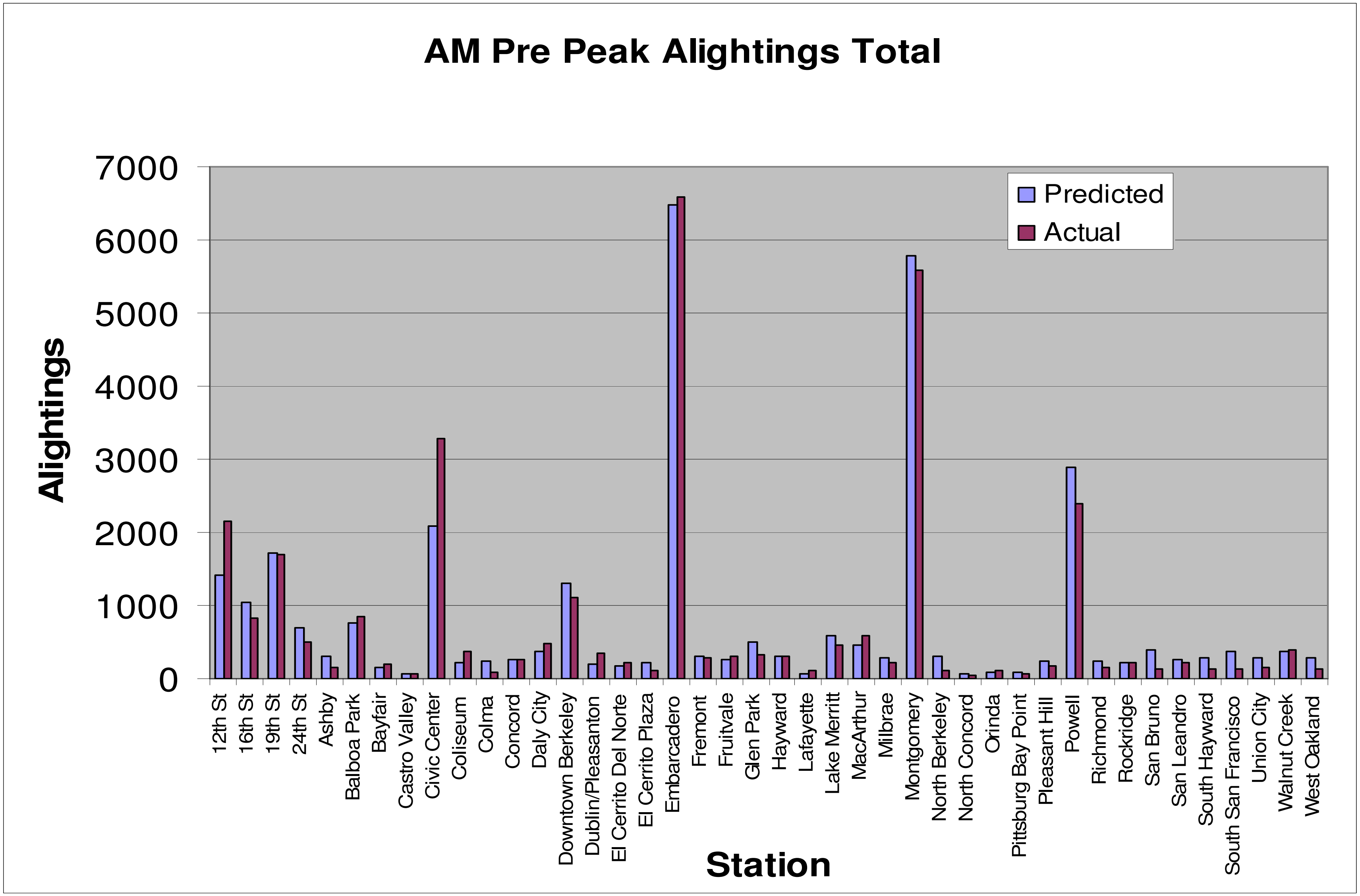
APPENDIX A

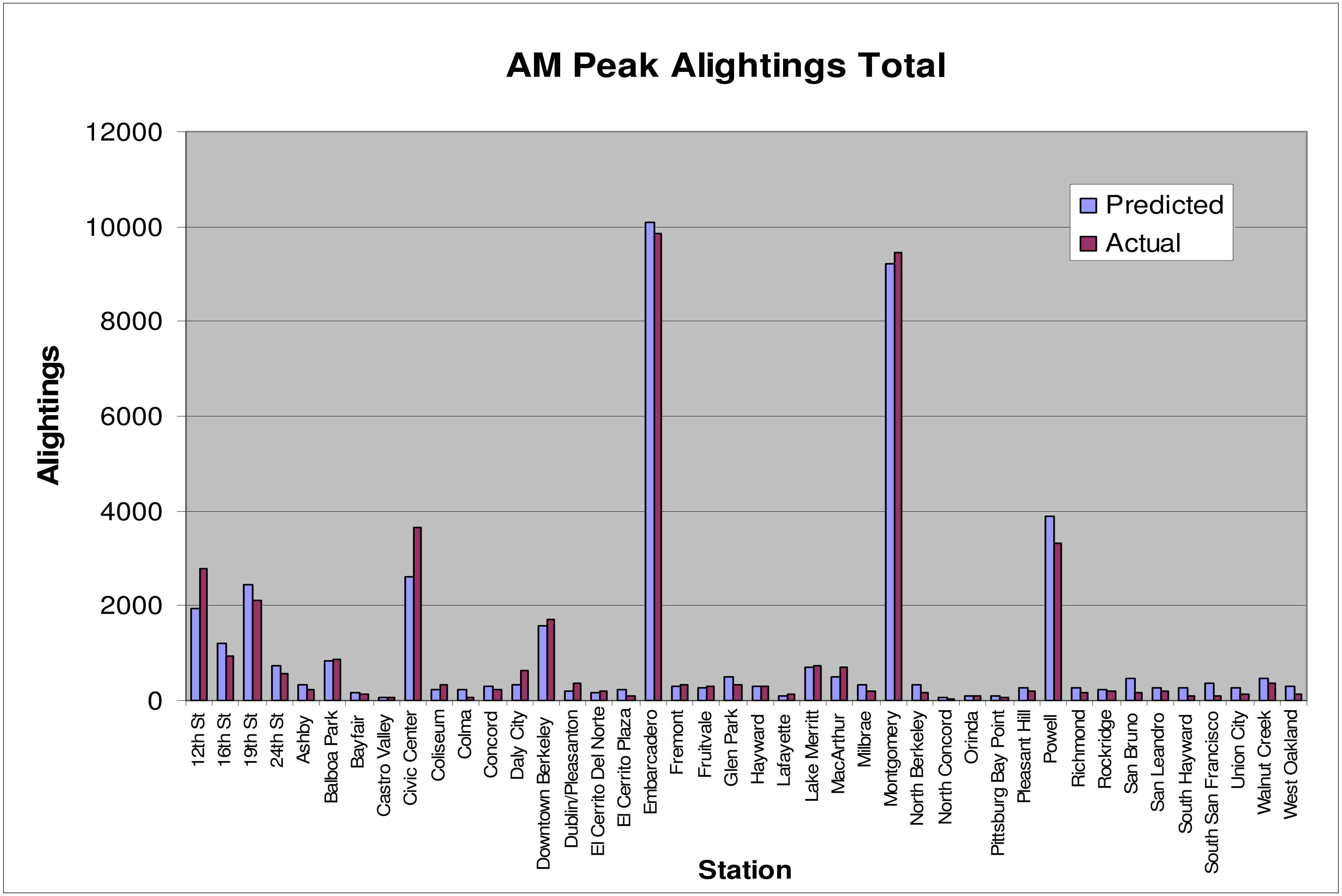
STATION-BY-STATION COMPARISON GRAPHS

2008 DIRECT RIDERSHIP MODEL

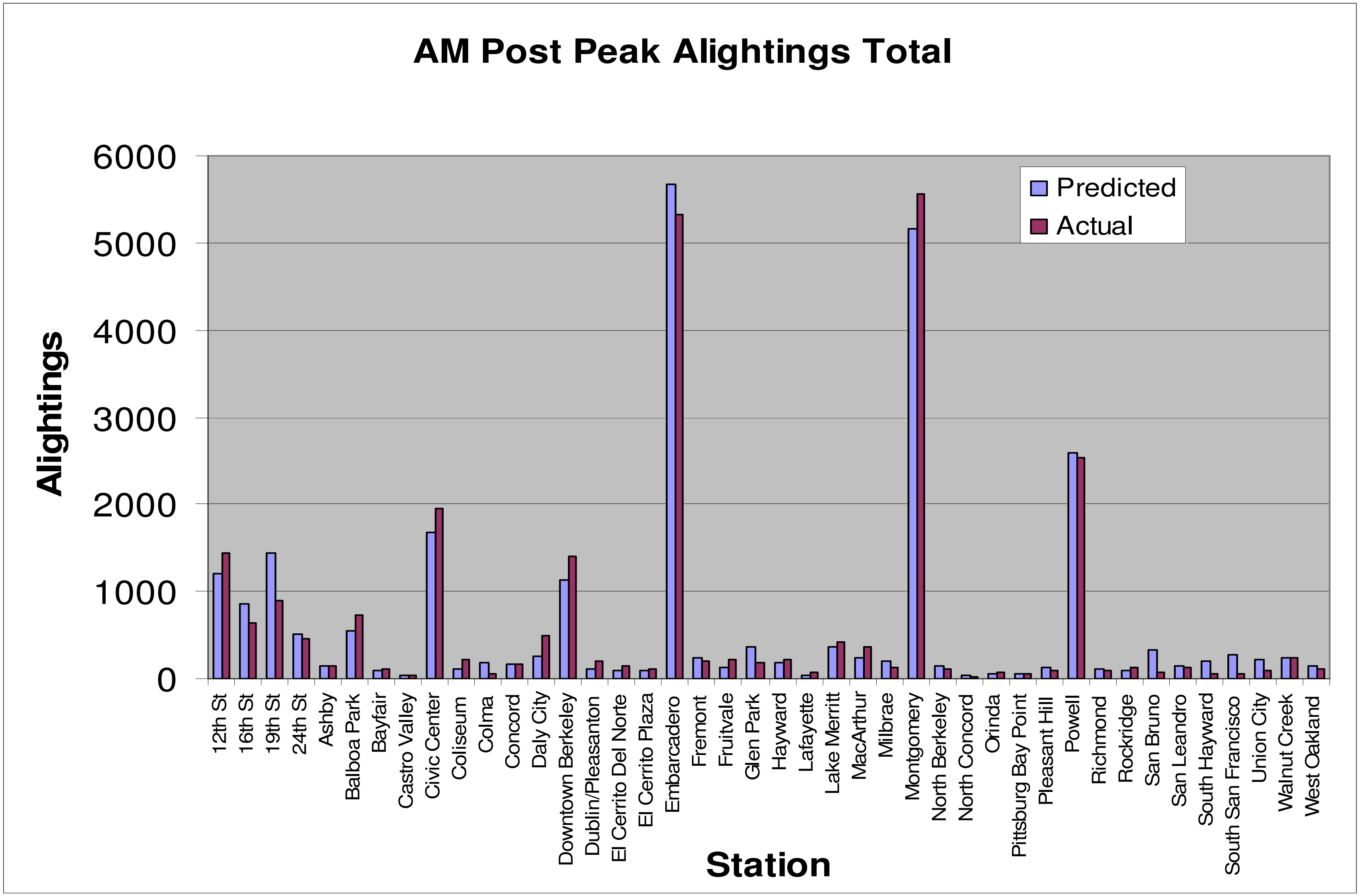


AM Early Alightings Total
Alightings
4000
3500
3000
2500
2000
1500
1000
500
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station


AM Pre Peak Alightings Total
Predicted
Actual
Alightings
0
1000
2000
3000
4000
5000
6000
7000
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station



AM Peak Alightings Total
Alightings
Station
Predicted
Actual
12000
10000
8000
6000
4000
2000
0
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland



AM Post Peak Alightings Total
Predicted
Actual
Alightings
6000
5000
4000
3000
2000
1000
0
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
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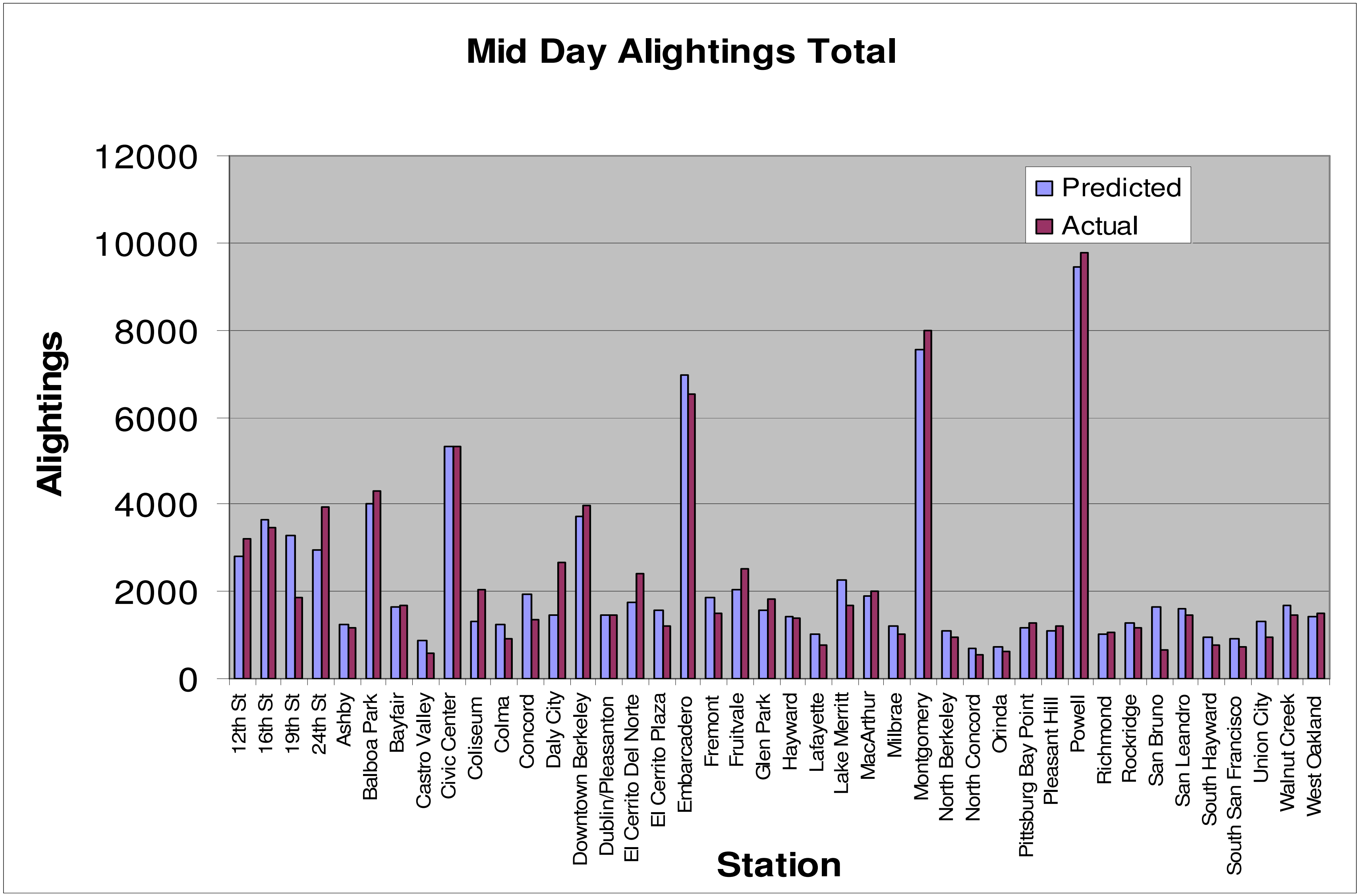
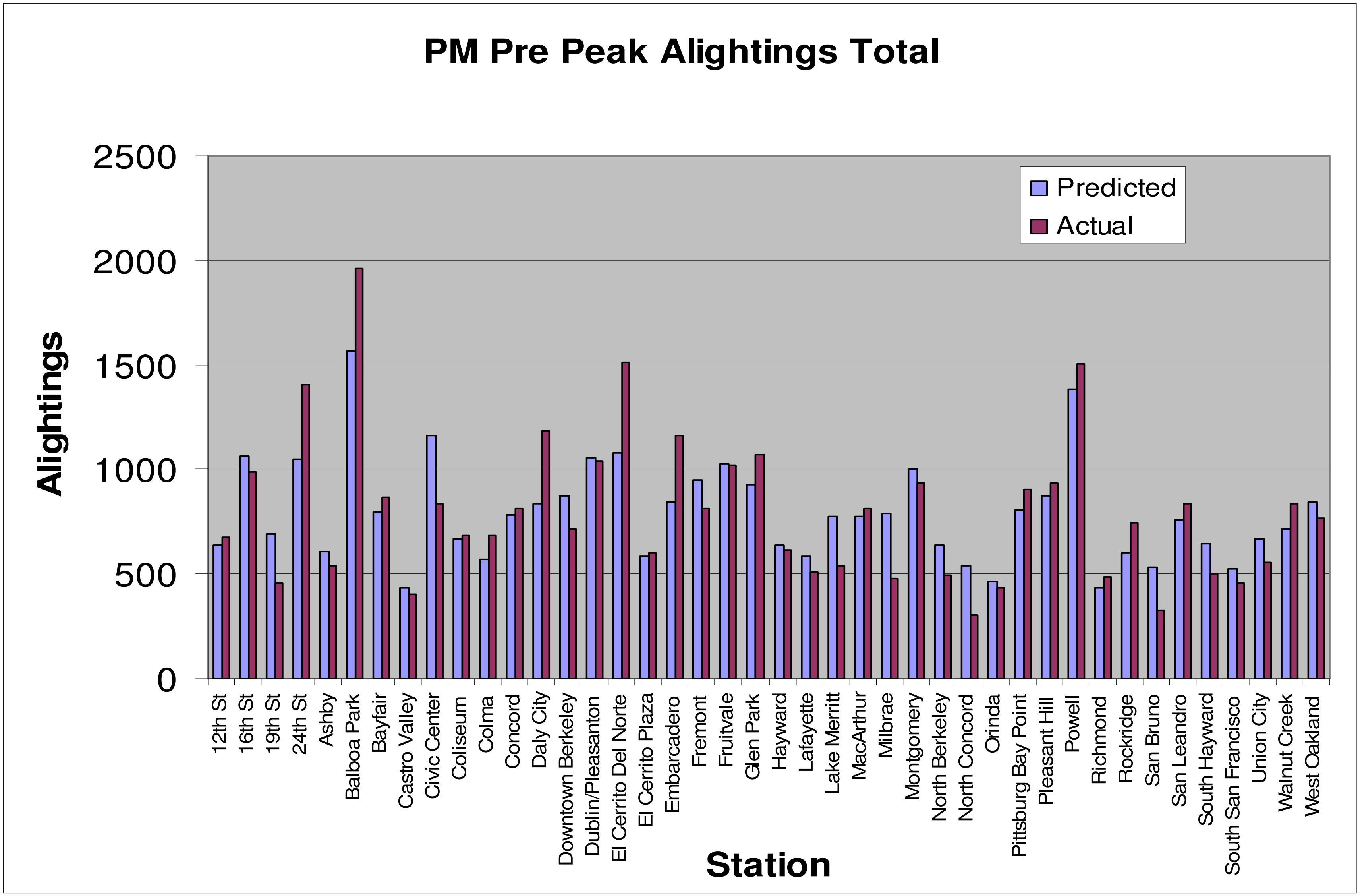
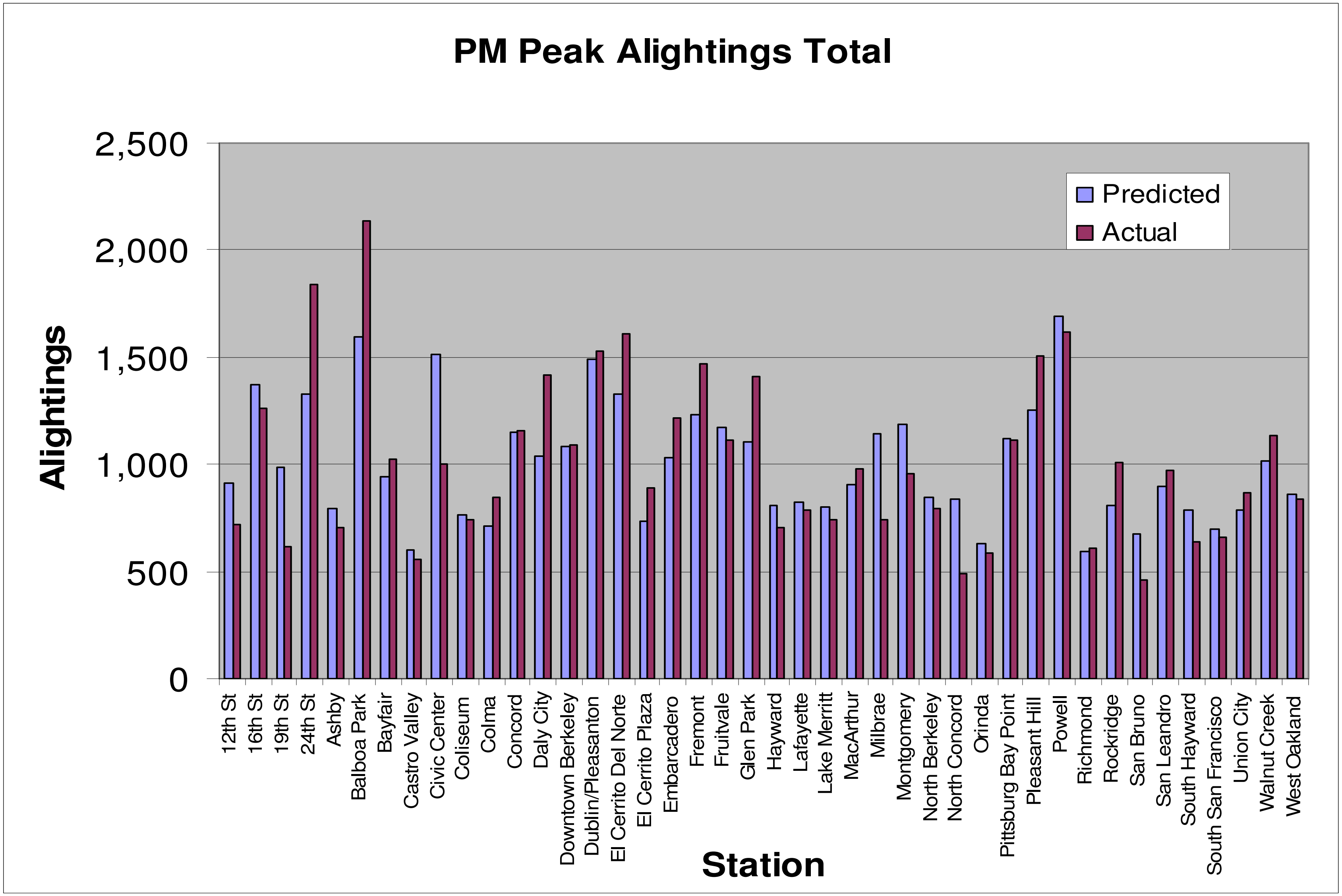
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

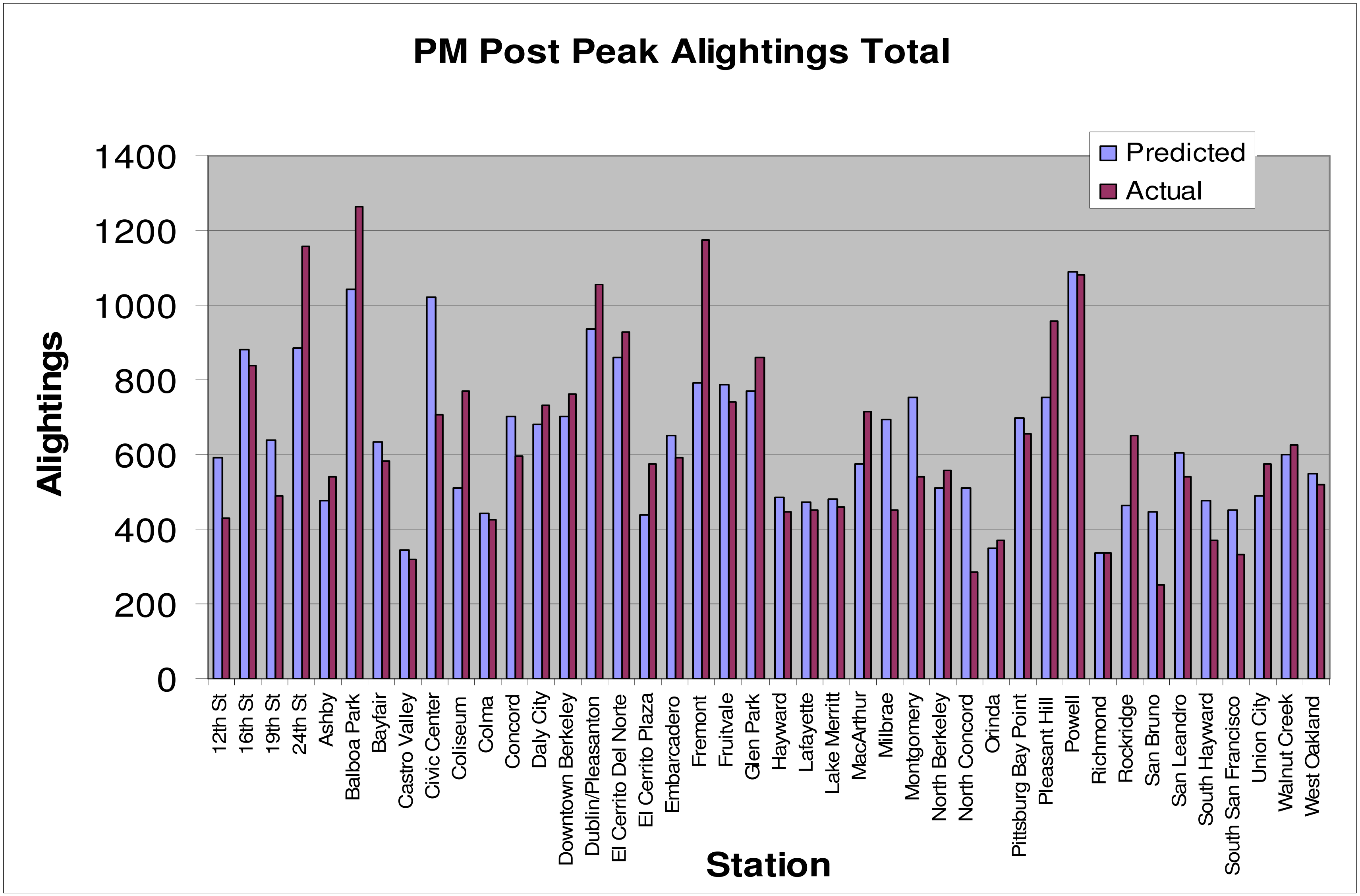


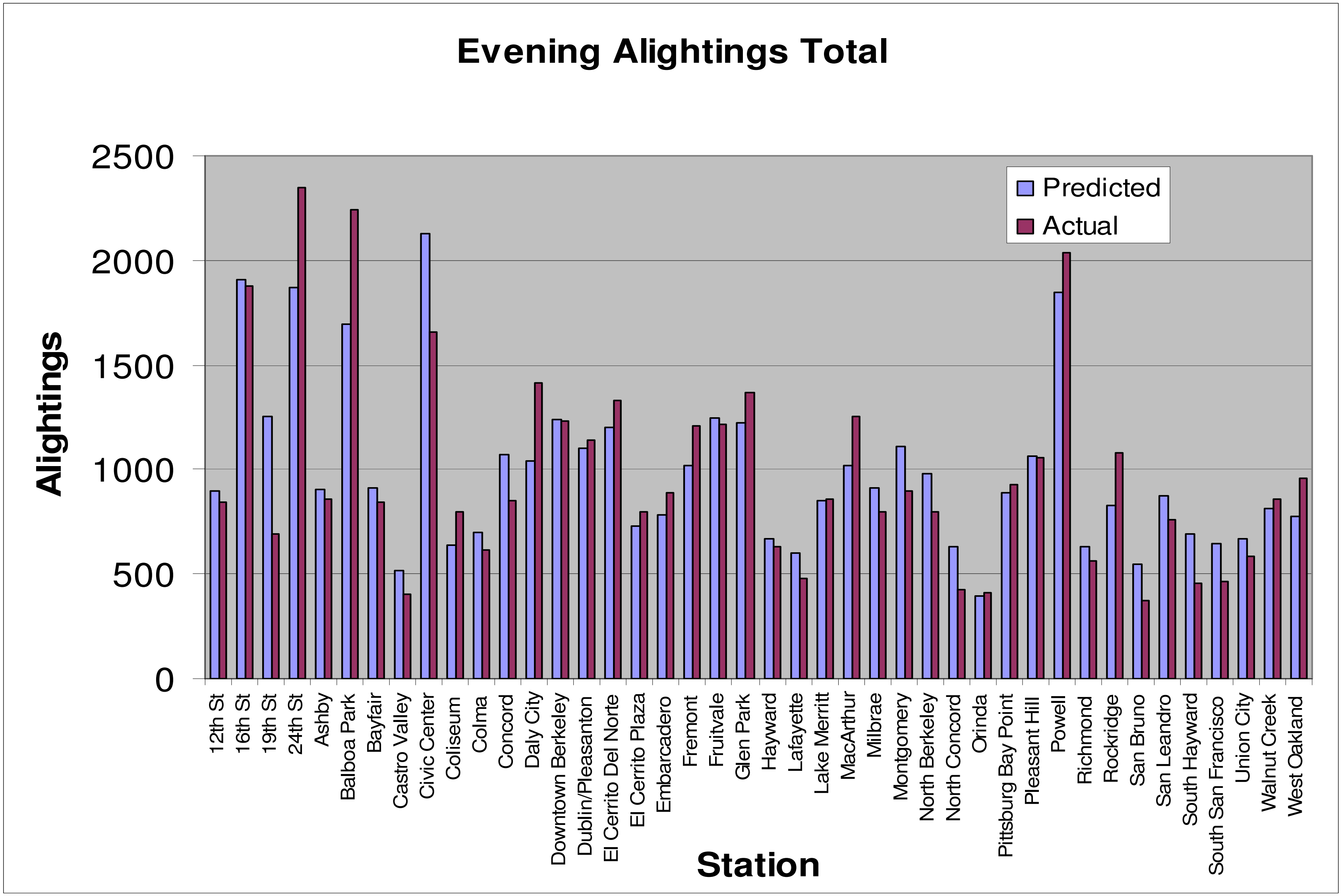
Mid Day Alightings Total
Alightings
12000
10000
8000
6000
4000
2000
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Milbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station



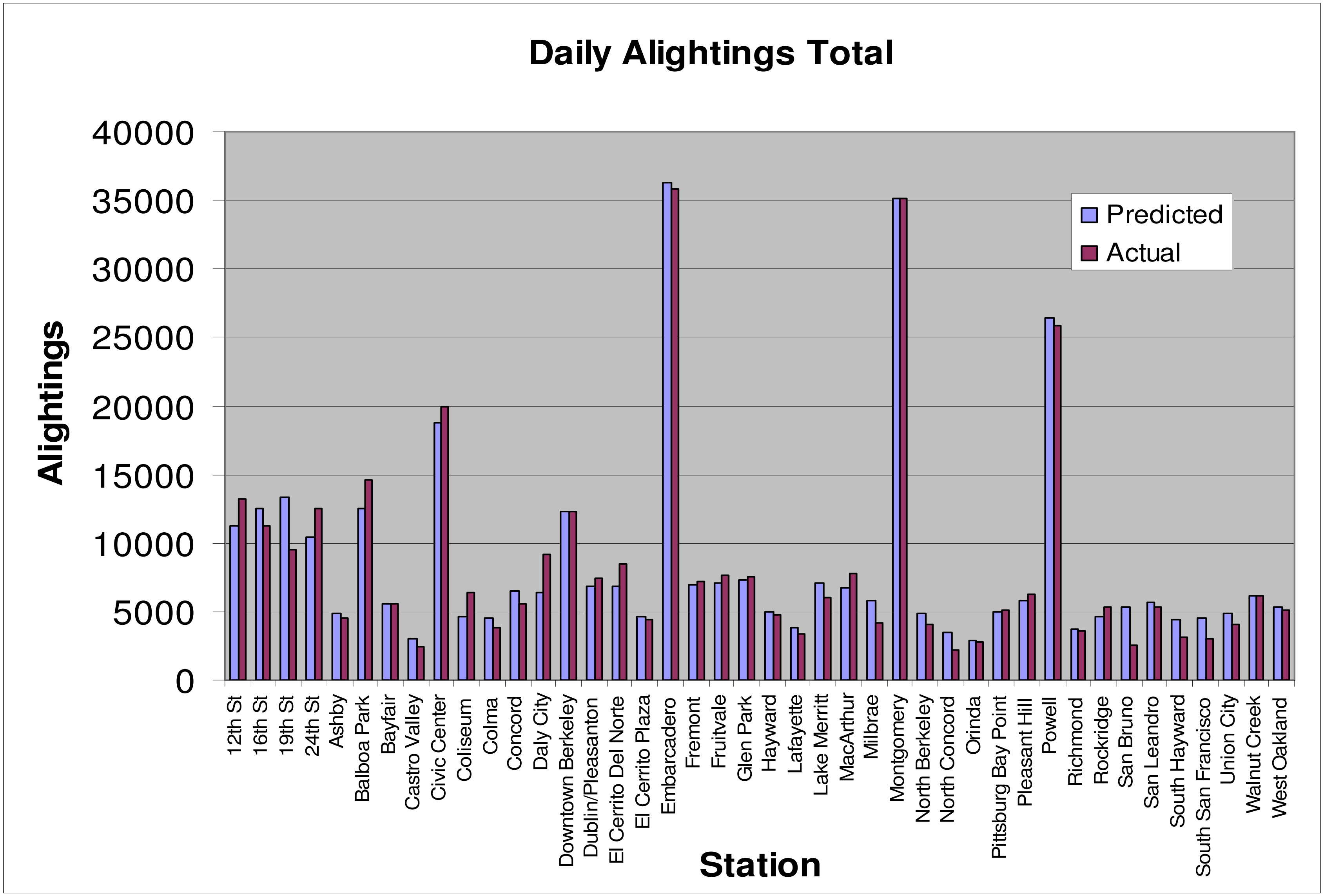
PM Pre Peak Alightings Total
Alightings
2500
2000
1500
1000
500
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

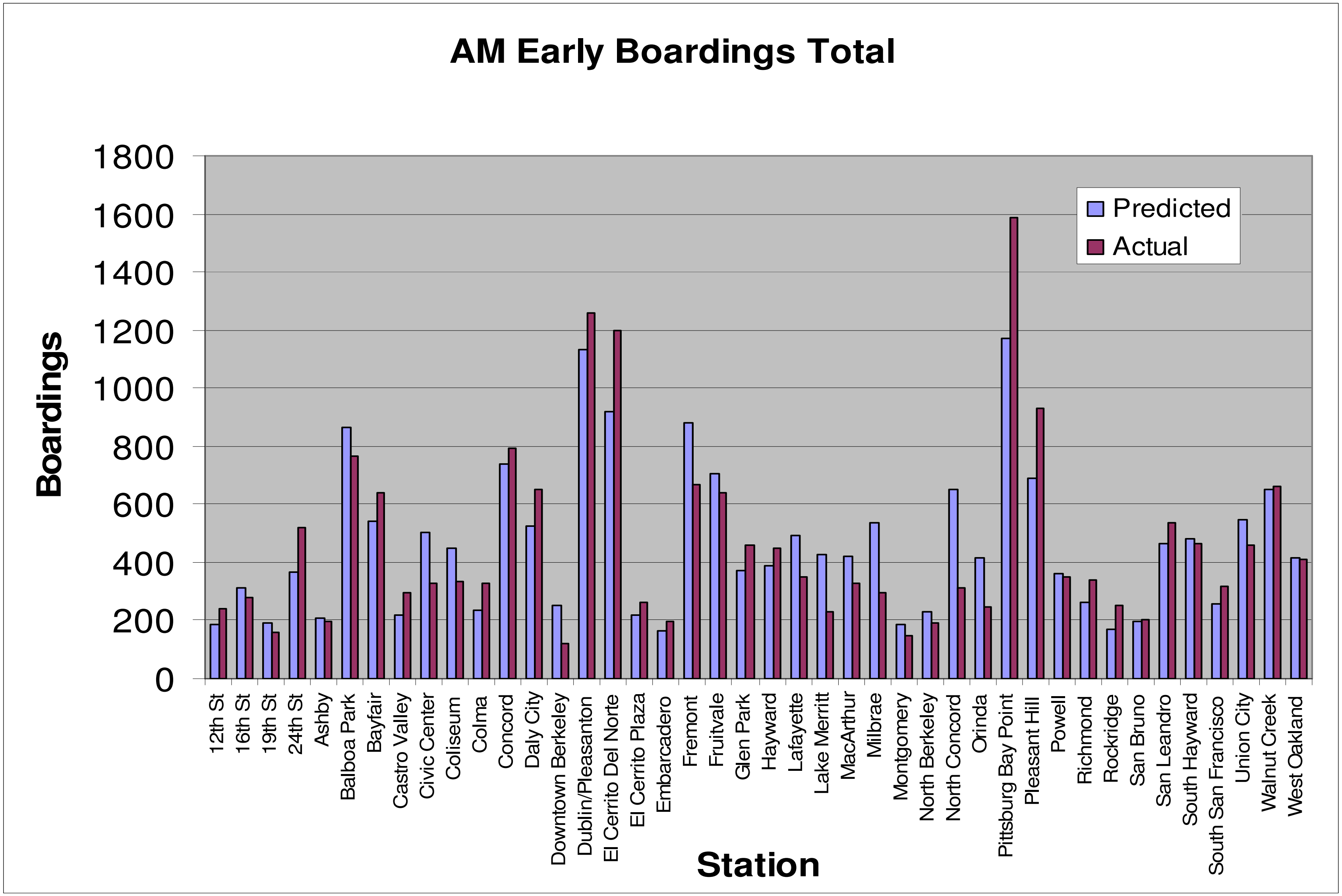

PM Peak Alightings Total
Alightings
2,500
2,000
1,500
1,000
500
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station


PM Post Peak Alightings Total
Predicted
Actual
Alightings
1400
1200
1000
800
600
400
200
0
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

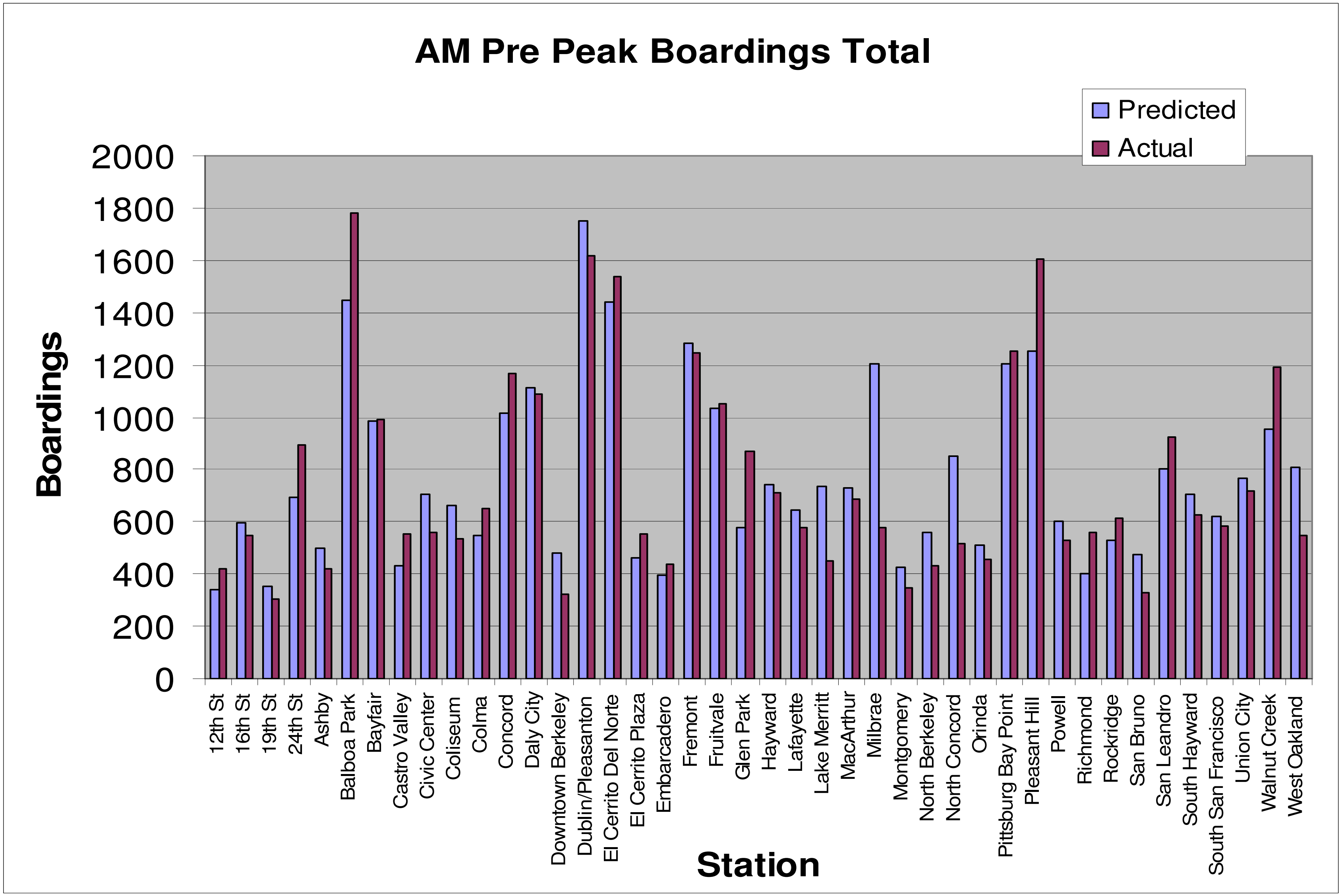


Evening Alightings Total
Alightings
2500
2000
1500
1000
500
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

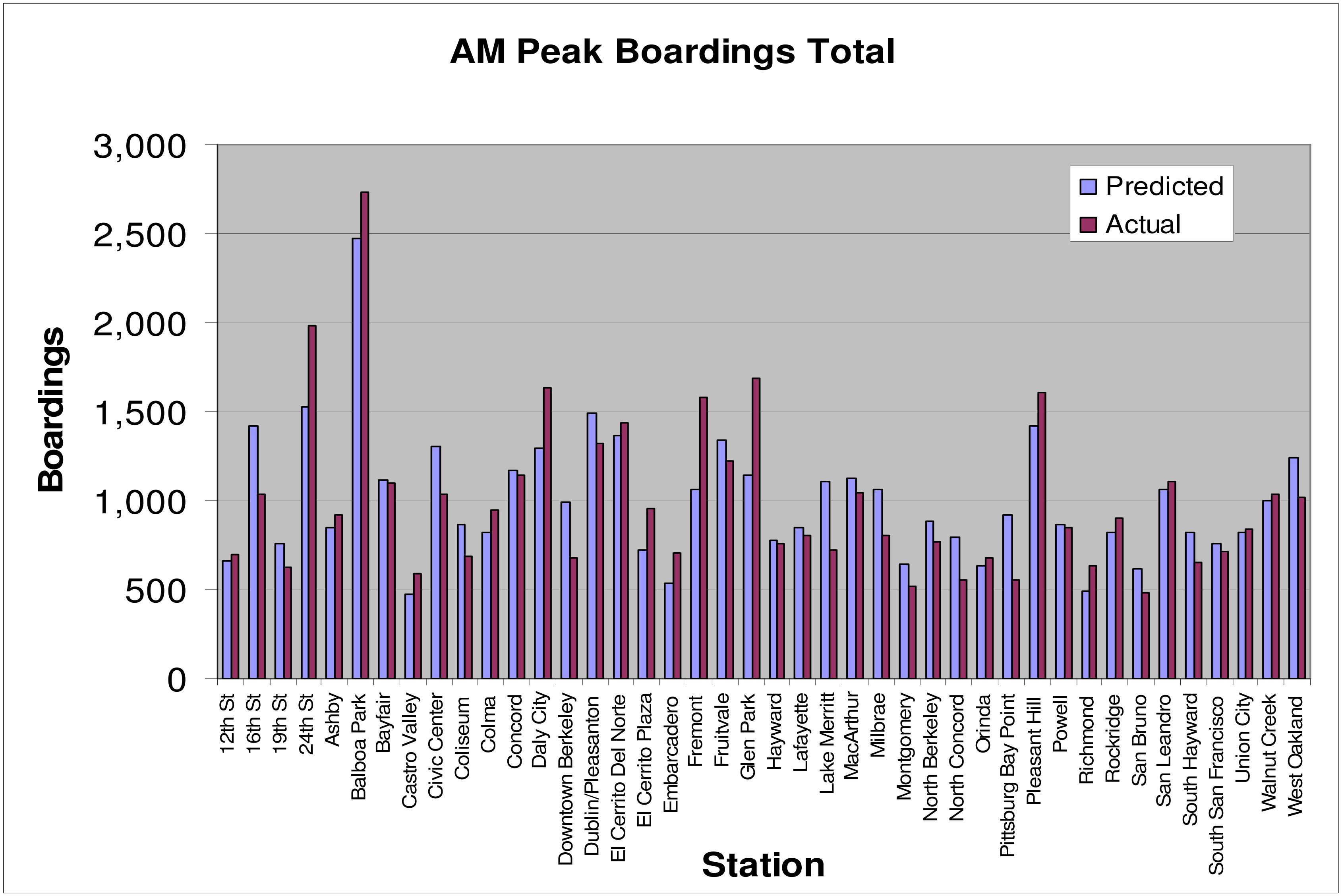

Daily Alightings Total
Alightings
40000
35000
30000
25000
20000
15000
10000
5000
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

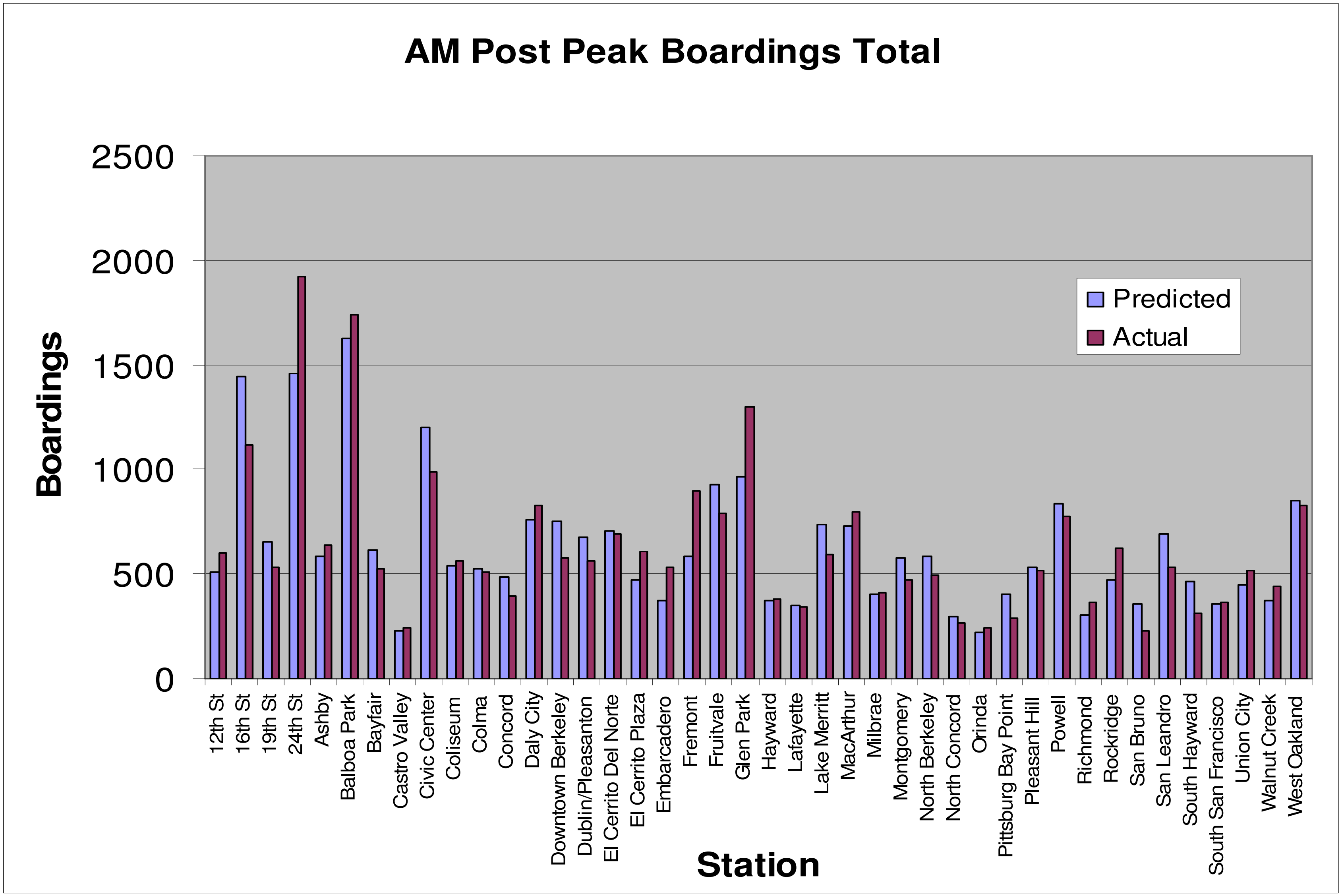


AM Early Boardings Total
Predicted
Actual
Boardings
0
200
400
600
800
1000
1200
1400
1600
1800
Station
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland

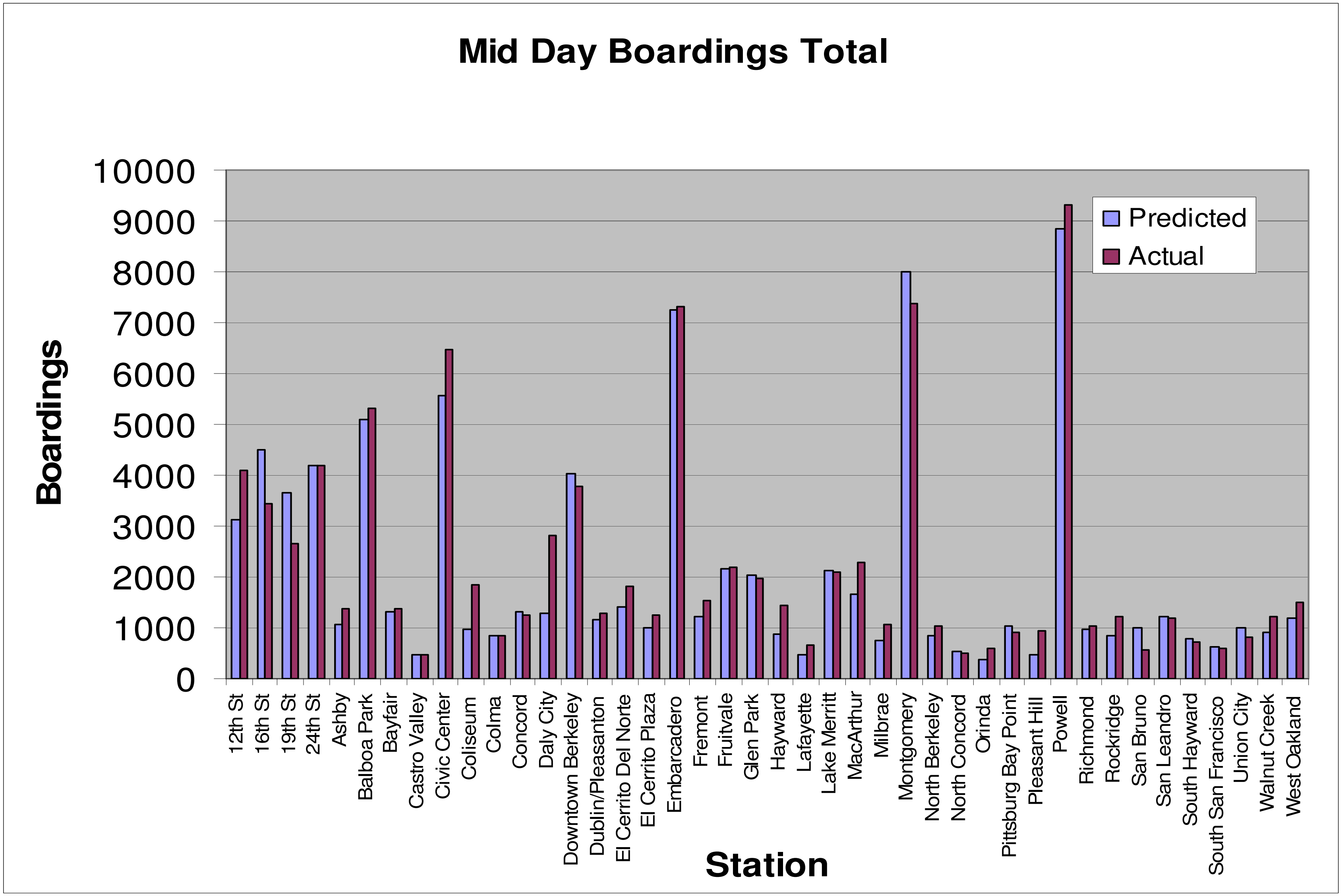


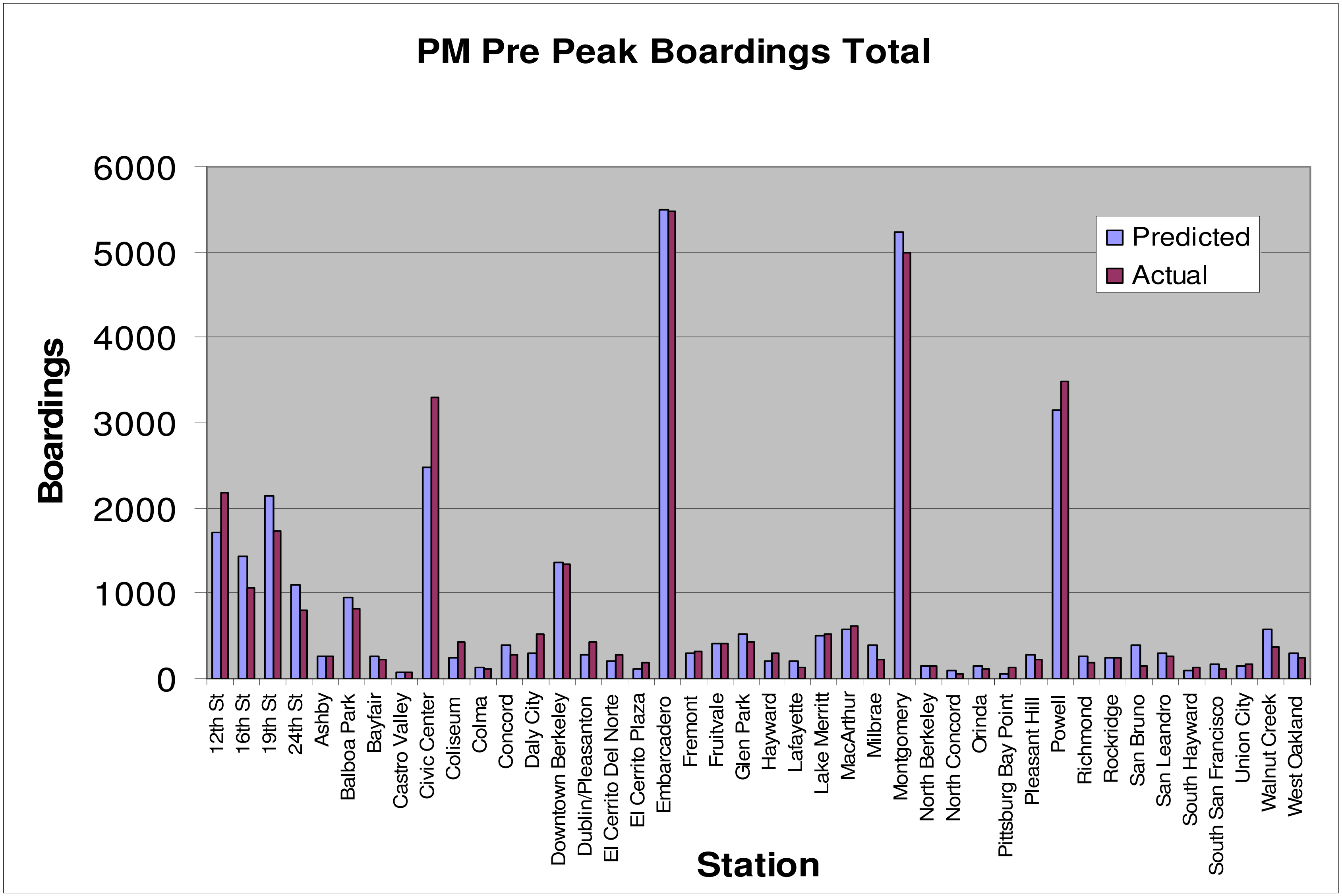
AM Pre Peak Boardings Total
Predicted
Actual
Boardings
2000
1800
1600
1400
1200
1000
800
600
400
200
0
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

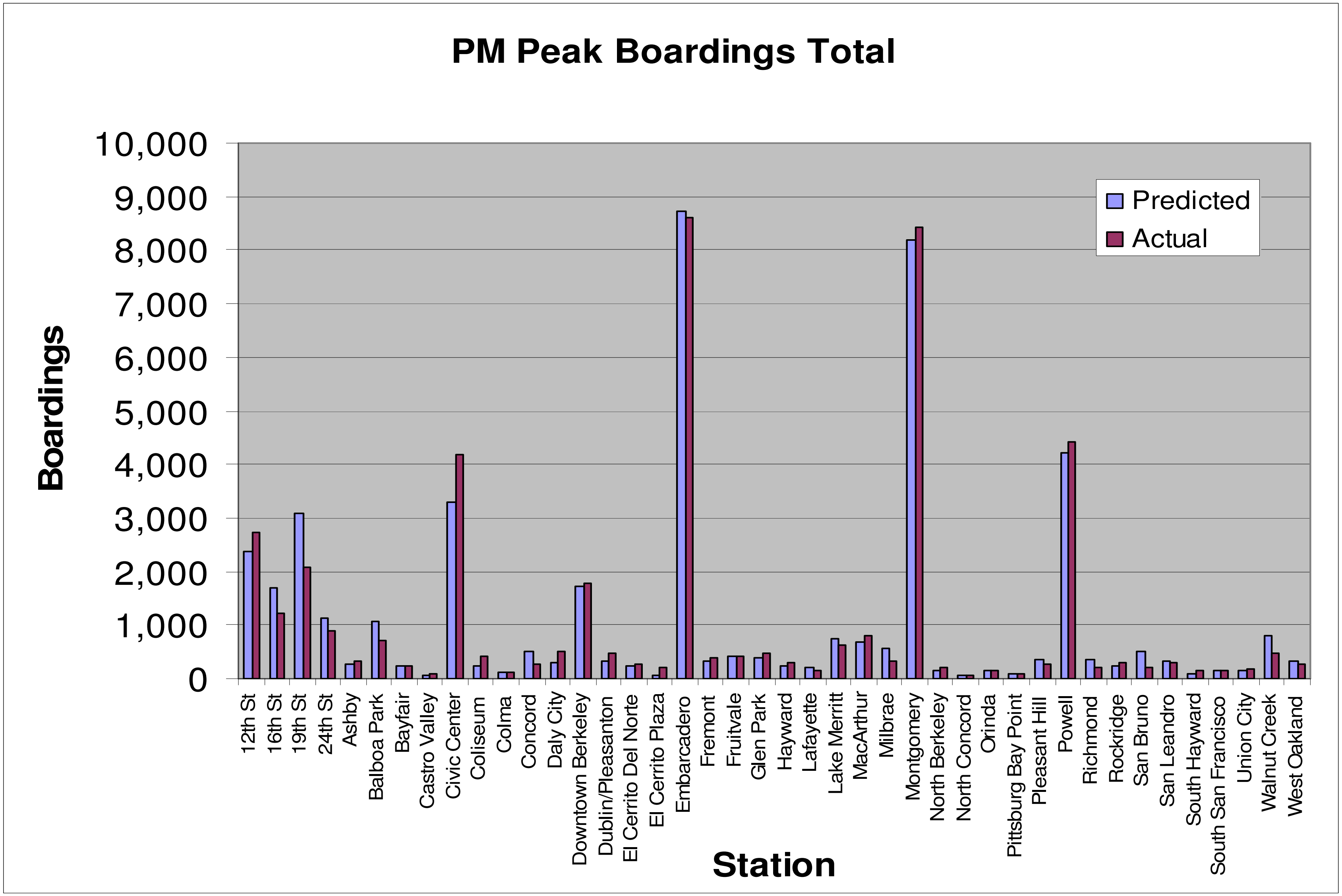

AM Peak Boardings Total
Predicted
Actual
Boardings
3,000
2,500
2,000
1,500
1,000
500
0
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

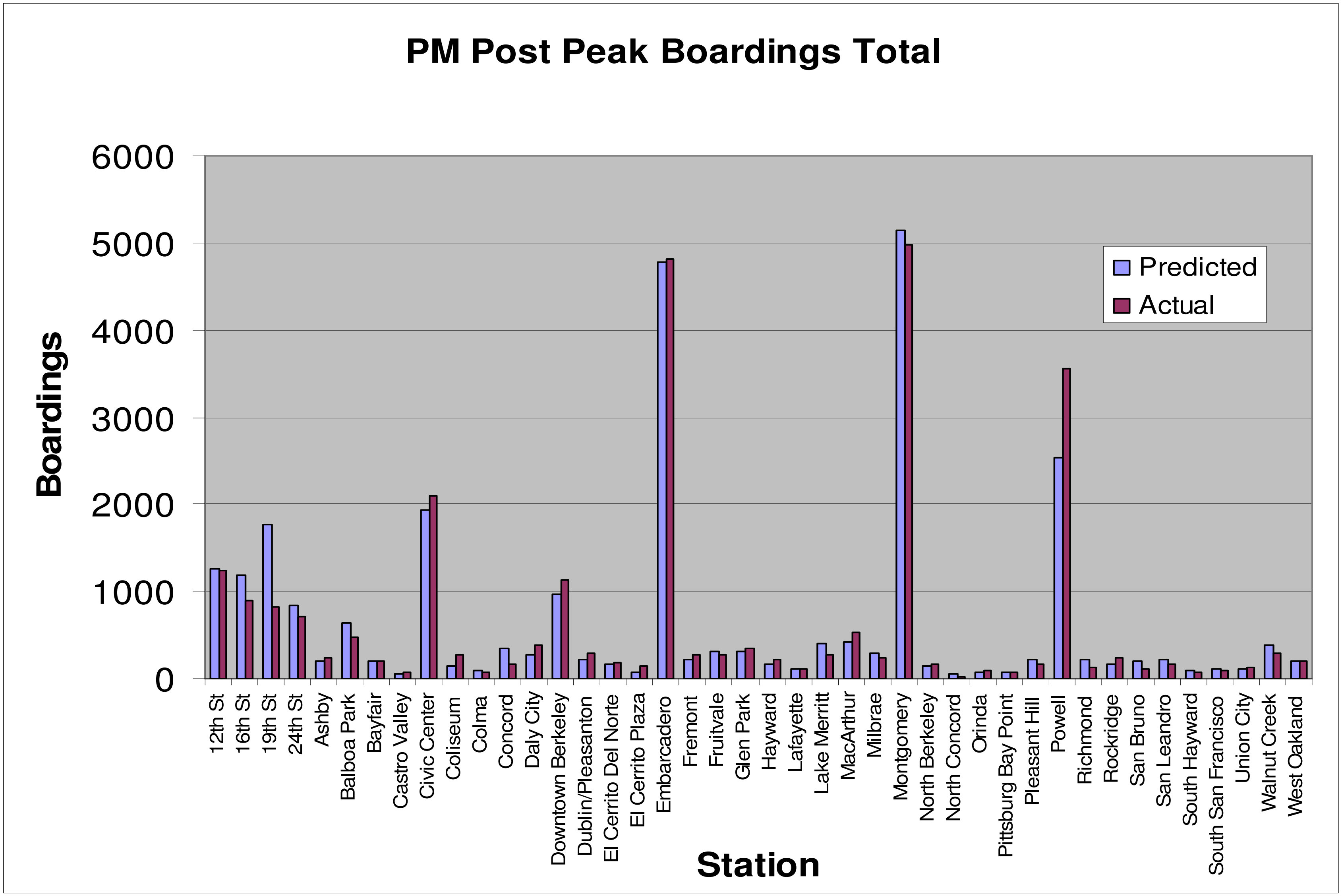


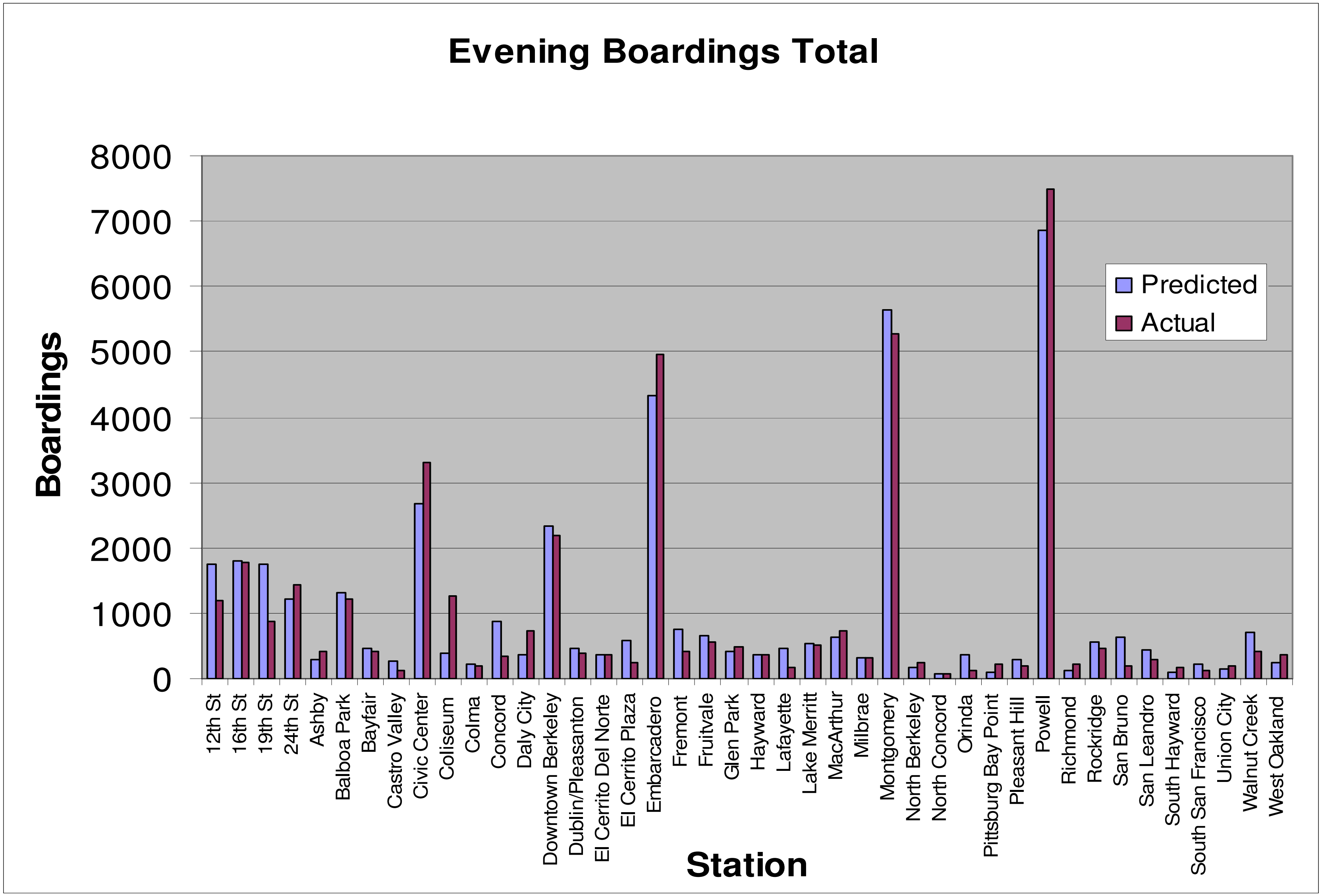
AM Post Peak Boardings Total
Boardings
2500
2000
1500
1000
500
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station


Mid Day Boardings Total
Boardings
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station

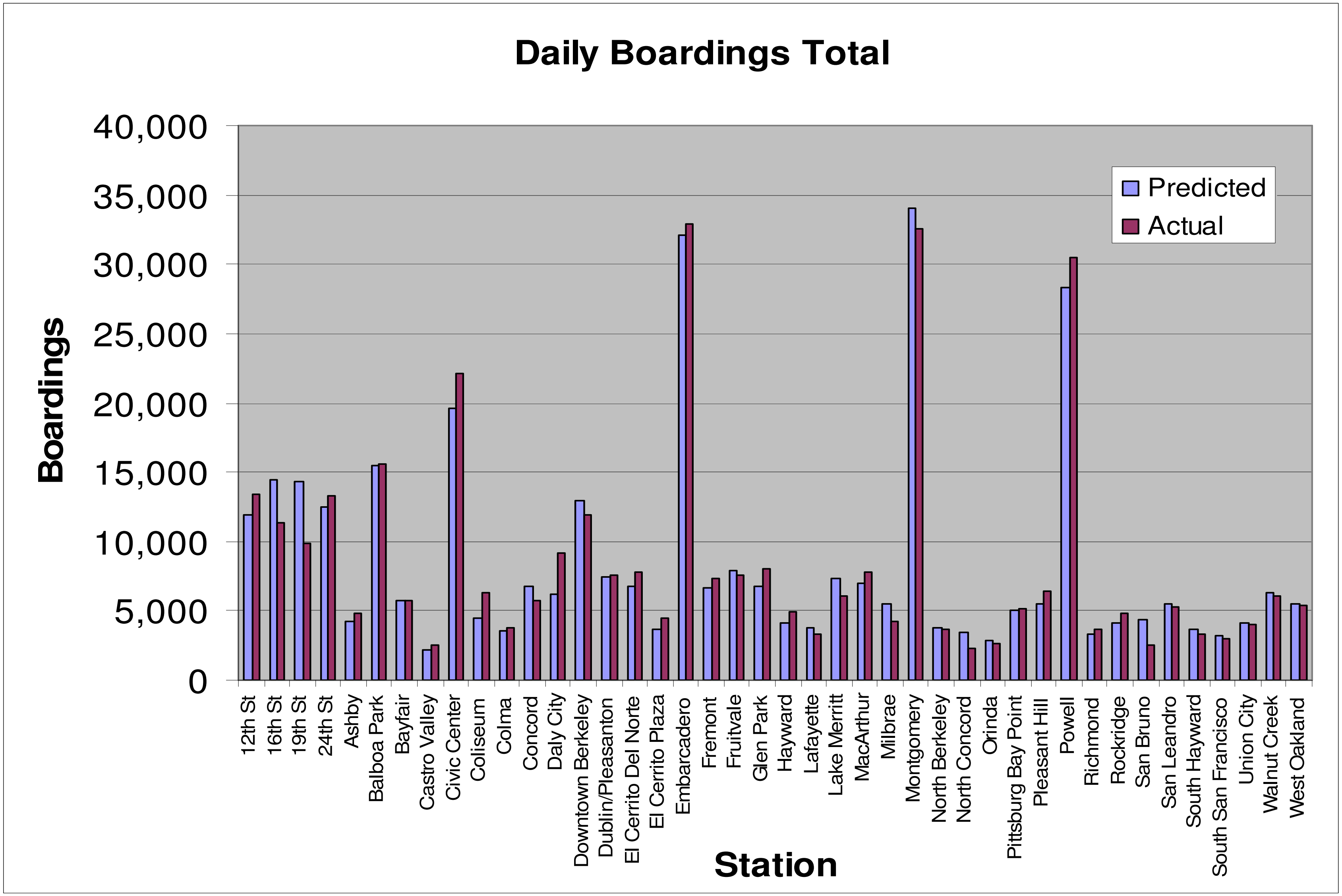

PM Pre Peak Boardings Total
Boardings
6000
5000
4000
3000
2000
1000
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station


PM Peak Boardings Total
Boardings
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station


PM Post Peak Boardings Total
Boardings
6000
5000
4000
3000
2000
1000
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland
Station



Evening Boardings Total
Boardings
Station
Predicted
Actual
8000
7000
6000
5000
4000
3000
2000
1000
0
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Milbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland


Daily Boardings Total
Boardings
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Predicted
Actual
Station
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown Berkeley
Dublin/Pleasanton
El Cerrito Del Norte
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Millbrae
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay Point
Pleasant Hill
Powell
Richmond
Rockridge
San Bruno
San Leandro
South Hayward
South San Francisco
Union City
Walnut Creek
West Oakland

APPENDIX B

DIRECT RIDERSHIP MODEL VARIABLES AND

R-SQUARED VALUES

TABLE B-2
VARIABLES USED IN BOARDINGS MODELS

	Walk Bike									Drive: Park [Drop-off]									Transit								
Variables[1]	AM Early	AM Pre Peak	AM Peak	AM Post Peak	Mid Day	PM Pre Peak	PM Peak	PM Post Peak	Evening	AM Early	AM Pre Peak	AM Peak	AM Post Peak	Mid Day	PM Pre Peak	PM Peak	PM Post Peak	Evening	AM Early	AM Pre Peak	AM Peak	AM Post Peak	Mid Day	PM Pre Peak	PM Peak	PM Post Peak	Evening
Population	✓	✓	✓		✓	✓	✓	✓		[✓]	[✓]	[✓]	[✓]	[✓]							✓	✓	✓	✓	✓	✓	✓
Single Family Dwell Units															✓[✓]	✓[✓]	✓[✓]	✓[✓]									
Multi Family Dwell Units															✓[✓]	✓[✓]	✓[✓]	✓[✓]									
Retail Employment					✓	✓			✓														✓				✓
Non-Retail Employment					✓	✓	✓	✓	✓																		
Population in Catchment										✓[✓]	✓[✓]	[✓]	✓[✓]	✓[✓]	✓[✓]	✓[✓]	✓[✓]	✓[✓]	✓	✓	✓	✓	✓				
Non-Retail Emp in Catchment															✓[✓]	✓[✓]	✓[✓]	✓[✓]						✓	✓	✓	✓
College Part Time Enrollment	✓	✓	✓	✓	✓				✓	[✓]	[✓]	[✓]	[✓]	[✓]					✓	✓	✓	✓	✓				
Jobs/Housing Ratio															[✓]	[✓]	[✓]	[✓]									
# of Parking Spaces					✓	✓	✓				✓	✓	✓														
Presence of Parking Lot	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					
Neighborhood Parking												✓	✓	✓													
Bike Parking at Station	✓	✓	✓	✓					✓																		
Neighborhood Network Connectivity		✓	✓	✓				✓	✓	[✓]	[✓]	[✓]	[✓]	[✓]	✓[✓]	✓[✓]	✓[✓]	✓[✓]		✓	✓						
Station Pedestrian Accessibility and Design		✓	✓	✓						[✓]	[✓]			[✓]	[✓]	[✓]	[✓]	[✓]			✓	✓	✓	✓	✓	✓	✓
Geographic Location										✓																	
In-Vehicle Travel Time (Time on BART)													[✓]	[✓]	✓[✓]	✓[✓]	✓[✓]	✓[✓]						✓	✓	✓	✓
# of Trains Departing			✓	✓						[✓]	✓[✓]	✓[✓]	✓[✓]	✓	✓[✓]	✓[✓]	✓[✓]	✓[✓]	✓	✓	✓	✓	✓	✓	✓	✓	
Feeder Transit	✓	✓	✓	✓						[✓]	[✓]	[✓]	[✓]	[✓]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Impedance Measures										✓[✓]	[✓]		[✓]	[✓]	[✓]	[✓]	[✓]	[✓]									

1. Land Use Variables (other than those that specify within catchment) are within ½ mile of the station.

Source: Fehr & Peers, 2009.

TABLE B-2
VARIABLES USED IN ALIGHTINGS MODELS

	Walk Bike									Drive									Transit								
Variables[1]	AM Early	AM Pre Peak	AM Peak	AM Post Peak	Mid Day	PM Pre Peak	PM Peak	PM Post Peak	Evening	AM Early	AM Pre Peak	AM Peak	AM Post Peak	Mid Day	PM Pre Peak	PM Peak	PM Post Peak	Evening	AM Early	AM Pre Peak	AM Peak	AM Post Peak	Mid Day	PM Pre Peak	PM Peak	PM Post Peak	Evening
Households					✓	✓	✓	✓	✓																		
Population																											✓
Retail Employment					✓	✓	✓	✓	✓																		
Non-Retail Employment					✓					✓	✓	✓	✓														
Population in Catchment														✓	✓	✓	✓	✓					✓	✓	✓	✓	✓
Non-Retail Emp in Catch.										✓	✓	✓	✓						✓	✓	✓	✓					
College Part Time Enrollment					✓																		✓	✓	✓	✓	✓
# of Parking Spaces		✓	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓									
Presence of Parking Lot						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓								✓	
Neighborhood Parking														✓													
Bike Parking at Station						✓	✓	✓	✓																		
Neighborhood Network Connectivity						✓	✓	✓	✓					✓													
Station Pedestrian Accessibility and Design	✓	✓	✓	✓															✓	✓	✓	✓	✓	✓	✓	✓	✓
In-Vehicle Travel Time (Time on BART)																											
# of Trains Arriving	✓									✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Feeder Transit						✓	✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Impedance Measures	✓	✓	✓	✓																							

1. Land Use Variables (other than those that specify within catchment) are within ½ mile of the station.

Source: Fehr & Peers, 2009.

TABLE B-3
INDIVIDUAL ALIGHTINGS MODEL STATISTICS

	Walk Bike							Drive						Transit					
Statistics	**AM Early**	**AM Pre Peak**	**AM Peak**	**AM Post Peak**	**Mid Day**	**PM 3Hr Peak**	**Evening**	**AM 3Hr Peak Plus Early**	**Mid Day**	**PM Pre Peak**	**PM Peak**	**PM Post Peak**	**Evening**	**AM 3Hr Peak Plus Early**	**Mid Day**	**PM Pre Peak**	**PM Peak**	**PM Post Peak**	**Evening**
R^2	0.97	0.95	0.98	0.98	0.96	0.83	0.82	0.67	0.78	0.78	0.84	0.82	0.76	0.82	0.65	0.74	0.72	0.80	0.88
Root Mean Squared Error	40%	46%	32%	32%	28%	35%	41%	35%	27%	32%	28%	32%	28%	48%	59%	57%	56%	45%	40%

Source: Fehr & Peers, 2009.

TABLE B-4
INDIVIDUAL BOARDINSG MODEL STATISTICS

	Walk Bike									Drive - Park						Drive - Drop Off					Transit							
Statistics	**AM Early**	**AM Pre Peak**	**AM Peak**	**AM Post Peak**	**Mid Day**	**PM Pre Peak**	**PM Peak**	**PM Post Peak**	**Eve**	**AM Early**	**AM Pre Peak**	**AM Peak**	**AM Post Peak**	**Mid Day**	**PM 3Hr Peak+ Eve**	**AM Early and Pre Peak**	**AM Peak**	**AM Post Peak**	**Mid Day**	**PM 3Hr Peak + Eve**	**AM Early and Pre Peak**	**AM Peak**	**AM Post Peak**	**Mid Day**	**PM Pre Peak**	**PM Peak**	**PM Post Peak**	**Evening**
R^2	0.81	0.87	0.80	0.86	0.97	0.98	0.98	0.96	0.96	0.86	0.85	0.83	0.81	0.69	0.54	0.76	0.69	0.55	0.64	0.65	0.74	0.89	0.81	0.72	0.79	0.85	0.81	0.68
Root Mean Squared Error	34%	28%	43%	41%	24%	29%	31%	44%	37%	37%	32%	27%	27%	29%	37%	37%	39%	47%	29%	31%	66%	49%	58%	57%	54%	51%	50%	86%

Source: Fehr & Peers, 2009.

TABLE B-5
AGGREGATE MODEL STATISTICS

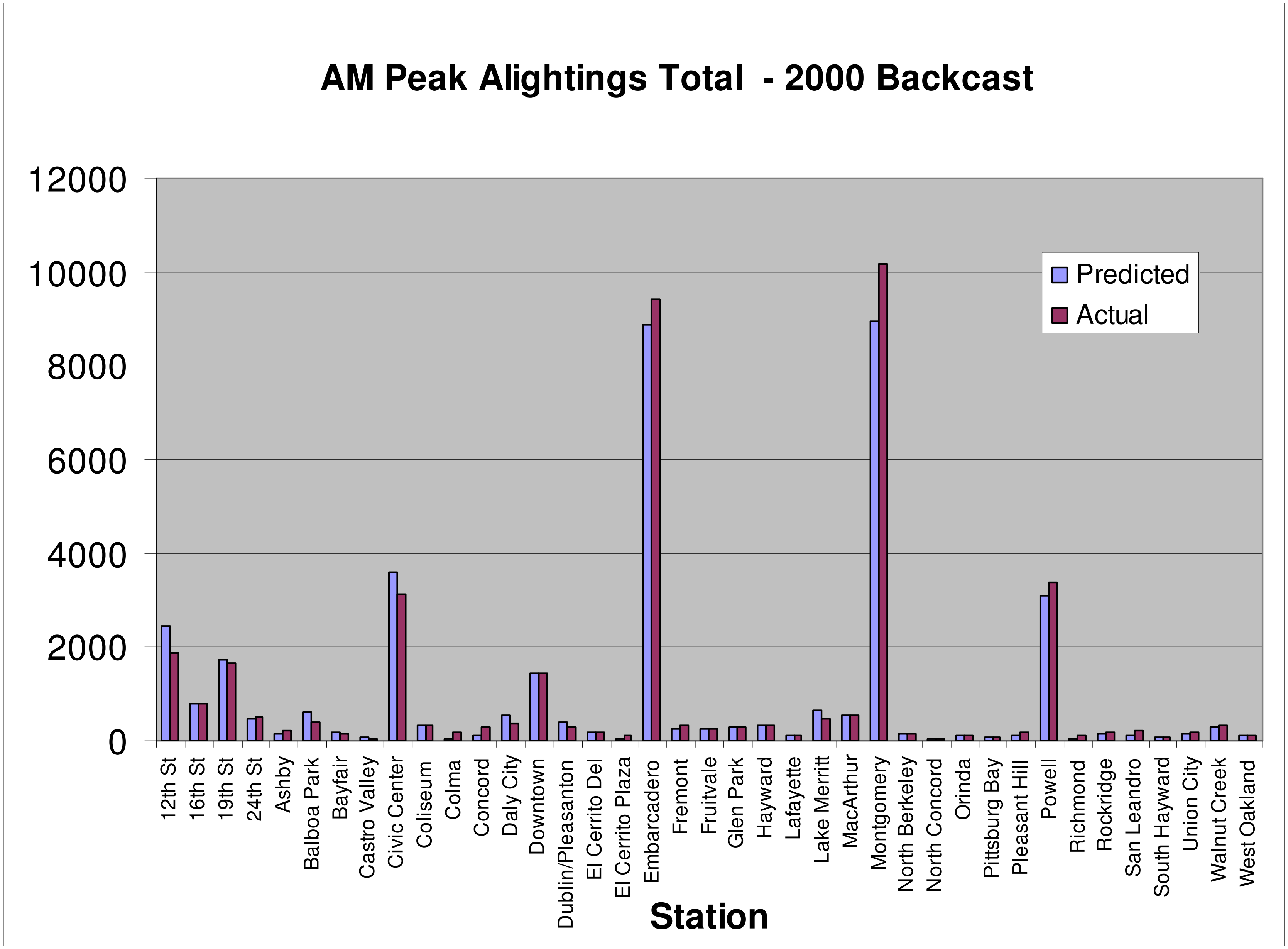
	Boardings										Alightings									
Statistics	**AM Early**	**AM Pre Peak**	**AM Peak**	**AM Post Peak**	**Mid Day**	**PM Pre Peak**	**PM Peak**	**PM Post Peak**	**Evening**	**Daily**	**AM Early**	**AM Pre Peak**	**AM Peak**	**AM Post Peak**	**Mid Day**	**PM Pre Peak**	**PM Peak**	**PM Post Peak**	**Evening**	**Daily**
R^2	0.80	0.78	0.75	0.83	0.95	0.97	0.98	0.96	0.95	0.97	0.97	0.97	0.98	0.98	0.95	0.73	0.67	0.66	0.81	0.97
Root Mean Squared Error	31%	24%	22%	23%	22%	26%	25%	36%	34%	16%	30%	34%	26%	28%	21%	23%	22%	23%	22%	15%

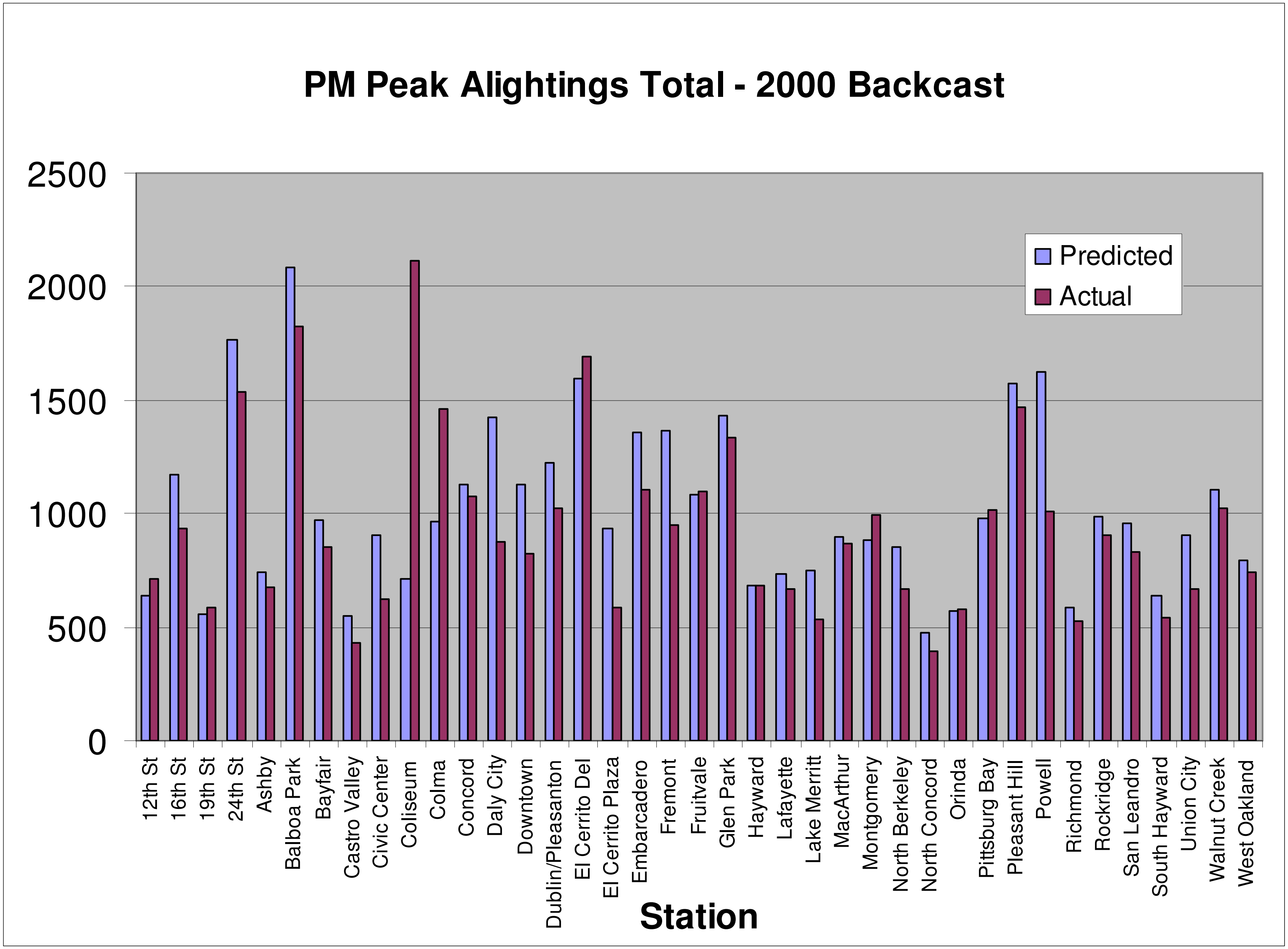
Source: Fehr & Peers, 2009.

APPENDIX C

STATION-BY-STATION COMPARISON GRAPHS

2000 BACKCAST


AM Peak Alightings Total - 2000 Backcast
12000
10000
8000
6000
4000
2000
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown
Dublin/Pleasanton
El Cerrito Del
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay
Pleasant Hill
Powell
Richmond
Rockridge
San Leandro
South Hayward
Union City
Walnut Creek
West Oakland
Station


PM Peak Alightings Total - 2000 Backcast
2500
2000
1500
1000
500
0
Predicted
Actual
12th St
16th St
19th St
24th St
Ashby
Balboa Park
Bayfair
Castro Valley
Civic Center
Coliseum
Colma
Concord
Daly City
Downtown
Dublin/Pleasanton
El Cerrito Del
El Cerrito Plaza
Embarcadero
Fremont
Fruitvale
Glen Park
Hayward
Lafayette
Lake Merritt
MacArthur
Montgomery
North Berkeley
North Concord
Orinda
Pittsburg Bay
Pleasant Hill
Powell
Richmond
Rockridge
San Leandro
South Hayward
Union City
Walnut Creek
West Oakland
Station

APPENDIX D

CATCHMENT AREA DEFINITION

TECHNICAL PROCEDURE

DATA COLLECTION

Data from the 2008 Passenger Profile Survey was used to define the station catchment areas. For each survey record with a trip origin at home, the MTC TAZ of the trip origin was determined by geocoding the origin address and using ArcGIS to relate the origin to the MTC TAZ in which it was located. This process was performed by Santa Clara VTA. Fehr & Peers received data in which each survey record contained the MTC TAZ of home origin and the station accessed on the origin end of the BART trip.

DATA PROCESSING

Adding the weighted passenger count for each station / TAZ combination resulted in a table in which each MTC TAZ had a total count for each of the BART stations (if any) accessed by its residents. The table was adjusted by zeroing out any counts less than 10 for any station / TAZ combination and zeroing out any stations which comprised less than 10% of the total BART trip origins for a given TAZ. This was done to eliminate as many cases as possible where either the survey was filled out incorrectly or where a TAZ only produced occasional BART riders. Some final cleanup of the data was done to eliminate any unrealistic station / TAZ combinations; for example, a TAZ in Lafayette should not be producing any BART trips which begin in downtown San Francisco.

FINAL CALCULATIONS

Each MTC TAZ's 2008 population was estimated by interpolating its 2005 and 2010 populations from ABAG *Projections 2005.* That population was divided proportionally among all the BART stations for which that TAZ had nonzero weighted passenger counts after all the data processing was complete. For example, TAZ 8, located in Downtown San Francisco just north of Market Street between the Powell and Civic Center stations, has a population of 7,789. Approximately 61% of the residents in this TAZ surveyed accessed Powell station at the origin of their trip, and the other 30% accessed Civic Center. So the 7,789 was divided by those percentages into populations of 4,722 for Powell and 3,067 for Civic Center.

The total catchment population for each station was then determined by adding up the populations (or partial populations) for all TAZs from which passengers accessed it.

APPENDIX E

EXAMPLES OF FORECAST CALCULATIONS

As discussed in the Forecasts section of this report, the forecasting process for a given station and time period and a given mode of access or egress will warrant one of two calculation methods, depending on how accurately the model performed for the 2008 base year. Examples of both methods are presented below.

EXAMPLE OF DIFFERENCE EQUATION

Pittsburg / Bay Point, PM Post-Peak Shoulder Transit Alightings
Actual Alightings: 92
2008 Model Predicted Alightings: 151

The prediction differs from the actual by more than 50% either above or below (151/92 – 1 = 64%), so the difference equation is used. This equation is (Forecast + X), where

X = 2008 Actual – 2008 Predicted

In this case, X = 92 – 151 = -59

The 2020 "Raw" Forecast (i.e., straight from the model equation) for Pittsburg / Bay Point Transit Alightings in the PM Post-Peak Shoulder is 162. Thus, to obtain our final forecast, we take 162 – 59 = 103.

EXAMPLE OF BLEND EQUATION

El Cerrito Del Norte, AM Peak Hour Walk / Bike Boardings
Actual Boardings: 235
2008 Model Predicted Boardings: 208

The predicted does not differ from the actual by more than 50% either above or below (208/235 – 1 = -11%), so the blend equation is used. This equation averages out the values of (Forecast + X) and (Forecast * Y), where

X = 2008 Actual – 2008 Predicted
Y = 2008 Actual / 2008 Predicted

In this case, X = 235 – 208 = 27 and Y = 235 / 208 = 1.13

The 2020 "Raw" Forecast (i.e., straight from the model equation) for El Cerrito Del Norte Walk / Bike Boardings in the AM Peak Hour is 330. Thus, to obtain our final forecast, we take the average of (330 + 27) and (330 * 1.13). This is the average of 357 and 373, or 365.