San Francisco Travel Demand Forecasting Model Development

MTC Consistency 2001

Final Report

prepared for
San Francisco County Transportation Authority

prepared by
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Updated by:
San Francisco County Transportation Authority

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General Approach (Product 1)

The San Francisco County Travel Demand Forecasting Model (San Francisco Model) was developed for the San Francisco County Transportation Authority (Authority) to provide detailed forecasts of travel demand for various planning applications. These applications included developing countywide plans, providing input to microsimulation modeling for corridor and project-level evaluations, transit planning, neighborhood planning, and land use impacts analysis for Congestion Management Program purposes. The objective was to accurately represent the complexity of the destination, temporal and modal options and provide detailed information on travelers making discrete choices. These objectives led to the development of an activity-based model that uses synthesized population as the basis for decision-making rather than zonal-level aggregate data sources. In its current form, the activity-based model has eight primary components. A ninth model component (to perform peak spreading) is under construction.

The consultant team estimated model components using household survey data collected in 1990 by the Metropolitan Transportation Commission (MTC) for San Francisco residents only. Each model component was calibrated using various observed data sources, then the full model was validated using traffic count and transit ridership data for each of five time periods. The model is applied as a windowed model, which combines trip making from the entire Bay Area (derived from the MTC's BAYCAST trip tables) with the travel demand from San Francisco residents produced by the activity-based model. All inter-county trip movements are derived from the MTC trip tables, stratified by trip purpose, mode, time period and direction.

Demographic, Economic and Land Use Forecasts

All demographic, economic and land use forecasts used in the San Francisco Model for San Francisco County are within 1 percent of the ABAG projections 2000 forecasts for the base year (2000) and the forecast year (2020) model runs. The San Francisco Model does not use demographic projections for forecasting trips originating from the other 8 counties in the San Francisco Model, since these trips are derived directly from MTC trip tables. This means that all demographic projections used in the San Francisco Model are consistent with MTC and ABAG projections.

Table 1. Comparison of ABAG and San Francisco Model Demographics (Product 2)

2000 Model Year	ABAG2000	SF Model	Percent Difference
Household Population	776,200	772,297	-0.5%
Households	315,550	315,548	0.0%
Jobs	628,860	628,868	0.0%
Employed Residents	422,100	420,451	-0.4%
2020 Model Year			
Household Population	785,600	782,055	-0.5%
Households	331,470	331,470	0.0%
Jobs	731,660	731,659	0.0%
Employed Residents	467,300	468,378	0.2%

Pricing Assumptions (Product 3)

The San Francisco Model uses the same assumptions for transit fares and bridge tolls in the current MTC Models. There may be slight differences in the inclusion of transit fares in TP+ compared to the MINUTP software used by MTC, but these have been coded to replicate as closely as possible the current fare matrices used by MTC. Auto operating costs were assumed at 12 cents per mile rather than the 8.8 cents per mile that MTC uses. This assumption was based on the evidence that auto-operating costs are higher within San Francisco County than for the Bay Area as a region[1]. The 12 cents per mile assumption is derived from the consultants experience in developing auto operating costs for other major metropolitan areas throughout the U.S.

The San Francisco Model uses more detailed parking costs for each San Francisco traffic analysis zone than the MTC Model. These parking costs are based on an evaluation of parking price data for hourly, 12-hour, 24-hour and monthly fees in different parking districts. These average parking rates were then factored based on the stated preference survey responses to the percent of people in an area who pay for parking compared to the percent of people who park for free. The appendix to this memo documents the comparison of peak and off-peak parking costs for the San Francisco and MTC Models.

Network Assumptions (Product 4)

The MTC highway and transit networks for 2000 and 2020 model years have been used for all facilities outside San Francisco County. These were converted to TP+ for integration with the San Francisco portions of the networks. The San Francisco portion of the networks is considerably more detailed, resulting in a total of 51,205 links, 19,450 nodes and 1,738 zones for the full 9 county network. For the 2020 networks, regionally significant network changes were limited to the current Transportation Improvement Program (TIP) projects, provided by MTC.

[1] MTC bases the 8.8 cents per mile assumption for auto operating costs on a retail gas price of $1.45 per gallon in 1998 (Table 3 historical and Projected Auto Operating Costs, 1990 – 2020). However, in San Francisco retail gas prices were recorded at a much higher level of $1.83 per gallon (http://www.cnn.com/2000/US/03/13/gas.prices.01/).

Auto Ownership Assumptions

Table 2 presents a comparison of the households with vehicles available from the San Francisco Model with the 1990 MTC Model[2]. This demonstrates that the San Francisco Model predicts household for each vehicle available category by super-district within two percent of the MTC Model for the same categories. Both models were calibrated to match the 1990 Census data for these categories.

The San Francisco vehicle availability model was estimated using the 1990 MTC Bay Area Travel Survey (BATS) for San Francisco residents only. Given the location of the household, the characteristics of the household members, and the primary work place location of each of its workers, the model estimates the probabilities of having none, one, two, or three or more vehicles available using a multinomial logit model.

The vehicle availability model is applied using the synthesized population dataset for San Francisco County and incorporates pedestrian environment and parking availability variables that were developed specifically for this project. A full description of the vehicle availability model is available in the Chapter on the Vehicle Availability Model in the *San Francisco Travel Model Development Draft Final Report* to be finalized by early 2002.

[2] Metropolitan Transportation Commission, *Base Year Validation of Travel Demand Models for the San Francisco Bay Area (BAYCAST-90) Technical Summary*, April 1998.

Table 2. Percent of Household with Vehicles Available (Product 5)

Super-District	Number of Vehicles			
	2000 San Francisco Model			
	0	1	2+	Total
1	12.4%	7.2%	2.7%	22.4%
2	8.2%	14.4%	8.2%	30.8%
3	6.3%	14.2%	12.1%	32.7%
4	1.9%	6.3%	5.9%	14.1%
Total	28.9%	42.1%	29.0%	100.0%
	1990 MTC Model			
1	11.6%	5.6%	1.7%	19.0%
2	8.7%	15.0%	7.7%	31.4%
3	7.7%	14.5%	11.9%	34.1%
4	2.4%	6.6%	6.6%	15.5%
Total	30.3%	41.6%	28.0%	100.0%
	Differences			
1	0.8%	1.6%	1.0%	3.4%
2	-0.5%	-0.1%	0.5%	-0.6%
3	-1.4%	-0.3%	0.2%	-1.4%
4	-0.5%	0.3%	-0.7%	-1.4%
Total	-1.4%	0.5%	1.0%	0.0%

Trip Generation

The San Francisco Model predicts tours by type rather than trips, so a direct comparison of the home-based work trips is difficult. These tours represent chains of linked trips. The San Francisco Model was originally calibrated using the 1990 MTC household survey, which is the same data source used to develop the current BAYCAST MTC Models. The 1996 MTC Survey was eventually used for calibration because the number of trips within San Francisco County was very low in the 1990 MTC Survey due to under-reporting of trips that occurred in this survey. A comparison of the trips by time of day from the 1990 and 1996 MTC surveys, expanded to represent 1998 population, is presented in Table 3. The under-reporting of trips is not consistent across time periods or across trip purposes, which may have influenced model estimation that was based on the 1990 MTC survey.

Table 3. Observed Trips by Time Period Made by San Francisco Residents

	1990 MTC survey	1996 MTC survey	Percent Difference
Early	15,947	32,135	102%
AM	463,432	502,516	8%
Midday	855,688	1,088,855	27%
PM	536,895	646,500	20%
Late	397,779	668,817	68%
Total	2,269,741	2,938,823	29%

The differences between trips by time period was confirmed with initial assignments by time periods using the uncalibrated San Francisco Model that revealed the off-peak time periods were significantly under-estimated compared to traffic counts. This evaluation led to investigation of the MTC surveys and the recommendation that the 1996 MTC survey be used for model calibration. This led to revisions of the full-day pattern tour models to increase other tours and work-based tours during these time periods.

There were other differences between the 1990 and 1996 MTC survey by tour type that were notable. The biggest difference was in other tours, where the 1996 survey captured 53 percent more trips than the 1990 survey. This would mean that the vast majority of under-reporting of trips in the 1990 MTC survey were in other tours. Table 4 summarizes these results.

Table 4. Observed Trips by Tour Type Made by San Francisco Residents

	1990 MTC survey	1996 MTC survey	Percent Difference
Work	867,635	995,642	15%
School	176,252	187,420	6%
Other	963,686	1,473,956	53%
Work-based	262,168	281,805	7%
Total	2,269,741	2,938,823	29%

The comparison of the 1990 and 1996 MTC survey trip rates with the San Francisco Model trip rates by tour type is presented in Figure 1. This figure highlights the differences between the 1990 and 1996 surveys, in terms of trip rates per household.

Figure 1. Comparison of Observed and Estimated Trip Rates by Source and Tour Type

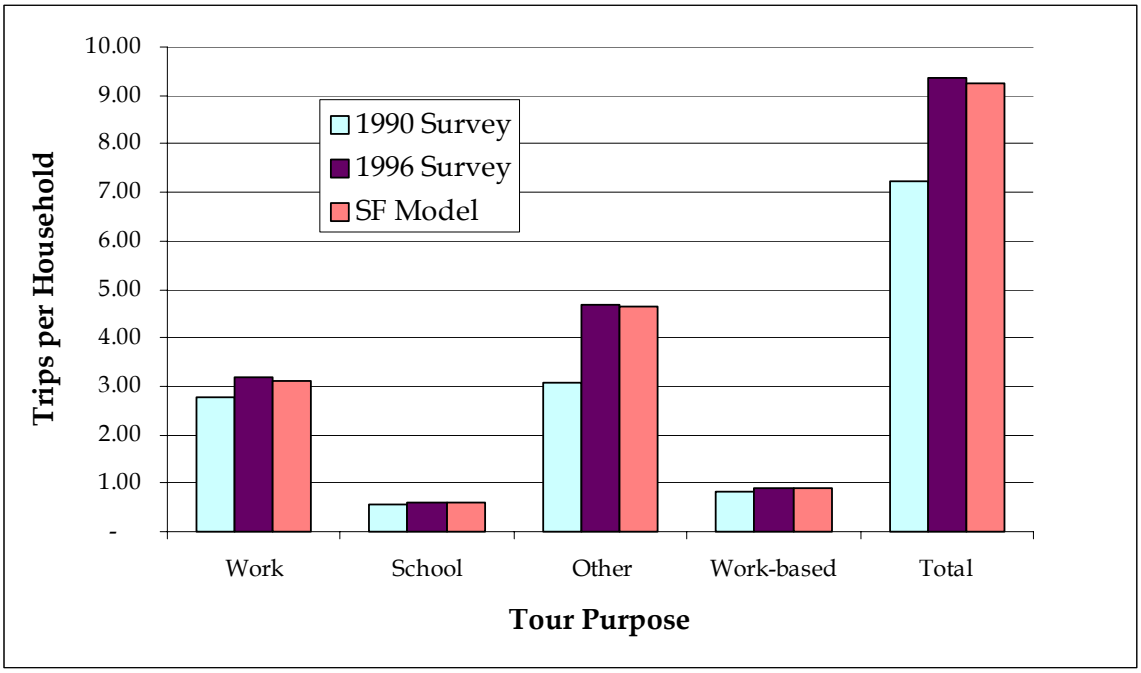


Table 5 presents a comparison of the calibrated San Francisco Model trips to the 1996 MTC survey by tour type. The shows that the all trips by tour type are within 10 percent of the 1996 MTC survey.

Table 5. Comparison of Observed and Estimated Internal San Francisco Trips by Tour Type

Person type	Tour type	MTC Weekday Trips from 1996 Household Survey	Calibrated SF Model Trips	Difference
Worker	HBWork	995,642	977,298	-1.8%
Worker	HBOther	619,526	561,218	-9.4%
Worker	WkBased	281,805	279,437	-0.8%
Student	HBEduc	187,420	186,017	-0.7%
Student	HBOther	169,474	157,704	-6.9%
Other	HBOther	684,956	737,511	7.7%
Total	Total	2,938,823	2,899,185	-1.3%

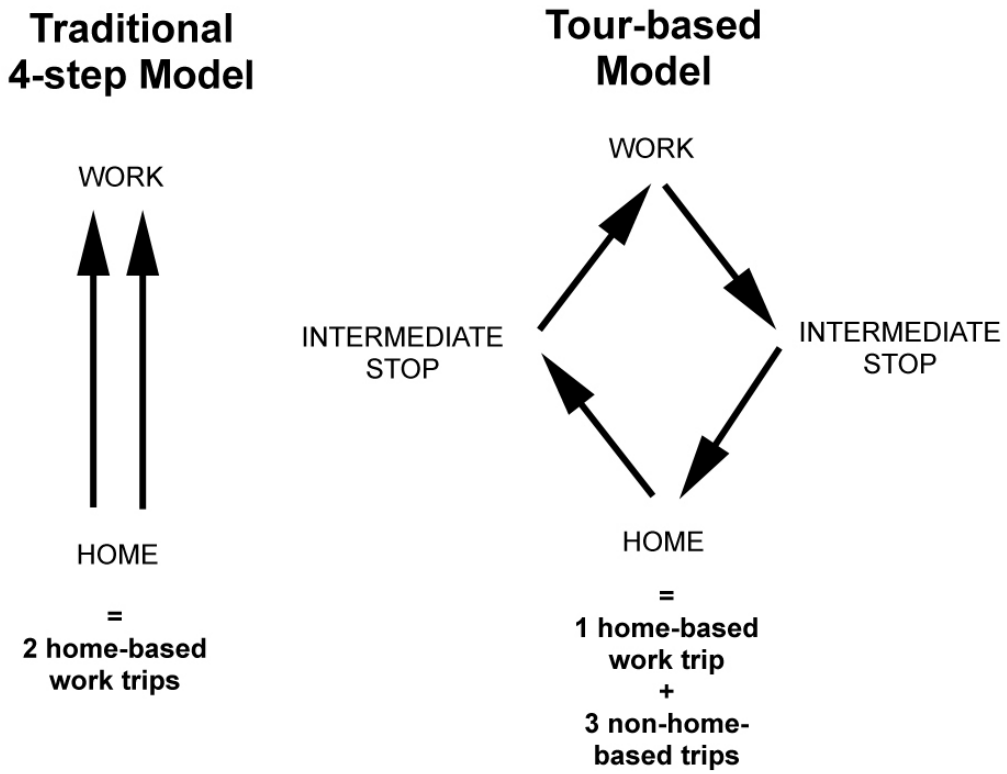
Trip rates per household were compared by trip purpose and are presented in Table 6, with expected results. This table reports the comparison of trips internal to San Francisco County only, because the model derives external trips from the regional model. Trip rates overall are similar, but the trips per household by trip purpose are quite different. For example, the model under-estimates work and school trips compared to the MTC survey, but this can be attributed to the definition of a trip to work or home in the survey containing all trips to and from work or school. The San Francisco Model differentiates between trips to work or school with an intermediate stop from those without an intermediate stop and thus has fewer trips identified as work or school trips and many more trips identified as non-home-based. Figure 2 illustrates this key difference.

Table 6. Comparison of Observed and Estimated Internal San Francisco Trip Rates by Purpose (Product 6)

	Trips		Trips per HH		Percent
Trip Purpose	**Observed***	**Estimated**	**Observed**	**Estimated**	**Difference**
Work	995,642	353,360	3.17	1.13	-65%
School	187,420	123,127	0.60	0.39	-34%
Other	1,473,956	1,367,285	4.69	4.35	-7%
Non-home-based	281,805	1,055,413	0.90	3.36	275%
Total	2,938,823	2,899,185	9.36	9.23	-1%

* Source: 1996 MTC Household Survey expanded to 1998 population

Figure 2. Trip Definitions: 4-step model vs. tour-based model



The above analysis is based on all trips made by San Francisco residents, which is how the San Francisco Model was estimated. Trips made by San Francisco residents that leave San Francisco County were replaced prior to trip assignment with trips from the MTC trip tables. The above comparison provides the most direct comparison of trips by type, but since some of these trips are replaced by MTC trips, the differences shown do not completely reflect the final differences.

Table 7 presents an evaluation of the trip rates.

Table 7. Trip Rate Analysis (Product 7)

Tour Types	Trips per Employed Resident	Trips per Household	Trips per Total Jobs	Trips per Person
Work	2.50	3.11	1.73	1.32
School	0.48	0.59	0.33	0.25
Other	3.73	4.64	2.58	1.96
Work-based	0.71	0.89	0.50	0.38
Total	7.42	9.23	5.14	3.91

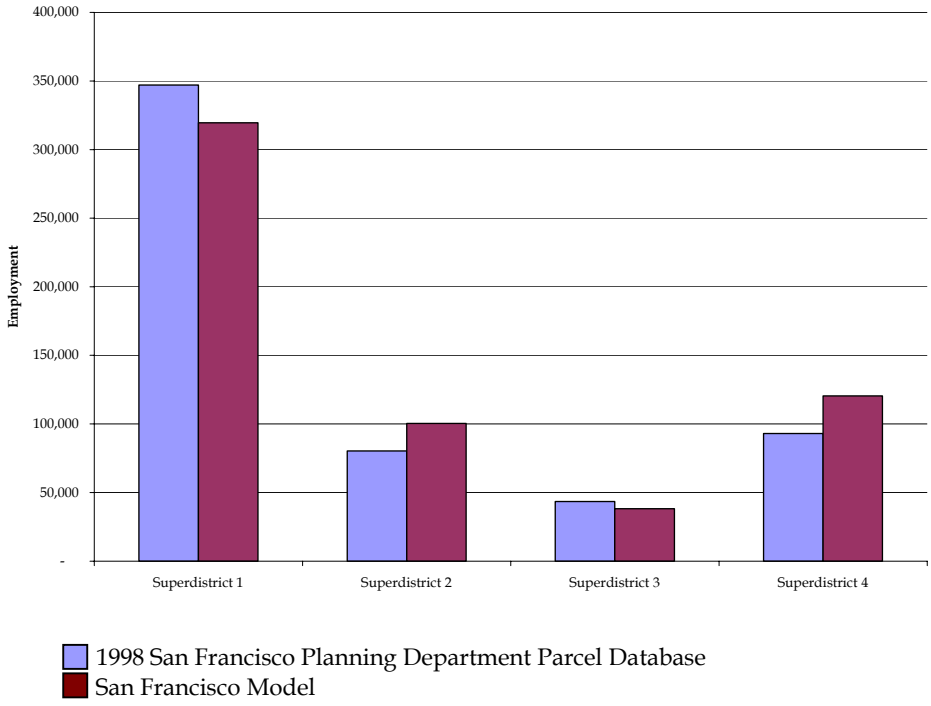
Product 8 is the description of sub-regional adjustment factors and is not applicable for this model.

Trip Distribution

Attraction Balancing (Product 9)

Product 9 contains the county and district-level tables showing attraction balancing analysis, but this is not applicable to the logit choice model approach to trip distribution and primarily is applicable to models that use the gravity model approach. A relative comparison is the summary of employment attracted to each zone as part of the work tour primary destination choice model. This is presented in Figure 3 by super-district. This comparison required the estimation of non-San Francisco residents who work in San Francisco by zone, which may have biased the comparison results to some degree.

Figure 3. Observed and Estimated Employment by Super-District



County and District Trip Tables (Products 10-11)

Product 10 is the county-to-county level trip table, which is not directly applicable in the San Francisco Model since it relies directly on MTC trip tables to provide trips to and from San Francisco County. The use of the MTC trip tables is discussed in the section beginning on page 17. Product 11 is the district-to-district level trip table for intra-county trips. This is presented in Table 8. This shows a strong correlation in percentage distribution of trips by district between the San Francisco and MTC Models, but a difference in total trips due to the under-estimation of trips discussed in trip generation and the explicit modeling of intermediate stops. The tables are not separated by trip purpose because the differences in tour types and trip purposes would make this comparison less useful. It should be noted that the MTC summary is based on converted MTC Trip Tables (please see the discussion of "Use of MTC Trip Tables" on page 17).

Table 8. Super-District Trip Table

Super-District	1	2	3	4	Total
SF Model Trips					
1	473,106	196,855	168,238	46,669	884,867
2	196,462	331,650	161,015	72,666	761,794
3	168,599	160,428	394,977	87,233	811,237
4	46,847	72,430	87,801	141,248	348,325
Total	894,686	678,947	812,031	347,816	2,806,223
SF Model Percent by District					
1	17%	7%	6%	2%	32%
2	7%	12%	6%	3%	27%
3	6%	6%	14%	3%	29%
4	2%	2%	3%	5%	12%
Total	32%	27%	29%	12%	100%
MTC Model Trips					
1	372,404	140,794	141,497	34,890	689,584
2	138,274	225,398	80,118	41,725	485,515
3	140,391	81,357	317,399	53,395	592,542
4	35,919	41,089	52,167	110,997	240,171
Total	686,987	488,638	591,181	241,006	2,007,813
MTC Percent by District					
1	19%	7%	7%	2%	34%
2	7%	11%	4%	2%	24%
3	7%	4%	16%	3%	30%
4	2%	2%	3%	6%	12%
Total	34%	24%	29%	12%	100%

Mode Choice

Trips by Mode (Product 12)

Trips by mode and super-district have been summarized in Table 9 for the San Francisco Model and the MTC Model trips. The San Francisco trips have been developed using separate mode choice models, documented the in *San Francisco Travel Model Development Draft Final Report* to be finalized by early 2002, and very detailed highway and transit networks. The primary difference between the San Francisco and MTC mode choice models are that the San Francisco Model estimates tour modes initially, and then trip modes for each tour segment, where the MTC Model estimates trip modes directly. Even with these differences, there is significant similarity between the results of the mode shares by super-district, resulting from the fact that both mode choice models were developed from the same 1990 MTC travel survey data.

Table 9 shows the greatest difference in the overall lower transit trip mode share and higher drive alone mode share relative to MTC. In the process of base year calibration (1998), it was not possible to match both mode shares across all purposes and total transit boardings. To illustrate, 2.9 million daily trips by San Francisco residents (expanded MTC survey) and a 33% walk-to-transit mode share across all purposes (MTC Model) would produce 957,000 walk-to-transit trips. Multiply this by a low transfer rate of 1.3, and 1.25 million walk-transit boardings are produced. However, MUNI and BART combined had less than 1 million boardings in San Francisco in the base year.

Because CTPP and MTC work mode shares were consistent, San Francisco Model work mode shares were targeted to these values and other purposes adjusted to accommodate the apparent inconsistencies in observed data. The experience with mode choice calibration strongly suggests the need to revisit the mode choice models with more current census, household survey and transit on-board survey information.

Vehicle Trips by Mode (Product 13)

Table 10 compares the vehicle trips by mode from the San Francisco Model to the MTC Model. In total, there is quite a bit of difference between the MTC vehicle trips and the San Francisco vehicle trips, resulting from the significant differences in trip rates discussed in trip generation. These are reported here as percent of total trips to evaluate the mode share properties of these trips, which show that drive alone trips are slightly

over-estimated in the San Francisco Model and transit trips are under-estimated compared to the MTC Model.

Table 9. Trips by Mode and Super-district (Product 12)

Super-District	San Francisco Model Trips	MTC Model Trips	Super-District	San Francisco Model Trips	MTC Model Trips
Drive Alone			**Walk**		
1	23%	11%	1	35%	43%
2	31%	26%	2	24%	24%
3	33%	29%	3	18%	17%
4	36%	32%	4	14%	13%
Total	30%	22%	Total	24%	27%
Shared Ride 2			**Bike**		
1	14%	5%	1	1%	1%
2	20%	12%	2	1%	1%
3	23%	14%	3	1%	1%
4	25%	15%	4	1%	1%
Total	20%	10%	Total	1%	1%
Shared Ride 3+			**Walk to Transit**		
1	5%	1%	1	22%	38%
2	7%	3%	2	16%	30%
3	9%	5%	3	15%	30%
4	11%	6%	4	13%	30%
Total	8%	3%	Total	17%	33%
			Drive to Transit		
			1	0%	1%
			2	0%	4%
			3	0%	4%
			4	0%	4%
			Total	0%	3%

Table 10. Vehicle Trips by Mode (Product 13)

Super-district	San Francisco Model Trips	Percent of Total	MTC Model Trips	Percent of Total
Drive Alone				
1	185,327	73%	74,669	80%
2	234,464	72%	127,198	80%
3	268,836	70%	170,471	77%
4	123,679	70%	76,467	78%
Total	812,306	71%	448,805	78%
Shared Ride 2				
1	56,829	22%	16,849	18%
2	75,774	23%	28,002	18%
3	91,380	24%	40,879	19%
4	43,132	24%	18,048	18%
Total	267,115	23%	103,778	18%
Shared Ride 3+				
1	10,794	4%	2,310	2%
2	15,622	5%	4,744	3%
3	21,809	6%	9,156	4%
4	10,848	6%	3,828	4%
Total	59,073	5%	20,038	3%
Total Vehicles				
1	252,950		93,827	
2	325,860		159,944	
3	382,025		220,506	
4	177,659		98,343	
Total	1,138,494		572,620	

Use of MTC Trip Tables

MTC person trip tables were used to provide all non-San Francisco trips for the San Francisco Model. This included using the 2000 and 2020 MTC trip tables for all trips into and out of and through San Francisco County. These trip tables were processed to provide trips by mode, purpose, time period and direction to support the five time period assignments used in the San Francisco Model. The San Francisco Model does not use a daily assignment, but adding together the volumes from the five individual time period assignments provides estimates of daily travel for comparison. The MTC Model does not currently provide trip tables by time period and direction for these time periods; so peaking factors were developed from the 1990 MTC Survey data by mode, purpose, time period and direction.

Initially, the 2000 MTC trip tables were assigned to the five detailed San Francisco Model networks to ensure that county crossings matched traffic counts for 2000. Discrepancies in the individual time period assignments and in some cases, the daily traffic volumes, resulted in a need to modify the MTC trip tables slightly to provide more accurate county crossings. These modifications focused on achieving more accuracy in time period and direction assignments to provide more accuracy for detailed planning applications. They do not significantly affect the distribution of the daily MTC trip tables and detailed documentation of these results is provided below.

In the case of the Golden Gate Bridge, the assignment of the 2000 MTC trip tables replicated the 10 percent over-assignment reported in the 1990 MTC Model Validation Report[3], but this was comprised of variation by time period and direction. These volumes are presented in Table 11. This level of accuracy was not considered good enough for detailed planning uses (specifically for the Doyle Drive Environmental & Design Study). In addition, the percent differences by time period were more significant. This is somewhat expected because the time period trip tables developed from MTC data were never validated as part of the MTC modeling process. There is a strong consistency to the differences, as shown in Figure 4, where the MTC Model over-estimates the peak direction in the peak periods and under-estimates the early AM and evening periods. This is directly related to the differences between the congestion represented in time period-specific assignments and daily assignments, which can only approximate the congestion represented over the course of the day.

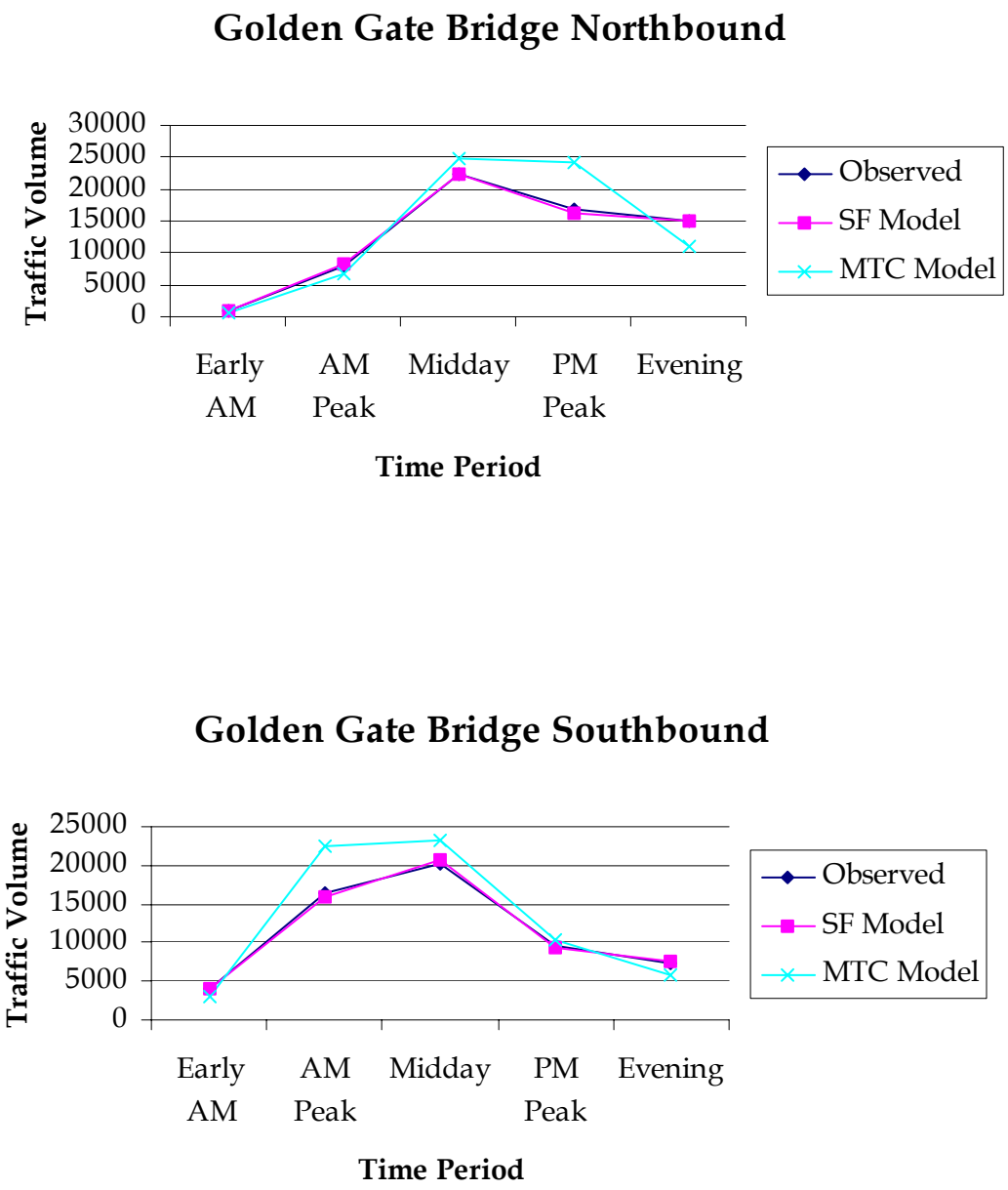
[3] Metropolitan Transportation Commission, *Base Year Validation of Travel Demand Models for the San Francisco Bay Area (BAYCAST-90) Technical Summary*, April 1998.

Table 11. Golden Gate Bridge Volumes by Time Period and Direction

Direction	Time Period	Observed*	SF Model Volume	Percent Difference	MTC Model Volume	Percent Difference
Northbound	Early AM	910	896	-1.5%	744	-18.2%
	AM Peak	8054	8184	1.6%	6843	-15.0%
	Midday	22282	22213	-0.3%	24905	11.8%
	PM Peak	16744	16209	-3.2%	24290	45.1%
	Evening	15025	15079	0.4%	11139	-25.9%
	Total	63015	62581	-0.7%	67921	7.8%
Southbound	Early AM	3931	4022	2.3%	3040	-22.7%
	AM Peak	16354	15995	-2.2%	22578	38.1%
	Midday	20132	20800	3.3%	23329	15.9%
	PM Peak	9531	9440	-1.0%	10318	8.3%
	Evening	7358	7482	1.7%	5846	-20.5%
	Total	57306	57739	0.8%	65111	13.6%

* Source: Counts conducted in 1998-1999 by the Golden Gate Bridge, Highway and Transportation District

Figure 4. Golden Gate Bridge Volumes by Time Period and Direction



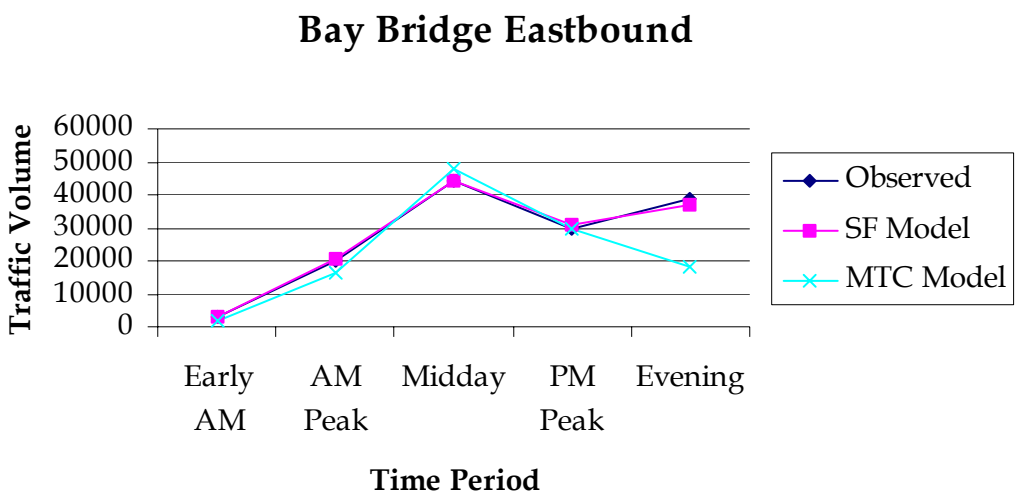
In the case of the Bay Bridge, the MTC Model under-estimates traffic volumes overall on the bridge, even though the 1990 MTC Model validation reports a 10 percent over-estimation on the Bay Bridge. This is likely due to the fact that there are some other options for trips heading across the Bay and congestion effects during individual time periods may cause some trips to choose these other options. Again, there is a direct correlation between the traffic volumes in the peak direction of the peak periods in the San Francisco Model and the MTC Model. This supports the conclusion that the MTC Model is replicating peak conditions with the daily assignments but is not accurately representing non-peak conditions with these assignments (and was not directly intended to do so). Table 12 presents a summary of the Bay Bridge volumes for the San Francisco Model and MTC Model compared to observed values for 1998. Figure 5 presents these results graphically by time period and direction.

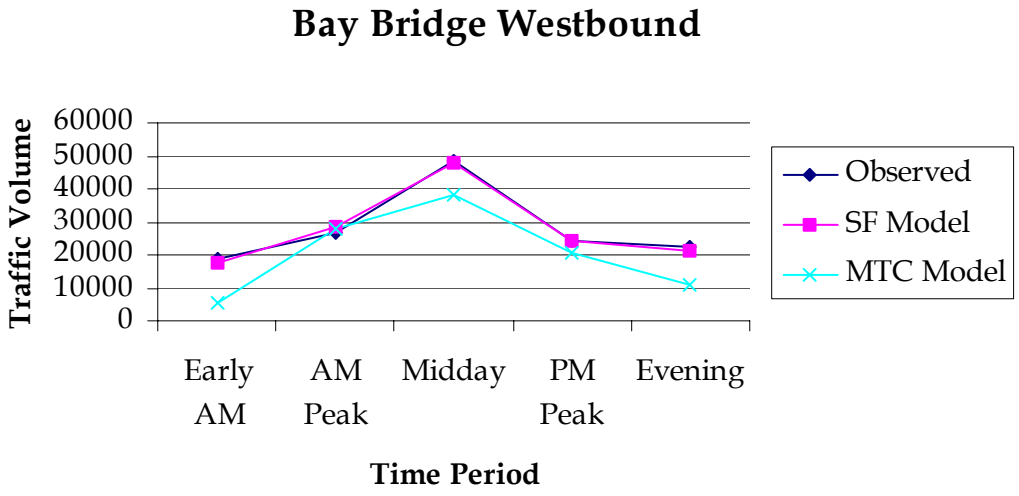
Table 12. Bay Bridge Volumes by Time Period and Direction

Direction	Time Period	Observed*	SF Model Volume	Percent Difference	MTC Model Volume	Percent Difference
Eastbound	Early AM	2987	2945	-1.4%	1876	-37.2%
	AM Peak	20260	20575	1.6%	16113	-20.5%
	Midday	44310	44509	0.4%	47883	8.1%
	PM Peak	29683	30657	3.3%	29575	-0.4%
	Evening	38893	36868	-5.2%	18458	-52.5%
	Total	136133	135554	-0.4%	113905	-16.3%
Westbound	Early AM	18601	17350	-6.7%	5223	-71.9%
	AM Peak	26865	28617	6.5%	27842	3.6%
	Midday	48576	47691	-1.8%	38453	-20.8%
	PM Peak	24238	24277	0.2%	20770	-14.3%
	Evening	22270	20935	-6.0%	10798	-51.5%
	Total	140550	138870	-1.2%	103086	-26.7%

* Source: Counts conducted in 1998-1999 by Caltrans.

Figure 5. Bay Bridge Volumes by Time Period and Direction





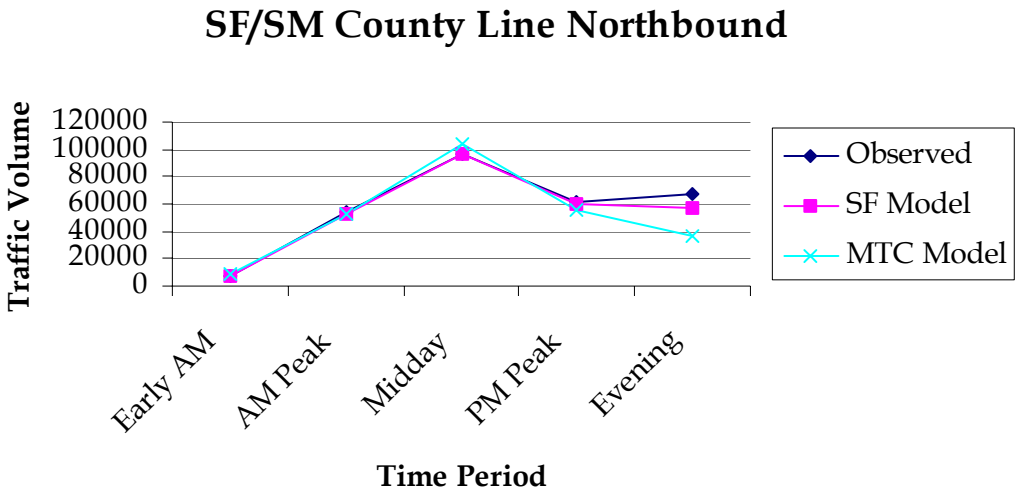
The MTC Model under-estimates volumes on the San Francisco/San Mateo County line, but only by 9 percent. This is almost entirely due to an under-estimation of volumes in the evening period, which is consistent with the results from the Golden Gate and Bay Bridge crossings. Again, these trip tables were modified slightly to achieve a higher degree of accuracy by time period and direction. Table 13 presents the results of the county line crossing evaluation and Figure 6 presents these results graphically.

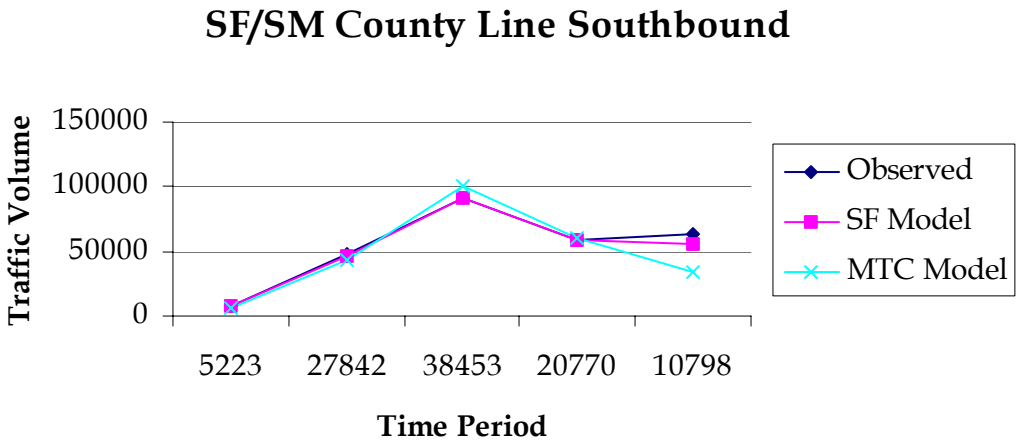
Table 13. San Francisco/San Mateo County Line Volumes by Time Period and Direction

Direction	Time Period	Observed*	SF Model Volume	Percent Difference	MTC Model Volume	Percent Difference
Northbound	Early AM	7396	7699	4.1%	8393	13.5%
	AM Peak	53683	53087	-1.1%	52917	-1.4%
	Midday	96723	96759	0.0%	104535	8.1%
	PM Peak	60737	60008	-1.2%	56277	-7.3%
	Evening	67661	57350	-15.2%	36498	-46.1%
	Total	286200	274903	-3.9%	258620	-9.6%
Southbound	Early AM	7869	7479	-5.0%	5980	-24.0%
	AM Peak	47672	47130	-1.1%	43746	-8.2%
	Midday	90862	91067	0.2%	100985	11.1%
	PM Peak	58595	58727	0.2%	60671	3.5%
	Evening	63856	55773	-12.7%	34755	-45.6%
	Total	268854	260176	-3.2%	246137	-8.4%

* Source: Counts conducted mainly in 1998-1999 by Caltrans, City of San Francisco Department of Parking and Traffic, and the San Francisco County Transportation Authority. (Counts in a small number of location were conducted before 1998.)

Figure 6. San Francisco/SM County Line Crossing by Time Period and Direction





Trip Assignment

Description of Methodology (Product 14)

Highway Assignment

The highway assignment is processed within the TP+ software environment for each of the five time periods. Each time period has an adjustment factor to convert capacity for the period into an hourly capacity value for use in the volume-delay functions. This factor was based on an analysis of observed countywide volumes by hour and time period. In addition, turn penalties and tow-away lanes are coded specific to each time period. Tow-away lanes are coded specifically in each network. Turn penalties are provided in separate files, as identified below. These time periods and adjustment factors are shown in Table 14.

Table 14. Time Periods used in San Francisco Model

Time Period	Hours	Factor used in Assignment to Adjust for Hourly Capacity (TPFAC)	Turn Penalties
Early	(3:00 AM to 5:59 AM)	58 percent	Off-peak
AM peak	(6:00 AM to 8:59 AM)	44 percent	AM Peak
Midday	(9:00 AM to 3:29 PM)	18 percent	Off-peak
PM peak	(3:30 PM to 6:29 PM)	37 percent	PM Peak
Late	(6:30 PM to 2:59 AM)	22 percent	Off-peak

The highway assignment uses a series of assumptions to implement a traditional equilibrium traffic assignment:

- 15 iterations are run for each time period assignment. At the time these procedures were developed, there appeared to be an error in that GAP was not correctly calculated by TP+ (or at least not in the way relative gap is typically defined). GAP was thought to not be a reliable measure, and thus a fixed number of iterations were defined for each highway assignment application. Fifteen iterations were prescribed because approximately 75% of links had their volume change by less than 3% after 15 iterations, as reported by TP+. Thus 15 iterations marked the point of compromise between execution time and what was thought to be an acceptably converged solution.
- Link impedance is defined as travel time in minutes.
- A multi-class assignment is performed on drive alone, shared ride 2 and shared ride 3+ vehicle classes. Trucks are estimated separately, but are not assigned as a separate class.

Volume-delay functions are defined by facility type, as presented in Table 15. This function is as follows:

```
Volume-Delay = T0*PKFAC*(1+A*(TPFAC*V/C)^6.0)*NOFIX + (LI.TSVA/100)*FIX
```

The variables in the volume delay functions can be defined as such:

- **T0** is free flow link travel time
- **PKFAC** is the peaking factor
- **A** is the BPR function coefficient
- **TPFAC** is the time period factor
- **V** is calculated in the previous iteration from the 3 classes of traffic volumes
- **C** is link capacity
- **NOFIX** is 1 if the link is not a fixed time link and 0 otherwise
- **FIX** is 1 if the link is a fixed time link and 0 otherwise
- **LI.TSVA** is the fixed time value if the link is a fixed time link and 0 otherwise

The basic functions, twelve in total, were originally taken from the MTC assignment model. For the San Francisco Model, the relevant link facility types, and therefore indices of the volume delay functions are identified in Table 15.

Table 15. Volume Delay Function Facility Type Indices

Link Type Code	Description	BPR Function Coefficient	T0 Factor for AM and PM Peak Periods (PKFAC)	T0 Factor for AM and PM Peak Periods (PKFAC)
Freeway to freeway connector	1	0.71	1.3	1.3
Freeway	2	0.88	1.0	1.3
Expressway	3	0.83	1.3	1.3
Collector	4	0.71	1.0	1.3
Freeway Ramp	5	0.71	1.3	1.3
Dummy Link	6	0.71	1.3	1.3
Major Arterial	7	0.83	1.6	1.3
Metered Ramp	8	0.71	1.3	1.3
Special (not used)	9	0.71	1.3	1.3
Special (not used)	10	0.71	1.6	1.3
Local Street	11	0.71	1.3	1.3
Minor Arterial	12	0.71	1.3	1.3

The peaking factor on T0 was included in order to raise the values of free flow travel times used in the volume delay functions. Free flow travel times are calculated internally by TP+ from the free-flow speed and distance fields found in the input network. Free flow speed values were derived from a lookup table of speeds based on area type and facility type. It was felt that these lookup speeds might be too high, and O/D travel time skims reflected that these values were probably too high. Therefore, adjustments to the volume delay functions were made to address this problem. The lookup table speeds could have just as easily been modified and the network free flow speeds updated based on this change instead of using this T0 factor. Changing the factor, though, was a more efficient way to get the desired effect and to calibrate the required factors through multiple executions of the highway assignment procedure.

The BPR coefficient and exponent are used to give the desired shape to the link travel time vs. link volume curves. The BPR functions are very commonly used in transportation demand models for representing congested travel time. NCHRP Report 365 gives some guidance as to the values to use based on urban link facility type and speed ranges. The values were taken to match the link types in the San Francisco Model as closely as possible, and then adjusted to replicate observed link volumes and travel times as best as possible. The coefficients were left pretty much unaltered, while the exponent value of 6.0 was the compromise between matching observed data and following the guidance in NCHRP 365.

The time of day volume factor is required to reduce the assigned volume stemming from the demand over the specific time period being modeled. This reduction is necessary because the capacity (C) in the volume delay function is an hourly capacity, while the volume is the volume for 3 hours in the AM period. Volume is likewise in excess of 1

hour in all the other time periods. The time of day volume factor reduces the assigned link volume to an expected hourly volume for the purpose of relating volume to capacity in the congested travel time functions. The values, e.g. 0.44 for the AM period, were derived from total observed link counts during the busiest hour of the time period divided by total observed link counts over the entire time period. These values do not have to strictly adhere to the above definition, since obviously a typical hour is not the busiest hour. The values can be used to fine-tune the assignment calibration if necessary, but for the San Francisco Model, the values derived as discussed above worked well and were not adjusted further.

Finally, the fixed time value divisor of 100 was used to convert the fixed times, entered in the input network in units of 100 minutes, to whole minutes so that they would be on the same scale as the travel time resulting from the normal BPR function calculations. The fixed time value is used in the volume delay function in conjunction with the variables `FIX` and `NOFIX`. If the `TSIN` field in the input network is coded as '`T`', then the link is to be treated as a fixed time link. The centroid connector links from the MTC Model were coded as fixed time links and maintained as such for the San Francisco Model. Another example of fixed time links are toll links on the Golden Gate Bridge and Bay Bridge. Tolls were represented by fixed time links where the toll cost was entered in equivalent minutes. Since `FIX` and `NOFIX` are complementary (0 or 1), the volume delay function for a link is either the BPR portion for non-fixed time links (`NOFIX` equals 1, `FIX` equals 0), or the fixed time portion for fixed time links (`NOFIX` equals 0, `FIX` equals 1).

Transit Assignment

The transit assignment is uses a multi-path algorithm, based on the assessment of optimal strategies, which is the assignment algorithm in TP+. The optimal strategy is the path for each traveler that minimizes the expected travel time, including time spent walking, waiting and riding. Time spent waiting for a transit vehicle is calculated based on the fact that there may be many transit vehicles traveling from a specific origin to a specific destination and the traveler will choose to take the *first* vehicle that arrives.

Although the program allows for multi-path assignments, each mode is assigned separately based on the results of the mode choice model and the preferred paths for each individual mode. There are four transit modes used in transit assignment:

- Local Bus (L) – including Muni Express Bus (1), Muni Local Bus (2), and regional local bus services (non-SF) (5)
- Local Muni Rail (M) – including Muni Metro and Cable Cars (3)
- Premium Service to San Francisco (P) – including Caltrain (9), ferries (9), SamTrans (6), Golden Gate Transit (7), and AC Transit (8).
- BART (B) (4).

The walk mode provides access to the transit modes (local bus, premium service and BART). Transit assignments are only carried out separately for each access and egress mode combination:

- Walk access to transit, walk egress
- Walk access to transit, auto egress
- Auto access to transit, walk egress

All transit assignment use a series of assumptions regarding specific parameters:

- Walk speed is 3 miles per hour; drive speed is derived from the highway network.
- There is a minimum initial wait time of 1 minute and a maximum initial wait time of 12 minutes. There is a maximum wait time of 40 minutes on transfers.
- Maximum run time is set at 240 minutes and maximum path time is set at 300 minutes to be consistent with MTC.
- There is a weighting factor of 2.0 for all out-of-vehicle time.
- There is a 6-minute transfer penalty for 2nd and 3rd boardings.

Peaking Factors and Vehicle Occupancy Assumptions (Product 15)

Peaking factors were developed directly from the 1990 MTC survey data, processed by mode, purpose and direction for each of the five time periods. These results are summarized in Table 16. Vehicle occupancies are assumed for each of the three auto modes, as follows:

- 1.0 person per vehicle for Drive Alone
- 2.0 persons per vehicle for Shared Ride 2
- 3.5 persons per vehicle for Shared Ride 3+

Table 16. Peaking Factors by Mode, Purpose, Direction and Time Period

	Drive Alone		Shared Ride 2		Shared Ride 3+		Walk		Bike		Walk to Transit		Drive to Transit	Drive from Transit
	PA	AP	PA	AP	PA	AP	PA	AP	PA	AP	PA	AP	PA	AP
Work Tours														
Early AM	6.1%	0.1%	5.4%	0.1%	7.8%	0.1%	4.1%	0.1%	1.6%	0.0%	7.4%	0.1%	11.1%	0.0%
AM Peak	34.1%	0.3%	37.2%	0.3%	41.3%	0.3%	30.9%	0.2%	35.9%	0.3%	38.8%	0.3%	36.4%	0.5%
Midday	7.3%	9.8%	6.3%	8.4%	5.4%	7.2%	10.5%	14.1%	7.8%	10.5%	6.1%	8.2%	2.3%	6.9%
PM Peak	1.2%	30.1%	1.2%	29.2%	1.1%	28.7%	1.2%	29.8%	1.3%	31.8%	1.3%	33.8%	0.1%	37.4%
Evening	0.6%	10.6%	0.6%	11.3%	0.4%	7.6%	0.5%	8.7%	0.6%	10.1%	0.2%	3.7%	0.0%	5.2%
School Tours														
Early AM	0.6%	0.1%	0.6%	0.1%			0.4%	0.0%	0.2%	0.0%	0.9%	0.1%		
AM Peak	26.6%	0.4%	45.3%	0.7%			40.0%	0.7%	41.3%	0.7%	39.3%	0.6%		
Midday	5.9%	34.0%	4.8%	27.5%			7.5%	43.1%	7.0%	40.3%	6.6%	38.3%		
PM Peak	2.7%	14.6%	2.6%	13.7%			1.1%	5.9%	1.2%	6.4%	1.8%	9.6%		
Evening	2.9%	12.2%	0.9%	3.8%			0.3%	1.1%	0.5%	2.2%	0.5%	2.2%		
Other Tours														
Early AM	0.4%	0.1%	0.4%	0.1%	0.6%	0.2%	0.5%	0.2%	0.3%	0.1%	0.8%	0.2%	0.0%	0.0%
AM Peak	7.7%	3.2%	6.8%	2.8%	7.5%	3.1%	11.5%	4.7%	4.6%	1.9%	9.9%	4.0%	16.0%	0.0%
Midday	24.7%	22.0%	19.9%	17.8%	18.6%	16.6%	22.6%	20.2%	17.8%	15.9%	36.5%	32.6%	18.0%	22.2%
PM Peak	10.7%	10.7%	12.4%	12.4%	12.8%	12.8%	11.0%	10.9%	19.8%	19.8%	5.6%	5.6%	10.0%	7.4%
Evening	7.1%	13.4%	9.5%	18.0%	9.7%	18.2%	6.4%	12.1%	6.9%	12.9%	1.6%	3.1%	6.0%	20.4%
Work-based Tours														
Early AM	0.5%		0.6%				0.2%		0.0%		0.5%			
AM Peak	11.4%		10.0%				5.5%		9.3%		10.6%			
Midday	62.2%		54.6%				79.2%		63.7%		60.6%			
PM Peak	20.6%		21.4%				10.6%		20.3%		20.3%			
Evening	5.3%		13.4%				4.6%		6.6%		8.0%			

Appendix. Comparison of Parking Cost by MTC Zones

MTC Zone	Average SF Off-Peak Parking Cost	MTC Off-Peak Parking Cost	Difference	Average SF Peak Parking Cost	MTC Peak Parking Cost	Difference
1	$ 0.50	87	$ (0.37)	$ 1.48	325	$ (1.77)
2	$ 0.90	87	$ 0.03	$ 2.99	217	$ 0.82
3	$ 1.17	54	$ 0.63	$ 3.98	217	$ 1.81
4	$ 1.06	54	$ 0.52	$ 3.57	217	$ 1.40
5	$ 0.91	43	$ 0.48	$ 3.01	65	$ 2.36
6	$ 0.93	43	$ 0.50	$ 3.37	65	$ 2.72
7	$ 1.00	54	$ 0.46	$ 3.64	108	$ 2.56
8	$ 1.80	65	$ 1.15	$ 5.51	271	$ 2.80
9	$ 1.62	65	$ 0.97	$ 4.77	244	$ 2.33
10	$ 1.80	54	$ 1.26	$ 5.51	189	$ 3.62
11	$ 1.14	43	$ 0.71	$ 4.23	162	$ 2.61
12	$ 1.12	43	$ 0.69	$ 4.35	65	$ 3.70
13	$ 2.74	43	$ 2.31	$ 2.18	65	$ 1.53
14	$ 2.74	43	$ 2.31	$ 2.18	65	$ 1.53
15	$ 1.79	43	$ 1.36	$ 5.64	65	$ 4.99
16	$ 0.50	87	$ (0.38)	$ 1.63	108	$ 0.55
17	$ 0.44	87	$ (0.43)	$ 1.33	271	$ (1.38)
18	$ 1.38	87	$ 0.51	$ 3.08	108	$ 2.00
19	$ 1.16	43	$ 0.73	$ 3.95	81	$ 3.14
20	$ 1.16	32	$ 0.84	$ 3.94	49	$ 3.45
21	$ 1.16	32	$ 0.84	$ 3.94	49	$ 3.45
22	$ 1.16	32	$ 0.84	$ 3.94	43	$ 3.51
23	$ 1.16	32	$ 0.84	$ 3.94	43	$ 3.51
24	$ 1.16	22	$ 0.94	$ 3.94	43	$ 3.51
25	$ 1.30	87	$ 0.43	$ 4.83	87	$ 3.96
26	$ 1.37	87	$ 0.50	$ 6.00	108	$ 4.92
27	$ 1.37	32	$ 1.05	$ 6.00	65	$ 5.35
28	$ 2.66	32	$ 2.34	$ 3.71	117	$ 2.54
29	$ 1.16	22	$ 0.94	$ 3.94	43	$ 3.51
30	$ 1.17	32	$ 0.85	$ 4.35	43	$ 3.92
32	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
33	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
34	$ 0.37	0	$ 0.37	$ 1.00	43	$ 0.57
35	$ 0.37	0	$ 0.37	$ 1.00	43	$ 0.57
36	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
37	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
38	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
39	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
40	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
41	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00

MTC Zone	Average SF Off-Peak Parking Cost	MTC Off-Peak Parking Cost	Difference	Average SF Peak Parking Cost	MTC Peak Parking Cost	Difference
42	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
43	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
44	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
45	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
46	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
47	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
48	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
49	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
50	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
51	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
52	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
53	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
54	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
55	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
56	$ 0.37	0	$ 0.37	$ 1.00	49	$ 0.51
57	$ 0.37	32	$ 0.05	$ 1.00	49	$ 0.51
58	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
59	$ 0.37	32	$ 0.05	$ 1.00	49	$ 0.51
60	$ 0.37	38	$ (0.01)	$ 1.00	43	$ 0.57
61	$ 0.49	38	$ 0.11	$ 1.46	43	$ 1.03
62	$ 0.43	16	$ 0.27	$ 1.21	27	$ 0.94
63	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
64	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
65	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
66	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
67	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
68	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
69	$ 0.37	0	$ 0.37	$ 1.00	22	$ 0.78
70	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
71	$ 0.37	0	$ 0.37	$ 1.00	27	$ 0.73
72	$ 0.37	0	$ 0.37	$ 1.00	27	$ 0.73
73	$ 0.37	0	$ 0.37	$ 1.00	27	$ 0.73
74	$ 0.37	0	$ 0.37	$ 1.00	27	$ 0.73
75	$ 0.37	16	$ 0.21	$ 1.00	27	$ 0.73
76	$ 0.46	16	$ 0.30	$ 1.35	27	$ 1.08
77	$ 0.53	22	$ 0.31	$ 0.75	60	$ 0.15
78	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
79	$ 0.83	30	$ 0.53	$ 1.78	60	$ 1.18
80	$ 0.69	0	$ 0.69	$ 0.50	0	$ 0.50
81	$ 0.62	0	$ 0.62	$ 0.60	0	$ 0.60
82	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
83	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
84	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00

MTC Zone	Average SF Off-Peak Parking Cost	MTC Off-Peak Parking Cost	Difference	Average SF Peak Parking Cost	MTC Peak Parking Cost	Difference
85	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
86	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
87	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
88	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
89	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
90	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
91	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
92	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
93	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
94	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
95	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
96	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
97	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
98	$ 0.48	0	$ 0.48	$ 0.83	0	$ 0.83
99	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
100	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
101	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
102	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
103	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
104	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
105	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
106	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
107	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
108	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
109	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
110	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
111	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
112	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
113	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
114	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
115	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
116	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
117	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
118	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
119	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
120	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
121	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
122	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
123	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
124	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
125	$ 0.45	0	$ 0.45	$ 0.88	0	$ 0.88
126	$ 0.37	0	$ 0.37	$ 1.00	0	$ 1.00
127	$ 0.37	0	$ 0.37	$ 1.00	0	$ 100