Built Environment Element
Transportation Technical Report #1

The Transportation System and Transportation Modeling

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EXECUTIVE SUMMARY

This technical report for the Built Environment Element of the Countywide Plan defines some of the terminology used in transportation planning and briefly describes the transportation modeling process used for the Countywide Plan update.

The report begins with a description of the types of roads and transit service in Marin. The types of roads include freeways, freeway ramps, primary arterials, secondary arterials, commercial collectors and streets, and residential collectors and streets. A freeway is a limited access, high speed, high volume facility designed to provide access between communities and to the rest of the region as well as providing for through traffic. Freeway ramps are single purpose road segments connecting the freeway with local streets. The purpose of a ramp is to allow motorists to make the transition between the slower speeds on local streets and the faster speeds of the freeway. A primary arterial is a limited access, moderate speed, high volume facility designed to provide access between communities or from a community to the freeway. A secondary arterial is a moderate access, moderate speed, moderate volume facility designed to provide access between various parts of a community. Commercial collectors are highly accessible, moderate to low speed, moderate to low volume facilities designed to provide access to individual commercial parcels and collect their traffic for access to arterial streets. Residential collectors and streets are highly accessible, low speed, moderate to low volume facilities designed to provide access to individual residential parcels and collect their traffic for access to arterial streets.

Transit service may be described as “corridor” or local. Corridor transit is service designed to carry many people in one vehicle for trips between counties. Buses and ferries provide corridor transit service from Marin to San Francisco, for example. Local transit is distinguished from corridor transit in that the service offers many origins and destinations within Marin County but not to San Francisco.

Each type of road has a theoretical design capacity, expressed as lane volume in the peak hour, but such factors as intersections, turning movements, driveways, pedestrians and environmental conditions affect actual operating conditions. A freeway, designed to have the fewest potential conflicting traffic movements, has a capacity of 2,000 vehicles per lane per hour. Local streets are evaluated according to time delay at intersections and average speed.

Level of Service is a qualitative measure used to describe operating conditions on lane segments and intersections. Letters A through F are used to indicate conditions ranging from free flow to severe congestion.

The modeling effort for the Countywide Plan includes five trip types: home-based work, home-based shopping, home-based social/recreational, home-based school, and non-home-based. Home-based trips have home as either an origin or destination. Non-home-based trips do not. For home-based work trips, four different modes were modeled: drive alone, two-person carpool, three-person carpool, and transit. The choice of a given mode determines how many vehicles will be on the roads and how congested the roads will be. Generally, the more carpooling and transit use, the less congested the roads (given the same number of people traveling). If relatively more people are using carpools and transit, the vehicle occupancy rate is higher.

The County's modeling process follows the standard methodology used in transportation modeling. The four steps of the process are trip generation, trip distribution, mode choice, and trip assignment. Trip generation is the number of trips produced and attracted by the land uses within traffic zones. These trips are then distributed to other traffic zones depending on the land use characteristics of other zones and the time of travel between zones. Mode choice is made according to the relative attractiveness of the alternatives and the income of the person making the trip. The computer software has an algorithm, which then assigns vehicles to the network according to specifications entered by the operator (e.g., number of lanes and posted speed limit). The software can print out a copy of the street network with the results printed along the street segments.

I. INTRODUCTION

This report is the first in a series of technical reports for the Built Environment Element of the Countywide Plan. The report will define some of the terminology used in transportation planning, explain some of the characteristics of traffic, and describe Marin County's transportation model, a microcomputer-based set of programs which simulate how the road network and transit system operate in Marin.

One purpose of the technical report series is to present background information and explanations of the work that contributes to the Transportation Element of the Countywide Plan. A second purpose is to provide the information necessary for Marin County residents, elected officials, and local government staff to understand transportation systems and traffic problems. With this understanding, concerned parties can generate solutions that are cost-effective, environmentally sensitive, and politically acceptable.

II. TRANSPORTATION SYSTEMS: DEFINITIONS AND CONCEPTS

A. THE ROAD NETWORK AND TRANSIT SERVICE

For purposes of the Countywide Plan update and discussions of transportation, it is important that everyone know the terms used in transportation planning. This section introduces a few of the most frequently used words and concepts associated with the road network and transit service. The road network consists of freeways, ramps, primary arterials, secondary arterials, commercial collectors and streets, and residential collectors and streets. Transit service consists of corridor transit and local transit.

Elements of the road network are classified according to their function, design, and operation. *Function* is the intended use of the facility, such as access to individual parcels, access to the other parts of the community, access to the rest of the region, and provisions for parking. *Design* characteristics include recommended vehicle speed, recommended traffic volume (the number of vehicles that may be accommodated), and features such as driveways, turning lanes, median barriers, intersections, acceleration/deceleration lanes and interchanges. *Operation* is how the facility performs, actual vehicle speeds (as distinguished from the design speed) and actual traffic volumes, meaning the influence of adjoining development on traffic flow.

The various types of road facilities and transit service are as follows:

1. Freeway

A freeway is a limited access, high speed, high volume facility designed to provide access between communities and to the rest of the region, as well as providing for through traffic. Access to the freeway is provided only at interchanges, via freeway ramps (described below). Opposite lanes are separated by a median. The design volume for a freeway lane is 2,000 vehicles per hour, the highest volume for all roads. Local freeway lanes carry 1,200-2,000 vehicles in the peak hour of operation, depending on conditions. The posted speed is currently 55 or 65 miles per hour, although portions of freeways may have been designed for speeds of 70-75 miles per hour. An example of a freeway is Highway 101 between the Golden Gate Bridge and Novato.

2. Freeway Ramps

Freeway ramps are single purpose road segments connecting the freeway with local streets. The purpose of a ramp is to allow motorists to make the transition between the slower speeds on local streets and the faster speeds of the freeway. While on a ramp, motorists can accelerate or decelerate to match the speed of vehicles on the freeway or local street. A second purpose of a ramp is to provide sufficient vehicle storage to allow the freeway to function independently of local streets. Ideally, the ramp should accommodate enough vehicles to prevent vehicles backing up onto local streets while trying to enter a congested freeway, or conversely, from backing up on the freeway while trying to enter congested local streets. Ramp capacities are similar to freeway capacities, accommodating up to 2,000 vehicles per hour, subject to the limitations imposed by freeway or local street congestion. An example of a ramp is the northbound segment of Irwin Street in San Rafael that enters Highway 101.

3. Primary Arterial

A primary arterial is a limited access, moderate speed, high volume facility designed to provide access between communities or from a community to the freeway. The opposing lanes of a primary arterial are usually divided by a median with access limited to intersections. Turn lanes are typically provided at intersections in order that turning vehicles do not obstruct through traffic. Parking is usually prohibited on arterials. Speeds on primary arterials range between 35 and 45 miles per hour but may vary depending on the specific location and facility. Volumes range between 500 and 1,500 vehicles per lane during the peak hours of operation. An example of a primary arterial is Sir Francis Drake Boulevard through Kentfield and Greenbrae.

4. Secondary Arterial

A secondary arterial is a moderate access, moderate speed, moderate volume facility designed to provide access between various parts of the community. Opposing lanes are divided by striping and turns to adjoining parcels on both sides of the street are usually allowed. Turn lanes are often provided at intersections. Bi-directional center turn lanes may be provided along the length of the road in commercial areas. On-street parking is permitted if the pavement is wide enough. Speeds on secondary arterials are 30 to 45 miles per hour but may vary depending on the specific location. Lane volumes are 200-600 vehicles per hour in the peak hour of operation. An example of a secondary arterial is Wolfe Grade between Greenbrae and San Rafael.

5. Commercial Collector and Street

Commercial collectors are highly accessible, moderate to low speed, moderate to low volume facilities designed to provide access to individual commercial parcels and collect their traffic for access to arterial streets. These facilities usually do not have median dividers and have frequently spaced curb cuts for driveways to individual parcels. In busy pedestrian areas, driveways may be limited to minimize interruption of pedestrian flow. On-street parking is usually permitted. Speeds on commercial collectors and streets range between 25 and 35 miles per hour. Peak-hour lane volumes are 200 to 600 vehicles. An example of a commercial collector is San Anselmo Avenue in San Anselmo.

6. Residential Collector and Street

Residential collectors are highly accessible, low speed, moderate to low volume facilities designed to provide access to individual residential parcels and to collect their traffic for access to arterial streets. These facilities rarely have median dividers or special turn lanes. Curb cuts for driveways to individual sites are common. On-street parking is typically permitted. Speeds on residential collectors and streets are 25 to 30 miles per hour. Peak hour lane volumes vary from 0 to 600 vehicles per hour. An example of a residential collector is Idylberry Road in Upper Lucas Valley.

7. Corridor Transit Service

Corridor transit service is designed to carry many people in one vehicle for trips between counties. Marin residents would use corridor transit for trips to San Francisco, Sonoma, or the East Bay. Sonoma residents would use corridor transit for trips to Marin or San Francisco. The Golden Gate Bridge, Highway, and Transportation District provides bus service between the three counties with emphasis on the transbay commute.

During the peak commute hours, buses circulate through one or more neighborhoods to pick up passengers, and then enter the freeway and travel to San Francisco, with a limited number of stops along the way. For example, a route that originates in Santa Rosa might involve stops in Rohnert Park, Petaluma, Novato, and San Rafael. Depending on ridership and operating costs, intermediate stops may be added or deleted (recent trends have been for stops to be deleted). Some routes involve no stops once the bus enters the freeway. Within San Francisco, buses may make several stops before reaching the Financial District, their final destination.

Outside the peak commuting hours, service involves buses following fixed routes at regular intervals, stopping at a variety of locations before entering another county.

The Bridge District and Red and White Fleet provide ferry service to San Francisco from Larkspur, Tiburon, and Sausalito. Commuters who use the ferry may drive or ride “feeder” buses to the terminals. Feeder buses follow regular routes through neighborhoods picking up passengers for rides to the ferry terminals.

Several operators provide specialized intercounty transportation. For example, Greyhound, which has a station in San Rafael, provides bus service to many cities within California and the nation. The Marin Airporter and Sonoma Airporter provide bus service from Marin and Sonoma to the San Francisco International Airport and Oakland International Airport.

Another type of intercounty service, the “club bus,” is being encouraged for major employers in Marin. People who share common origins, destinations, and commute times would charter or lease a bus to carry them to and from work. Similar to express service, a club bus would make several stops to take on passengers, and then carry them non-stop to one destination. Club buses are especially useful for long distance commuting.

8. Local Transit

Local transit is distinguished from corridor transit in that the service offers many origins and destinations within Marin County but not to other counties. For a given passenger, there may be many stops between origin and destination. Buses run along fixed routes at regular intervals. Transfers between routes are often necessary. In Marin, local transit service is provided by the Golden Gate Bridge District under contract with the Marin County Transit District.

B. ROAD NETWORK CAPACITY AND OPERATIONS

Each of the road types listed above has a capacity, expressed as lane volume in the peak hour. Although every road type has a maximum theoretical capacity inherent to its design, day-to-day capacity is determined by operations. For analytical convenience, traffic engineers observe three types of capacity: segment, weaving, and intersection. The combination of segment and weaving capacities are used to evaluate freeway operation; the combination of segment and intersection capacities is used to evaluate local streets.

The freeway is designed to maximize lane carrying capacity by eliminating potential conflicts such as intersections and left turns across oncoming traffic. Maximum capacity is also facilitated by eliminating friction, such as parking along the right lane and turns into driveways. As a result, the segment capacity in an uninterrupted section of freeway is set by the interaction of drivers in the lane, the distance drivers allow between vehicles, occasional topographical changes (e.g., hills), weather conditions, and the number of lanes. The typical freeway lane is designed to carry approximately 2,000 vehicles per hour.

As volume reaches capacity, speeds decrease and vehicle density per lane increases (vehicle density is the number of vehicles per unit of road space, usually one mile). As the traffic volume on the freeway and ramps feeding the freeway continue to build, the weave between the ramp traffic and through traffic becomes critical ("weave" is the merging of vehicles from the ramp onto the freeway). When both the freeway and ramps approach capacity, they do not function independently: the weave becomes 1 to 1. Each vehicle from the ramp merges between two vehicles on the freeway. This results in 900 merging vehicles combining with 900 freeway vehicles to fill the freeway lane capacity. The theoretical capacity of 2,000 vehicles is not reached because of inefficiencies in the merge. Additional through traffic on the freeway must then shift to the left if there is available capacity in other lanes; if not, traffic backs up.

On the local street system it is generally turning movements at intersections that restrict traffic flow. If there are many turns, the time delay at intersections may exceed 40 seconds. Traffic engineers try to regulate the turning movements in a way that allows the most vehicles to proceed through the intersection while minimizing interference with through traffic. Examples of regulations include special left- or right-turn lanes, prohibiting left or U-turns, prohibiting parking within a certain distance of an intersection (red curb), time limits on parking (e.g., no parking between 4 and 6 p.m.), and timed sequences of signals from traffic lights. At a signalized intersection, compatible movements may be allowed in one signal phase while other, conflicting movements are accommodated in separate phases. In each phase there is a critical movement, which requires the greatest amount of time. An example would be a left turn across several lanes of opposing traffic. The sum of the time required for critical movements from each phase provides a numerical index for evaluating the intersection's operation.

Road segment capacity is usually not adversely affected unless there is a reduction in the number of lanes, a decrease in lane width, or many turns into driveways or parking spaces. If there are many turning movements, the average travel speed along the segment may fall to between 9 and 17 miles per hour. Engineers measure time delay and speed reductions due to turning movements to evaluate segments. They also calculate “friction factors,” a delay of speed caused by decreased lane width or the presence of parked vehicles along a segment. Given a certain traffic demand, engineers use these measures to design a road segment or indicate what improvements may be necessary to upgrade a poorly performing one.

C. LEVEL OF SERVICE

Level of service is a qualitative measure describing traffic conditions on freeways and local streets. The first six letters of the alphabet, A through F, are used to designate conditions ranging from free flow (Level of Service A) to forced flow or breakdown (Level of Service F). The level of service definition is described in terms of speed and travel time, freedom to maneuver, interruptions, comfort, convenience, and safety. For a given road segment with a certain number of lanes, intersections, parking spaces, driveways, etc., each letter beyond A represents increasing vehicle density, decreasing speeds, and greater time delay (i.e., increasing congestion).

Level of service is related to capacity in that level of service deteriorates as the road approaches or reaches capacity. Generally, Level of Service E is associated with traffic flowing at the capacity of a road. Speeds are low and unstable; maneuvering is difficult; comfort and convenience levels are poor; user frustration is high. When the freeway is at capacity, the vehicle density per lane mile is 67 vehicles. Freeway speeds fall below 30 miles per hour. If more vehicles are added to the road, breakdowns or stop-and-go traffic is experienced (Level of Service F).

It may seem like a contradiction in terms to state that when a road is carrying its capacity, its users suffer “high frustration,” but recall that capacity is the maximum number of vehicles that can pass by a point in a given period of time under specified conditions. It is also important to note that capacity is reached for only a short time during the commute period in urban areas. In Marin, levels of service E and F are experienced on Highway 101 in the San Rafael area during the peak periods. In the morning, congestion may extend north to Novato; in the evening, south to Mill Valley.

Because Levels of Service E or F are unacceptable to most motorists, local officials choose Level of Service D as the desired target on congested roads, those already suffering Levels of Service E and F. (Level of Service D is accepted as a standard for suburban street operations nationwide.) At Level of Service D, maximum freeway lane volume is 1,850 vehicles per hour, vehicle density per lane mile ranges from 30 to 42 vehicles, and speeds range from 54 to 46 miles per hour.

Although level of service is described in qualitative terms, it is necessary to quantify each level in order to measure it for different types of roads. The transportation model uses such measures as speed, travel time, and volume-to-capacity ratio to determine level of service. Each of these variables is output from the model for each road segment. The volume-to-capacity ratio is the number of vehicles divided by the theoretical design capacity; density is the number of vehicles per unit area of road space, and flow rate is the number of vehicles passing a point during one hour, usually the peak hour.

D. TRIP TYPES

The analysis of transportation demand for the Countywide Plan includes the five different trip types, which have been developed by the Metropolitan Transportation Commission ("MTC") for regional modeling. Those trip types are home-based work, home-based shopping, home-based recreation, home-based school, and non-home-based.

"Home-based" means that the trip either originates from or returns to home. Home-based work trips are commutes that are typically concentrated in the morning and evening peak hours. The distinction between home-based shopping and recreation trips is necessary to reflect the difference in trip lengths: home-based shopping trips are usually much shorter than recreation trips. The non-home-based trips are work-related errands or personal errands performed on the way to or from work or during working hours. Table 1 on page 9 shows trip types as a percentage of total daily trips generated in Marin County.

Table 1. Trip Types as Percentage of Total Daily Trips in Marin County

Type of Trip	Percentage of Total Daily Trips
Home-based Work	26.9%
Home-based Shopping	25.4%
Home-based Recreation	12.4%
Home-based School	7.7%
Non-home-based	27.6%
Total	100.0%

E. MODE CHOICE

Mode choice is defined as the means a person uses to travel from place to place. For most trips, the modes are walking, bicycling, driving alone, or riding in a carpool, vanpool, bus, train, or ferry. How a person chooses to travel is of major importance to designers of transportation systems and services. In oversimplified terms, the number of people who choose to drive determines how many lanes a road should have and how congested the road will be after it is built. The number of people who choose transit determines how many buses, trains, or ferries should be provided and how often they run. It should be noted that there are often significant financial, physical, and political constraints associated with road building or the provision of transit services. These constraints may influence mode choice by limiting the alternatives a person has when choosing how to travel.

Mode choice is one of the most challenging concepts to model. There are many factors that influence a person's choices. In addition to the three general ones mentioned above, the most important factors are a person's income, travel time to the destination, cost of operating a car, transit fares, and employment density at the destination. Employment density greatly influences how effectively an area is served by automobile or transit. It also influences the price and availability of parking. For example, a low-density center is poorly served by transit; parking is often easily obtainable and free. People who work there are far more likely to drive alone than take transit. In contrast, a high-density center is effectively served by transit; parking is limited and very expensive. People who work there are far more likely to take transit or carpool to work.

The factors that influence mode choice may change for the same person if the circumstances change. For example, a branch manager of a bank located in Novato may choose to drive alone to work from his home in Novato. The distance is short and there is free employee parking. But if he gets promoted to the main office in San Francisco's financial district, he may choose to carpool or ride the bus. Not only is the travel time greater, but also the price of parking (if he gets a space at all) may be very high. He may not wish to spend his increased income on parking. The longer travel time may prompt him to seek others who are going to the same destination to share commuting costs.

F. VEHICLE OCCUPANCY

Vehicle occupancy, the result of a person's mode choice, is the number of persons riding in a given type of vehicle at one point in time. In practical usage, vehicle occupancy is given as a rate or average. For example, since 1995, vehicle occupancy rates have ranged from 1.5-1.6 persons per vehicle on Highway 101 during peak periods. This is an average representing the total number of people traveling on the highway divided by the total number of vehicles.

Vehicle occupancy is an important measure for studying the capacity of a road system. Roads are designed to carry a certain number of vehicles during the most heavily congested hour of the day. If the vehicle occupancy rate is high, the road can serve a greater number of trips (or people). Vehicle occupancy can directly affect congestion as well. If, because of more carpooling or transit usage, vehicle occupancy rates increase, congestion will decrease.

Vehicle occupancy information is collected manually by observers counting the number of people in a vehicle. Generally, the only vehicle observed is the automobile. Rarely are truck or van occupancies determined. Train, bus, and ferry occupancies are calculated via fare receipts. The sources of vehicle occupancy information available to the Countywide Plan update effort are the California Department of Transportation ("Caltrans") annual vehicle occupancy counts for the San Francisco Bay Area freeway system and Golden Gate Bridge District fare receipts. To obtain this information, Caltrans stationed observers at selected points along Highway 101 and its ramps. The observers counted the number of automobiles with one, two, or three or more people in them. They also counted the number of vans, motorcycles, buses, and trucks but not the number of people in them.

G. TRANSPORTATION DEMAND MANAGEMENT

As roads become more congested in urban areas and financial, physical, and political constraints make expanding the road network more difficult, if not impossible, engineers and planners are turning to Transportation Demand Management ("TDM") to encourage more efficient use of existing transportation resources. There are many different TDM strategies with a variety of impacts. Some improve the transportation options available to consumers, while others provide an incentive to choose more efficient travel patterns. Some reduce the need for physical travel through mobility substitutes or more efficient land use. TDM strategies can change travel timing, route, destination, or mode.

Travelers can, via their mode choice, reduce congestion substantially during peak periods. If travelers shift to higher occupancy vehicles (e.g., carpools, vanpools, buses, trains, and ferries), fewer vehicles will be necessary to carry the same number of people. Fewer vehicles result in less congestion. In addition, if travelers shift their times of travel out of the most congested hour by telecommuting or alternative work schedules, fewer vehicles will be on the road during that hour. Another alternative is to limit the type of trip taken during the most congested period to those that are necessary. Discretionary trips may be taken before or after the period of greatest congestion.

Some major employers in Marin County, including the County government, are implementing TDM programs at their workplace for their employees. The programs are designed to help relieve traffic congestion and focus on providing incentives to employees for commute options other than the single-occupant vehicle. Typically, these programs are managed by a transportation coordinator who helps employees find prospective carpool passengers in the company, provides preferential free parking for carpools and vanpools, and provides financial assistance for offsetting the cost of vanpools or transit.

III. THE MARIN COUNTY TRANSPORTATION MODEL

A. OVERVIEW OF THE MODEL

The Marin County Transportation Model is sets of equations that simulate traffic and transit operations and a microcomputer-based software package, EMME/2 (the name EMME is a French/English acronym for “Multi-modal Equilibrium”). The software uses the model equations and other information as input to perform all calculations and then graphically represent traffic volumes on a road network.

The County’s modeling process follows the standard methodology used in transportation modeling. The four steps of the process are trip generation, trip distribution, mode choice, and trip assignment. Trip generation is the number of trips produced and attracted by the land uses within traffic zones. These trips are then distributed to other traffic zones depending on the land use characteristics of other zones and the time of travel between zones. Mode choice is made according to the relative attractiveness of the alternatives and the income of the person making the trip. EMME/2 has an algorithm that assigns vehicles to the network according to specifications entered by the operator. The software can print out a copy of the network with the results printed along the road segments.

B. SETTING UP THE MODEL

Before modeling may begin, the operator must provide both graphic and numeric inputs. The graphic inputs are traffic zones, the street network, and transit routes. The numeric input includes values for the variables in the equations and parameters for the software’s algorithms.

1. Graphic Input: Traffic Area Zones

The county has been divided into 117 small geographical areas called Traffic Area Zones. The zone boundaries have been drawn to contain individual neighborhoods, commercial areas, or office developments. Although the zones appear as areas on a paper map, in the EMME/2 software they are represented as points. Each point is called a centroid, and all information associated with the traffic zone is attached to the centroid. One or more road links connect the centroid to the road network. The centroid is defined by a code number, an x, y coordinate, and operator-supplied data. For example, operator-supplied data for a residential area could be population, number of households, average household income, and average number of automobiles per household.

Traffic zones in San Francisco and Sonoma counties are for the most part, U. S. Census Tracts. Other counties in the Bay Area are represented by "super districts," a large area of many Census Tracts used by the MTC for their transportation modeling.

The Association of Bay Area Governments ("ABAG") has provided the data describing the traffic zones outside Marin.

2. Graphic Input: Street Network

EMME/2 represents the street network in an abstract fashion using links and nodes. A link is a line between two nodes. Road segments are links and intersections are nodes. For example, the portion of Sir Francis Drake Boulevard between College Avenue and Bon Air Road would be a link. The intersections at College Avenue and Bon Air Road would be nodes. In the software, a node is designated by a code number and an x, y coordinate. The computer uses the x, y coordinates to plot maps of the network. Each node has three user-defined bits of information associated with it. A link is defined by the numbers of the two nodes it connects. Each link has nine bits of information associated with it:

1) Modes allowed on link (e.g., cars, buses, trains);
2) Type of link (e.g., freeway, primary arterial, ramp);
3) Length of link, usually measured in miles;
4) Number of lanes;
5) Volume-delay function (a mathematical formula that describes how speeds decrease as the link becomes more congested);
6-9) User defined data, such as a.m. and p.m. peak-hour volumes or Average Daily Traffic volumes.

Relatively few of Marin's roads are in the model. Only roads that carry appreciable amounts of traffic are represented. They include freeways, ramps, primary and secondary arterials, and commercial collectors. The road network for other Bay Area counties is the same network used by the MTC for their transportation modeling.

3. Graphic Inputs: Transit Routes

Overlaying the road network are the transit routes. Transit routes may use the same link as automobiles or may run on their own link. Examples of separate links are high occupancy vehicle lanes, ferry lines, and train tracks. A variety of information about transit travel, such as type of vehicle and fare, is associated with the transit route.

4. Numeric Inputs: Trip Production and Attraction

The second phase of setting up the model consists of creating the equations that explain the relationships among land uses, population, employment, trip making and travel patterns. The equations designate a functional relationship between a "dependent variable" and one or more "independent variables." For example, the dependent variable, home-based work trips, is a function of the independent variables, number of households, workers per household, and household income.

Each traffic zone has land uses that either produce or attract trips. Residences produce the trips; job centers, retail and service centers, and recreational facilities attract trips. The concept of trip producers and attractors applies to home-based trips. Non-home-based trips occur between two attractors. For modeling those trips, one attractor is assigned the role of producer. For each traffic zone there will be ten calculations: five trip types each for producers and attractors. The independent variables used to calculate the number of trips produced and attracted from each traffic zone are listed below. The formal equations are listed in Appendix A.

Home-based work trips

Production: Number of households, workers per household, household income

Attraction: Number of jobs (may be disaggregrated by industry)

Home-based shopping trips

Production: Auto ownership, household income, persons per household

Attraction: Retail and service employment as a percentage of total employment, employment density (jobs per acre or square feet of buildings)

Home-based recreation trips

Production: Auto ownership, household income, persons per household, service employment density

Attraction: Retail and service employment, population, vacant land

Non-home school trips

Production: Number of households, persons per household, household income

Attraction: Population

Non-home-based trips

Production: Retail, service and other employment, number of households

Attraction: Retail, service and other employment, number of households

The values of the independent variables have been obtained from a variety of sources. For Marin traffic zones the primary sources are the Marin County Community Development Agency land use database and ABAG projections. For other counties, the data are from the MTC's regional transportation model (ABAG supplies MTC's land use and demographic information). The data sources for the Countywide Plan update effort are:

1) Land use data from the Marin County Community Development Agency's database;
2) Projections from ABAG;

3) The 1980, 1990, and 2000 Census;
4) Travel surveys from Caltrans and the MTC;
   Data from MTC's regional transportation model; and
   Actual traffic counts.

The independent variables used to calculate trip production include employed residents, number of workers per household, number of households, average persons per household, average household income, and average number of automobiles per household. The values of these variables were used in equations for trip generation, trip distribution, and mode choice. The source of information for each variable is as follows:

> *Employed Residents:* The number of employed residents from ABAG's projections by census tract were allocated to traffic zones proportional to the number of housing units with employed residents.
>
> *Workers per Household:* The number of employed residents divided by the number of households.
>
> *Households:* The number of housing units from the Assessor's Property Files were summed by traffic zone. Vacancy rates from current surveys were applied to the zones according to the zip code of the zone (the vacancy rates are reported by zip code). This yielded the number of households (occupied housing units).
>
> *Average Persons per Household:* Persons per household was taken from ABAG's projections by census tract and applied proportionally to the traffic zones.
>
> *Average Household Income:* Income data were available from ABAG projections and were applied proportionally to traffic zones, or Census Tract data from the U.S. Census were applied proportionally to traffic zones.
>
> *Average Autos per Household:* The average number of autos per household was obtained from the U.S. Census and MTC's regional transportation model. The county total was cross-checked with current automobile registration from the Division of Motor Vehicles. Projections of automobile ownership were obtained from MTC's regional transportation model.

On the attractions side, the variables used were retail, service, manufacturing and total employment, total employment density (jobs per acre of land) and service employment density. The values of these variables were used in equations for trip generation, trip distribution, and mode choice. The source of information for each variable is listed below.

> *Retail Employment:* The square footage of retail space per traffic zone was drawn from two surveys of commercial parcels in Marin, the second of which consisted of phone calls to occupants of the parcel to obtain the exact number of employees. The number of employees was calculated according the average square feet of retail space per employee. For example, if a building has 3,500 square feet of space and there is an average of 500 square feet per employee, it is assumed that 7 employees work at the

site. Site information was summed to the traffic zone level and then summed to the census tract level. The results were cross-checked with ABAG's projections and the employer survey.

Service, Manufacturing and Total Employment: These were calculated using the same method described in "Retail Employment" above.

Service Employment Density: The number of service employees divided by acres per traffic zone.

Total Employment Density: The total number of employees divided by acres per traffic zone.

The trips generated from productions and attractions were distributed between traffic zones via a gravity model (described below). Data from origin-destination surveys were processed to create production-attraction matrices. These, in turn, were used to calibrate the model output.

5. Numeric Inputs: Mode Choice

The model determines mode choice by calculating the probability that a person will choose a particular mode over alternatives based on the "utility" he derives from that mode compared to the others. Utility is calculated by weighing the factors a person considers choosing between alternatives and then adding the factors. Although there may be subjective considerations such as comfort, convenience and prestige that influence a decision, the model is limited to using quantitative information to represent the factors. "Convenience," for example, is indirectly measured by travel time and employment density. Comfort and prestige are not modeled. The rationale for this is that when it comes to commuting, people put much more weight on time and cost. The mode split component of the model was developed by MTC. All local governments, which would like to receive State and Federal funds passed through MTC, are required to use this set of equations. The factors (independent variables) that determine the utility of each mode are listed below. The formal equations are listed in Appendix A.

Utility of transit: In-vehicle travel time, cost, out-of-vehicle travel time, requirement for automobile access, automobiles per household (when an automobile is required for transit access);

Utility of three-person carpool: Total employment density, automobiles per household, workers per household, household income, in-vehicle travel time, cost, out-of-vehicle travel time;

Utility of two-person carpool: The same factors as used for the three-person carpool above; and

Utility of driving alone: Same factors as used for carpools above plus number of persons per household who drive alone.

C. OPERATING THE MODEL

The Marin Transportation Model has four modules that correspond to the four steps of transportation modeling. The first step is calculating the number of trips produced by and attracted to a given traffic zone. Trips are then distributed among the zones. After a mode choice has been made, these trips are converted into numbers and types of vehicles. Then the vehicles are assigned to the road system according to the shortest travel time between traffic zones. The result is a count of vehicles on each road segment.

1. Trip Generation

The first step in operating the model is to calculate the productions and attractions for each of the four types of trips for each traffic zone. The equations used have been described in the preceding section on numeric inputs. The output is the number of person trips per day of each type per zone.

2. Trip Distribution

After the number of trip productions and attractions for each trip type has been calculated for each traffic zone, the model distributes traffic from productions to attractions using a "gravity" model. The hypothesis behind a gravity model is that trips between two zones are a function of the trips produced in one zone, the relative trip attraction in another zone, and the travel time between those zones. (Some gravity models also add a socioeconomic factor to account for travel characteristics unique to a given area. Examples of socioeconomic factors are household income, land values, and wage rates.)

The advantage of a gravity model is that it is sensitive to travel times. As the road system becomes more congested and travel times increase, the model will predict that fewer trips will be made to congested areas. Instead, people will travel to less congested areas. This is especially valuable for long-range planning: planners can get an idea of shifting travel patterns and what portions of the transportation system need to be improved to reduce travel times.

The gravity model equations are calibrated by comparing the trip exchanges from the model to the zonal exchange data developed by MTC, Caltrans, and the County of Marin (which show actual trip exchanges). Because travel times between zones are not known before the model is run, a gravity model assignment does not produce the same production-attraction matrix as that shown by surveys. The gravity model must be run several times until its distribution closely approximates that shown by the surveys. While running, the gravity model calculates "friction factors," how much time it takes to travel between zones. (To get the travel times, the model must go through the mode choice and assignment modules also.) This calibrated gravity model is used to distribute future trips.

The production and attraction matrices show the number of daily trips exchanged between zones. These daily trips are factored to represent evening peak-hour trips (a known percentage of daily trips occur in the evening peak hour). The source of the factors is the observed number of trips occurring between zones from the origin-destination surveys. In addition, a "directional split" must be calculated for the trips between each zone. Because any two traffic zones may have both trip producers and attractors, trips occur in both directions between the zones. The amount of travel in each direction is calculated according to the relative number of trip producers and attractors in each zone and compared to actual origin-destination surveys.

3. Mode Choice

After the distribution of trips has been set, the mode choice module is invoked. As explained above, the mode choice model calculates the probability that a person will choose a particular mode based on the utility he derives from it compared to other modes. The output is the number of trips in each of the following modes: single-occupant automobile, two-occupant automobile, three-occupant automobile, and transit (buses, trains, ferries).

Although the Marin County transportation model has a fully calibrated and validated mode choice module available, the coefficients of the variables have been adjusted because the County model has smaller traffic zones and a more refined road network. The Planning and Public Works Departments have used survey information from the MTC, Caltrans, the Golden Gate Bridge District, and their own studies to evaluate the mode choice module's output.

4. Network Assignment

After the mode choices have been made, the EMME/2 software assigns vehicle trips to the road network. Automobile and transit trips are assigned separately, but, if both share the same road, transit vehicles are assigned according to their headways (the elapsed time between consecutive vehicles).

On the first assignment, the model is programmed to assign automobiles along the shortest path to the zone of attraction. As vehicles are loaded onto the road network, the computer keeps a count of the number vehicles and calculates vehicle speeds as congestion worsens. After the first iteration, travel times are reported for all links. With each subsequent iteration, the program seeks the quickest route based on the current travel time associated with a link on the network. The hypothesis is that drivers try to reduce their travel time given several choices of routes. If there are alternate routes, the model pulls automobiles off "slow" links and assigns them to "faster" links to the same zone. If there is no alternative, vehicles remain assigned to the route. The EMME/2 model objective is to achieve equilibrium throughout the entire system: the travel time between each zone should be equal across all routes.

These vehicle counts are then compared to actual counts on road segments in the county. The purpose of comparison is to "validate" the model, that is, to make sure it accurately reflects the travel behavior of area residents. To the extent that there is a significant discrepancy, the representation of the network, road speed/time delay functions, land use/demographic inputs or coefficients of the model equations must be examined.

The counts used for comparison come from several sources. Local governments in Marin County take traffic counts on local streets as part of construction or traffic signalization programs. Counts from over 200 local street segments and interchanges covering the period from 1980 to 2001 have been gathered for the Countywide Plan update. Counts have also been gathered by consulting firms as part of the Environmental Impact Report ("EIR") for major developments. Counts for Highway 101 and its ramps have been made by Caltrans through 2001. The County's and Caltrans' counts are for road segments only; they do not include turning counts at intersections. (Some turning counts are available for specialized study areas such as downtown San Rafael and the Marinship area of Sausalito. These were obtained from EIRs of development projects and are also used as a check for the model.)

The counts taken by local governments include average weekday traffic, average weekday morning peak hour, and average weekday evening peak hour. The morning peak hour was between 7:30 a.m. and 8:30 a.m.; the evening peak was between 5:00 p.m. and 6:00 p.m. The counts provided by Caltrans include morning and evening peak *periods* plus some 24-hour counts. Counts were made at 15-minute intervals for both peaks. The morning peak period was between 6:00 a.m. and 9:00 a.m.; the evening peak period was between 4:00 p.m. and 7:00 p.m.

APPENDIX 1. MARIN TRANSPORTATION MODEL EQUATIONS

TRIP PRODUCTION AND ATTRACTION

Home-based work trips:

Trips produced per household = K + (c)household income + (c)number of households + (c)workers per household - 1

Trips attracted per job = (c)total employment or (c)retail employment + (c)service employment + (c)manufacturing employment + (c)other employment

Home-based shopping trips:

Trips produced per household = K - (c)variable for auto ownership + (c)household income + (c)persons per household

Trips attracted per job = K + (c)ratio of retail employment to total employment + (c)ratio of service employment to total employment - (c)constrained natural logarithm of employment density

Home-based recreation trips:

Trips produced per household = K + (c)persons per household + (c)household income - (c)variable for automobile ownership - (c)service employment density

Trips attracted per facility = (c)retail employment + (c)service employment + (c)population + (c)vacant land

Home-based school trips:

Trips produced per household = K + (c)household income + (c)number of households + (c)persons per household

Trips attracted per facility = (c)total population

Non-home-based trips:

Trips produced or attracted = (c)retail employment + (c)service employment + (c)other employment + (c)households

NOTE: K is a constant used to calibrate the set of independent variables with the resulting value of the dependent variable; (c) is a coefficient or weight for each variable. It is calculated when the model is calibrated.

TRIP DISTRIBUTION (GRAVITY MODEL)

[(Productions in zone i multiplied by Attractions in zone j) divided by travel Time between i and j] divided by (sum of attractions in all zones divided by travel time between zone i and all other zones

Symbolically:

$$\frac{P_iA_j/T_{ij}}{\text{sum } \frac{A_x}{T_{ix}}}$$ where x is all zones 1 through 293

MODE CHOICE

P[M,i,j] = Exp [u (M,i,j)] / Exp [u (M,i,j)] summed over **K**

P is the probability that mode **M** is chosen from a set of **K** modes by workers living in zone i and working in zone j. Exp is the exponent used to calibrate the relationship between the independent variables. U is the utility derived from choosing mode **M** to travel from i to j. The utilities are linear functions of household and modal characteristics as follows:

Utility of transit = (c)in-vehicle travel time + (c)fare + (c)out-of-vehicle travel time + (c)variable for transit trips requiring auto access + (c)number of automobiles per household for transit trips requiring automobile access

Utility of three-person carpool = (c)variable for three-person carpool (note: it equals 1 for a three-person carpool, 0 for other modes) + (c)natural logarithm of employment density + (c)number of automobiles per household + (c)number of workers per household + (c)household income + (c)in-vehicle travel time + (c)cost + (c)out-of-vehicle travel time + (c)aggregate validation adjustment constant (note: used when summing the results of traffic zones to larger areas)

Utility of two-person carpool = (c)variable for two-person carpool (note: it equals 1 for a two-person carpool, 0 for other modes) + (c)natural logarithm of employment density + (c)number of automobiles per household + (c)number of workers per household + (c)household income + (c)in-vehicle travel time + (c)cost + (c)out-of-vehicle travel time + (c)aggregate validation adjustment constant (note: used when summing the results of traffic zones to larger areas)

Utility of driving alone = (c)variable for drive alone mode (note: it equals 1 for drive alone mode, 0 for other modes) + (c)natural logarithm of employment density + (c)number of automobiles owner per household + (c)number of workers per household + (c)number of persons per household + (c)household income + (c)in-vehicle travel time + (c)cost + (c)out-of-vehicle travel time + (c)aggregate validation adjustment constant (note: used when summing the results of traffic zones to larger areas)

NOTE: (c) is a coefficient or weight for each variable; it is calculated when the model is calibrated.

APPENDIX 2. TRANSPORTATION SYSTEM ROAD LINKS

List of Streets by Class

Freeway:

Highway 101 between the Golden Gate Bridge and Atherton Avenue exit, Novato
Highway 37 between Highway 101 at Novato and Sonoma County
Highway 580 between the Richmond Bridge and Highway 101 in San Rafael

Freeway Ramps:

Sausalito Lateral, all directions
Wolfback Ridge Road/Spencer Avenue
Monte Mar Drive, Sausalito
Rodeo Avenue, Sausalito
Bridgeway/Donahue Street, Sausalito
Shoreline Highway (State Route 1)
Redwood Highway Frontage Road, Strawberry
Tiburon Boulevard/Blithedale Avenue, Tiburon/Mill Valley
Tamalpais Drive/Paradise Drive, Corte Madera
Tamal Vista Boulevard, Corte Madera
Fifer Avenue/Paradise Drive, Corte Madera
Sir Francis Drake Boulevard
Highway 580/Francisco Boulevard
Irwin/Hetherton at Second Street, San Rafael
Irwin/Hetherton at Mission Street, San Rafael
Los Ranchitos/Lincoln Avenue, San Rafael
San Pedro Road, San Rafael
Manuel T. Freitas Parkway/Civic Center Drive, San Rafael
Lucas Valley Road/Smith Ranch Road, San Rafael
Miller Creek Road/St. Vincent's Drive, San Rafael
Alameda del Prado/Nave Drive, Novato
Ignacio Boulevard, Novato
South Novato Boulevard/Highway 37, Novato
Atherton Avenue on Highway 37, Novato
Rowland Boulevard, Novato
De Long Avenue, Novato
San Marin Drive/Atherton Avenue, Novato

Primary Arterials:

Bridgeway Avenue, Sausalito
Shoreline Highway (State Route 1), Tamalpais Valley
Miller Avenue between Almonte Boulevard and Miller Lane, Mill Valley
Camino Alto between Miller Avenue and East Blithedale, Mill Valley
East Blithedale Avenue between Camino Alto and Highway 101
Tiburon Boulevard between Highway 101 and Cove Road, Tiburon
Tamalpais Drive between Redwood Avenue and Paradise Drive, Corte Madera
Bon Air Road between Magnolia Avenue and Sir Francis Drake, Larkspur/Greenbrae
Sir Francis Drake Boulevard
Bellam Boulevard, San Rafael
Point San Pedro Road from Third Street to Riviera Drive, San Rafael
Second and Third Streets, San Rafael
Fourth Street between Second Street and San Anselmo border
Red Hill Avenue between San Anselmo border and Sir Francis Drake Boulevard
North San Pedro Road between Los Ranchitos Road and Golf Drive
Manuel T. Freitas Parkway
Smith Ranch Road
Lucas Valley Road between Highway 101 and Las Gallinas Avenue
Miller Creek Road to Las Gallinas Avenue
Ignacio Boulevard to Young Court
Bel Marin Keyes Boulevard to Frosty Lane
Novato Boulevard to Simmons Way
Redwood Boulevard between Rowland Boulevard and San Marin Drive
De Long Avenue
Highway 101 from Atherton Avenue to Sonoma County border

Secondary Arterials:

Tiburon Boulevard between Cove Road and Mar West Street, downtown Tiburon
San Rafael Avenue between Tiburon Boulevard and Golden Gate Avenue, Belvedere
Trestle Glen Drive between Tiburon Boulevard and Paradise Drive, Tiburon
Paradise Drive between Trestle Glen Drive and Highway 101
East Blithedale Avenue between Camino Alto and Throckmorton, Mill Valley
Camino Alto between East Blithedale and Corte Madera border, Mill Valley
Corte Madera Avenue between Corte Madera border and Doherty Drive, Corte Madera
Madera Boulevard, Corte Madera
Tamal Vista Boulevard, Corte Madera
Doherty Drive, Corte Madera
Magnolia Avenue, Larkspur
College Avenue, Kentfield
Wolfe Grade, Greenbrae
D Street, San Rafael
Andersen Drive, San Rafael
East Francisco Boulevard, San Rafael

East Kerner Boulevard on east side of Bellam to dead end, San Rafael
Fourth Street between Second Street and Lincoln Avenue, San Rafael
Grand Avenue, San Rafael
Lincoln Avenue between Fourth Street and Highway 101, San Rafael
Center Boulevard San Anselmo
Broadway Avenue, Fairfax
Bolinas-Fairfax Road to Meadow Country Club
Butterfield Road, Sleepy Hollow
Point San Pedro Road between Riviera and North San Pedro
North San Pedro Road between Point San Pedro and Golf Avenue
Civic Center Drive between North San Pedro and Redwood Road
Redwood Road between Civic Center Drive and Smith Ranch Road
Los Ranchitos Road
Las Gallinas Avenue
Northgate Drive
Lucas Valley Road between Las Gallinas and McKinley Road
Alameda del Prado
Nave Drive, Novato
Sunset Parkway, Novato
Center Road between South Novato Boulevard and Gregor Lane, Novato
Tamalpais Avenue between Center Road and Vallejo Avenue, Novato
Hicks Valley Road between Stafford Lake and Novato Boulevard, Novato
Grant Avenue, Novato
Olive Avenue, Novato
San Marin Drive, Novato
Atherton Avenue, Novato
Seventh Street between Vallejo Avenue and San Marin Drive, Novato

Commercial Collectors:

Caledonia Street, Sausalito
Harbor Drive, Sausalito
Strawberry Drive, Strawberry
Millwood Street, Mill Valley
Grove Street, Mill Valley
Hill Street, Mill Valley
Forrest Street, Mill Valley
Parkwood Avenue, Mill Valley
Laurelwood Street, Mill Valley
Ross Common, Ross
San Anselmo Avenue, San Anselmo
Golden Gate Drive, San Rafael
Dodie Street, San Rafael
Jacoby Street, San Rafael
Irene Street, San Rafael
Belvedere Street, San Rafael

Lisbon Street, San Rafael
Castro Avenue, San Rafael
Louise Street, San Rafael
Vivian Street, San Rafael
Medway Road, San Rafael
Hoag Avenue, San Rafael
Harbor Street, San Rafael
Front Street, San Rafael
Mill Street, San Rafael
Bay Street, San Rafael
Beach Park Road, San Rafael
Francisco Boulevard West, San Rafael
DuBois Street, San Rafael
Irwin Street, San Rafael
Lovell Avenue, San Rafael
Jordan Street, San Rafael
Lindaro Street, San Rafael
Tamalpais Avenue, San Rafael
A Street, San Rafael
Portions of B, C, and D Streets
Loch Lomond Drive, San Rafael
Redwood Frontage Road, San Rafael
Joseph Court, San Rafael
Mitchell Boulevard, San Rafael
Mark Drive, San Rafael
Carlos Drive, San Rafael
Paul Drive, San Rafael
Hamilton Drive, Novato
Galli Drive, Novato
Pimentel Court, Novato
Commerce Way, Novato
Scott Avenue, Novato
Blodgett Avenue, Novato
Machin Avenue, Novato
Sweetser Avenue, Novato
Nugent Lane, Novato
Vallejo Avenue, Novato
Orange Avenue, Novato
Madrone Avenue, Novato
Rose Street, Novato