Truck Travel in the San Francisco Bay Area

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In travel demand forecasting, truck travel demand is often combined with automobile demand and converted to automobile equivalencies. This typically increases automobile person-trip forecasts by 5 to 15 percent. This practice does not accurately reflect the actual origins and destinations of trucks or the travel demand on those roadways where trucks are restricted. Since data on truck travel are sparse, a research program was conducted to provide information to develop a travel demand model for trucks. The model was needed to evaluate alternatives in the I-880 Intermodal Corridor in western Alameda County, California, extending from Oakland to San Jose. Although the study area focused on this corridor, the model and data base include the entire nine-county San Francisco Bay Area. The study area includes this region to consider the many trucks that had one trip end in Alameda County or passed through the county. The process by which the truck travel demand model was developed included the definition of trip types and the expansion of survey results as well as the development of four submodels: trip generation, trip distribution, peak-hour factoring, and trip assignment. The model validation showed that the truck model does a reasonable job of reproducing existing truck travel in the Bay Area. Future project scenarios will be tested later.

This paper documents and summarizes the findings and conclusions of a study conducted by Barton-Aschman Associates, Inc., to collect truck travel data and produce a truck travel model for Alameda County and adjacent counties in the San Francisco Bay Area. [Alameda County has an area of 1,906 km^2 (736 mi^2) and a population of approximately 1.3 million.] The report is part of the I-880 Intermodal Corridor Study sponsored by the California Department of Transportation (Caltrans) and the Federal Highway Administration.

The truck travel model was created to improve the ability to estimate future congestion in the study corridor (see Figure 1) and understand how trucks contribute to this congestion, since truck travel is not explicitly modeled in the existing Alameda Countywide Multimodal Transportation Model.

FINDINGS FROM OTHER STUDIES

Two other urban areas have recently conducted surveys on regional truck travel for input into truck travel forecasting models—Chicago and Phoenix (*1–3*). Both of these cities conducted extensive data collection programs and had some common findings:

1. Trip length distribution by size of truck: Generally, the larger the truck, the longer the average trip length.
2. Number of daily trips by size of truck: Generally, the larger the truck, the fewer the number of average daily trips.
3. Daily peak patterns: Truck travel is heaviest in the midday period and declines before the p.m. commute period.
4. Land uses served by trucks: A majority of truck trips are destined for retail establishments (25 percent), manufacturers (20 percent), or terminals/warehouses (20 percent).
5. Sensitivity to local conditions: Truck (or commercial vehicle) travel characteristics may vary in each urban area. For example, Chicago is a central hub for truck and rail, Phoenix is on a through route from the east to Southern California, and Alameda County is a coastal port with very little through travel.

Key factors include, but are not limited to, labor rules (e.g., Port of Oakland), break-of-bulk points (e.g., Chicago), the location of specific industries (e.g., wholesale distribution, trucking companies, and certain manufacturers), and geographic and physical constraints (e.g., tunnels, bridges, low undercrossings, mountains, etc.).

TRUCK TRAVEL SURVEYS

The primary objective of the truck travel research program was to obtain a more accurate and detailed understanding of current truck travel. Existing data are limited. Three gaps in present knowledge of truck travel in the San Francisco Bay Area were identified: time-of-day patterns, origin and destination data, and goods carried.

Four travel surveys were conducted to obtain information regarding travel patterns of trucks operating within the San Francisco Bay Area:

- Truck classification counts at 11 freeway locations (see Figure 2) for a 5- to 7-day period;
- Truck-intercept surveys at five California Highway Patrol (CHP) weigh stations, which resulted in completion of more than 8,000 interviews (see Figure 3), and at four toll bridge crossings, which produced almost 700 completed postcard surveys;
- Employer surveys of truck trips generated; and
- Surveys and interviews with truck drivers, terminal operators, and planning staff at the Port of Oakland, which

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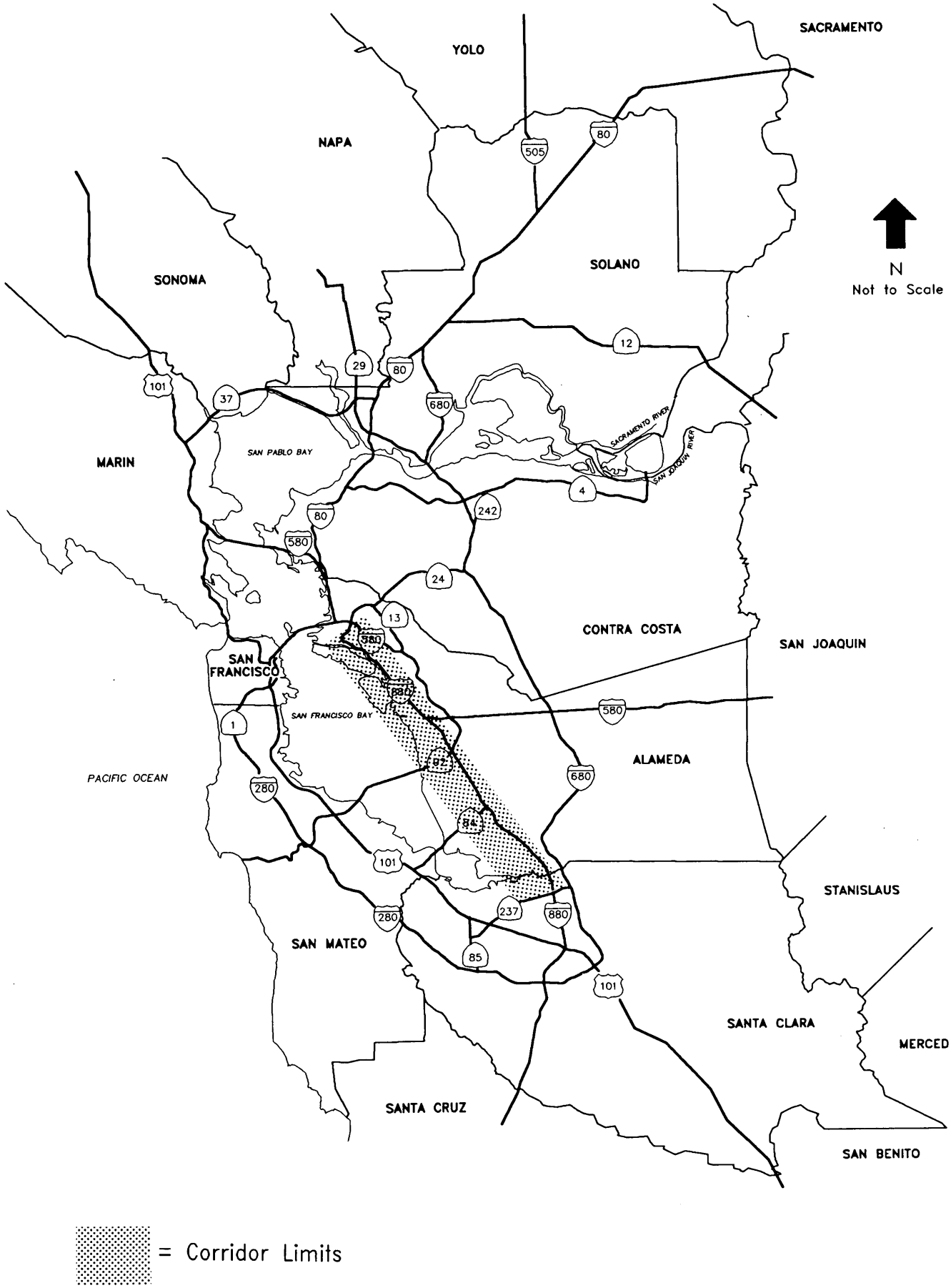

FIGURE 1 Study location.

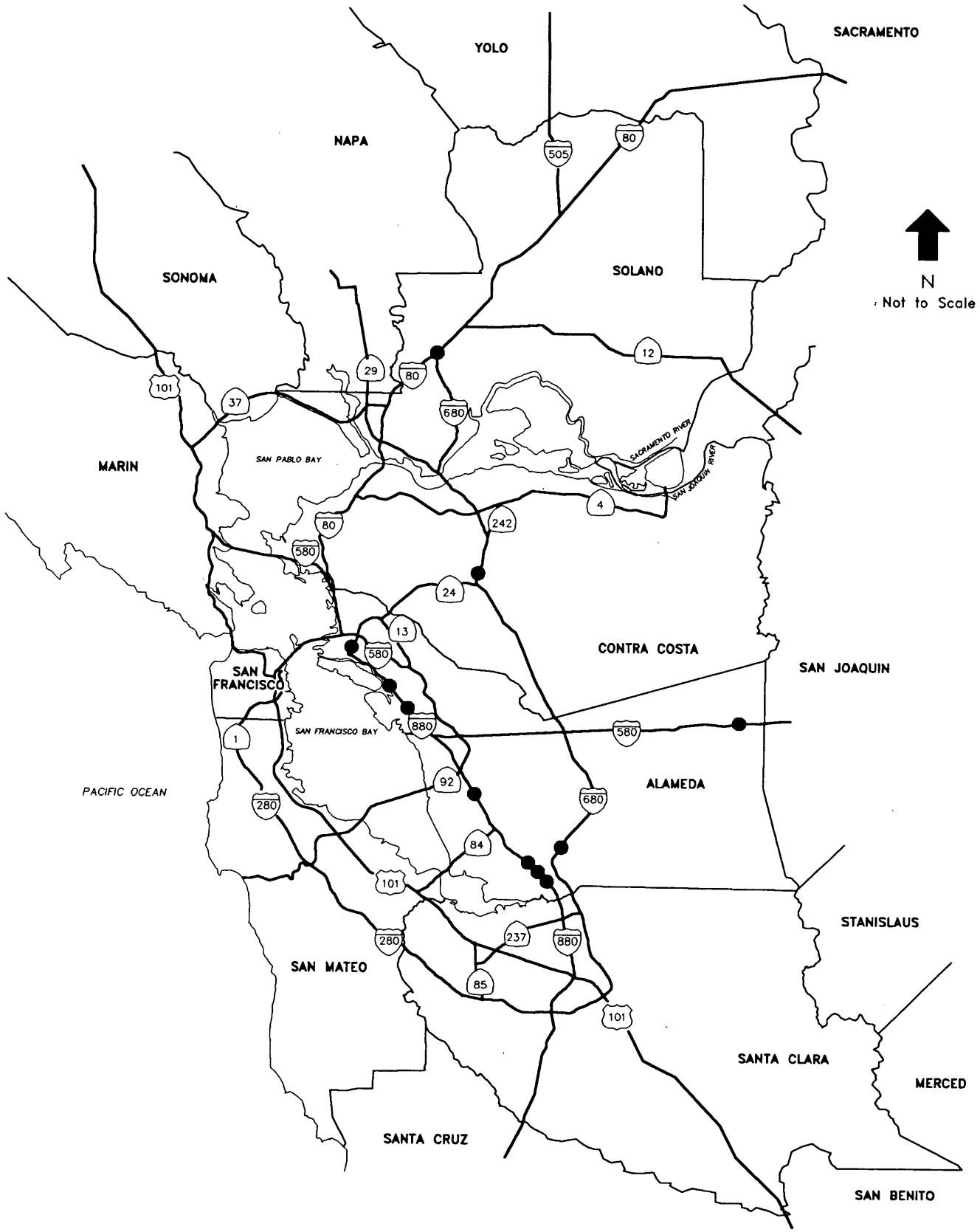

FIGURE 2 Truck classification count locations.

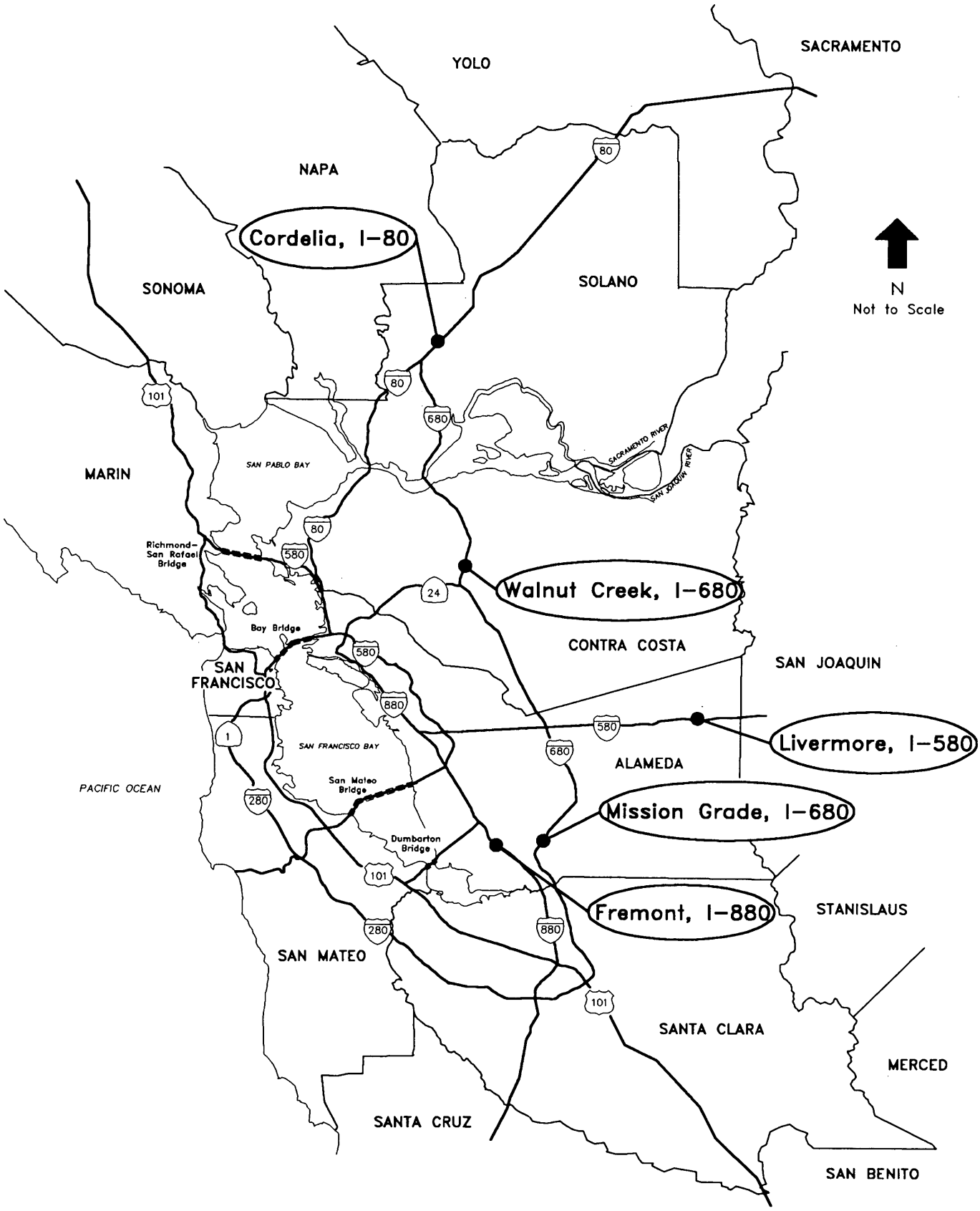

FIGURE 3 Truck intercept interviews station locations, number and direction of travel.

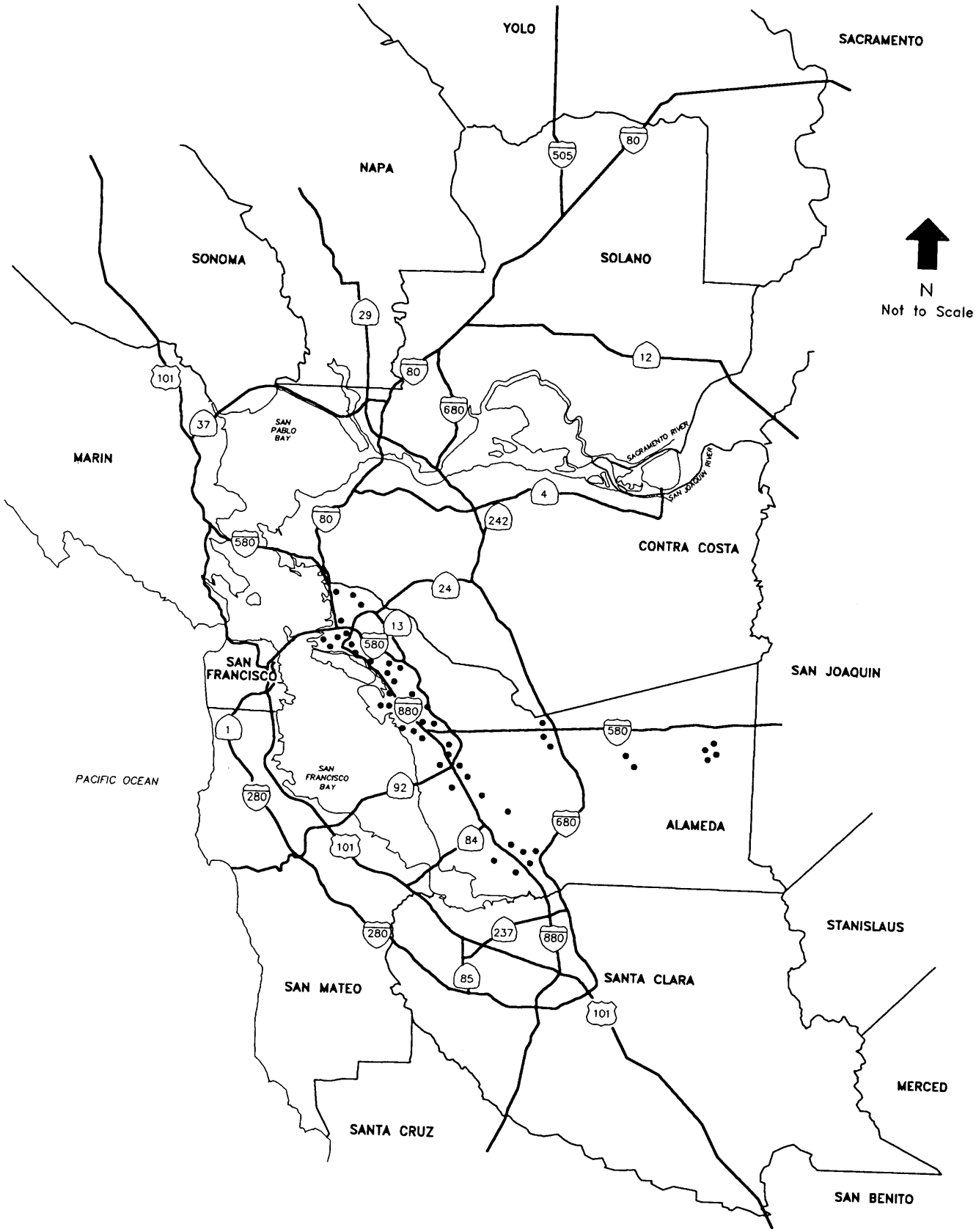

FIGURE 4 Employer survey, concentration of companies.

resulted in 1,172 surveys that represented 3,800 daily truck trips generated by the port.

In the employer surveys of truck trips generated, a combined telephone and mail-back survey contacted 698 employers in Alameda County (see Figure 4) representing more than 36,000 employees. The overall response rate exceeded 79 percent. Responses from 87 companies that had trucks provided detailed trip data for 2,700 truck trips.

The results of these data-gathering efforts were used to develop the model.

SURVEY CONCLUSIONS

The most important findings of the truck travel research program are the following:

- The peak period for truck travel is midday, not in either the a.m. or the p.m. peak commute periods. This is consistent with findings from other Bay Area and national studies (*4,5*) (see Figure 5).
- Most truck trips in the San Francisco Bay Area are within the nine-county Bay Area. At five CHP weigh stations and four bridge crossings, 98 percent of the truck trips surveyed had either origin or destination in one of the nine Bay Area counties.
- Many of the approximately 5,000 daily truck trips in the Port of Oakland area are local trips that never access a freeway. Trucking is an important component of the port's complex, intermodal network of transportation facilities and services. Most of the truck trips at the port (59 percent) originate in the nine-county Bay Area. The San Joaquin Valley, east of the Bay Area, accounts for 19 percent of originating truck trips to the port.
- Most employers (68 percent) do not own or lease trucks. Brief telephone interviews established which employers did not own or lease trucks and which might have trucks and should be mailed a truck trip log. For one category of employers (business services), more than 97 percent of those contacted did not own or lease trucks.
- Overall, 35 percent of the employers own or lease trucks. However, this percentage varies by employer type and size (see Table 1). Large employers are more likely to have trucks than small employers. Manufacturing firms are four times as likely to own or lease trucks as business service firms. Only 11 percent of business services firms own or lease trucks, whereas 45 percent of manufacturing firms do. A large proportion (45 percent) of "other employers," a category that includes wholesale companies, own or lease trucks.
- The disproportionate stratified sample of employers used in this study provided a sample of employers that included all sizes and industries while minimizing the number of interviews. The survey obtained information about the number

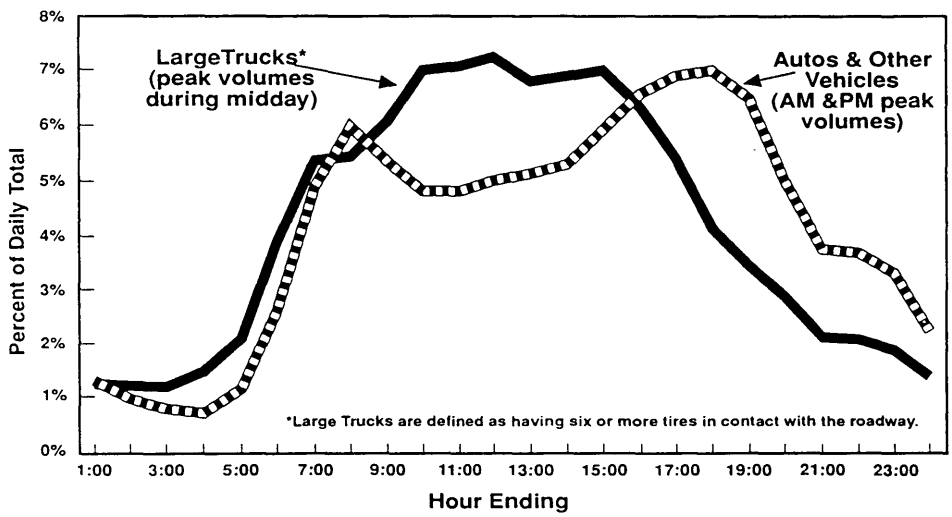

FIGURE 5 Hourly traffic distribution as a percentage of the 24-hr total.

TABLE 1 Percentage of Employers that Have Trucks, by Size and Type of Company

	Number of Employees			
Employer Type	1-9	10-99	100 +	All Sizes of Employers
Business Services	11	20	28	13
Manufacturing	41	49	54	45
Other (includes wholesale)	39	64	68	45
Retail	NA	35	39	35
All Types of Employers	24	34	48	35

of employees the company had and the type of business, as well as the truck trip information. This type of survey lends itself to creating models of truck travel and goods movements because the truck trips can be directly related to employment through the use of employer data bases that are readily available. In this study, Equifax Marketing Decision Systems and Rich's Everyday Business Directory provided the employer data. Employment data are commonly forecast by regional planning organizations, so future truck travel can be estimated by relating existing truck trip rates to employment forecasts.

- The intercept surveys combined with the classification counts at the weigh stations worked well. They provided reliable data at a reasonable cost with no complaints or accidents.

GOODS MOVEMENT

Although goods movement is the most common reason for urban truck travel, collecting detailed commodity data was beyond the scope of this study. Furthermore, the relationships among industries, modes of transport, and commodities are too complex for the present analysis.

Some commodity data were collected during the truck intercept surveys and employer interviews by asking what types of goods were being hauled, if any. (No details about weight or volume of goods carried were sought.)

For this study, goods were classified into 10 categories. The categories and some examples are given in the following table.

Goods Category	*Examples of Goods*
Agriculture	Tomatoes, meats, plants
Chemicals	Chlorine, liquid nitrogen
Construction	Backhoe, forklift
Construction materials	Bricks, concrete
Empty	Empty
Manufacturing	Packing supplies, bottles
Miscellaneous freight	Plastic parts, Port-a-Pits
Retail	Food, furniture
Service	Tow truck, utility
Waste	Garbage, sewer sludge

Figure 6 summarizes goods distribution by category. Empty trucks represented a large proportion of trips. Retail-related trips were the next highest among the 10 goods categories.

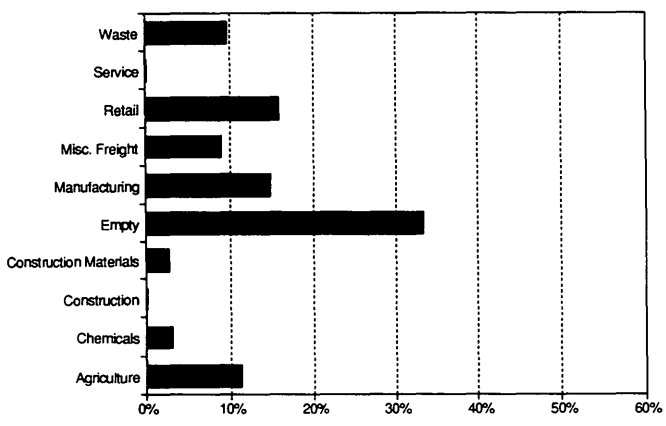

FIGURE 6 Goods distribution, port survey—inbound direction.

PURPOSE OF THE TRUCK TRAVEL MODEL

The truck travel demand model was developed as part of the I-880 Intermodal Corridor Study. The study area is a 48-km (30-mi) corridor in western Alameda County, but the truck travel study area was expanded to include the entire nine-county San Francisco Bay Area. The model was not intended to forecast goods movement but, rather, truck travel. Specifically, it was designed to forecast average weekday and p.m. peak-hour volumes for two-, three-, and four-or-more-axle trucks.

TRUCK TRAVEL MODEL DEVELOPMENT

The truck travel forecasting process consists of four components: trip generation, trip distribution, peak-hour factoring, and trip assignment. The model was developed using existing Bay Area highway networks, 1990 Metropolitan Transportation Commission socioeconomic data, and results of various surveys conducted in 1991 as part of the overall truck study. Truck volume counts from 1991 were used to validate the travel model.

The four surveys described earlier produced three types of data, all of which were used to create the model: (*a*) interview survey data from employers, which provided a representative sample of truck travel that occurred within the Bay Area; (*b*) intercept survey data, which provided an accurate representation of truck travel for vehicles having at least one end of a trip outside of the Bay Area; and (*c*) classification counts at various freeway locations, which provided the information needed to determine the diurnal travel patterns and to calibrate the model.

Since each survey represents only a sample of truck activity, the results were expanded to represent all trucks for each trip type. This study assumed that truck travel and goods movements remain constant from day to day during the weekdays and from week to week during the year.

The model was designed to estimate travel for three general truck trip types and three truck types. The three truck types are two-, three-, and four-or-more-axle. The three general trip types are external-external, internal-external, and internal-internal. "External" refers to an origin or destination outside the nine-county Bay Area region. Internal-external trips have either an external origin or destination and include external-internal trips. Internal-internal trips are further subdivided into garage-based and linked trips. Garage-based trips are trips in which the truck travels from its origin to its destination and returns to its origin. Linked trips involve departure from the origin and travel to several destinations before returning to the point of origin. The internal trips were classified into these two categories since there are many trips of both types (see Table 2), and they are significantly different. Garage-based trips tend to start in industrial areas and travel elsewhere, whereas linked trips occur throughout the region.

External-external trips were modeled by estimating a trip table of these trips from the intercept surveys and then factoring this trip table on the basis of employment growth for future years. Trip generation and distribution models were created for internal-external and internal-internal trips by truck type.

TABLE 2 Employer Survey Trips by Truck Type and Trip Type

Trip Type	Number of Axles	Trips	Percent
Internal Garage-Based			
	2	552	20
	3	240	9
	4+	178	6
Subtotal		970	35
Internal Linked			
	2	826	30
	3	519	19
	4+	290	10
Subtotal		1,635	59
Internal-External			
	2	48	1
	3	15	1
	4+	87	3
Subtotal		150	6
Total		2,755	100

For trip generation, equations were formulated for productions and attractions using methods similar to those used when creating a typical regional model. The garage-based trip productions were estimated as trip rates using the employer survey (see Table 3). The garage-based trip attractions were estimated by testing numerous relationships between survey trip destinations and the socioeconomic data for the cities in Alameda County using multiple linear regression. The socioeconomic data considered included total employment, retail employment, manufacturing employment, service employment, other employment, population, households, and average household income. The analysis showed that the most meaningful correspondence between socioeconomic categories and trip ends was achieved by using either "total employment" or "other employment" categories. This happened because the survey trip end data were collected at the city level, and the cities in Alameda County are large enough that there tended to be a better relationship between the different types of socioeconomic data than between the socioeconomic data and the survey trip end data.

Linked trips were estimated in a way similar to non-home-based trip equations. This is because they are similar in that most of these trips do not have one end at the employer's location. Instead, they are typically delivering goods to a series of stores. Both the trip productions and the trip attractions were estimated in the same way as the garage-based trip attractions. The trip rates are also given in Table 3.

The internal-external trip productions were estimated using the truck volumes at the external stations, and the attractions were estimated by relating the internal ends of the intercept survey trip to the socioeconomic data for each city in the Bay Area (see Table 3).

All of the trip generation equations were refined through an interactive process in which the model-estimated volumes were compared with the observed volumes for each truck type. This method produced the final trip generation rates, as given in Tables 2 and 3.

To better understand the approximate number of trips per employee by truck type and employment type, the trip rate data used to construct this model are summarized in Table 4, which indicates that there are 85 truck trips per thousand employees for the Bay Area.

The survey data provided information adequate to develop trip distribution submodels for each trip and truck type category. The trip distribution submodels consisted of standard gravity models with friction factors but no K factors. Table 5

TABLE 3 Trip Production and Attraction Rates by Trip Type, Employment Type, and Truck Type—per 1,000 Employees

Trip Type/ Employment Type	Truck Type 2-Axle	3-Axle	4+ Axle
Internal Garage-Based Productions			
Manufacturing	11	2	4
Retail	14	–	–
Business Services	1	–	–
Other Employment	5	4	8
Internal Garage-Based Attractions			
Other Employment	–	5	14
Total Employment	23	–	–
Internal Linked Productions & Attractions			
Total Employment	32	4	7
Internal-External Productions			
Manufacturing	–	2	22
Other Employment	–	1	9
Total Employment	4	–	–

TABLE 4 Trip Rates by Trip Type and Truck Type—Trips per 1,000 Employees

Trip Type	Truck Type 2-Axle	3-Axle	4+ Axle	All Trucks
Garage-Based	23	2	4	29
Linked	32	4	7	43
Internal-External	4	1	7	12
All Types	60	6	19	85

TABLE 5 Comparison of Trip Length Distribution—Average Trip Length in Minutes

Trip Type	Survey Data	Model Result
Internal Linked Trips		
2-Axle Trucks	16	16
3-Axle Trucks	20	20
4-or-More-Axle Trucks	29	29
Internal Garage-Based Trips		
2-Axle Trucks	24	25
3-Axle Trucks	25	26
4-or-More-Axle Trucks	40	40
Internal-External Trips		
2-Axle Trucks	54	53
3-Axle Trucks	59	58
4-or-More-Axle Trucks	59	59
Internal-Internal Port Trips		
3-Axle Trucks	16	16
4-or-More-Axle Trucks	23	22

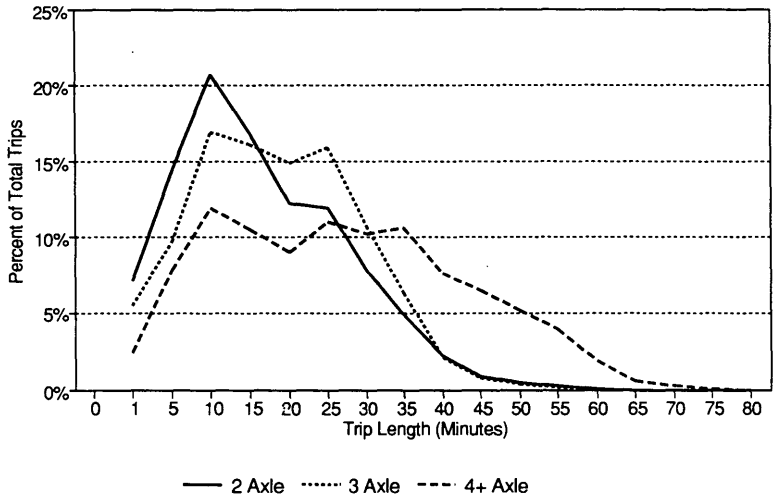

FIGURE 7 Estimated trip length distribution for internal linked trips.

summarizes the average trip lengths calculated for the survey data and the model for each trip and truck type. The model results come very close to replicating the survey data, with no more than a 1-min difference for any trip type. In general, the two-axle truck trips are the shortest, and the four-or-more-axle trips are the longest. Linked trips were approximately 30 to 50 percent shorter than garage-based trips. Trip-length distributions by truck type for internal linked trips are shown in Figure 7.

The p.m. peak hour (5:00 to 6:00 p.m.) trip tables were created by factoring the daily trip tables for each truck type and trip type. These factors were first derived from the survey data and the external station classification counts. The factors were then refined using an interactive process in which the factors were adjusted until the estimated volumes matched the classification counts as well as possible. The final peak-hour factors are given in Table 6.

MODEL VALIDATION

Daily and p.m. peak-hour trip tables were created for two-, three-, and four-or-more-axle truck trips. These trip tables were then assigned to the Bay Area highway network. From these assignments, the estimated vehicle-kilometers traveled (VKT) and percent root mean square error (RMSE) were calculated. Percent RMSE is the variation between observed and estimated data that is expected to occur approximately 66 percent of the time. The daily validation statistics are given in Table 7, and the p.m. peak-hour validation statistics are given in Table 8.

TABLE 6 P.M. Peak-Hour Truck Trip Factors by Truck Type and Trip Type

Truck Type	Internal-Internal	Internal-External	External-External
2-Axle	0.05	0.04	0.05
3-Axle	0.04	0.05	0.04
4-or-More-Axle	0.04	0.03	0.04

TRUCK TRAVEL SUMMARY

As indicated by the validation statistics, the truck forecast seems reasonable when examined both by county subareas and on a link-by-link basis. However, the model has not been used to test alternative future scenarios yet.

Table 9 summarizes the number of daily trips in the Bay Area generated by the model for each truck type and trip type. Except for the internal-external port trips, external-external trips constituted the lowest percentage of total truck trips. The daily vehicle-hours traveled (VHT) for each trip type and axle type are presented in Table 10.

The following observations can be made from Tables 9 and 10:

- Daily internal-external trips were 14 percent of the total truck trips, yet they constitute 32 percent of the total VHT.

TABLE 7 Daily Truck Travel Validation Statistics

Truck Type	Estimated/Observed VKT	Percent Root Mean Square Error
2-Axle	1.004	30.6
3-Axle	1.003	57.3
4-or-More-Axle	1.026	54.9

TABLE 8 P.M. Peak-Hour Validation Statistics

Truck Type	Estimated/Observed VHT	Percent Root Mean Square Error
2-Axle	0.993	37.8
3-Axle	1.000	68.9
4-or-More-Axle	1.000	70.4

TABLE 9 Daily Truck Trip Summary

Trip Type	2-Axle Trucks	3-Axle Trucks	4-or-More-Axle Trucks	Total	Percent
Internal-Internal					
Linked	99,521	11,972	22,209	133,702	50
Garage-Based	72,086	4,730	14,176	90,992	34
Port	0	1,430	2,779	4,209	2
Subtotal	171,607	18,132	39,164	228,903	86
Internal-External	13,481	1,852	21,593	36,926	14
Internal-External Port	0	167	914	1,081	0[a]
External-External	233	26	1,251	1,510	1
Total	185,321	20,177	62,922	268,420	101
Percent	69	8	23	100	

[a] Less than 0.5%.

TABLE 10 Daily Truck Vehicles-Hours Traveled

Trip Type	2-Axle Trucks	3-Axle Trucks	4-or-More Axle Trucks	Total	Percent
Internal-Internal					
Linked	32,427	4,306	11,149	47,882	37
Garage-Based	22,971	1,667	9,803	34,441	27
Port	0	395	1,028	1,423	1
Subtotal	55,398	6,368	21,980	83,746	65
Internal-External	14,782	2,291	24,958	41,671	32
Internal-External Port	0	196	1,066	1,261	1
External-External	454	50	2,346	2,849	2
Total	70,634	8,905	49,990	129,529	100
Percent	55	7	39	100	

- Three-axle trips accounted for the smallest percentage of total travel (8 percent of trips) and the smallest portion of VHT (7 percent).
- Whereas large trucks (with four or more axles) accounted for one-third as many trips as two-axle trucks, the corresponding VHT for four-or-more-axle trucks was more than 70 percent of two-axle truck VHT.

RECOMMENDATIONS

The following suggestions are offered on the basis of the experience with this study:

1. The origins and destinations of trips that begin or end within the study area should be geocoded to the transportation analysis zone rather than to zones representing entire cities. This would allow the creation of more accurate trip production and attraction equations.
2. A larger sample of employers (perhaps three times as many, or about 1,800) would be desirable. Since the number of employers with three-or-more-axle trucks was very small, a larger sample size would increase confidence in the trip generation and trip distribution submodels.

REFERENCES

1. J. P. Reilly and J. J. Hochmuth. Effects of Truck Restrictions on Regional Transportation Demand Estimates. In *Transportation Research Record 1256*, TRB, National Research Council, Washington, D.C., 1990, pp. 38–48.
2. F. G. Rawling and J. P. Reilly. CATS Commercial Vehicle Survey of 1986: A Discussion of Project Management Issue. *Chicago Area Transportation Study (CATS) Research News*, Vol. 26, No. 1, Feb. 1987, pp. 5–27.
3. J. P. Reilly, A. Rosenbluh, and F. G. Rawling. Factoring and Analysis of the Commercial Vehicle Survey. *Chicago Area Transportation Study (CATS) Research News*, Vol. 26, No. 1, Feb. 1987, pp. 29–45.
4. L. R. Grenzeback, W. R. Reilly, P. O. Roberts, and J. R. Stowers. Urban Freeway Gridlock Study: Decreasing the Effects of Large Trucks on Peak-Period Urban Freeway Congestion. In *Transportation Research Record 1256*, TRB, National Research Council, Washington, D.C., 1990, pp. 16–26.
5. J. W. Ogden. *Urban Goods Movement*. Ashgate Publishing Company, 1992.

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