Cordon Line Highway Survey for the Delaware Valley Region

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Described are the design, conduct, and results of a cordon line highway survey for the Delaware Valley region. The survey was successfully conducted in 1989 by the Delaware Valley Regional Planning Commission (DVRPC) in cooperation with the state departments of transportation, county planning departments, and turnpike and bridge commissions. The purpose of the survey was to update traffic data collected in 1960 by the Penn-Jersey Transportation Study for the development of regional highway plans, especially for facilities in the growing areas near the cordon line of the region. In order to minimize cost and traffic delay, selected motorists at 26 sampled cordon line stations were interviewed or handed survey questionnaires and requested to return the completed forms to DVRPC, postage paid. Questions dealt with trip origin, destination and purpose, vehicle type and registration, and highways used by motorists to reach the destinations from the survey points. The survey on each highway was conducted for 2 days, 1 day to sample traffic in the morning peak and off-peak, and another in the evening peak and off-peak hours. The survey results indicate that traffic volumes and patterns have changed significantly since 1960. The findings are being used to validate DVRPC simulation models for forecasting external and through trips, and to develop plans and programs for improving highway facilities throughout the region.

Cordon line traffic volumes, patterns, and forecasts are required for the development of transportation plans and facility designs that are scaled to future travel demand and available resources. The most recent comprehensive regional cordon line traffic survey conducted in the Delaware Valley region was done in 1960 by the Penn-Jersey Transportation Study (PJTS), the predecessor agency to the Delaware Valley Regional Planning Commission (DVRPC). The 1960 survey data are of limited use today because they do not reflect major growth in the suburbs that has occurred since, and were collected on the PJTS cordon line, which is well inside the line used today by DVRPC (see map shown in Figure 1).

As shown in Figure 1, the DVRPC region includes four suburban counties in Pennsylvania (Bucks, Chester, Delaware, and Montgomery); four suburban counties in New Jersey (Burlington, Camden, Gloucester, and Mercer), and Philadelphia. The DVRPC region includes an area of 3,833 mi^2 and a population of more than 5.2 million. There are 352 minor civil divisions or municipalities, including such large cities as Camden, Trenton, and Chester. The old cordon area used by PJTS encompasses about one-third of the area of the DVRPC region and includes the heavily urbanized area and major cities.

In FY1989, as part of a major update of its traffic data, DVRPC conducted a cordon line survey on the nine-county boundary. The survey was designed to collect information on traffic volumes and patterns generated by vehicles entering and exiting the DVRPC region at 128 points, or cordon stations. The survey asked about trip origin, destination, and purpose, the highways used, and the vehicle type, registration and occupancy. It was conducted with the cooperation of the Pennsylvania, New Jersey, and Delaware departments of transportation; the nine county governments served by DVRPC, the New Jersey Turnpike Authority, the Pennsylvania Turnpike Commission, the Atlantic City Expressway Authority, and the Delaware River Joint Toll Bridge Commission. Most of the survey information was collected by direct roadside interview. On a few highways, however, motorists were handed questionnaires and asked to answer the questions and return the completed survey forms by mail, postage paid.

In order to minimize cost and traffic delay, a representative sample of cordon line stations, including freeways, arterials, and local roads, was chosen for the survey. The interviews on each selected highway were conducted on two different days, one day to sample traffic in the morning peak and off-peak periods, and another in the afternoon to collect information on traffic patterns during the evening peak and off-peak hours.

The survey procedures and results are described, with particular emphasis on sample size, data collection, and major findings. The findings are essential for developing regional and local plans and capital improvement programs, especially for highways and roads located in the growing residential, commercial, and industrial areas near the perimeter of the region.

SURVEY DESIGN, PREPARATION, AND CONDUCT

Travel to or from points outside the cordon line of the region can be divided into two types: trips that pass through the region with no major stops (through trips), and those crossing the cordon line with origins or destinations inside the region (internal-external or external-internal trips). In 1987, the sum of the numbers of these two types of trips was about 1.1 million per day. Through trips by automobiles and trucks make up a significant portion of total vehicle miles of travel (VMT) because of their longer trip length. Some drivers may need to travel more than 80 mi or spend over 2 hr to traverse the region from one end to another. On the other hand, external trips, which include most of the trips entering or leaving the region, are bound for destinations in or near major towns or centers scattered around the cordon line.

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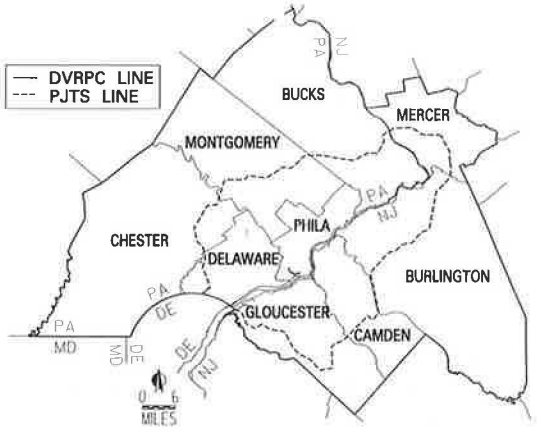

FIGURE 1 Map indicating PJTS and DVRPC regional cordon lines.

Currently, forecasts of through and external trips are estimated by Frater and gravity-type models, respectively. These models were calibrated with 1960 data and updated with 1980 census journey-to-work information. However, nonwork trips, which constitute the major portion of these trips, could not be validated with census data. Thus, new and comprehensive survey data are essential to update the parameters of these models in order to produce accurate travel forecasts for highway planning and design.

Design of Survey Questionnaire

Similar to previous cordon line surveys, the DVRPC survey questionnaire was designed to collect information about traffic patterns and vehicle characteristics (*1–3*). As shown in Figure 2, seven questions were included in the survey form, which was used in the mail-back and the roadside interviews surveys. Drivers were requested to complete the questionnaire and return it to DVRPC by mail, while interviewers were instructed to record the answers to the questions directly on the survey form.

Trip Origins and Destinations

Questions 1 and 2 are perhaps the most important questions in the survey because they produce detailed origin-destination information needed to define traffic patterns inside and outside the region. Frequency of trip destination and trip length are needed for validating trip distribution models and estimating VMTs. Street address or nearest street intersection, as well as town, city, county, state, and zip code were specified to code the survey information to DVRPC traffic analysis zones (TAZs).

Trip Purpose

Question 3 was intended to collect information on trip purpose, including work, school, home, shopping, and social or

The Delaware Valley Regional Planning Commission, in cooperation with the Pennsylvania, New Jersey, and Delaware Departments of Transportation and the counties of Bucks, Chester, Delaware, Montgomery, Burlington, Camden, Gloucester, and Mercer, is conducting this survey to assess your transportation needs. Please complete this questionnaire and return it to us.

1. Where did you begin this trip?

   _____
   Street address or nearest intersection

   _____
   Town or City County State ZIP Code

2. Where will this trip end?

   _____
   Street address or nearest intersection

   _____
   Town or City County State ZIP Code

3. What is the purpose of this trip? (Check one)

   1[ ] Work
   2[ ] School
   3[ ] Home
   4[ ] Shopping
   5[ ] Social/Recreational
   6[ ] Other (Specify)_____

4. What type of vehicle are you using for this trip? (Check One)

   1[ ] Car
   2[ ] Pick-up, Panel, Van
   3[ ] Bus
   4[ ] Truck - Single Unit.....(2, 3, or 4 axles)
   5[ ] Truck - Single Trailer...(3, 4, 5, or 6 axles)
   6[ ] Truck - Double Trailer.....(5, 6, or 7 axles)
   7[ ] Other (Specify) _____

5. How many persons are in your vehicle (include driver)? _____

6. Where is this vehicle registered? (Check one)

   1[ ] Pennsylvania
   2[ ] New Jersey
   3[ ] Delaware
   4[ ] Maryland
   5[ ] New York
   6[ ] Ohio
   7[ ] Virginia
   8[ ] Other (Specify) _____

7. From this survey point, what is/are the major highway(s) that you will take to reach your destination?

   1st highway _____

   2nd highway _____

   3rd highway _____

THANK YOU

FIGURE 2 DVRPC traffic survey.

recreational. All other trip purposes were grouped in one category, under "other."

Vehicle Type, Occupancy, and Registration

Question 4 identified the type of vehicle surveyed, including cars, vans, trucks, and buses. Trucks were further classified by type of unit and number of axles.

Vehicle occupancy information was obtained from Question 5, which was needed to determine the average vehicle occupancy. Question 6 identified the state of vehicle registration. Seven states were specifically listed in the questionnaire, including Maryland and Delaware, which have contiguous borders with the DVRPC region.

Highways Used

Question 7 is not usually included in traditional cordon line surveys. Under this question, drivers were asked about the major highways that they would use to reach their destinations from the survey stations. This information is especially useful for comparison of actual paths with those obtained from the traffic assignment model.

The survey information is also essential for the planning and evaluation of alternative transportation strategies and programs to relieve highway congestion, such as transit options, alternative route selection, high-occupancy vehicle lanes (HOV), and park-and-ride lots.

Sample Size and Selection of Survey Stations

In the past, large sums of money were spent on cordon line surveys. Most vehicles crossing the cordon line were interviewed on major as well as on local roads. Sometimes surveys were conducted for 24 hr a day to account for day as well as night trips. For example, PJTS conducted more than 310,000 interviews, about 61 percent of the total number of vehicles that crossed the cordon line on a typical weekday (*4*). In the early 1970s, the FHWA recommended a sample size of 25 percent of the traffic during off-peak hours on highways with volumes of 10,000 vehicles per day or less, and 10 percent during peak hours on highways with daily volumes over 10,000 vehicles (*5*).

Recently, however, almost all regional cordon line surveys have been based on small samples because costs have increased significantly. In 1980, the Georgia Department of Transportation chose a sample of about 13 percent of the total traffic volume crossing the cordon line of the Atlanta metropolitan area. About 57,000 vehicles were selected for interview on 82 roads crossing the Atlanta cordon line (*2*). The 1986 external trip survey for the Phoenix metropolitan area was based on a sampling technique that reduces the number of interviewers and uses effective bypass procedures to minimize traffic delay (*6*).

Design of Sample Size

Statistical theory indicates that the sample size or number of interviews required for the survey is a function of the following five variables (*7–9*):

- Tolerable sample error,
- Desirable level of statistical confidence,
- Data variation around the mean,
- Level of data aggregation and cross classification, and
- Type of variable being estimated.

The sampling error is usually expressed as the percent discrepancy of sample data from the real or true value of the population. Because the sampling error is inversely dependent on the sample size, the accuracy obtained can be improved by increasing the size of the sample, but this incurs greater costs. Basically, accuracy is a trade-off between what is desired and what can be afforded.

The confidence coefficient specifies the desired level of statistical confidence in the sample data that fall within the specified error. It can also be represented as a percent indicating the number of standard errors required to provide the desired level of confidence.

The coefficient of variation is the ratio of the standard deviation of the measured variable to its mean. It is not usually determined until the survey has been completed. However, previous travel surveys have shown that the coefficient is close to 1 (*10–13*).

The sampling error increases with the increase in the disaggregation of survey data and cross classification of the results. For example, the sample size needed to make statistical inference at the regional level (for all highways) is smaller than that needed to estimate the same variable by route type or area type.

Finally, the sample size varies significantly depending on the type of survey variable being estimated. Previous research efforts have shown that accurate trip distribution at the level of TAZ would sometimes require a large sample, close to 100 percent (*10*). There are 1,335 TAZ aggregated into 71 county planning areas in the region. In order to reduce the sample size, county planning areas were substituted for TAZ. On the basis of 1987 simulated data, the highest trip interchanges between cordon stations and county planning areas ranged between 60 and 16,000 trips per day with a mean value of about 3,000 trips per day. This range was assumed in the estimation of the sample size.

On the basis of these statistical principles and assumptions, and experience gained in previous DVRPC surveys containing similar questions to this survey, alternative sample sizes were estimated (*11–13*). Table 1 presents the assumptions used to determine the minimum sample size needed for two groups

TABLE 1 ALTERNATIVE MINIMUM SAMPLE SIZE FOR DVRPC CORDON LINE SURVEY

Survey Question	Sampling Assumptions: Confidence Coefficient (%)	Sampling Assumptions: Sampling Error (%)	Minimum Sample Size: Percent	Minimum Sample Size: Interview
Questions 1 and 2 (Trip Origin and Destination)	90	20	3.0	33,000
	90	15	4.1	45,000
	90	10	9.6	106,000
Questions 3, 4, 5, 6 and 7 (Trip Purpose, Vehicle Type, Occupancy, Registration, and Highways Used)	90	10	0.04	400
	90	5	0.10	1,100
	95	5	0.10	1,500

of survey questions: (a) origin and destination, and (b) the remaining survey questions. The sampling error was assumed to range from 5 to 20 percent, and the confidence coefficient from 90 to 95 percent. As mentioned previously, the coefficient of variation and average daily trip interchange between cordon stations and county planning areas were assumed to be equal to 1 and 3,000, respectively.

In transporation planning surveys, it is desirable to design a sample that provides 5 percent accuracy at 95 percent confidence coefficient. However, these desired values cannot be proposed for trip origin and destination because they result in a very large sample size (see Table 1). For most trip interchanges between county planning areas and a cordon station, the required sampling rate may exceed 60 percent, six times the highest rate in Table 1.

Because of budget constraints, the sample size finally chosen was 33,000 interviews, which were distributed among the sample cordon stations. The margin of error in the survey results is expected to range from ±1 to ±20 percent, depending on the variable being estimated.

Selection of Cordon Stations

The simplest procedure for conducting the survey is to maintain a uniform sampling rate (3.0 percent) among the 128 cordon stations, but this would have been costly and provided an inadequate sample size for local roads with small traffic volumes. Accordingly, it was decided to sample the principal highways at a lower percentage than secondary roads. A sampling rate ranging from 3 percent for heavily traveled highways to 16 percent for local roads was selected.

Cordon Station Traffic Volume (AADT)	*Required Sample Size*	
	Percent of AADT	*Number of Interviews*
≤ 2,500	≥16	400
2,500– 5,000	16–12	400– 600
5,000–10,000	12– 8	600– 800
10,000–20,000	8– 5	800–1,000
20,000–40,000	5– 4	1,000–1,600
40,000–80,000	4– 3	1,600–2,400
≥80,000	≤ 4	3,200

The interviews on each highway were then divided into four groups for the purpose of sampling traffic patterns and characteristics during peak and off-peak hours. On the basis of actual traffic counts, the required minimum and maximum sample sizes were divided as follows:

Interview Time	*Station Sample Size (Interviews)*	
	Minimum	*Maximum*
7:00 a.m. to 9:30 a.m.	110	900
10:30 a.m. to 1:00 p.m.	90	700
Subtotal	200	1,600
1:00 p.m. to 3:30 p.m.	90	700
4:30 p.m. to 7:00 p.m.	110	900
Subtotal	200	1,600
Total	400	3,200

The final step in the sampling design was the selection of cordon stations that represent the traffic patterns crossing the cordon line. Analysis of the 128 roads that cross the cordon line resulted in the selection of the following sampling stations:

- Turnpike, freeway, and expressway cordon stations (10) were all selected for the survey because they are heavily traveled by different users throughout the region;
- All local roads (*14*) carrying less than 700 vehicles per day were excluded from the survey; and
- A sample of the remaining arterials and local roads (20 out of 104) was selected at random on the basis of highway traffic volume, physical characteristics, and geographic location.

Thus, 30 out of a total of 128 cordon stations were finally selected for the survey, in which 33,000 interviews were apportioned (see map shown in Figure 3).

Preparation and Conduct of the Survey

The survey questionnaire was printed on 5.5 × 8.5-in. cardboard stock in two different colors for inbound and outbound traffic. To maintain control, the survey forms required for each station were packaged in eight envelopes, four for inbound traffic and four for outbound traffic. (Traffic was surveyed during the morning and afternoon peak and off-peak periods.)

The DVRPC staff requested and received manpower assistance from the Pennsylvania and New Jersey departments of transportation, the planning departments of DVRPC counties, and state and local police departments. Survey signs and equipment, such as Traffic Survey Ahead, Stop, Arrow, Cone, Red Flag, Night Reflector Light, Left Lane Closed, Right Lane Closed, 25 MPH, Hard Hats, and Slow, were borrowed from state departments of transportation for the conduct of the survey.

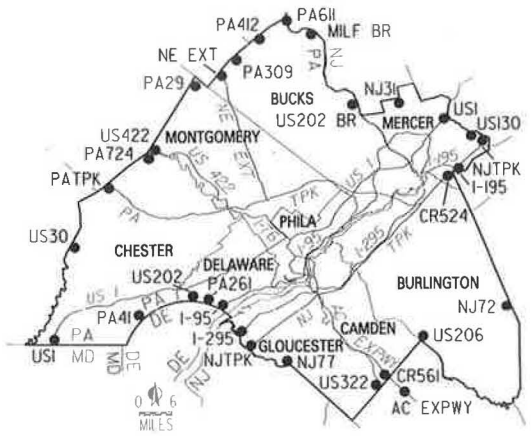

FIGURE 3 Map indicating cordon line stations selected for the DVRPC traffic survey.

Training Program for Surveyors

The DVRPC staff held several training sessions for interviewers and survey supervisors. The training program covered the following major items:

- Discussion of the survey goals and objectives, including accuracy required in the answers to the survey questions.
- Description of the cordon stations, including location, area, and highway physical characteristics.
- Review of the survey questionnaire, including possible answers to the questions.
- Description of the survey signs and equipment and how they should be set up in the field.
- Definition of role and responsibility of each member of the survey crew, including reporting time, transportation, equipment, and survey conduct.
- Clarification of any ambiguous questions or statements.

Conduct of the Survey

Safety was the most important consideration in locating the survey sites on highways. Station layouts were devised in cooperation with traffic engineers from PennDOT and NJDOT according to their safety manuals (*15*). A traffic control plan for each station was developed on the basis of the highway traffic volume and physical characteristics. Generally, straight and level sections of roads with unrestricted sight distances and wide shoulders with parking areas were selected. Two policemen were assigned to each survey station and requested to arrive 30 min before the start of the survey to allow time to inspect the site layout and survey signs. During the survey, police directed drivers selected at random to the survey sites, where they were interviewed by field personnel. Other drivers were allowed to bypass the station when interviewers were occupied. This platooning method was used at all stations, including those designed for mail-back survey. The number of interviewers needed at cordon stations varied depending on the number of surveys and ranged from 5 to 11 persons per station per day.

The survey was conducted in the fall of 1988 and spring of 1989. Interviews were conducted at 21 stations and a mail-back survey approach was used at five stations, including four surveyed by the Delaware Department of Transportation (*3*). In the Delaware survey, all stations were operated during daylight hours, from 7:00 a.m. to 6:00 p.m. These hours allowed surveys to be conducted in both the morning and evening peak and off-peak hours, but they may have introduced some bias in the results. Although different from DVRPC's survey questionnaire, the Delaware survey cards were processed and used by DVRPC for these stations.

On the Pennsylvania and New Jersey turnpikes, motorists were handed the survey form at all interchanges as they entered the turnpike (*16, 17*). These two surveys were conducted in 1985 and 1986 to determine trip purpose, trip frequency, vehicle class and occupancy, trip origin before entering the turnpike, and trip destination after leaving the turnpike. This information was also used by DVRPC for four cordon stations.

The response to the DVRPC survey was excellent. There were no accidents, traffic delay was minimal, and only a few persons complained. The completed interviews and mail-back questionnaires were then packaged for coding, keypunching, and processing.

SURVEY RESPONSE AND PROCESSING

The response rate to the mail-back survey at five cordon stations ranged from 14 to 28 percent. For the remaining 21 stations, the number of completed interviews was in most cases equal to that estimated in the sample design. However, weather or daylight conditions sometimes resulted in a smaller sample than that specified in the design.

More than 27,000 survey interviews and mail-back questionnaires were received for the 26 stations, not including the surveys returned by the users of the Pennsylvania and New Jersey turnpikes, which were processed and evaluated in 1986 by a consulting firm. Table 2 presents the number and type of stations surveyed and the valid forms prepared for coding and processing. All turnpike, freeway, and expressway cordon stations were included in the survey, but a sample ranging from 10 to 33 percent of local roads and arterial highways was surveyed.

About 6 percent of the motorists entering or leaving the region at the sampled stations were surveyed. As designed, the sample size ranged from 3.9 percent on freeways and expressways to 12.2 percent on local roads. The sample rate on the Pennsylvania and New Jersey turnpikes was about 10 percent (*16,17*).

Coding and Keypunching

The completed survey forms (interview and mail-back surveys) were screened and those with apparent mistakes were discarded. The remaining forms were than geocoded manually and keypunched according to a specific record layout for computer processing.

Manual coding of trip origin (Question 1), trip destination (Question 2), and highways used (Question 7) was performed (see Figure 2). If the trip origin or destination was inside the region, the coding was done at the TAZ level; otherwise it was performed at the minor civil division, county, or state

TABLE 2 CORDON STATIONS AND VALID SURVEY FORMS SAMPLED BY HIGHWAY TYPE

	Cordon Stations			Sampled Cordon Stations		
Highway Type	Total	Sampled	% of Total	Volume AADT (000)	Traffic Survey Forms (000)	Valid % of AADT
Turnpike*	4	4	100	-	-	-
Freeway & Expy.	6	6	100	201	7.7	3.9
Arterial	43	14	33	248	15.3	6.2
Local	61	6	10	32	3.9	12.2
TOTAL	114	30	26	481	26.9	5.6

*Turnpike surveys were processed in 1986 by Wilbur Smith Associates, Consultants to the Turnpike Commission

level. The number of cordon station for through trip was also coded manually on the basis of the responses to Questions 2 and 7, which defined the place of destination and highways used to reach the destination, respectively.

Data Processing and Survey Tabulation

After the completion of punching of survey information, the responses were processed and tabulated for

- Each cordon station,
- Freeway and expressway stations,
- Arterial stations,
- Local road stations, and
- All stations.

Previous DVRPC FORTRAN and UTPS programs were used to process the survey information and produce tabulation for the following:

- External and through trips, frequency of trip distribution, and average trip length inside the region.
- Trip purpose, vehicle type and occupancy, and state of registration. This information was tabulated by traffic direction (inbound and outbound) and time of interview (a.m. and p.m. peak and off-peak).
- Frequency of highways used to reach the destination by motorists interviewed at each station.
- Cross tabulation of information on vehicle type and occupancy, and state of registration by trip purpose.

SURVEY RESULTS

Examination of the survey results indicated some bias in the mail-back surveys conducted at five of the cordon stations. Only a few commercial truckers completed and returned the survey form; conversely, the response of commuters to the survey was overwhelming. In addition, some questions were misunderstood, and others were not completed by respondents. The use of a mailback survey has increased the percentage of work trips at a few stations. At the US-1 station, for example, 66 percent of the surveys covered work trips, about 20 points higher than the average of all surveys.

Most of the survey results, including traffic pattern and characteristics, were computed on the basis of the sample. In the future, the survey information will be factored to estimate total travel, including the number and type of trips and vehicle miles of travel. It will also be used to calibrate and validate DVRPC trip generation and distribution models, which produce regional travel forecasts for external and through trips.

Daily and Hourly Traffic Volumes

Directional and total daily and hourly traffic volumes on each of the 26 highways sampled were counted by portable traffic recorders for a minimum 48-hr weekday period. The counts were then factored to convert the shorter term counts to annual average daily traffic (AADT), which account for daily and seasonal variation in traffic. Figure 4 shows the distribution of total AADT crossing the cordon line at the sampled stations. About 7.5 percent of the 24-hr traffic was recorded in the morning peak hour (7:00 to 8:00 a.m.), while 8.0 percent was observed in the evening peak hour (4:00 to 5:00 p.m.). The figure also shows that traffic volume between 5:00 and 6:00 p.m. was nearly as heavy as the previous hour. The traffic peak in the morning period was sharper than in the evening peak, mainly because of the presence of many nonwork trips in late afternoon and early evening. Approximately 54 percent of the vehicles during the morning peak hour were outbound, while 52 percent of the vehicles in the evening peak hour were inbound. This pattern indicates that the number of workers who live in the DVRPC region and work in the neighboring regions is higher than the number of those who commute to the Delaware Valley from other regions.

Trip Origins and Destinations

As stated before, trip origins and destinations inside the DVRPC region were coded to TAZs. For the purpose of DVRPC traffic simulation, external-internal trips were assumed to be produced at cordon stations and attracted to TAZs. Conversely internal-external trips were assumed to be produced at TAZs and attracted to cordon stations. The places of origins and destinations, or production and attraction, were aggregated to minor civil division, county, and state levels. For example, the map in Figure 5 shows the places of destinations of external and through trips entering the region at the Atlantic City Expressway station. Most of these trips had destinations close to the cordon station. About 61 percent of the trips were destined for Camden, Gloucester, and Philadelphia counties. No more than 10 percent of the vehicles traveled through the region from this station (*18*).

In general, the distribution of destinations matched trip origins. Trips entering the region at a cordon station had similar traffic patterns to those which left the region. However, the distribution of origin and destination may differ slightly because evening return trips were not captured and some drivers may not have used the same highway for their return trips.

Of the 627,800 vehicles that crossed the cordon line at the sampled stations, 12.5 percent completed their journeys through

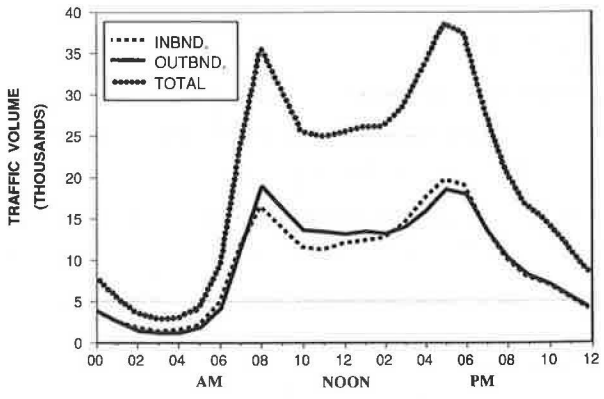

FIGURE 4 Distribution of total daily traffic volume.

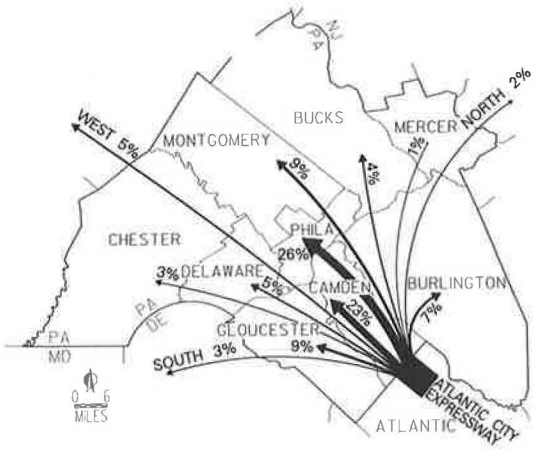

FIGURE 5 Map indicating Atlantic City Expressway cordon station and distribution of inbound trips by place of destination.

the region without major stops. A large portion of through trips was accommodated on the Pennsylvania and New Jersey turnpikes, on which almost 43 percent of the trips had both their origins and destinations outside the region. Most of these were on the New Jersey Turnpike, which extends from the Delaware Memorial Bridge to US-46 in northern New Jersey.

On the basis of previous travel time and speed run surveys, trip length and time were estimated. Excluding turnpike travel, the average trip length of through trips inside the region was 37.2 mi. The average driver crossed the region in 57 min at a speed of 39.2 mph.

Figure 6 shows the trip length frequency distribution for all external trips by travel time and distance. As shown in the figure, a major portion of external trip origins and destinations was clustered within 6 mi of the cordon line. The average trip length and variance were estimated to be 18.7 and 237.6 mi, respectively. Almost 34 percent of the origins and destinations were within a drive of 15 min from the cordon line. The average trip length and speed of external trips inside the region varied significantly by highway type as follows:

	External Trips		
Highway Type	*Distance (mi)*	*Time (min)*	*Speed (mph)*
Freeways and expressways	24.9	43.7	34.2
Arterial highways	17.7	33.6	31.6
Local roads	10.7	20.7	31.0
All highways	18.7	34.5	32.5

Trip Purpose

Trip purpose is defined by the motorist's next major stop after leaving the cordon station. For example, a home-to-work commute in the morning is a work trip, and the return trip in the evening is a home trip, provided no major stops are made en route. If a stop is made at a mall, then the first leg is a shopping trip and the second is a home trip. Figure 7 shows that 46 and 24 percent of the trips sampled were work and home trips, respectively. Home and social or recreational trips may have been underestimated because no surveys were taken after 7:00 p.m. when many of these trips occurred.

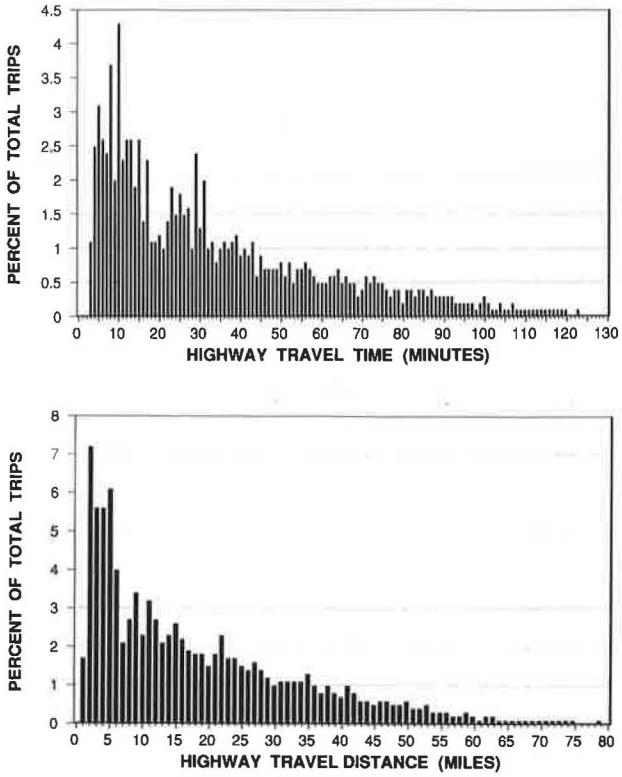

FIGURE 6 Trip length frequency distribution for external-internal and internal-external trips.

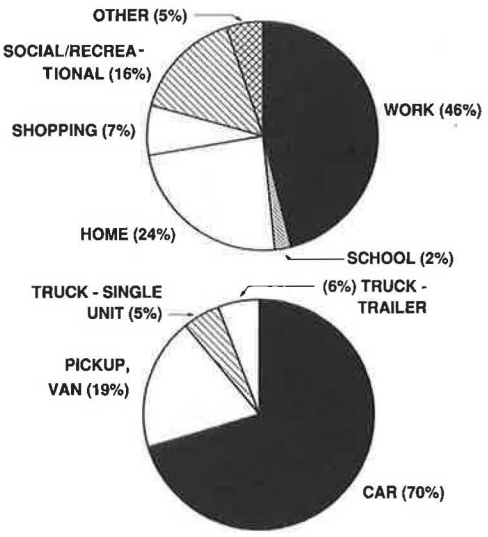

FIGURE 7 Trip purpose and vehicle type.

Social or recreational trips constituted approximately 16 percent of the total. This relatively high proportion of cordon line trips is not surprising because the survey was conducted on some highways serving entertainment, recreational, and resort centers, including the Pennsylvania Dutch Country, Pocono Mountains, New Jersey shore resorts, and Atlantic City. Shopping trips amounted to almost 7 percent of the total.

Vehicle Type

Vehicle type was estimated from the survey as well as from data collected by a field recorder for 24 hr. In some cases, 8-hr manual classification was performed in the peak and off-peak hours. Figure 4 also shows that automobiles were the predominant vehicle type on all highways, accounting for more than 70 percent of total traffic. Pick-ups, panels, and vans made up the second largest portion of traffic with almost 19 percent of the total. Because these vehicles are used primarily for the movement of people, approximately 11 percent of the vehicles entering or leaving the region were used for the movement of goods. If turnpike traffic was included, the percent of medium and heavy trucks would have increased to 12.6 percent of total cordon line traffic. Buses accounted for 0.4 percent.

Vehicle Occupancy

The number of vehicle occupants, including the driver, was checked on the survey questionnaire. The driver was the sole occupant in about 71 percent of the vehicles surveyed. In contrast, 1 percent of the vehicles had five or more, and about 8 percent had three or more persons (see Figure 8). The average vehicle occupancy of all trips was 1.5 persons per vehicle. Trip purpose was the greatest determinant of vehicle occupancy, which ranged from 1.25 for work trips to 2.15 for social or recreational trips. The average vehicle carried 1.45 and 1.73 persons for home and shopping trips, respectively.

Vehicle Registration

The state of registration was taken from the vehicle license plate at the time of the interview, or was checked by the driver on the mail-back survey. In general, the state of registration indicates where the vehicle is garaged. As shown in Figure 7, almost 85 percent of the vehicles were registered in Pennsylvania and New Jersey, in which the DVRPC region is located. About 8 percent were registered in Delaware and 2 percent in Maryland. These two states have contiguous borders with Pennsylvania to the south. The remaining vehicles were registered in other distant states, including New York (1.1 percent), Ohio (0.6 percent), and Virginia (0.5 percent).

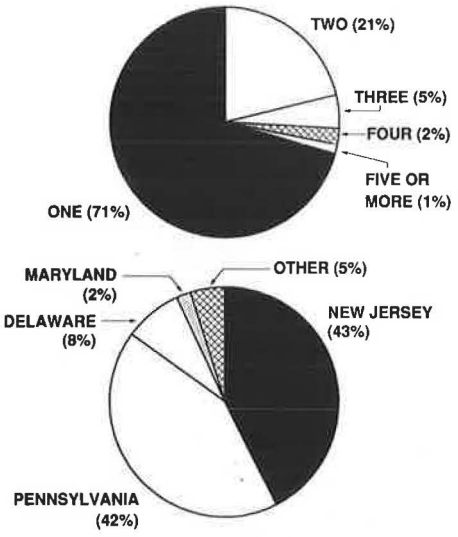

FIGURE 8 Vehicle occupancy and registration.

Major Highways Used

Drivers were asked to list the major highways they would be using to reach their destinations after leaving the survey point. Many drivers did not list any additional highways, either because none were used, or because they did not wish to answer the question. However, the highways listed were useful to identify exit stations of through trips and to define traffic flow within the DVRPC region. For each station, the highways used and frequency of use were tabulated. Analyses of the survey results indicate that the highways used constitute a natural extension of the highways surveyed. In other words, traffic flow between a cordon station and a community within the region is generally accommodated on the highway with the shortest travel time. Most of the traffic remains in the highway corridor. The traffic pattern is consistent with the concept of the gravity model in which trip interchange between two TAZs is directly proportional to the relative attraction of each of the zones and inversely proportional to some function of the spatial separation between zones.

Comparison of Survey Results with 1987 Simulation

In 1987, DVRPC conducted a major travel simulation for the Delaware Valley Region, including cordon-line-through and external trips. The simulation process resulted in extensive tabulations of socioeconomic data, external and through-trip generation, internal-trip generation, trip distribution, modal split, and highway and transit assignments. Comparison between counted and simulated highway screenline volumes indicated that the simulation models produced acceptable levels of accuracy both in highway and in transit assignments (*14*).

In Table 3, the survey results are compared with those produced by the simulation models. The table indicates that the difference between traffic counts and simulated volumes is small (4.8 percent). Also, survey and simulated data on percent of trucks do not show a significant difference (7.9 percent). However, the models resulted in 92 percent overestimation of through trips. On freeways and expressways, through trips were overestimated by 125 percent. The overestimation of through trips was offset by a 13 percent underestimation of external trips.

As presented in Table 3, the average trip length of external trips inside the region on all highways computed from the survey data is very close to that simulated by the model (18.7 versus 17.5 mi). However, the model underestimated trip length on expressways and freeways by about 33 percent. Conversely, trip length on local roads was overestimated in the simulation by 54 percent. These findings are significant and should be incorporated in the next validation of simulation models of external and through trips.

TABLE 3 COMPARISON OF SURVEY RESULTS WITH 1987 TRAFFIC SIMULATION

Variable	Survey	Simulation	Percent Difference (%)
1987 Total Traffic Volume (AADT in thousands)	1,071	1,122	4.8
Percent of Trucks (%)	12.6	13.6	7.9
Percent of Through Trips (%)			
Turnpikes	42.5	74.3	74.8
Expressways	11.6	26.1	125.0
Arterials	8.9	14.8	66.3
All Highways	12.5	24.0	92.0
Percent of External Trips (%)	87.5	76.0	(13.1)
Average Trip Length of External Trips (miles)			
Expressways	24.9	16.8	(32.5)
Arterials	17.7	18.1	2.3
Local	10.7	16.5	54.2
All Highways	18.7	17.5	(6.4)

Survey Cost

The DVRPC cordon line survey project was divided into three phases completed in two calender years at a total cost of $186,000, or about $9,000 per cordon station. Phase I of the study covered the survey design, preliminary planning, and discussion of survey procedures. Phase II included field preparation, conduct of the survey, coding, keypunching, and tabulation of some survey results. The third phase covered the completion of fields surveys, tabulation and analysis of total survey results, and preparation of the final report for each station.

If the cost of services received from member governments, such as the assistance provided by PennDOT and NJDOT, was included, the total survey cost would have increased to $250,000, or about $12,000 per cordon station. The total cost of each interview or mail-back survey questionnaire was about $12.00, which included the cost of collecting sample data, coding, punching, tabulating and analyzing survey results, and preparing the final reports. This is the minimum cost required for conducting such a survey for the purposes of regional planning and travel forecasting of through and external trips.

CONCLUSIONS

The 1989 DVRPC cordon line survey provided essential information on trip origin, destination, and purpose; vehicle type, occupancy, and registration; travel time, distance, and speed; and highways used by motorists entering and leaving the Delaware Valley region. Such data are required for the evaluation of alternative transportation strategies and programs to relieve highway congestion, particularly in the growing suburban areas near the perimeter of the region, and to update information collected in 1960 by the PJTS for travel forecasting and transportation planning.

In order to avoid major traffic delay and reduce costs, a sample of automobile and truck drivers was surveyed at 26 out of a total of 114 highways and roads. More than 27,000 survey forms were processed and evaluated, and information on traffic patterns at four turnpike cordon stations was obtained from previous mailback surveys. Strict safety procedures were followed in setting up the interviewing stations. Stations layouts were devised according to the state safety manual, and no accidents occurred. While some minor traffic delay occurred on high-volume roads, only a few persons complained and traffic delay was minimal during the peak hours. The mail-back survey forms had some incomplete answers or bias in the results, primarily because of the low response rate of commercial truckers; conversely, the response of commuters to the survey was overwhelming. Despite these problems, the margin of error both in interview and in mail-back surveys was acceptable for all planning purposes.

Analysis of the survey results indicates that the volumes and traffic patterns of through and external trips crossing the cordon line have changed significantly in the past three decades. Comparison of the survey results with those already produced by simulation models indicates that the models should be recalibrated to reflect the new survey information. For example, simulated through trips should be decreased 92 percent and external trips increased by about 13 percent. Also, the average trip length of simulated external trips on expressways and freeways should be increased by 33 percent. On local roads, however, the trip length should be decreased by 54 percent.

The assistance received from the Pennsylvania and New Jersey departments of transportation, the nine county planning departments, and the bridge and turnpike commissions was invaluable. Without such cooperation, the survey cost would have increased by about 33 percent. The total cost of each completed interview or mail-back survey was about $12.00, or $12,000 per cordon station. This included the cost of collecting sample data, coding, punching, tabulating, analyzing survey results, and preparing the final reports.

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