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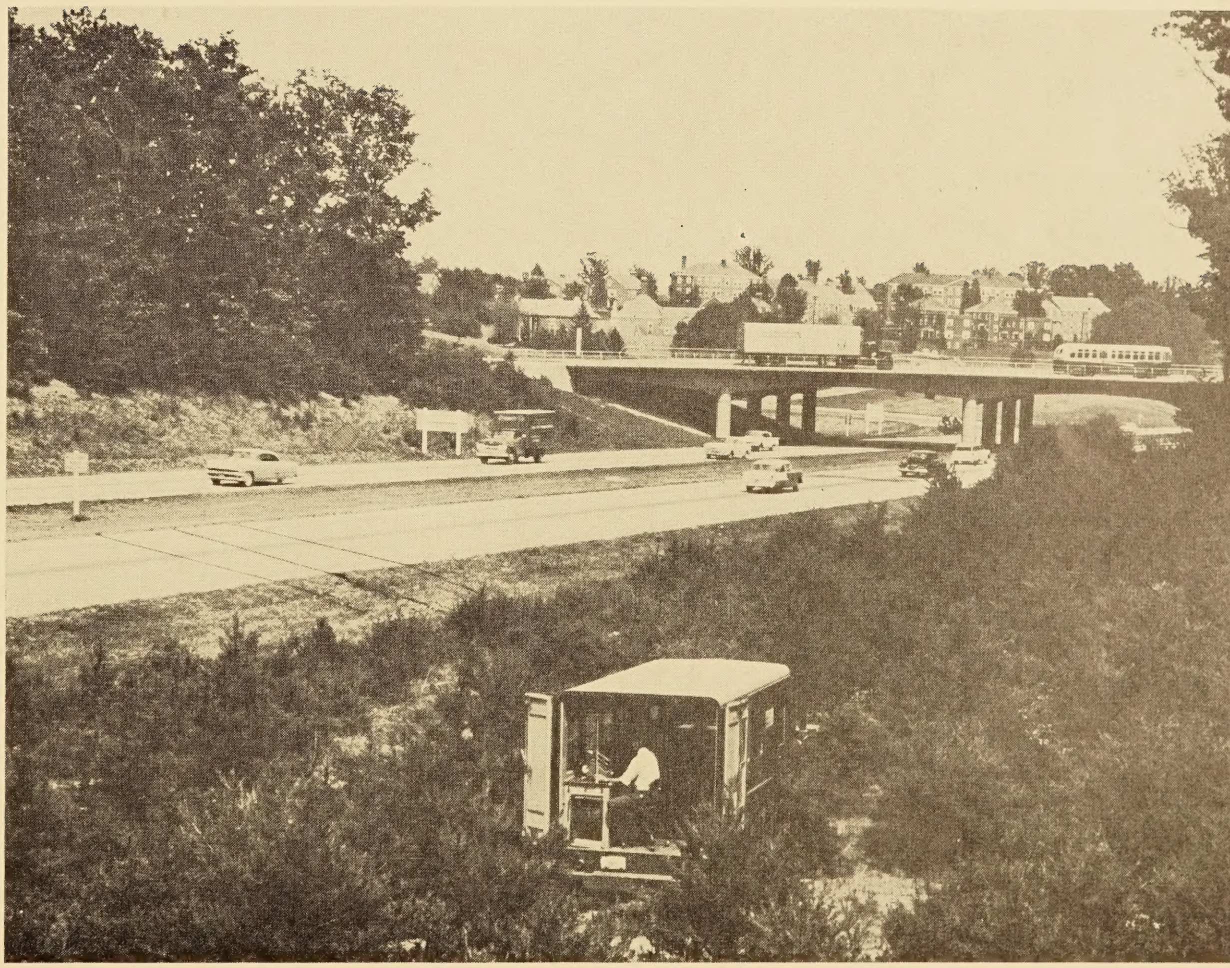

IN THIS ISSUE: The development and use of the traffic analyzer vehicle.

(Virginia Route 350, southwest of Washington, D.C.)

IN THIS ISSUE

Characteristics of Travel to a Regional Shopping Center, *by J. Silver and W. G. Hansen* . . . 101

The Effects of Enforcement on Traffic Behavior, *by R. M. Michaels* 109

Appraisal of O-D Survey Sample Size, *by A. B. Sosslau and G. E. Brokke* 114

A Traffic Analyzer: Its Development and Application, *by A. Taragin and R. C. Hopkins* . . . 120

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Characteristics of Travel to a Regional Shopping Center

BY THE DIVISION OF HIGHWAY PLANNING
BUREAU OF PUBLIC ROADS

Reported by JACOB SILVER, Transportation Economist, and WALTER G. HANSEN, Highway Research Engineer

This article describes many of the characteristics of travel associated with a shopping center which has a regional market area. The shopping center studied was located in a Virginia suburb of the Washington, D.C., metropolitan area.

Almost one-half of the trips generated by the shopping center for convenience-goods merchandise (food, drug, personal service, etc.) were made by residents living within 10 minutes driving time from the center. The average duration of parking for all convenience-goods shoppers was less than 50 minutes. Trips made to the center for the purpose of obtaining shopping-goods merchandise (apparel, furniture, etc.) were found to be greater in number, farther in distance, and longer in parking duration.

Only a limited degree of attraction to the center was due to its multiple-purchase characteristics. However, one-half of the weekly trips were made for apparel merchandise.

This article also points out the additional demand placed upon the arterial in the immediate vicinity of the center and how the additional traffic conflicts with normal peak-hour traffic movement. Also, an estimate of the impact of the shopping center upon other commercial complexes is discussed.

COMMERCIAL concentrations or "shopping centers" are continuing to be established in the increasingly populated suburban areas of our cities. The increasing traffic problems resulting from the change in the pattern and distribution of shopping travel to these new retail centers have become familiar to many highway and traffic engineers, as well as to metropolitan planners.

In 1955, a home-interview transportation survey—origin-destination (O–D)—was conducted in the Washington, D.C., metropolitan area. Shortly after the completion of this survey, a shopping center with a regional market area was opened in one of the Virginia suburbs. A special survey of travel to this center was undertaken for the purpose of updating the 1955 O–D survey data and, secondly, to provide information that would be useful in estimating the travel to similar types of centers that were expected to be built in the future.

This report is an analysis of the travel to this regional center. Although limited in scope, it presents some of the characteristics of travel that can be expected when a trip attractor of this nature is established. It should, therefore, be helpful to those responsible for the location, design, and operation of these centers and the highway facilities which serve them.

Summary

This article describes some of the characteristics of travel associated with a regional shopping center. It shows that this type of commercial development generates traffic at sufficient volumes during the normal peak hours of travel so as to create serious problems of traffic congestion on the arterials in the immediate vicinity of the center.

An analysis made of the trips for shopping goods and for convenience goods showed that for comparable floor area size, shopping-goods trips were generated at a rate significantly greater than the number of trips generated for convenience goods. Also significant were the differences in trip length and parking. Convenience-goods traffic generated shorter trips with shorter durations of parking than did shopping-goods traffic. From the data collected, it was found that convenience-goods traffic utilized parking space approximately twice as effectively than did the shopping-goods traffic.

Even though Seven Corners offered a large selection and variety of merchandise, which would permit multiple purchases at a single stop, the center only derived a limited degree of attraction to it due to this characteristic. The bulk of the trips attracted were for the purpose of purchasing shopping-goods merchandise, particularly apparel. This one group accounted for one-half of the total weekly trips.

Trips were attracted to the shopping center from throughout the area under study. The frequency of trips originating at a given distance or residential area, however, is dependent upon that center's location, composition, and size relative to these same factors of competing centers.

Seven Corners Shopping Center

Seven Corners shopping center, as shown in figure 1, is located at the eastern edge of Fairfax County, Va., at the intersection of several major highways. This location, approximately 7 miles, or 30 minutes driving time, from the District of Columbia central business area, was at the periphery of the urban development at the time of the study. The distribution of population in terms of driving time from the shopping center is shown in table 1. The *inboard* and *outboard* designations used in this table and subsequently refer to an arbitrary division of the market area into two parts, and are used only for comparative purposes to indicate that shopping characteristics were not uniform throughout the study area. The inboard area designates the area between the Seven Corners shopping center and the District of Columbia CBD; outboard designates the area from the shopping center away from the CBD. The dividing line is shown in figure 1.

The site of the shopping center is triangular in shape and, at the time of the study, encompassed a total area of 32 acres. The shopping center was bounded on the north by U.S. Route 50, a major east-west 4-lane highway, and on the south by Virginia State Route 7, a 4-lane, northwest-southeast highway. These two routes, together with other intersecting arterials in the vicinity of the center, make this location highly accessible for the residents of the Virginia section of the Washington, D.C., metropolitan area.

The site plan, illustrated in figure 2, indicates the location of the building structures, the parking areas, and the points of vehicle-access to the center. The main building is an I-shaped, 2-level structure with a department store at each end. The remaining establishments, with the exception of a supermarket and an automobile parts and service establishment, are located along a covered promenade (at both levels) between the two department stores.

The total floor area of the center, at the time of the study in 1957, was 600,000 square feet, of which approximately 503,000 was gross rental area. The types and number of estab-

Figure 1.—Seven Corners shopping center and other commercial concentrations in the Virginia section of the Washington, D.C., metropolitan area.

lishments of the center, along with the space occupied by each category, are shown in table 2. Approximately one-half of the total gross rental area was used for the actual retailing of merchandise. About 1,000 persons were employed full or part time at the center.

Customer parking areas were convenient to both the upper and lower levels of the center, and provided space for 2,025 vehicles, or 4 spaces per 1,000 square feet of gross rental area. In addition, 235 parking spaces were provided for employees in an area opposite the shopping center, across U.S. Route 50.

The Travel Survey

The survey of travel to Seven Corners shopping center was conducted from April 8 through April 13, 1957, 6 months after the center was officially opened. Although 6 months was a relatively short period of time, it was considered sufficient for the people of the area to have become familiar with the new shopping and service opportunities and to eliminate possible bias created by sightseers to the new center.

Since Easter was on April 21, it was realized that the results would be affected somewhat by the holiday shopping. However, there is a considerable seasonal fluctuation in the purchase of many categories of merchandise and a survey made in any one week would not be representative of the entire year. In this case, the purchase of apparel was probably above average and this should be taken into consideration in appraising the results.

Information concerning the origin, length, purpose, and duration of trips to the center, as well as automobile occupancy and vehicle registration, was obtained by personal interviews. Every tenth parking space in the main parking area was designated as an interview space. Interviews were obtained on arrival for each family represented by the occupants of the cars which parked in those interview spaces. To be comparable with the 1955 travel survey, children less than 5 years of age were not included in the sample. In all, 1,558 interviews were obtained, representing about 7 percent of all the families arriving at the center during the interview periods.

Interviews were made on three days, Wednesday, Thursday, and Saturday, and were expanded to represent weekly volumes

Table 1.—Distribution of population and the average income for each of several travel-time groups to Seven Corners shopping center

1957 travel time to Seven Corners (minutes)	For total area:[1]			Distribution of each travel-time group			
				Inboard		Outboard	
	Population [2]		Average family income [2]	Percent of population	Average family income	Percent of population	Average family income
	Number	Percent					
0–4	5,600	1	$6,500	68	$5,800	32	$8,500
5–9	54,400	13	7,800	57	8,600	43	6,600
10–14	129,500	32	7,500	65	8,200	35	5,900
15–19	73,700	18	7,900	89	8,000	11	5,800
20–24	73,600	18	6,900	61	7,500	39	5,800
25–29	32,000	8	6,400	74	7,000	26	4,400
30 and over	39,300	10	5,500	31	5,800	69	5,400
Total or average	408,100	100	7,100	65	7,900	35	5,800

[1] Only includes area in Virginia section of the Washington, D.C., metropolitan area.
[2] Unpublished data, Mass Transportation Survey, National Capital Planning Commission and National Capital Regional Council, 1955.

on the basis of directional traffic counts made throughout the week of the study at each of the eight access points shown in figure 2.

The interviews made on Wednesday were expanded on the basis of hourly traffic counts to represent trips made during the two days, Tuesday and Wednesday, when a majority of establishments were closed evenings. Interviews made on Thursday were expanded to represent trips made during Monday, Thursday, and Friday, when the entire center was open evenings. Saturday interviews were expanded to represent only Saturday trips. No attempt was made to adjust the data for any seasonal variations which might have existed.

No interviews were obtained from persons walking to the center or those arriving by bus. Pedestrian trips were omitted after the study indicated that the distances between the shopping center and most nearby residential developments, as well as the heavily traveled arterials surrounding the center, were not conducive to walking trips, and few walking trips were actually observed. Transit trips were omitted from the survey after sample counts showed an average of less than 150 persons per day arriving by bus.

In addition, no interviews were made in the area set aside for employee parking. Comparatively few employees actually used this space. Except for Saturday, less than 50 vehicles per day were parked there. Many employees parked in the customer parking area, even though there were regulations to the contrary. Also, observations showed that many of the employees were parking in the adjacent apartment development, while still others were brought to work by vehicles which did not park.

The work-trip data presented in the following sections are only for the center employees and noncenter workers, e.g., carpenters and delivery men, who parked their vehicles in the customer parking area. As a result, work trips are considered to be substantially underreported.

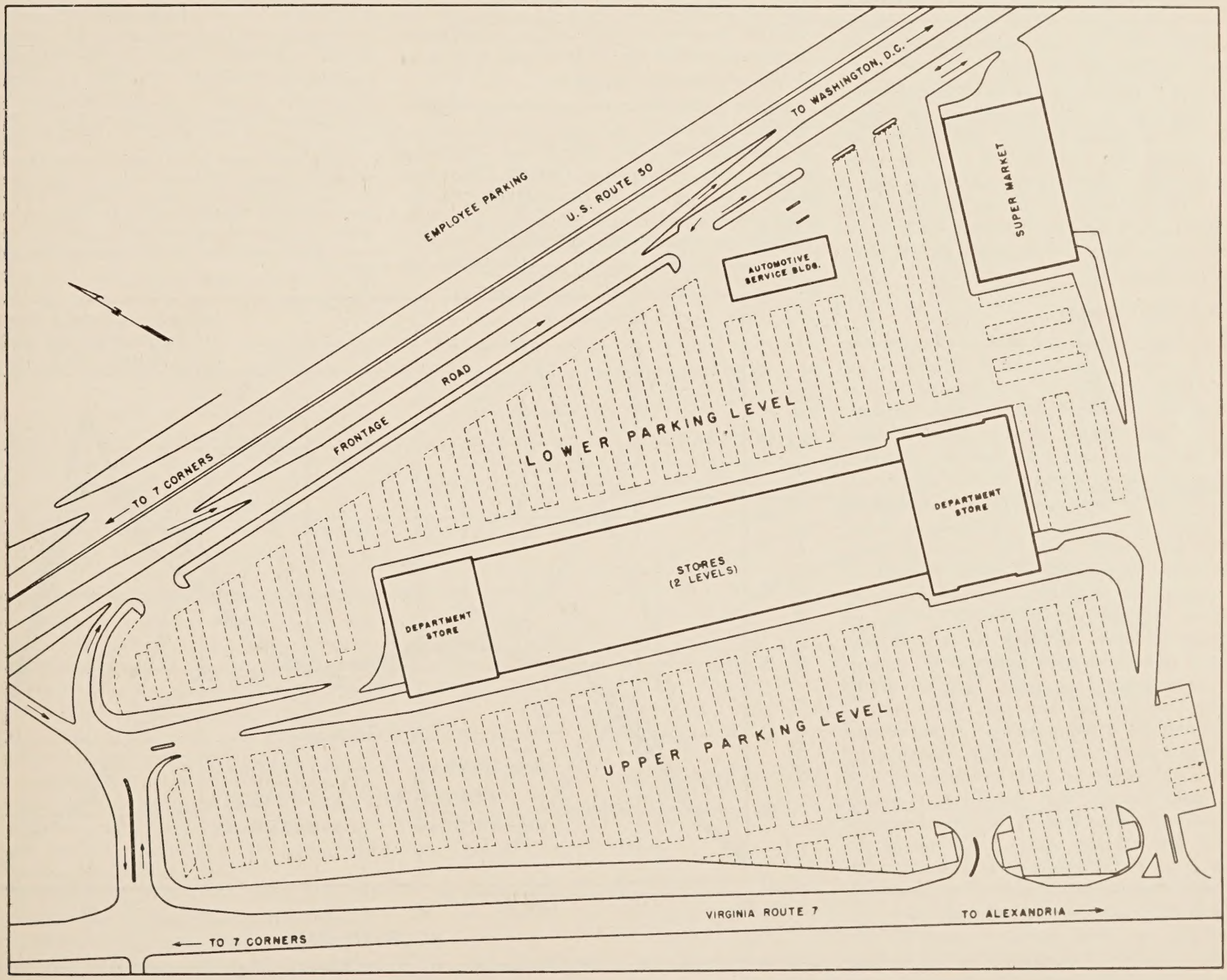

Figure 2.—Physical layout of Seven Corners shopping center.

Table 2.—Distribution of gross rental space at Seven Corners shopping center [1]

Category of business establishment	Number	Gross rental space	
		Area (square feet)	Percent of total
Department store	2	210,700	42
Apparel	13	100,300	20
Food, drug, hardware, variety	7	96,000	19
All other shopping	11	50,500	10
Eating	1	15,900	3
Service	6	9,300	2
Occupied space	40	482,700	96
Unoccupied space	4	20,100	4
Gross rental space	44	502,800	100

[1] Data as of April 8, 1957.

Findings of the Study

During the week of the study, a total of 52,500 passenger vehicles, carrying an estimated 96,300 persons, entered the Seven Corners shopping center. These volumes were distributed among the days of the week as follows: Monday, Thursday, and Friday, 17 percent each; Tuesday and Wednesday, 12 percent each; and Saturday, 25 percent.

The volume of passenger vehicles entering the center by hour for each day of the week is shown in figure 3. Three distinct patterns were observed: One for those days when the center was open in the evening; one for those days when the majority of the establishments were closed in the evening; and one for Saturday. Of particular interest was the lack of any appreciable variation in the weekday volumes between the hours of 8 a.m. and 4 p.m. The fact that the center was open during an evening seems to have little or no effect on the volume of shopping during these daytime hours.

Peak traffic volumes

The peak period for traffic entering the center occurred on Saturday afternoon between noon and 5 p.m. The greatest volume during this sustained peak occurred between 2 and 3 p.m. when a total of 1,550 vehicles, or 3 percent of the total vehicles attracted during the week, arrived at the center. If the volume for this one hour were expressed as a proportion of the average daily weekday traffic (the usual base for reporting peak-hour traffic movement), it would be equal to 21 percent of the total number of motor vehicles arriving at the center during an average weekday, Monday through Friday. If both the arrival and departure of vehicles were considered, the peak hour of traffic occurred during the same hour with a total movement of 3,100 vehicles. This volume was also 3 percent of the weekly movement.

Although absolute peak volumes of traffic are important to the design of a center, particularly with respect to the design of access, the volumes which occur during the hours of peak-traffic flow on adjacent arterials are also of considerable importance; especially as it is this movement which will affect the operation of the highway proper. The normal Monday-through-Friday peak-hour flow on the highways in the Seven Corners area occurred between 5 and 6 p.m. The shopping center generated an average of 1,500 vehicle trips, arrivals plus departures, during this time period (the volume entering and exiting was evenly divided between the two adjacent arterials, Routes 50 and 7). Of the 1,500 vehicle trips, approximately 80 percent had originated at home and were not making intermediate stops as part of the work-to-home rush-hour movement. These 1,200 home-based vehicle trips give some indication of the additional demand placed upon the arterials in the immediate vicinity of the shopping center. If these volumes were not anticipated, this additional burden, conflicting with normal peak-hour traffic movement, would be large enough to create a serious problem of traffic congestion on the arterials serving this type of commercial development.

Parking facility

How much parking space should be provided is always one of the major problems in the design of a shopping center. As may be seen in figure 4, there were only 10 hours during the study week when the accumulation of vehicles at Seven Corners reached 50 percent or more of parking space capacity—2,025 spaces. On Saturday, the accumulation of vehicles surpassed the capacity of the parking area by 2 percent, resulting in considerable congestion within the parking area as well as at the entrances to the center.

Figure 4 also shows the percentage of parking spaces used for the two major categories of merchandise being purchased—shopping goods and convenience goods. *Shopping goods* were those which the customer, in the process of selection and purchase, characteristically compared the suitability, quality, price, and/or style of the goods; where the customer willingly made a special added effort in the purchase of these goods. For the purposes of this study, trips for shopping goods included apparel, furniture, and specialty merchandise, such as flowers and jewelry.

Convenience goods were generally items which the customer desired to purchase frequently, immediately, and with a minimum of effort. Habit played an important part in the purchase of convenience goods. For the purposes of this study, trips for this category included food, drug, variety, and hardware merchandise, as well as personal services, such as barber shop, laundry, and dry-cleaner establishments.

The rate at which vehicles arrive at the center and the length of time that they remain are two factors in the determination of the amount of parking space required at a shopping center. The average duration of parking by trip purpose at Seven Corners is shown in figure 5. The most significant comparison to be made is the difference in the duration of parking between trips to purchase shopping goods and those made to purchase convenience goods. Fifty-five percent of the trips attracted for the purchase of shopping goods parked 1 hour or less; the average duration of parking was 1.5 hours. In comparison, 80 percent of the trips attracted for convenience-goods purchases parked for less than 1 hour, with an overall average duration of parking of 0.8 hours.[1] The above percentages mean that given equal and sustained rates of arrival, shopping-goods traffic, on the

[1] The curve in figure 5 pertaining to trips for the purpose of eating is undoubtedly somewhat in error as evidenced by the large percentage, 25 percent, of trips with durations in excess of 1 hour. This error is felt to be due to an oversight in the survey procedures which did not ascertain whether or not people coming to eat at the center were also planning to shop.

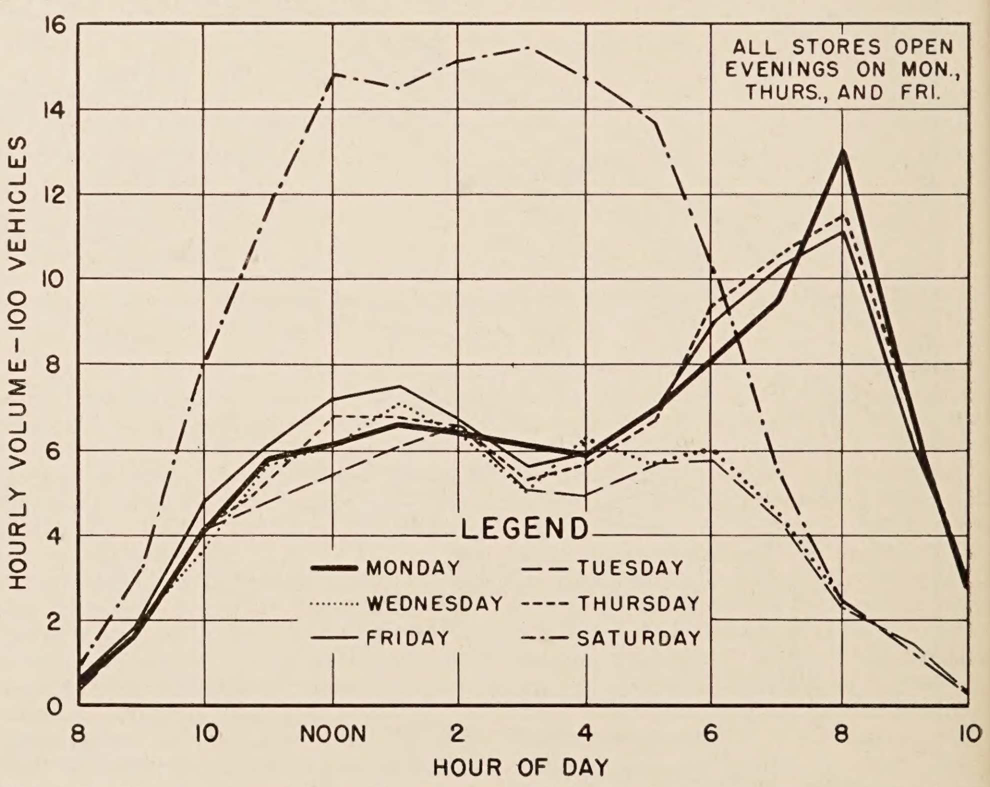

Figure 3.—Volume of vehicles arriving at Seven Corners shopping center by time of day and day of week.

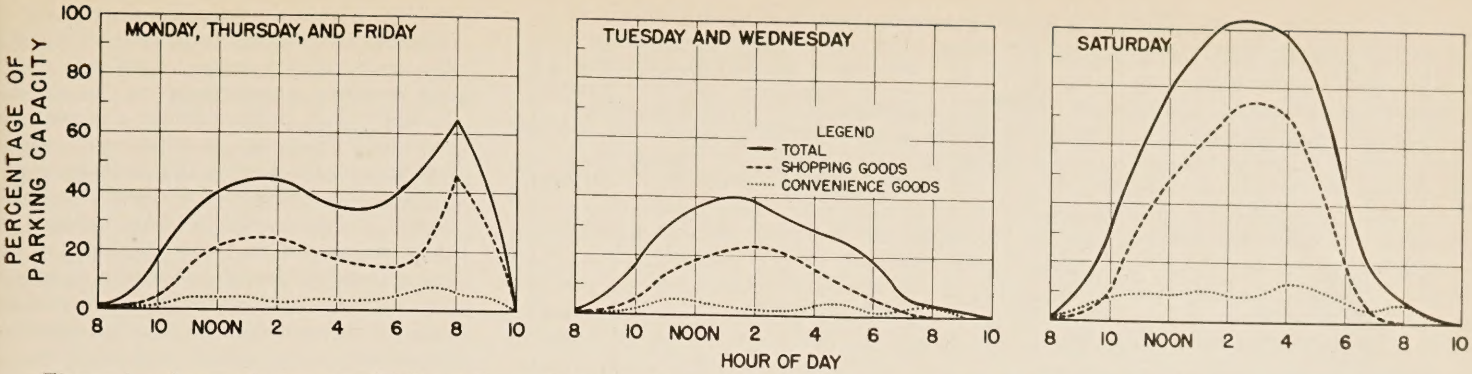

Figure 4.—Accumulation of vehicles at Seven Corners shopping center as a percentage of the 2,025-vehicle-space parking area.

average, required about twice as much parking space as did the convenience-goods traffic.

To provide a measure of the overall parking requirements for the traffic generated by these two classifications, the peak accumulation for each category, as shown in figure 4, was divided by the corresponding total weekly volumes of traffic. These measures, expressed in terms of parking spaces per 1,000 vehicles per week, were 48 spaces for shopping-goods traffic, and 26 spaces for convenience-goods traffic. For all purposes, 39 parking spaces per 1,000 vehicles a week were required.

Trip purpose distribution

The distribution of total trips arriving at Seven Corners shopping center by purpose of trip is summarized in table 3. Since the famiiy is considered to be the basic consumer unit attracted to suburban shopping centers, the analysis of family trips has been emphasized in this report. For the purposes of this study, a family was considered to be either a single member of a family or two or more persons of the same family residing in the same dwelling unit, and family trips were measured by the number of families represented by persons arriving at the center.

As indicated in table 3, shopping-goods merchandise attracted slightly more than three times the volume of family trips than that which was attracted for convenience goods. The importance of apparel merchandise in attracting trips to the center is apparent because over one-half of the total travel to the center was made for this purpose.

The purpose distribution of all shopping trips made to the center, shown in table 3, indicated only the primary purpose for which a trip was made to the Seven Corners shopping center. Inasmuch as one of the stated advantages of a large regional center is to permit multipurpose shopping in a single stop, additional information was obtained to determine the extent to which people planned to shop for more than one category of merchandise before coming to the center. This is not to say that once the consumer began shopping at the center, other purposes were not considered; however, in the latter case, the secondary purchase was not considered by the individual upon leaving his place of origin.

Of the approximately 1,300 families interviewed who came to the center for the primary purpose of shopping, only 18 percent planned to shop for more than one type of merchandise at the time they arrived at the center. The number of primary trips and the percentage distribution of the secondary shopping trips are shown in table 4. In general, families who were primarily at the center to shop for convenience items and services were more likely to also be shopping for other categories of goods than were those primarily interested in shopping goods. This information would seem to indicate that although the regional shopping center offered a number of different types of merchandise which would permit multipurpose shopping at a single stop, the center attracted only a limited percentage of trips due to this factor.

Trip generation rates

The rates at which trips were attracted to Seven Corners are shown in table 5. There is a noticeable difference in the rate of attraction between the two major merchandise categories; the floor area devoted to shopping goods attracted family trips at a rate that was 20 percent greater than the floor area devoted to convenience goods. This differ-

Table 3.—Volume of trips to Seven Corners shopping center, by purpose

Purpose of trips	Weekly total of— Vehicle trips: Number	Vehicle trips: Percent	Family trips: Number	Family trips: Percent	Person trips: Number	Person trips: Percent
Shopping goods:						
Apparel	27,573	52	31,322	53	53,996	56
Other	2,465	5	2,586	4	4,071	4
Unknown	1,877	4	2,407	4	3,555	4
All shopping goods	31,915	61	36,315	61	61,622	64
Convenience goods:						
Food	3,768	7	3,851	7	7,376	8
Drug, hardware, variety	4,337	8	4,628	8	7,373	8
Services	1,836	4	1,856	3	2,520	2
All convenience goods	9,941	19	10,335	18	17,269	18
Total shopping	41,856	80	46,650	79	78,891	82
Work	4,248	8	4,849	8	5,301	6
Personal business	581	1	670	1	877	1
Eat	4,829	9	6,161	10	9,773	10
Serve passenger	968	2	968	2	1,426	1
Total trips	52,482	100	59,298	100	96,268	100

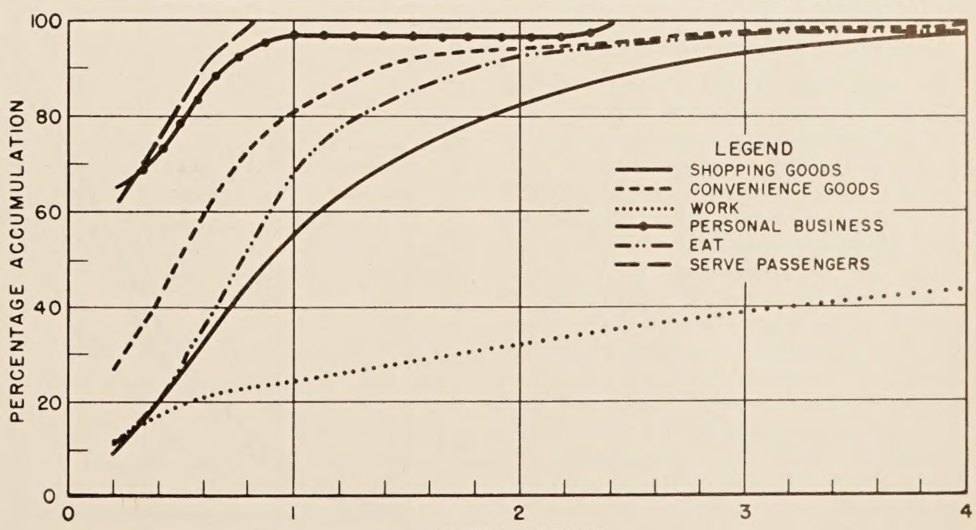

Figure 5.—The duration of time vehicles were parked at Seven Corners shopping center, by trip purpose.

Table 4.—Distribution of multiple-purpose family shopping trips

Primary purpose	Total	Percentage with no secondary purpose	Percentage of trips with secondary purpose: Shopping goods: Apparel	Shopping goods: Other	Convenience goods: Food	Convenience goods: Drugs, hardware, variety	Convenience goods: Services
Shopping goods:							
Apparel	31,322	84	------	4	4	7	1
Other	2,586	90	3	------	1	4	2
Convenience goods:							
Food	3,851	54	17	8	------	18	3
Drugs, hardware, variety	4,628	94	3	3	------	------	------
Services	1,856	60	26	11	------	3	------
Unknown	2,407	------	------	------	------	------	------
Total or average	46,650	82	3	4	3	7	1

Table 5.—Distribution of sales floor area and the trip-generation rates, by type of merchandise

Classification	Sales floor or dining area (square feet)	Percentage of floor area	Weekly volume of trips per 1,000 square feet of sales floor area: Vehicle trips	Family trips	Person trips
Shopping goods:					
Apparel	132,100	52	209	237	409
Furniture	16,000	6	} 43	45	71
Specialty items [1]	41,400	16			
Total or average	189,500	74	168	192	325
Convenience goods:					
Food	21,700	9	174	178	340
Drugs	13,900	5			
Hardware	9,300	4	} 111	119	189
Variety	14,800	6			
Services	5,800	2	317	320	435
Total or average	65,500	26	152	158	264
Total merchandise	255,000	100	164	183	309
Restaurant and lunch counters	10,000	--------	483	616	977
Gross rental area [2]	--------	--------	104	118	192

[1] Specialty items included jewelry, books, records, etc.
[2] Based on total gross rental area of 502,800 square feet.

ence in rate of attraction, however, is somewhat less when considered in terms of vehicles since persons purchasing shopping goods arrive, on the average, with slightly more than one family per vehicle.

The aforementioned rates of attraction have been expressed in terms of total weekly traffic. If they were to be expressed in terms of average weekday traffic, they would be equal to approximately 15 percent of the values shown in table 5.

Geographic Distribution of Trips

The spatial distribution of persons making trips to a regional center is important not only to the location and operation of a center, but also to the design and operation of adjacent and access arterials since the distribution of the market area helps determine the major directional movement of traffic to the center. In this article, only the results of trips to the Seven Corners shopping center by residents of the Virginia section of the Washington, D.C., metropolitan area [2] are analyzed. These trips accounted for approximately 89 percent of the total travel to the center. The other 11 percent of travel, derived from the District of Columbia, Montgomery and Prince Georges Counties, Md. (6 percent), and all other areas outside those already noted (5 percent), are not included in the following discussion.

The accumulated distribution of trips by travel time for residents of the Virginia section is compared with the distribution of dwelling units in the same area in figure 6. The more rapid increase in the curve of all trip purposes, as compared to the curve of dwelling units, indicated that a greater percentage or frequency of trips were made by residents living close to the shopping center.

There was found to be an even distribution in the actual number of trips between the areas designated as being inboard and outboard from the center. However, as may be seen in figure 7, if trip frequency is compared rather than total volumes, there is a significant difference in the distribution of trips. In general, the trip frequency to Seven Corners by families residing in the outboard area, was greater than those made by families residing in the inboard area.

In figure 7, the extreme fluctuation in the 3 curves representing trip frequency from the outboard area between 15 and 30 minutes is believed to be a result of the procedure used in analyzing the data. In summarizing trip and population information by distance, zones of the 1955 O–D traffic study were used. As a result, it was necessary to arbitrarily assign total zone figures to a single increment of distance even though zones in this general area were large and may have overlapped several time-distance bands.

From the more densely populated inboard area, where many of the competing commercial concentrations are located, including the Washington, D.C., central business district, there was an average attraction of 310 weekly family trips per 1,000 dwelling units. From the outboard area, which had no major competing centers, the average attraction was 556 weekly family trips per 1,000 dwelling units. This difference in trips indicates the marked effect that competing shopping centers have on the rate at which trips will be attracted to a shopping center.

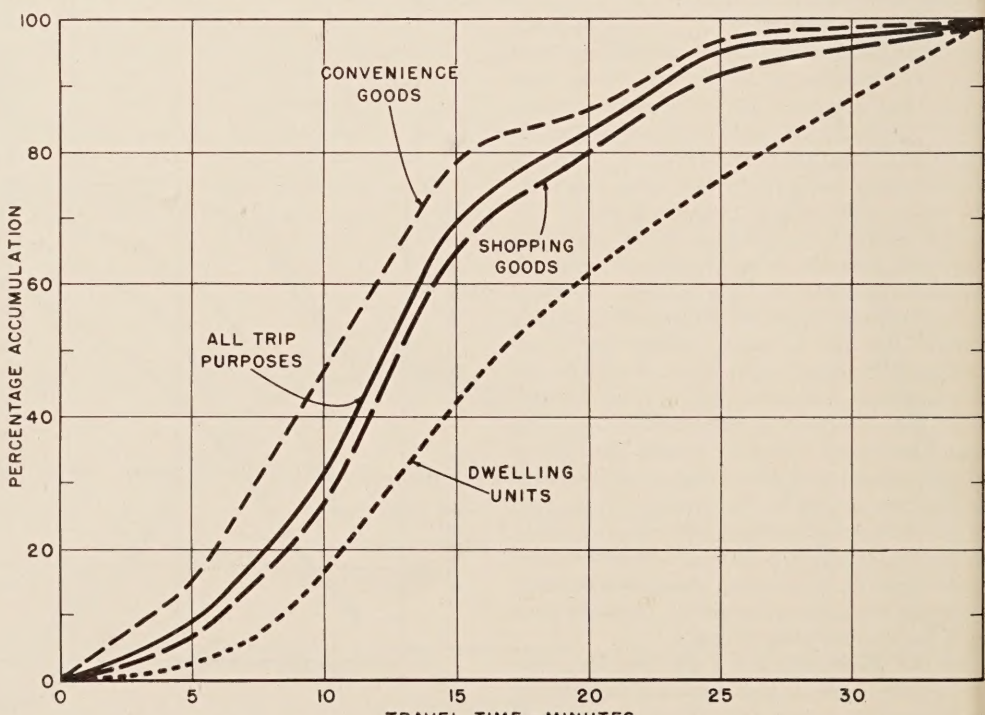

Figure 6.—Accumulated distribution of dwelling units and family trips made to Seven Corners shopping center, by travel time and trip purpose.

[2] The Virginia section of the metropolitan complex included all of Arlington and Fairfax Counties and the cities of Alexandria and Falls Church. This area had a total population of 408,000 in 1955.

Although the frequency at which trips were attracted for both shopping and convenience goods decreased as driving time to the center increased, the rate of this decrease, as illustrated in figure 7, was less rapid for shopping-goods trips than for convenience-goods trips. The relative shortness of trips for convenience goods is further emphasized by the information illustrated in figure 6; almost one-half of the trips for convenience goods were made by families residing within 10 minutes driving time of the center. These families accounted for only one-fourth of the trips for shopping-goods purchases. Shopping-goods trips, on the average, tended to be approximately 25 percent longer than the convenience-goods trips.

Impact on Other Commercial Concentrations

The estimated impact of the Seven Corners shopping center on trips to other commercial concentrations is shown in figure 8. These estimates are based on shopping travel data obtained from the 1955 Washington metropolitan area transportation survey and the assumptions that the frequency with which people shop (i.e., trips per weekday per dwelling unit) would remain constant between 1955 and 1957, and that the relative attraction of trips to the selected commercial concentrations other than Seven Corners would remain the same in 1957 as it was in 1955.

Based on the above assumptions, the total number of shopping trips made by residents in 1957 within the Virginia section of the 1955 transportation study cordon, was obtained by multiplying the estimated 1957 dwelling units by the 1955 frequency of shopping trips per dwelling unit. After these totals were reduced by the average daily number of trips attracted to Seven Corners, the remainder was distributed to the other commercial centers in the same proportion as they were in 1955.

The three major commercial groups that compete with Seven Corners shopping center for shopping-goods purchasers were then selected for a comparison of shopping trips before and after the establishment of the center. Due to their close proximity and the relative ease of traveling from one to the other, the data for the three separate commercial concentrations in the Clarendon complex and the two separate concentrations in the Alexandria complex were combined into single groups. The third major commercial group was the Shirlington shopping center.

At the time of the study, there was no department store at the Shirlington shopping center. The Alexandria complex had two department stores, both limited in size, while the Clarendon complex had three department stores of 120,000 square feet or more.

Within the limitations imposed by the methods of estimation, the results illustrated in figure 8 give an indication of the changes in the directional movement of shopping travel that have resulted from the establishment of the Seven Corners shopping center. The major point indicated is not that the competing centers attracted fewer trips as a result of Seven Corners, for these losses will be offset for the most part by future population increases in the metropolitan Virginia area; but rather, it points up the fact that the frequency and volume of trips attracted to a given shopping center from a particular distance or residential area are dependent upon the location, composition, and size of that shopping center, relative to these same factors for other competing centers.

As this study was limited to an examination of travel to Seven Corners only, it was not possible to measure these "relative" characteristics with other commercial centers. Therefore, the relationships shown here are only indicative of the magnitude of the effect that Seven Corners had on the shopping habits and travel patterns of the area under study and are not directly applicable to a shopping center in a different setting.

The location of the four commercial concentrations and the percentage distribution of shopping trips estimated for each concentration is shown in figure 8. The areas, in which in 1957 each concentration attracted a greater percentage of shopping trips than did the other concentrations, are numbered I through IV to correspond to the Arabic numbers locating each concentration. Also shown is a comparison of domination for the years 1955 and 1957, before and after construction of the Seven Corners center. It may be seen that except for two areas, designated IA and IIA, each commercial concentration was dominant in the general area where the concentration was located For example, the Clarendon complex was dominant throughout Arlington County except for the southwestern and extreme western sections where Shirlington and Seven Corners were located. It was difficult to explain the existence of the two exceptions, IA (where Seven Corners was dominant) and IIA (where the Clarendon complex was dominant), although there were several possible explanations. One explanation was that each area was located on or adjacent to a direct route to the centers of dominance. Another possible explanation advanced was that there was a special attraction to particular stores, especially department stores, within these centers as a result of such factors as charge accounts, quality, price, or type of merchandise, etc. (Fig. 8 is shown on following page.)

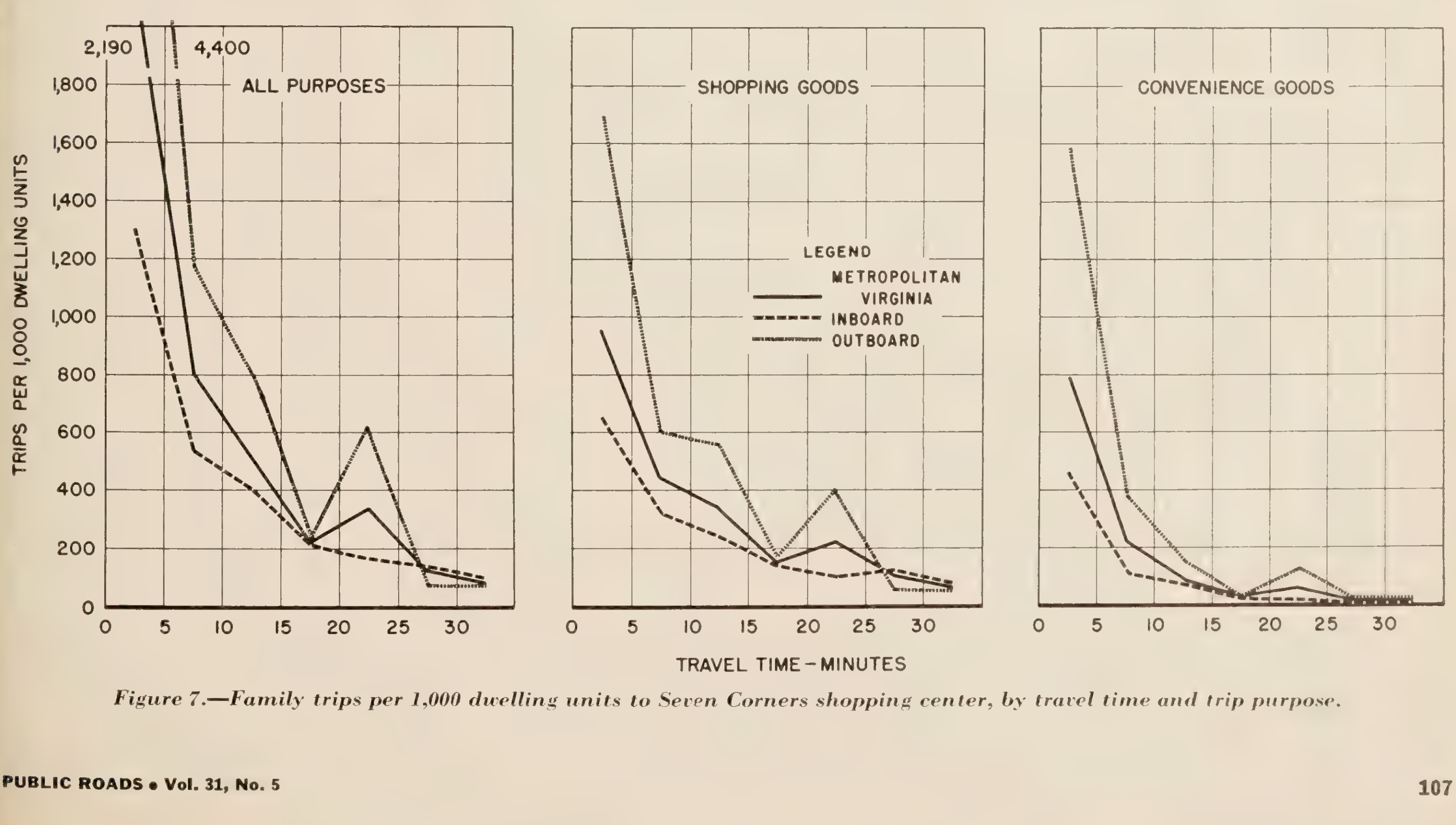

Figure 7.—Family trips per 1,000 dwelling units to Seven Corners shopping center, by travel time and trip purpose.

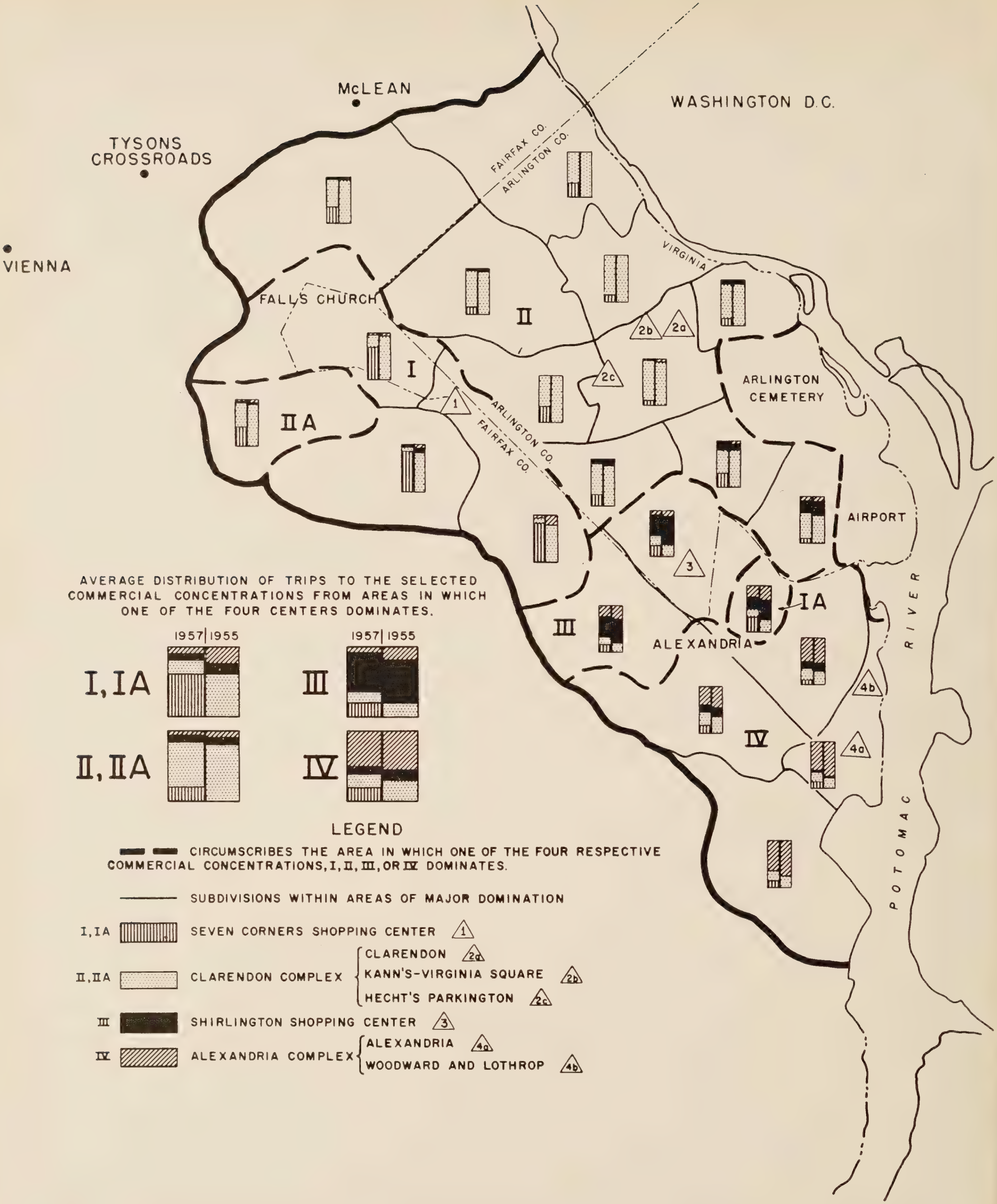

Figure 8.—Percentage distribution of estimated shopping trips to selected commercial concentrations in 1955 and 1957.

The Effects of Enforcement on Traffic Behavior

BY THE DIVISION OF TRAFFIC OPERATIONS
BUREAU OF PUBLIC ROADS

Reported by RICHARD M. MICHAELS, Research Psychologist

A carefully controlled study was conducted on the effect of different amounts of highway police patrol on accidents, traffic diversion, and speed. Analysis of the data indicated that although there was no significant change between test and control routes in average speed or percentage over the speed limit there was a significant reduction in the variance of speeds which was directly related to the enforcement level. However, no effects were found on diversion or accidents. The latter finding was at variance with the original report of the study and was due to the nature of the assumption about the accident distributions. In general, the results of the study indicated that the effects of enforcement may be very subtle and may influence traffic behavior in a very indirect fashion.

Finally, this article demonstrates the difficulties involved in the conduct of many kinds of field research. The inability to obtain adequate control over the experimental variables and the limited kind of measures available in such research often make interpretation of results difficult and generalization often suspect.

IT IS GENERALLY BELIEVED that police patrol significantly influences accident incidence, especially where the patrol is employed selectively. In addition, there is some evidence to indicate that enforcement techniques affect the speed distribution of the traffic in its area (*1*).[1] However, there has been no clear-cut proof in support of either of these effects of enforcement, that is, on accidents or speed. Furthermore, there are no data to demonstrate how the amount of patrolling is related to changes in traffic behavior.

The purpose of the study reported here was to examine the effects of different degrees of enforcement on three traffic variables. First, it was hypothesized that the speed distribution of traffic should be affected in direct proportion to the amount of enforcement. Three specific effects or combinations of them are possible: (1) the mean speeds are significantly reduced; (2) the percentage of drivers exceeding the speed limit is significantly reduced; and (3) the variance in speed is significantly reduced. Second, if police patrol tends to inhibit drivers, they may then take alternate routes where available. Thus, it was hypothesized that traffic volumes on the patrolled routes should decrease while those on the parallel control routes should increase. Again, the change in volume should be directly related to the amount of enforcement. Third, if patrolling influences accidents, then it was hypothesized that accident incidence on the test routes should be reduced in direct relation to the amount of enforcement.

The experimental design and the data in this study were developed by the Traffic Institute of Northwestern University as part of a cooperative project with the Bureau of Public Roads and the Wisconsin State Highway Patrol. The work was originally presented in a report by R. P. Shumate (*2*).[2]

The present study is a re-evaluation of that data and arose in part out of a difference of opinion over the statistical assumptions employed in the original analysis of the accident data. The statistical assumptions employed here lead to different conclusions from the original report. The fact that there were differences indicates that conclusions may be highly sensitive to the statistical analysis employed, and that extreme care must be exercised in the choice of method.

A second and even more important reason for extended analyses of these data concerns the design of the experiment. It is believed that this study was one of the best designed studies that has been conducted in the enforcement area. It was actually because of this belief that a further analysis was worthwhile, for it allowed an insight into certain aspects of enforcement as well as the problems inherent in the conduct of this type of research. It should be clear, therefore, that the differences between the two reports are due to differences in the analysis and interpretation of the data and not to the design and conduct of the research.

Summary

The present study was an examination of the effect of differing levels of enforcement on three traffic variables: accidents, speed, and volume. It was hypothesized that as the level of enforcement was increased, accident frequency would go down; traffic would divert to alternate routes; and the mean and variance of the speed distributions would decrease. Measurements were made on four test routes in different parts of the State of Wisconsin. In three of the four cases a parallel control route was used.

The results indicated that the first two hypotheses were not supported. No reliable reduction in accidents occurred on any of the test routes when compared with their controls. No significant diversion of traffic occurred using deviation from volume trend as a measure of change. For the speed distributions, a decrease in mean speed was observed but was of the same order of magnitude as on the control routes. The variance of these distributions did, however, decrease for three of the four test routes while they did not for the control routes. The observed decreases were statistically significant. In addition, the decreases gave some indication of being directly related to the level of enforcement.

It was suggested that the results indicated that the effects of enforcement on traffic behavior were, at the very least, indirect. The enforcement had a relatively small effect on all the variables measured. The reasons for this were felt to be the crudeness of the measures employed and the unreliability of measurements inherent in any field study of this magnitude.

Procedure

In October 1955, study of the distribution of accidents throughout the State of Wisconsin was begun to select four routes on which to conduct tests. The principal criterion for selection of the test routes was frequency of accidents. In order to have any possibility of demonstrating some effects on accidents by enforcement, it was necessary to employ sections having a large number of accidents, since the reliability of any accident reduction requires a reasonably large sample of accidents.

Before January 1956, four test routes were selected. Each had an expected accident frequency high enough to provide an adequate sample. These routes, as shown in figure 1, are:

Test route No. 1—26 miles of U.S. Route 41, a 4-lane, divided highway from the Illinois State line to the Milwaukee County line.

Test route No. 2—52 miles of U.S. Routes 12, 18, and 51 in Dane County of which approximately 4 miles are 4-lane, divided highway with partial control of access and the remainder 2-lane highway.

Test route No. 3—104 miles of U.S. Route 41, a 2-lane highway from the north Milwaukee County line to Green Bay. Parts of this section had to be eliminated from the study because of major highway construction.

Test route No. 4—208 miles of U.S. Route 12, a 2-lane highway from Baraboo to the Minnesota State line.

To insure that data from the test routes did not merely reflect a general decrease or

[1] Italic numbers in parentheses refer to a list of references on page 124.

[2] For ease in presentation, the study procedure as described in Mr. Shumate's report has been incorporated in this article.

increase in accidents throughout the area, a series of control routes were established (fig. 1). Each control route had approximately the same length and the same design standards as the test route for which it acted as a control, but was geographically removed from the test sites and was not subjected to any enforcement increase. Each control route was evaluated in the same manner as the test routes. Such a control route was available for three of the four test routes.

Method of measuring enforcement

To make meaningful comparions between test routes it was necessary to have a measure of intensity of enforcement. Common methods of measuring enforcement effort use the number of recorded enforcement actions taken by officers in a specified time and area, such as arrest, citations, or warnings. Such methods were considered and rejected because probability of violation and subsequent detection will vary considerably from one test route to another. The method finally adopted is based on the probable frequency with which a driver traveling a section of highway could theoretically encounter a readily identified patrol vehicle, either stopped or in motion. It is expressed as the average number of patrol units a driver would pass per mile of travel. Thus,

$$\overline{M}=\frac{R}{M}$$

where:

$\overline{M}$ = The average number of miles driven for each patrol unit observed.

M = Miles of highway in the route under consideration.

R = The number of patrol units assigned to the route.

To study the effect of various intensities of patrolling, as defined in the preceding paragraph, it was necessary to vary either the number of enforcement units assigned to each test section or the linear miles of highway. The difficulty of finding four short sections of highway which had a sufficiently large number of accidents prompted the decision to vary miles of highway under enforcement rather than varying the number of enforcement units and keeping the length of test section constant. The variable highway mileage was doubled for each test route while the patrol units were maintained at eight for each test route.

Methods of assignment

Methods of assignment within the test routes were standardized. Patrol units assigned to test routes were relieved of all duties which would take them away from the test route. In those instances where assigned personnel were required to be away from the test routes for extended periods relief units were substituted.

To distribute patrol evenly over the test route, enforcement units were assigned to route sections ranging from 3 miles in test route No. 1 to 25 miles in test route No. 4. Enforcement units were required to work within their assigned sections except for emergencies or when in pursuit of violators. All enforcement units were readily identifiable as such, being marked by colored decals, two-tone color schemes, special number plates, roof lights, and police radio antennas. Occasionally unmarked units were used, but so seldom that any special effect they may have had would be negligible. No attempt was made to standardize enforcement techniques. Personnel had been taught several methods and were permitted to use whatever method seemed most appropriate at the time.

In the interest of economy it was decided to maintain enforcement units on duty for only 18 hours each day. Study of accident patterns revealed that accidents during the 18 hours of highest frequency each day exceeded 80 percent of the total number of accidents occurring in any given period. The peak 18 hours for each test area was predetermined and assignments made accordingly. Work assignments were varied for different days of the week to accommodate differences in the daily accident pattern.

Figure 1.—Highway test routes and control routes used in Wisconsin enforcement study.

In January 1956, the first group of 24 enforcement officers were assigned to test route No. 1. Enforcement units, each consisting of a patrol car operated by a single uniformed officer, were assigned so that eight units were on duty for each of the 18 hours of highest accident frequency. This required 16 men daily. The remaining eight men were used as relief for days off, sickness, and vacations. This method of assigning personnel was followed on each of the subsequent test routes.

In April 1956, test route No. 2 was placed under patrol using methods previously described. In August and November of the same year test routes Nos. 3 and 4, respectively were placed under police patrol. Table 1 summarizes pertinent data concerning each test route.

Accident data

Accident experience for each of the test routes was compiled by year from 1950 through

Table 1.—Assignment of patrol units by test route

Route No.	Patrol began	Duration of patrol, months	Miles of highway	Men assigned	Average units on duty (18 hours)	Patrol units passed by average vehicle per mile of driving
1	January 1956	24	26	24	8	0.307
2	April 1956	18	52	24	8	.154
3	August 1956	17	104	24	8	.077
4	November 1956	13	208	24	8	.038

Table 2.—Accident data on the experimental routes for years 1950–57

Year	Number of accidents on route No. 1				Number of accidents on route No. 2 [1]		Number of accidents on route No. 3				Number of accidents on route No. 4			
	Test route		Control route		Test route		Test route		Control route		Test route		Control route	
	Fatal and nonfatal injury	Property-damage-only	Fatal and nonfatal injury	Property-damage-only	Fatal and nonfatal injury	Property-damage-only	Fatal and nonfatal injury	Property-damage-only	Fatal and nonfatal injury	Property-damage-only	Fatal and nonfatal injury	Property-damage-only	Fatal and nonfatal injury	Property-damage-only
1950	88	92	24	26	83	108	58	84	27	41	223	329	86	164
1951	83	143	8	34	108	165	60	112	31	67	197	315	87	178
1952	100	136	14	15	102	187	65	78	56	47	219	388	126	188
1953	97	219	16	28	101	201	65	87	29	54	221	377	95	169
1954	109	170	15	24	97	199	50	64	27	48	131	327	98	171
1955	94	154	24	21	144	200	69	85	29	40	184	327	92	167
1956	78	190	17	31	114	187	81	91	33	37	189	315	97	171
1957	72	176	18	22	102	167	52	56	36	47	170	284	97	144

[1] No control route.

1957. These data were obtained from spot maps maintained by the State Highway Commission. Since Wisconsin law required every driver involved in an accident which exceeded $100.00 in total damage, or where a physical injury was sustained, to submit a report to the State Motor Vehicle Department, information on the spot maps was compiled from the accident reports.

Accident data included accidents occurring throughout all 24 hours of the day. Lack of complete records made it impossible to separate accidents occurring only during the 18 hours each day that enforcement units were on duty. However, because on the average 80 percent of all accidents occurred during the 18 hours of increased enforcement effort, it was assumed that changes in this large a portion of the total would not influence the magnitude of the entire sample.

Traffic volume data on each test section were obtained by years from 1951 through 1957 from the State Highway Commission. Samples of vehicle speeds at selected locations within the test areas were also obtained for periods of time both before and after the beginning of patrol operations.

Application of the chi-square test

A different statistical analysis was used for each hypothesis tested. For the accident data, in all but one case, a 2×2 chi-square test was employed to compare test and control routes for the 2 years, 1955 and 1957. In the single exception, route No. 2, where there was no control route, a simple chi-square was computed for the test route over the same 2-year time period. Thus, the chi-square test, in utilizing only 2 years of data—the before and after time period—disregards all other historical data that were available.

In the original report of this study, the assumption was made that there was a positive trend in accidents over time. Therefore, a trend line was fitted to the accident frequency, covering a 9-year period for which accident data were available. On this basis it was possible to predict what the accident frequency should have been in subsequent years if there had been no enforcement. By measuring the deviation of the accident frequency for the period of increased enforcement from that predicted by the regression line, it was inferred that a significant reduction in accidents occurred on the experimental routes. The existence of a trend was an extremely strong assumption, and it could not be wholly validated from the data. If, in fact, there was no reliable trend, then use of a trend equation with a positive slope would tend to insure a significant reduction in post-enforcement years.

Use of the chi-square test does not require such strong assumptions. On the contrary, the chi-square is a conservative test which used the control route data as the basic determinant of any significant changes in accident frequency on the experimental route. The test assumed no change in accident frequency from before to after, or that any changes in the test routes were due to factors extraneous to the enforcement variable which may have been expected to influence the control route equally.

The volume data were analyzed by measuring the deviation from the volume trends for the years 1950–56. Thus, a trend line was fitted to the data for these years. Changes occurring in volume in 1956 and 1957 were determined and compared with the volume expected on the basis of the trend line. The assumption that traffic volume is increasing with time is a reasonable one on the basis of national data (*3*).

The speed data were analyzed using the analysis of variance. The mean and standard deviation of the speed distribution on each route were computed for both the before year (1955) and the after year (1957). It was possible then to make comparisons both within and between each route.

Results of Analysis

The accident data for the test and control routes for the years 1950–1957 are shown in table 2. Analysis of the before and after data are shown in table 3. On all routes except No. 2, a 2×2 table was available and a chi-square test performed.

In the chi-square tests, the .05 level of significance was used. That is, the hypothesis that there was no reduction in accidents was rejected only if the measured decrease in accidents could have occurred by chance 5 or less times in 100. As may be seen, only in the case of test route No. 2, having 0.154 patrol units passed per mile, was there a significant reduction in fatal or injury accidents. In this one case, no control route was available so that a simple comparison was made between 1955 and 1957. It should be noted from table 2 that 1955 was an abnormally high year for accidents on this route. Consequently, ascribing a reduction in accidents to the increased patrol was probably unwarranted. Comparison of the accident data on the test routes with those of the rest of the State and with all the control routes are also shown in table 3. As may be seen, a significant reduction in number of accidents, both for test and control routes, occurred for all conditions except for property-damage-only accidents where the combined test and control data were used.

Table 3.—Effects of enforcement level on accidents, by test and control routes

Route No.	Patrol units passed per mile on test route	Year	Number of fatal and nonfatal injury accidents			Number of property-damage-only accidents		
			Test route	Control route	Significance of change [1]	Test route	Control route	Significance of change [1]
1	0.307	1955 1957	94 72	24 18	N.S.	154 176	21 22	N.S.
2	.154	1955 1957	144 102	— —	P=.05	200 167	— —	N.S.
3	.077	1955 1957	69 52	29 36	N.S.	85 56	40 47	P<.05
4	.038	1955 1957	184 170	92 97	N.S.	327 284	167 144	N.S.
Combined test routes vs. State totals.		1955 1957	501 396	3,788 4,222	P<.01	766 683	6,711 6,591	P<.02
Combined test routes vs. control sections.		1955 1957	501 396	145 151	P<.05	766 683	228 213	N.S.

[1] N.S.=not significant.

Table 4.—Comparison of changes in traffic volumes on test routes Nos. 1 and 4 after increased patrol with traffic volumes on control routes with no increase in patrol

Year	Test route				Control route			
	No. 1		No. 4		No. 1		No. 4	
	Change from expected value	Level of significance [1]	Change from expected value	Level of significance [1]	Change from expected value	Level of significance [1]	Change from expected value	Level of significance [1]
1956	−4.3	N.S.	----------	----------	+6.3	N.S.	----------	----------
1957	−8.7	P>.07	−2.62	N.S.	+3.2	N.S.	−1.5	N.S.

[1] N.S.=not significant.

These results indicate that for the more discriminating comparison between the matched test and control routes there appeared to be little reliable effect due to enforcement. Regardless of level of patrol, the differences between test and control routes were consistently small. Also, the significant differences found on comparing test routes with the State as a whole had to be interpreted with caution. Although enforcement may have been one of the determining influences, at least two other alternatives are possible. One alternative is the accident frequencies of the test routes which may have been abnormally high prior to the study period. In this case accident frequencies would reasonably show a regression toward the expected value thereafter. This would appear as a significant reduction when compared to the more reliable State figures. A second alternative concerns the large numbers of statewide accidents relative to the test route frequencies. Very large cell frequencies in only one of the two halves of the matrix used to compute the chi-square increases the probability of a significant chi-square, regardless of the magnitude of change in the half of the matrix with the lower cell frequency. Either of these alternatives could account for the anomalous differences among the data shown in the tables.

Traffic volumes and speeds

The results on changes in traffic volume are shown in table 4. For the change in volume over the 7-year period, a trend equation was derived by using the method of least squares. Control limits were derived using the standard error of estimate. The volume in the test year was compared with what was expected on the basis of the trend equation. The level of significance column shown in the table is the probability of the observed change in volume being due to mere chance. As may be seen, on neither test nor control routes did the volume change significantly. Consequently, it is reasonable to conclude that enforcement did not cause a significant diversion of traffic regardless of the intensity of enforcement.

A sample of approximately 3,000 vehicle speeds was obtained for both 1955, the last prepatrol year, and 1957, the first full year that patrol units were operating on all test sections. A control sample of approximately the same size was obtained for the same 2 years. The control sample was obtained from highways having characteristics of design and volume similar to the test sections, but far enough removed from the test routes to minimize any carryover effect from enforcement. The speed samples were taken by the highway department as part of their annual survey of vehicle speeds and were obtained during daylight hours and while traffic was moving freely. All samples were taken at points where speed limits were 65 m.p.h. for passenger cars and 45 m.p.h. for trucks.

The statistics of the speed distributions for passenger cars and trucks are shown in table 5. In general, the mean speed for both trucks and passenger cars decreased for both test and control routes from 1955 to 1957. In view of this, it is difficult to place much reliance in a hypothesis that increased enforcement reduced the average speed of vehicles. While there were definite decreases in average speeds in 1957, as compared with 1955, such decreases followed a similar pattern throughout the State and could not be related to an increase in enforcement activity.

The percentage of drivers exceeding the speed limit followed the same pattern as the mean speeds. There were decreases from 1955 to 1957 on both experimental and control routes. However, the changes on the test routes had no clear-cut relation to enforcement level. Thus, although there were decreases in the proportion of vehicles over the speed limit, there was little evidence to support the hypothesis that this was due to the increased patrol.

Difference in variance

The variances on the test and control routes were compared using an F test. The F test is a test of the differences between variances (S^2) and is the ratio of the larger variance to the smaller. The data are shown for passenger cars and trucks in table 6. It should be noted that for passenger cars there was a significant reduction in the variability in speed in three of the four test routes but in none of the control sections. For trucks only, test routes Nos. 1 and 4 show a significant decrease. However, the control route for No. 4 also showed a significant change from 1955 to 1957. It should be further noted that the magnitude of the F test ratios decreased for the first three test routes as the amount of enforcement decreased. This occurred for both passenger cars and trucks. A plot of the variance ratio against enforcement level is shown in figure 2. For the enforcement levels of zero shown in the curve, the values of the ratio of speed variances were obtained by averaging the ratios for the control sections as shown in table 6. This may indicate that one effect of enforcement is to cause drivers to cluster more nearly about the mean speed and to do so in some relation to the frequency with which drivers as a whole encounter police patrol.

Discussion of the Data

The results of this study as analyzed here indicate quite clearly that any effects of enforcement on traffic behavior are quite indirect. In part, this was due to the measures used to infer the effects of police patrol. Accidents are an obviously inefficient measure. They are rare events in both time and space, having complex causes. The variety of contingent factors underlying their occurrence limits their use as a reliable criterion of improvement techniques except under the most restricted of conditions. In the normal field situation this is rarely the case. In addition, the number of interacting factors involved in the generation of an accident are generally so large that the effect of any one variable will be negligible. Such complexity almost insures defeat in the isolation of the influence of enforcement on traffic behavior.

Table 5.—Speeds of passenger cars and trucks on test and control routes for 1955 and 1957

Route No.	Test routes						Control routes					
	1955			1957			1955			1957		
	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size
Passenger cars:	*M.p.h.*	*M.p.h.*		*M.p.h.*	*M.p.h.*		*M.p.h.*	*M.p.h.*		*M.p.h.*	*M.p.h.*	
1	60.64	7.88	809	56.79	4.74	911	55.90	7.86	410	51.80	8.76	419
2	54.56	8.78	1,512	54.58	7.54	454	50.23	8.61	898	48.15	8.35	1,127
3	52.53	7.08	573	46.68	7.34	879	57.04	8.47	780	54.62	8.89	661
4	57.52	7.25	910	51.74	6.60	916	49.32	7.81	505	46.35	7.94	1,189
Trucks:												
1	48.21	4.31	140	42.50	2.72	135	49.17	4.65	93	41.75	3.97	127
2	46.51	6.16	268	43.45	5.52	120	48.75	7.37	160	42.62	6.49	125
3	51.25	5.08	180	44.07	5.54	147	53.72	6.62	192	44.37	6.01	147
4	47.58	5.84	197	45.40	4.82	186	49.12	5.12	77	43.33	6.86	186

Enforcement influence on speed

It would seem more reasonable to examine a feature of traffic behavior more directly sensitive to events occurring in traffic and which are under the conscious control of the driver. This is generally the case with vehicle speed, for this is one of the basic modes of vehicle control available to the driver and should be, therefore, one to which he is most responsive. It would seem reasonable that speed would be a primary dimension that a driver would employ to compensate for any pressure he felt from the presence of enforcement. Thus, speed would be one basic variable for detecting the influences of enforcement on traffic behavior.

The mechanisms by which police patrol may operate to influence speed changes are obviously complex. However, such social symbols, i.e. police, may be expected to function at least as agents for inducing conformity in social behavior. In terms of drivers' speed responses this may take one of two forms. First, those drivers who are exceeding the speed limit would be the ones most responsive to patrol. Therefore, it is reasonable to predict that the proportion of the drivers exceeding the speed limit should decrease. Comparison of the test and control routes for the study years, 1955 and 1957, indicate that such a hypothesis is not supported. Although there was a reduction in the proportion of drivers exceeding the speed limits, this reduction was similar on both control and test routes.

The second hypothesis is that patrol influences all drivers. In the case of speed, it is most reasonable to believe that any movement toward conformity would take the form of a general regression of all speeds toward the mean of the traffic stream. This would naturally lead to a reduction in the variance of the speed distribution. The data obtained in this study indicate that this second hypothesis is quite reasonable. From table 6 it may be seen that for passenger cars in three of the four test routes, the amount of reduction in variability of speed seems to decrease in direct proportion to the amount of enforcement.

These data are of interest in light of some recent findings on the relation between accident rate and travel speed (*4*). It was shown that the accident involvement rate rose rapidly for vehicle speeds less than 40 m.p.h. These speeds were observed on roads on

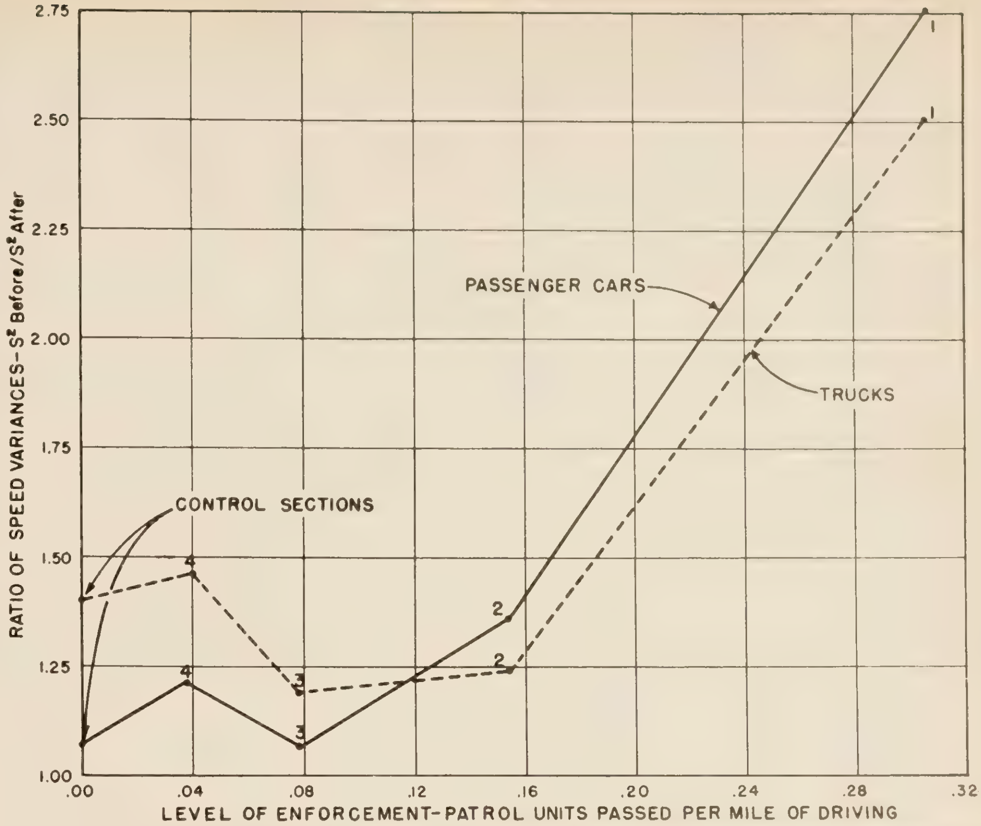

Figure 2.—The change in the variance of speeds under different levels of enforcement (Numbers 1–4 represent the test routes).

which the average speed was 52 m.p.h. A similar, but less conspicuous, increase was observed for speeds in excess of 75 m.p.h. on the same roads. Thus, drivers operating in the extremes of the speed distribution tended to come into traffic conflict more frequently (on a rate basis) than those travelling at or near the mean. This suggests that when the variance of the speed distribution is high, the frequency and magnitude of the speed difference judgments that drivers must make are also high. Any corrective action these judgments require may be similarly extreme. Consequently, errors of judgment or response may be magnified sufficiently to generate an accident. In light of this analysis, the present data are suggestive of a way in which enforcement may influence accidents. For if, in fact, police patrol causes a reduction in the variance of speed, then it would reduce the frequency of extreme judgments and decisions in driving. Thus, the driver would be forced to make fewer extreme responses with their attendant possibilities for extreme errors, i.e., accidents.

If this is, in fact, one way in which police patrol does function, then it is understandable why little reliable evidence exists relating accidents and level of enforcement activity. First of all, policing would be related to accidents only through second order or mediating processes, e.g., speed. Its effects would then be highly indirect. Secondly, speed is not a unique determinant of accidents, but only one of many. Thus, the proportion of all accidents in which speed differences are an important determinant may be a relatively small part of the total accident distribution. Consequently, the accident reduction occurring when enforcement is increased will vary in each situation depending upon the type of interactions among the variables determining the accident distribution. From the present data, it would appear that speed variability, on the test routes used, represented only a small factor in the total accident process.

It should be pointed out that the results of this study do not offer clear proof of the above analysis. The data are at best suggestive. Several considerations prevent an unequivocal interpretation of the data. One consideration is the obvious discrepancy in the data for test route No. 4 which had the lowest level of enforcement. From table 6 it may be seen that this route showed a significant reduction in speed variability. From the available data it is difficult to explain this change. However, test route No. 4 was the longest of the four

Table 6.—Differences between variances (S^2) of passenger cars and trucks for 1955 and 1957

Route No.	Test routes				Control routes			
	S^2(1955)	S^2(1957)	F	Probability [1]	S^2(1955)	S^2(1957)	F	Probability [1]
Passenger cars:								
1	62.09	22.46	2.76	<.01	61.77	76.73	1.18	N.S.
2	77.08	58.37	1.35	<.01	74.13	69.72	1.06	N.S.
3	50.12	53.87	1.07	N.S.	71.74	79.03	1.02	N.S.
4	52.56	43.56	1.21	<.01	60.99	63.04	1.03	N.S.
Trucks:								
1	18.57	7.39	2.51	<.01	21.62	15.76	1.38	N.S.
2	37.94	30.47	1.24	N.S.	54.31	42.12	1.29	N.S.
3	25.80	30.69	1.19	N.S.	43.82	36.12	1.21	N.S.
4	34.10	23.23	1.47	<.01	26.21	47.06	1.78	<.01

[1] N.S.=not significant.

(Continued on page 124)

Appraisal of O-D Survey Sample Size

BY THE DIVISION OF HIGHWAY PLANNING
BUREAU OF PUBLIC ROADS

Reported [1] by ARTHUR B. SOSSLAU and GLENN E. BROKKE, Highway Research Engineers

The objective of this research was to determine the relationship between home-interview type of origin and destination survey sampling rates and the error that can be expected in the volumes accumulated from such a survey.

The data analyzed were taken from the home-interview phase of the 1957 Phoenix-Maricopa County, Ariz., traffic study. Since individual zone-to-zone movements have insufficient volume to be reliable indicators, a method called "trip tracing" was used to accumulate individual zone-to-zone trip volumes for statistical study.

The results indicate that the accuracy of accumulated trip volumes is considerably less than the accuracy predicted by a purely theoretical approach. However, the results agree qualitatively with theory in that the accuracy of trip volumes varies with the square root of sample size and very nearly with the square root of the volume. The equations developed should allow the selection of a sample rate commensurate with the funds available and the degree of accuracy required.

TRAVEL BY INDIVIDUALS has the characteristic of being habitual. Furthermore, the travel habits of different individuals are similar for the many types of trips generally made. For these reasons, sampling procedures, such as the home-interview type of origin and destination survey developed by the Bureau of Public Roads, can be used to determine travel information for a metropolitan area.

The accuracy of information developed from a home-interview survey, and indeed from any type of sampling procedure, is to an important degree dependent upon the sampling rate used. Sampling rates employed in origin and destination surveys have usually been based on population and area. In a large, densely populated area a smaller sampling rate is used than in a small, less densely populated area. The sampling rate determined is based, predominantly, on the number of interviews needed to provide a reliable representation of the overall travel in the city. The zone-to-zone movements developed, however, have been used to present a picture of travel desires and to aid in the location of needed transportation facilities.

The results of an origin-destination survey are also accumulated on, or assigned to, proposed highway facilities for design considerations. How accurate are these accumulated values that have been expanded from the survey sample to represent average daily movements? The purpose of the study, herein reported, was to determine the relationship between the home-interview type of origin and destination survey sampling rates and the accuracy of volumes that are accumulated therefrom.

Measures of the accuracy of accumulated volumes have been determined for various sampling rates and predictive equations developed for determining the sampling rate needed for a desired accuracy at any volume. Since sample rate affects the accuracy of volumes used for design purposes, an estimate can be made of the frequency that facilities so designed will be loaded beyond capacity or conversely, the frequency that such facilities will have more lanes than are actually required.

Source of Data

The data used for this study were developed from the home-interview phase of the 1957 Phoenix-Maricopa County, Ariz., traffic survey. The survey area covered 225 square miles and contained a population of 397,000 persons. Of the survey area, the city of Phoenix occupied 36.3 square miles and included 192,500 persons. The survey area was divided into 135 zones, which were smaller in area in the downtown section of Phoenix and larger in the outlying areas.

The sample rate used in the home-interview phase of the origin and destination survey was 1 in every 15 dwelling units, or 6.67 percent. This rate resulted in a total sample of 8,743 dwelling units. The trips analyzed were those having both origin and destination within the survey area. All trips, regardless of mode of travel, were considered. The total expanded number of internal trips was 839,398. Separated by mode, it was as follows:

Automobile drivers	548, 439
Automobile, truck, and taxi passengers	233, 536
Bus passengers	57, 423

The survey personnel had checked the expanded household data against the 1950 decennial census and the 1953 special census with satisfactory results. Also the expanded travel data had been compared with two screenline ground counts made during the survey. The survey data accounted for 89.3 percent of the vehicles crossing the screenlines from 6 a.m. to 10 p.m. on an average weekday.

Method of Study

Individual zone-to-zone movements obtained from a home-interview type of origin and destination survey cannot be used as the basis for sound conclusions regarding sample size due to the predominance of small volume movements between many zones.[2] Any sample size, within the limits of economic feasibility, would be too small to produce accurate expanded values for these small movements; but the individual zone-to-zone movements do not necessarily have to be accurate if their summation reasonably represents travel accumulations throughout a city.

A method referred to as trip-tracing,[2] has provided the means for determining and checking distribution of travel throughout an area. By this method zone-to-zone movements are traced across a city in a straight line between origin and destination. After the equation of the straight line between the two zones has been obtained, the points of intersection of this line with previously established gridlines are determined. The volume of trips being traced is added to volumes previously accumulated, for other zone-to-zone movements, at the section of the gridline being crossed. After all zone-to-zone movements have been similarly traced across the city, the result is the accumulated number of trips per section of gridline.

The length of the sections of gridline, in which the volumes are accumulated, is chosen in accordance with the size of the accumulations desired. If large accumulated volumes are desired, large sections are used, and vice versa.

A grid system was superimposed over the Phoenix-Maricopa County traffic study area and is illustrated in figure 1. The southwest corner of the city was designated as origin of the rectangular coordinate system. North-south gridlines were placed at 2, 3, 4, 5, 5.5, 6, 7, 8, 9, 10, 12, and 14 miles from the origin, and east-west gridlines at 4, 6, 7, 8, 8.3, 9, 10, 11, 12, 13, and 15 miles from the origin. The closer spacing of gridlines was at the more densely populated part of the study

[1] This article was presented at the 39th Annual Meeting of the Highway Research Board, Washington, D.C., January 1960.

[2] *Evaluating trip forecasting methods with an electronic computer*, by Glenn E. Brokke and William L. Mertz. PUBLIC ROADS, vol. 30, No. 4, Oct. 1958, pages 77–87.

area. Each gridline was broken into ¼-mile sections for volume accumulation purposes, as shown diagrammatically in the upper right corner of figure 1. The north-south gridlines were 17 miles long and the east-west lines, 16 miles long. This resulted in 1,520 ¼-mile sections (17 miles × 4 sections per mile × 12 gridlines + 16 miles × 4 sections per mile × 11 gridlines). The volumes accumulated on the ¼-mile sections ranged from 0 to 35,000 trips.

Features of the procedures that have been described are as follows:

1. The result of the trip-trace accumulation is a spatial distribution of trips throughout the city representing the travel desires of the population. The trips are traced in such a manner that each zone-to-zone movement is made by the most desirable path—a straight line.

2. Long trips are weighted more heavily than short trips since more gridlines are crossed. This is analogous to long trips using more of a road network than shorter trips.

3. The resulting accumulation of trips presents a picture of travel analogous to accumulations of trips on a street system.

The trip-tracing procedure, much too lengthy for manual computation methods, is readily adaptable to computation on an electronic computer of medium size. Therefore, a computer program was developed to trace the Phoenix-Maricopa County trips across the survey area. Computer programs were also developed to handle the various statistical computations that were necessary for this study. A simplified flow chart of the trip-tracing program is shown in figure 2. Generally, the following computations were carried out:

Table 1.—Volume group summary

Volume group No.	Volume group range (average daily person trips)	Number of sections having volumes within range [1]	Mean volume of group [2] (average daily person trips)
1	0.1– 199.9	268	91.1
2	200.0– 399.9	88	283.2
3	400.0– 599.9	69	486.7
4	600.0– 799.9	45	682.0
5	800.0– 999.9	50	893.3
6	1,000.0– 1,499.9	80	1,244.5
7	1,500.0– 1,999.9	56	1,763.4
8	2,000.0– 2,499.9	58	2,257.4
9	2,500.0– 3,499.9	86	2,998.6
10	3,500.0– 4,499.9	62	4,001.4
11	4,500.0– 5,499.9	42	5,020.9
12	5,500.0– 7,999.9	67	6,759.3
13	8,000.0– 9,999.9	41	8,961.8
14	10,000.0–14,999.9	34	12,401.3
15	15,000 and over	28	21,689.9

[1] The number of sections do not equal 1,520 since some sections did not have any trips traced across them.
[2] The mean volume was determined from the total sample.

1. From the coordinates of the two zones being handled, the equation of the straight line passing between them was determined.

2. The points of intersection of the line and the north-south and east-west gridlines, to the nearest quarter of a mile, were determined.

3. The number of trips being traced were then added to the volumes previously accumulated in the computer memory locations representing the 1,520 ¼-mile sections.

All of the internal Phoenix-Maricopa County home-interview trip cards, representing the expanded results of the 1-in-15 dwelling-unit sample, were processed through the trip-tracing program to determine the spatial distribution of trips throughout the survey area. The original deck of cards was then sorted by sample number into two one-half subsamples, each representing a 1-in-30 dwelling-unit sample. Each one-half subsample was then separately run through the computer to determine the spatial distribution of the two 1-in-30 dwelling-unit samples. Similarly, the original deck was systematically stratified by sample number into 3 one-third subsamples, and 10 one-tenth subsamples, and each subsample processed through the trip-tracing program.

Statistical procedure

Use of the total Phoenix-Maricopa County traffic survey data resulted in accumulated average daily volumes, in the 1,520 ¼-mile sections, ranging from 0 to 35,000 person-trips. Similarly, each of the subsamples processed through the trip-tracing program resulted in accumulated volumes in each section. It should be noted that, as each subsample zone-to-zone movement was traced, the volume was expanded to represent actual movement. For example, as each one-third subsample trip card was processed, the trip factor on the card was multiplied by three.

The data resulting from the trip-tracing program were analyzed by comparing, on a ¼-mile section basis, the expanded subsample accumulations against the total sample accumulations. It was not, however, considered practical to report the error for each section. Instead, the 1,520 ¼-mile sections

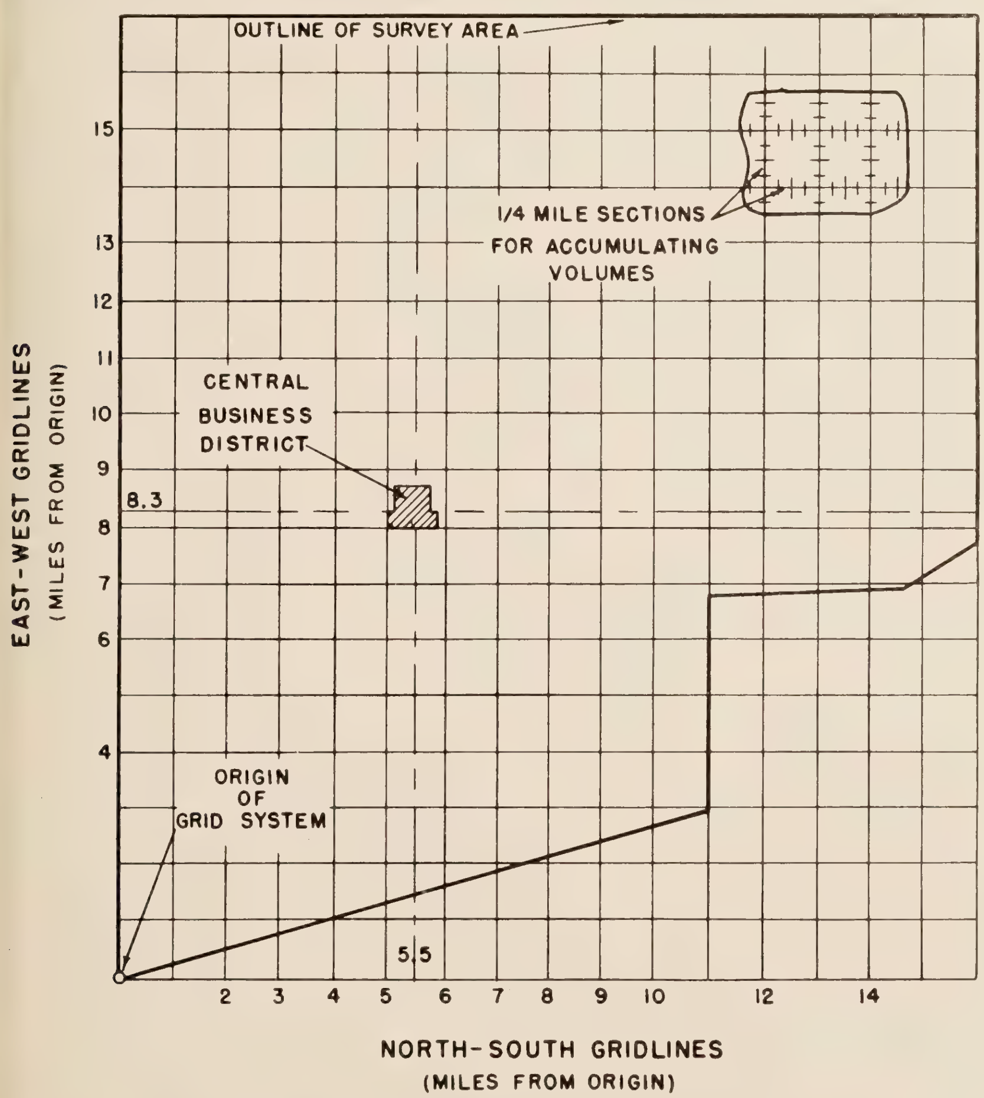

Figure 1.—Design of the Phoenix-Maricopa County grid system.

were stratified into 15 volume groups, and the individual errors were accumulated and summarized for each volume group. Such a process produced, for each of the 3 subsamples tested, 15 errors and the average volume at which the error occurred. The range, the number of sections, and the average volume of each volume group are shown in table 1. The sections of gridline were stratified into volume groups in accordance with the volumes accumulated in the sections from the expanded total sample.

The summarization of results, per volume group, for each subsample consisted of determining the differences in volumes accumulated per section from the original sample and the subsample, squaring the differences and accumulating the results of the squaring. The resulting summation was then divided by the number of sections in the volume group and the square root of the quotient taken. The result of this procedure is the root-mean-square error (RMS error) of the subsample as compared with the total sample. The equation for determining this error is:

$$\text{RMS error} = \sqrt{\frac{\sum_{i=1}^{i=n} (V_{ss} - V_s)^2}{n}}$$

Where

V_{ss} = volume accumulated in section i from subsample.

V_s = volume accumulated in section i from total sample.

n = number of sections in volume group.

The RMS error is comparable, statistically, to the standard deviation of a group of values around their mean. For example, if the RMS error for a one-third subsample volume compared with the original sample volume is 50 person-trips, one would make little error by assuming that two-thirds of the expanded volumes obtained from the subsample would lie within 50 person-trips of the total sample volume.

RMS errors were developed for each subsample. That is, a RMS error was developed for each of the one-half subsamples, for each of the one-third subsamples, and for each of the one-tenth subsamples. However, since little could be gained by reporting and analyzing each subsample RMS error, a mean error was determined from the 3 one-third subsamples, from the 2 one-half subsamples, and from the 10 one-tenth subsamples.

A RMS error was computed for each volume class, and the percent root-mean-square error was determined by dividing the numerical error by the average volume of the volume class being considered. The results of the one-third subsample comparison are presented in table 2.

Results of the Study

The results of the trip-tracing program and the statistical procedure used are the percent root-mean-square (percent RMS) errors for the one-half, the one-third, and the one-tenth subsamples, each measured against the total Phoenix-Maricopa County sample. These results are shown in table 3 for each volume group.

As was to be expected, the percent RMS error for any particular volume group is invariably greatest for the smallest subsample rate, and vice versa. For example, for an average volume of 1,763 trips, volume group No. 7, the percent RMS error for the one-half subsample was 15.3; for the one-third subsample, 23.5; and for one-tenth subsample, 49.4. In addition, the percent RMS error, for each subsample, decreased as the volume increased.

It should be understood that the one-half subsample errors are in reality the percent RMS errors between a 1-in-30 and a 1-in-15 dwelling-unit sample. Likewise, the one-third subsample rate is actually a 1-in-45 dwelling-unit sample and the one-tenth subsample is a 1-in-150 dwelling-unit sample, the error in each case being measured against the 1-in-15 sample.

The values tabulated in table 3 can be used in the following manner. If it is desired to estimate trips from a home-interview survey at the 4,000 average daily person-trip level, volume group No. 10, for some specific design

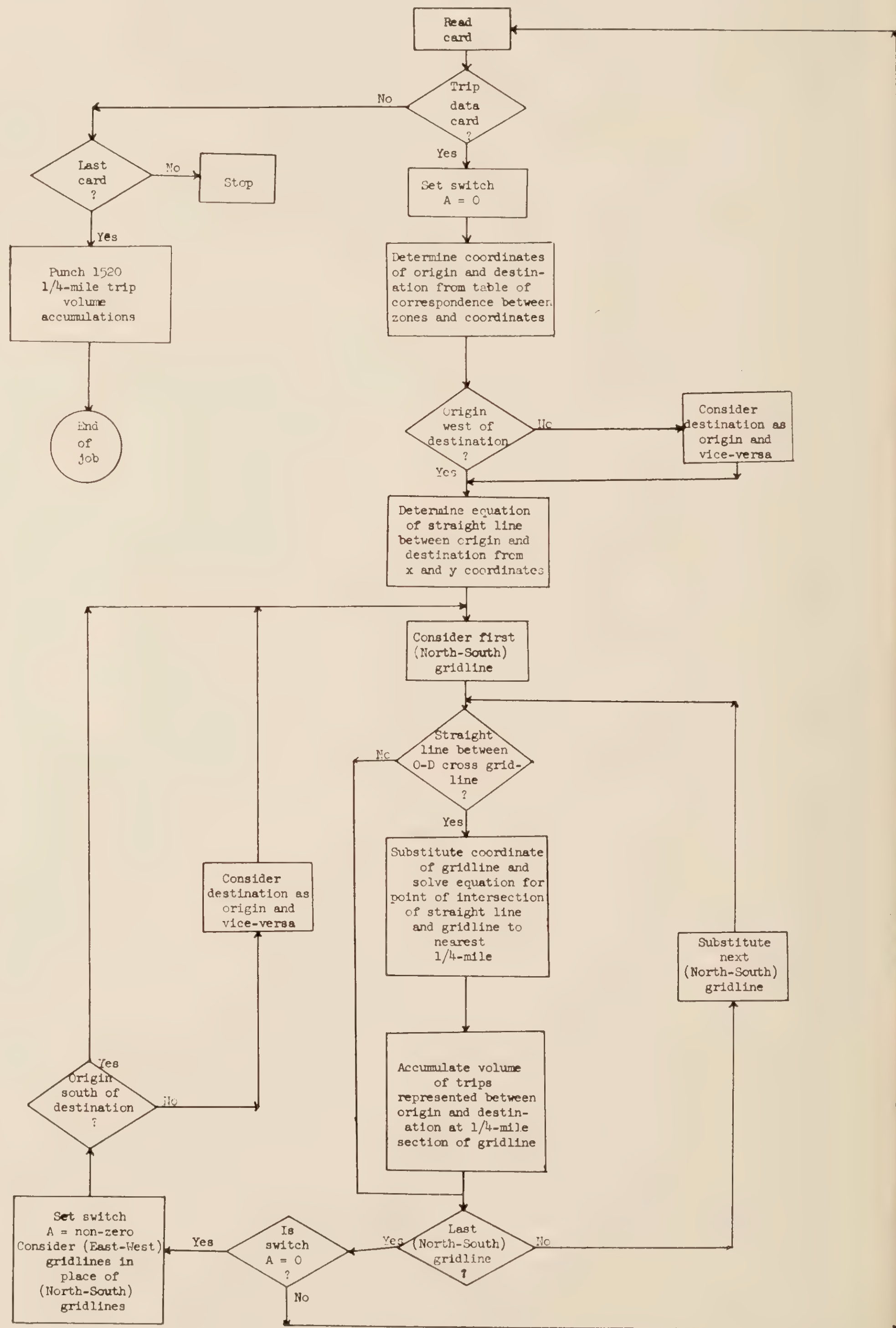

Figure 2.—Generalized electronic computer flow chart for tracing trips across a grid system.

Table 2.—Results of one-third subsample comparison with total sample

Volume group No.	Mean volume of group (total sample)	Mean volume[1] (1st) One-third subsample	(2d) One-third subsample	(3d) One-third subsample	Mean error[2] (1st) One-third subsample	(2d) One-third subsample	(3d) One-third subsample	RMS error[3] (1st) One-third subsample	(2d) One-third subsample	(3d) One-third subsample	Percent RMS error[4] (1st) One-third subsample	(2d) One-third subsample	(3d) One-third subsample	Average RMS error of three samples: Absolute error: RMS error $\frac{(1st)+(2d)+(3d)}{3}$	Percent error: $\frac{\text{Absolute error}}{\text{Original Sample Volume}}$
1	91.1	83.2	90.6	99.4	−7.9	−0.4	+8.3	77.5	75.1	78.9	85.07	82.44	86.61	77.2	84.74
2	283.2	231.2	309.5	308.9	−52.0	+26.3	+25.7	160.5	153.5	168.3	56.67	54.20	59.43	160.8	56.78
3	486.7	392.9	545.0	522.2	−93.8	+58.3	+35.5	205.6	237.4	225.7	42.24	48.78	46.37	222.9	45.80
4	682.0	623.2	710.9	711.9	−58.8	+28.9	+29.9	307.8	253.6	295.6	45.13	37.18	43.34	285.7	41.89
5	893.3	749.9	977.1	952.7	−143.3	+83.8	+59.5	300.5	306.4	267.8	33.64	34.30	29.98	291.6	32.64
6	1,244.5	1,153.8	1,325.3	1,254.2	−90.6	+80.9	+9.7	308.9	335.2	349.7	24.82	26.93	28.10	331.3	26.62
7	1,763.4	1,772.5	1,883.2	1,634.4	+9.1	+119.8	−128.9	390.8	427.0	424.9	22.16	24.21	24.10	414.2	23.49
8	2,257.4	2,123.7	2,631.0	2,287.5	−133.7	+373.6	+30.1	470.6	537.9	391.4	20.85	23.83	17.34	466.6	20.67
9	2,998.6	2,886.6	3,118.3	2,990.9	−112.0	+119.7	−7.7	513.6	578.4	503.6	17.13	19.29	16.79	531.9	17.74
10	4,001.4	3,938.8	3,995.6	4,069.8	−62.6	−5.8	+68.4	666.1	654.7	644.7	16.65	16.36	16.11	655.2	16.37
11	5,020.9	4,903.9	5,136.4	5,022.5	−117.0	+115.5	+1.6	727.0	667.7	729.5	14.48	13.30	14.53	708.1	14.10
12	6,759.3	6,490.2	6,628.3	7,159.4	−269.1	−131.0	+400.1	774.5	751.7	922.5	11.46	11.12	13.65	816.2	12.08
13	8,961.8	8,896.1	8,923.1	9,066.4	−65.7	−38.8	+104.5	878.5	780.4	910.2	9.80	8.71	10.16	856.4	9.56
14	12,401.3	12,285.2	12,461.4	12,457.2	−116.1	+60.1	+55.9	909.7	913.7	1,156.3	7.34	7.37	9.32	993.2	8.01
15	21,689.9	21,555.2	22,046.2	21,468.2	−134.7	+356.3	−221.7	1,741.0	1,808.9	1,655.6	8.03	8.34	7.63	1,735.2	8.00

[1] Mean volume = $\frac{\sum\left(\text{Segment volumes in volume group}\right)}{\text{Number of sections}}$

[2] Mean error = $\frac{\sum\left[\left(\text{Subsample volume}\right)-\left(\text{Original sample volume}\right)\right]}{\text{Number of sections}}$

[3] RMS error = $\sqrt{\frac{\sum\left[\left(\text{Subsample volume}\right)-\left(\text{Original sample volume}\right)\right]^2}{\text{Number of sections}}}$

[4] Percent RMS error = $\frac{\text{RMS error}}{\text{Mean volume}}$

purpose, the use of a 1-in-30 dwelling-unit sample would produce a volume that is within 11.7 percent of the value that would have been obtained with a 1-in-15 sample two-thirds of the time. Likewise, the use of a 1-in-45 dwelling-unit sample would result in a volume that is within 16.4 percent of the value obtained by a 1-in-15 sample two-thirds of the time. If the probability of being within the 1-in-15 sampling rate volume 95 percent of the time is desired, 2 times the percent RMS error would be used. An expectancy of 99 percent would require 3 times the percent RMS error.

By using the values tabulated in table 3, the expected results of a 1-in-30, a 1-in-45, and a 1-in-150 dwelling-unit sample can be compared with that of a 1-in-15 sample. However, the primary purpose of this study was to determine the error between the volume determined from any dwelling-unit sample and the actual volume; the actual volume being the average daily person-trips measured over the study period. It is evident that only through an overwhelming expenditure of time and money could every person in a city be interviewed every day during the study period. However, through statistical procedures, using the comparisons of the 1-in-30, the 1-in-45, and the 1-in-150 dwelling-unit sampling rate with the 1-in-15 sample, an estimate of the error between any size sample and the total population could be determined.

Source of error

The error between a volume determined from any of the subsamples and the true volume consists of two parts: First, the error between the subsample volume and the total Phoenix-Maricopa County sample volume; and second, the error between the total sample volume and the true volume. In statistical computations, for the analysis of variance, the total variance of a group of samples is equal to the "between sample" variance plus the "within sample" variance:

$$\sigma^2_{\text{total}}=\sigma^2_{\text{within}}+\sigma^2_{\text{between}} \qquad (1)$$

where: σ^2 = variance.

The percent RMS errors computed for this study, as mentioned previously, are statistically comparable to the standard deviation of a group of values about their mean. Therefore, an equation for relating percent RMS errors, comparable to equation (1) above is:

$$E^2_{ss\text{-}o}=E^2_{ss\text{-}s}+E^2_{s\text{-}o} \qquad (2)$$

Where:

$E_{ss\text{-}o}$ = percent RMS error of subsample volume measured against true volume.

$E_{ss\text{-}s}$ = percent RMS error of subsample volume measured against total sample volume.

$E_{s\text{-}o}$ = percent RMS error of total sample volume measured against true volume.

An equation for estimating the error for a sample from the error found for another independently selected sample is:

$$E_{ss\text{-}o}=E_{s\text{-}o}\sqrt{\frac{N_s}{N_{ss}}} \qquad (3)$$

Where:

N_s = number of interviews taken in original survey.

N_{ss} = number of interviews represented in subsample.

Assuming that equation (3) is an acceptable approximation to the situation being considered, and by combining equations (2) and (3) the following equation results:

$$\frac{N_s}{N_{ss}}\times E^2_{s\text{-}o}=E^2_{ss\text{-}s}+E^2_{s\text{-}o}$$

or

$$E^2_{s\text{-}o}=\frac{E^2_{ss\text{-}s}}{\frac{N_s-N_{ss}}{N_{ss}}}$$

therefore:

$$E_{s\text{-}o}=\frac{E_{ss\text{-}s}}{\sqrt{\frac{N_s}{N_{ss}}-1}} \qquad (4)$$

Considering equation (4) for determining the percent RMS error between the total sample volume and the actual volume, from the error determined from the one-tenth subsample, equation (4) then becomes:

$$E_{s\text{-}o}=\frac{E_{1/10\text{-}s}}{\sqrt{\frac{N_s}{1/10N_s}-1}}=\frac{E_{1/10\text{-}s}}{\sqrt{10-1}}$$

$$E_{s\text{-}o}=\frac{E_{1/10\text{-}s}}{3} \qquad (5)$$

Likewise, the equations for determining the error of the total sample from the one-half and one-third subsample errors are:

$$E_{s\text{-}o}=\frac{E_{1/2\text{-}s}}{\sqrt{1}}=E_{1/2\text{-}s} \qquad (6)$$

$$E_{s\text{-}o}=\frac{E_{1/3\text{-}s}}{\sqrt{2}}=\frac{E_{1/3\text{-}s}}{1.41} \qquad (7)$$

Stability of error computation

Equations (5), (6), and (7) were used to determine independent estimates of the percent RMS errors in the total sample volumes,

Table 3.—Percent root-mean-square error of subsample volume as measured against total sample volume, by different sample sizes

Volume group No.	Percent RMS error of subsample volume measured against total sample mean volume of group: One-half original sample	One-third original sample	One-tenth original sample
1	67.5	84.7	193.0
2	41.4	56.8	120.7
3	28.4	45.8	88.2
4	27.6	41.9	80.2
5	23.1	32.6	67.7
6	18.0	26.6	55.7
7	15.3	23.5	49.4
8	13.4	20.7	45.0
9	14.2	17.7	36.6
10	11.7	16.4	33.8
11	10.2	14.1	29.0
12	9.3	12.1	26.4
13	6.7	9.6	21.4
14	5.4	8.0	18.5
15	3.8	8.0	16.0

Table 4.—Estimated percent root-mean-square error of original sample volume as measured against population volume

Volume group, No.[1]	Estimated percent RMS error from— One-half original sample	One-third original sample	One-tenth original sample	Mean
1	67.5	59.9	64.3	63.9
2	41.4	47.3	40.2	43.0
3	28.4	32.4	29.4	30.1
4	27.6	29.7	26.7	28.0
5	23.1	23.1	22.6	22.9
6	18.0	18.8	18.6	18.5
7	15.3	15.9	16.5	15.9
8	13.4	14.7	15.0	14.4
9	14.2	12.6	12.2	13.0
10	11.7	11.6	11.3	11.5
11	10.2	10.0	9.7	10.0
12	9.3	8.6	8.8	8.9
13	6.7	6.8	7.1	6.9
14	5.4	5.7	6.2	5.8
15	3.8	5.7	5.4	5.0

measured from the actual volume, from the one-tenth, one-half, and one-third subsample errors, respectively. If each of these independent calculations produced consistent estimates of the RMS error for the 1-in-15 sample, it appears reasonable to assume that other sampling rates would be equally consistent. These independent estimates of the error in the total sample are shown in table 4.

A comparison of the estimated percent RMS errors of the 1-in-15 dwelling-unit sample, for each volume group, shows little variation. The mean of the three estimates was, therefore, determined and plotted on logarithmic paper (fig. 3). A least-squares fit determined from the points is also shown in figure 3. The equation of the developed line is:

$$\text{Percent RMS error of 1-in-15 dwelling-unit sample} = \frac{629.0}{\text{volume}^{.4884}} \quad (8)$$

The coefficient of correlation developed is approximately 1, indicating an almost perfect functional relationship between the two variables considered. In other words, the variation in percent RMS error is explained almost entirely by the variation in volume. Since this is a logarithmic relationship the standard error of estimate for the line is a constant percent of the estimated value rather than a constant percent error. The error, which is 5.65 percent of the estimated values, means that at a volume of 1,000 trips, the standard error is about 1.2 percent (5.65 percent×21 percent) and at 10,000 trips the standard error is about 0.4 percent (5.65 percent×6.8 percent).

Equation (3) can be used, in the following form, for determining the relationship between percent RMS error and volume for any sample rate:

$$E_{i-o} = E_{1/15-o} \times \sqrt{N_i} \quad (9)$$

Where:

E_{i-o} = error of any sample i.

$E_{1/15\ o}$ = error of 1-in-15 dwelling-unit sample.

N_i = number of times the sampling rate of survey i is less than 1-in-15. For example, if a 1-in-60 rate is used, N_i would be 4. If the rate was 1-in-5, N_i would be 1/3.

If a 1-in-1 sample were taken, that is, every person in the city interviewed once, the equation for determining percent RMS error would be:

$$\text{Percent } RMS \text{ error} = \frac{629.0\sqrt{N_i}}{\text{volume}^{.4884}}$$

where: $N_i = 1/15$

therefore:

$$\text{percent } RMS \text{ error for 1-in-1 dwelling-unit sample} = \frac{162.4}{\text{volume}^{.4884}} \quad (10)$$

It should be noted that the error for a 1-in-1 dwelling-unit sample is not zero, since a 1-in-1 sampling rate is not a 100-percent sample for determining average daily traffic during the survey period. Every person in a city would have to be interviewed about his travel for every day during the survey in order to obtain the universe of travel for that period.

Equation (10) can be used for determining the equation for percent RMS error at any sample rate. Simply multiply equation (10) by the square root of the denominator of the sample rate ratio used. For example, if a 1-in-30 home-interview sample rate is used, multiply equation (10) by the square root of 30. Figure 4 presents predictive lines for estimating percent RMS errors for volumes between 100 and 100,000 person-trips per day for various sampling rates.

Comparison of Results

A theoretical approach to the problem of estimating the accuracy of various sample sizes relies on the estimation of the standard deviation in volumes determined from the samples. The theory states that the expected deviation is expressed as follows:

σ = expected deviation

V = Volume

S = percent sample

$$\sigma = \sqrt{V\left(\frac{S}{100}\right)\left(1-\frac{S}{100}\right)}$$

Since the probable volume ($\overline{V}$) is equal to the volume obtained from the survey times the sample rate:

$$\frac{\sigma}{\overline{V}} = \frac{\sqrt{V\left(\frac{S}{100}\right)\left(1-\frac{S}{100}\right)}}{V\frac{S}{100}}$$

or

$$\text{percent } \sigma = 100\sqrt{\frac{100-S}{VS}}$$

A comparison of the errors predicted by the above theory with the relationship developed in this article is shown in table 5 for various volumes and sample sizes. It can be seen that the observed root-mean-square errors are from 1.7 to 1.9 times as great as the error predicted by theory. This difference may be due to nonsampling errors such as response and coding errors. For example, a study made in Cincinnati, Ohio, showed that those interviewed reported too few trips in some cases and too many trips in other cases.

In table 5 it is found that the observed error is almost two times as great as the theoretical error. This means that in order to maintain a desired degree of accuracy, it is necessary to increase the sampling rate to almost four times the rate indicated by the theoretical standard deviation computation.

Use of Results

The curves plotted in figure 4 have been developed for total person-trips and can be utilized to determine the sample rate to be used

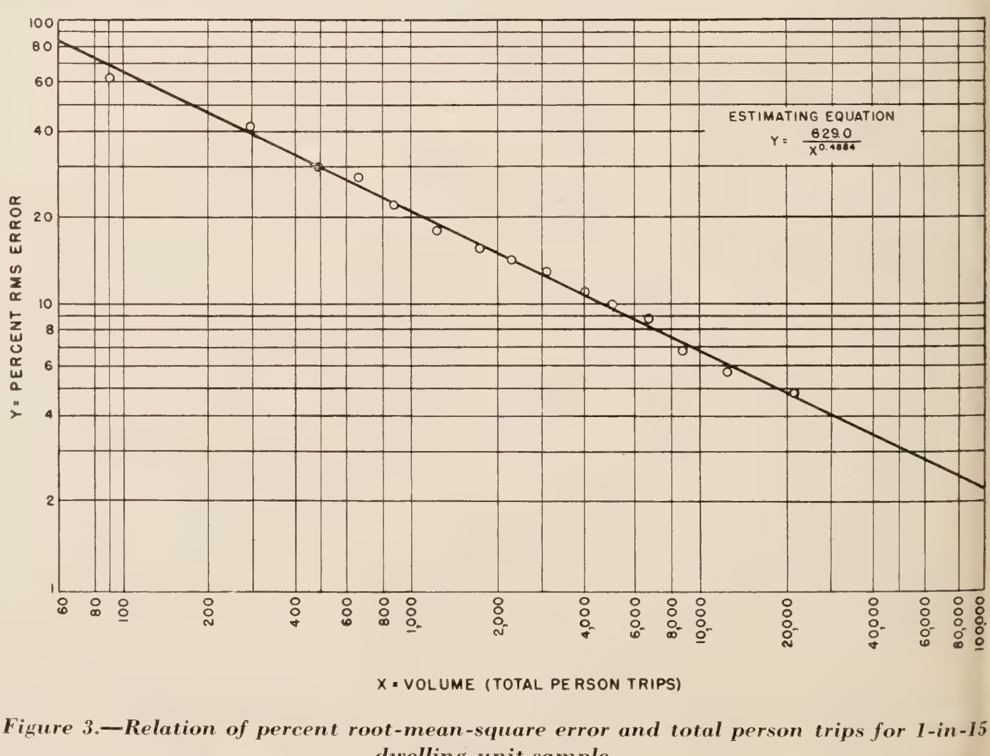

Figure 3.—Relation of percent root-mean-square error and total person trips for 1-in-15 dwelling-unit sample.

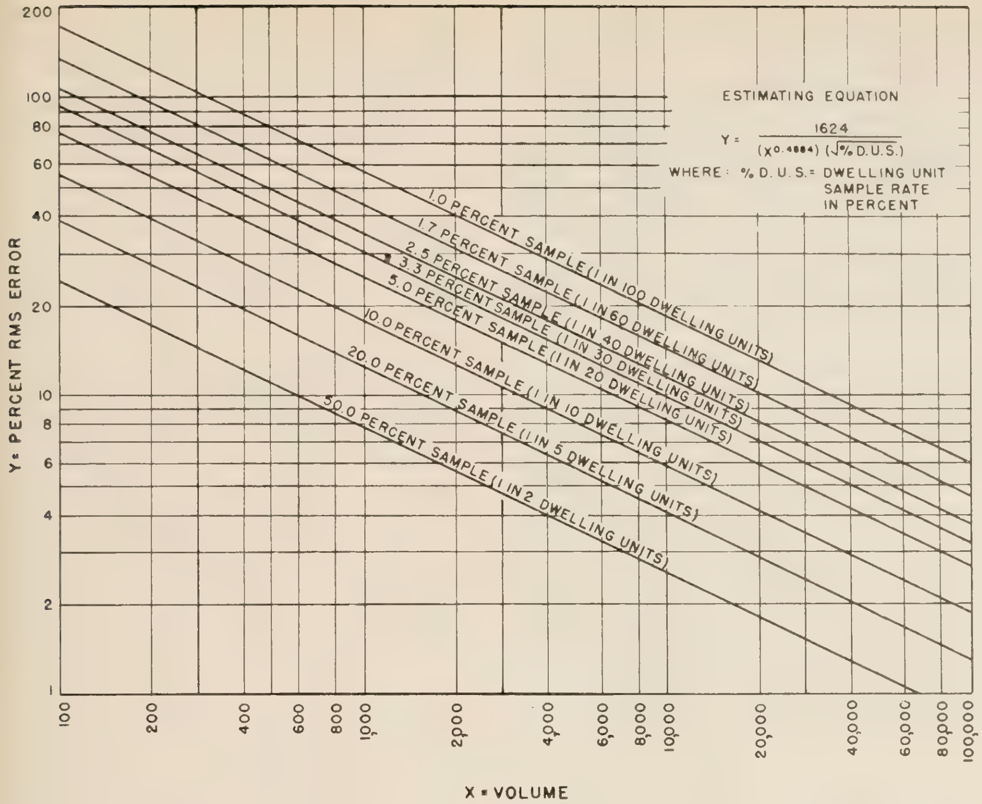

Figure 4.—Relation of percent root-mean-square error and volume for various dwelling-unit sample rates.

when desiring an estimate of volume with a desired degree of accuracy. For example, if it is desired to estimate an average daily volume at the 10,000 person-trip level, and be within 8 percent of the true value 95 percent of the time, from figure 4 at volume equal to 10,000 and percent RMS error equal to 4 percent (8 percent÷2 for 95 percent confidence), it is found that a 20-percent sample should be taken. Similarly, the curves can be used to estimate the error in accumulated volumes after the results of an origin-destination survey are obtained. For rates not plotted, equation (10) would be used in the following form:

$$\text{Dwelling-unit sample rate in percent} = \left[\frac{1,624}{(\text{Percent RMS error})(\text{volume}^{.4884})}\right]^2 \quad (11)$$

For the problem explained, a dwelling-unit sample rate of 20.4 percent would result from the use of equation (11), indicating that one out of every five dwelling units should be interviewed.

More often than not, the highway engineer is interested in the number of vehicle-trips rather than the number of person-trips—vehicle-trips being the figure used for highway design purposes. Therefore, the question arises: can the curves developed for person-trips be used as an indicator of error for vehicle-trips?

The volume of automobile vehicle-trips throughout a city is less than the volume of person-trips, but is similarly distributed. The errors, if developed between the subsamples and total sample for automobile vehicle-trips, should not, therefore, be any different from the errors determined for all person-trips. That is, a percent RMS error for 10,000 automobile vehicle-trips should be no different from the error determined for 10,000 person-trips. The curves presented in figure 4 and the equations developed can therefore be used for total person-trips, automobile vehicle-trips, bus-passenger trips, truck- and taxi-passenger trips, and automobile passenger-trips. The results of this study can also be applied to any home-interview type of origin and destination survey since accumulation of trips and not individual zone-to-zone movements are being compared.

Table 5.—Comparison of observed errors and theoretical sampling errors

Sample rate (percent)	Volume	Observed error [1]	Theoretical sampling error [2]	Observed error ÷ theoretical sampling error
		Percent	*Percent*	
1	100	171.31	99.50	1.7
	1,000	55.64	31.46	1.8
	10,000	18.07	9.95	1.8
	100,000	5.87	3.15	1.9
3	100	98.91	56.87	1.7
	1,000	32.21	17.98	1.8
	10,000	10.43	5.69	1.8
	100,000	3.39	1.80	1.9
4	100	85.65	48.99	1.7
	1,000	27.82	15.49	1.8
	10,000	9.04	4.90	1.8
	100,000	2.94	1.55	1.9
5	100	76.60	43.60	1.8
	1,000	24.90	13.80	1.8
	10,000	8.10	4.36	1.8
	100,000	2.62	1.38	1.9
10	100	51.50	30.00	1.7
	1,000	16.70	9.50	1.8
	10,000	5.43	3.00	1.8
	100,000	1.76	.95	1.9

[1] This is the percent RMS error as developed in this article.
[2] This is the theoretical percent standard deviation error.

A Traffic Analyzer: Its Development and Application

BY THE DIVISION OF TRAFFIC OPERATIONS BUREAU OF PUBLIC ROADS

Reported [1] by ASRIEL TARAGIN, Chief, Traffic Performance Branch, and RICHARD C. HOPKINS, Chief, Instrumentation Branch

From the early graphic recording equipment to the modern electronic digital recorders, the Bureau of Public Roads has continuously been seeking faster and more reliable means for recording and analyzing traffic data. This article presents the development of the Bureau's digital speed-placement equipment—the traffic analyzer.

IN THE PAST 20 YEARS significant advances in the development of improved standards for geometric highway design have stemmed primarily from the increasing knowledge of traffic performance, driver behavior, and highway capacity. A better understanding of the many problems has been made possible by the detailed study of the speed and placement of each vehicle in the traffic stream and its relation to the speeds, the lateral placements, and the longitudinal positions of vehicles ahead, behind, and adjacent.

Development of Equipment

In the early stages of research, traffic data were recorded by observers using stopwatches and pavement markings. The necessity for more complete knowledge of the factors determining highway capacity became increasingly evident. Improvement and refinement in the field technique was imperative because more data were needed, with greater precision, as added features of design had to be evaluated, and the results had to be analyzed more quickly.

Increasing use was made of automatic graphic recording equipment as reliable and sophisticated instruments became available for field use. By the late 1930's, the Bureau of Public Roads had developed a reliable speedmeter and placement detector with digital outputs to the time bases available in graphic records.[2] The accuracy and dependability of this equipment was proven in its continuous field use. However, the data had to be scaled from the long rolls of pen-line graphs produced by the equipment before they could be put on punch cards; and the considerable amount of manpower and time required for this greatly delayed the availability of the data for use and limited the volume of data that could be handled. It was only natural, therefore, that means of actual digital recording would be sought, from which machine tabulating cards could be prepared easily, accurately, and quickly, and in large volume.

This thinking became a reality in 1946 when automatic digital recording of data for two lanes of traffic was made available by means of mounting hand-wound solenoids over the keys of a standard adding machine and devising a digital clock to indicate the time of each recording. This assembled equipment proved so successful that a year later it was permanently mounted in a panel truck, and studies were conducted with the equipment in many States throughout the country. With minor improvements in components, but no changes in the basic design, this 2-lane digital speed-placement equipment served well the Bureau of Public Roads, the cooperating State highway departments, and other agencies for 10 years.

In 1956 the recording capabilities of the digital speed-placement equipment were increased to cover four lanes of traffic. The time was then opportune to improve some points of basic design which the availability of recently developed electronic components made feasible. The traffic analyzer was developed by Bureau engineers, modernizing and redesigning the older speed-placement recording equipment.

The problems of transportability and the shortcomings of the standard panel truck were solved by installing the equipment in a custom body on a commercial delivery-truck chassis. This provided a short wheelbase for maneuvering in close quarters at traffic study sites and allowed a maximum of usable interior space for equipment placement and operator comfort. (A typical position for the operation of the traffic analyzer vehicle is shown on the magazine cover.)

Figure 1 shows in block diagram the instrument design of the traffic analyzer. Special vehicle detectors may be placed at any or all of

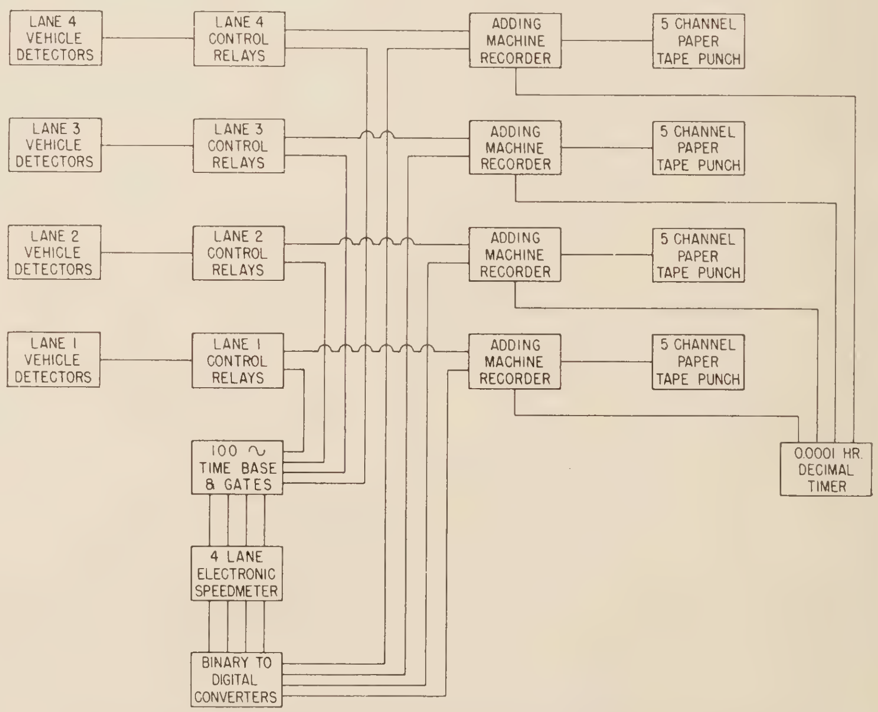

Figure 1.—A block diagram of the traffic analyzer instrument system.

[1] This article was presented at the 30th Annual Meeting of the Institute of Traffic Engineers, Chicago, Ill., September 1960.

[2] *New techniques in traffic behavior studies*, by E. H. Holmes and S. E. Reymer, PUBLIC ROADS, vol. 21, No. 2, April 1940, pp. 29–45.

four different positions where vehicular traffic data are desired. The usual detectors consist of either two pneumatic tubes or two positive contact strips to detect speeds and a segmented detector designed and built by the Bureau to detect vehicle placement.

Figure 2 shows a typical field setup of the detectors on one roadway of a 4-lane divided highway. The speed detectors are spaced from 12 to 36 feet apart, depending on the average speed of traffic, to provide a known distance for speed timing. A 5-foot dead space is left between the active sections of the detectors in adjacent lanes to prevent lane-straddling vehicles from being recorded in more than one lane.

The segmented lateral placement detector is used in lengths of 12, 24, 36, or 48 feet, depending on the roadway width being studied. The detector is segmented into 1-foot units, each segment having an active contact of 7½ inches and a dead space of 4½ inches. The 4½-inch spacing between the active contacts permits a precise determination of vehicle placements.

The speed and placement detectors are connected by extension cables to placement relays and to several control relays for each lane of data recording.

Figure 3 shows the interior of the traffic analyzer vehicle. Along the left side, under the windows, a built-in desk provides four operating positions. At each operating position is a solenoid-operated adding machine. The recording units are commercially available 14-bank adding machines containing "read-out" units which transmit the data to the 5-channel paper tape punches mounted on the shelf above the recorders. Specially designed 115-volt a.c. solenoids are mounted over the keys of the adding machines. These solenoids receive electrical impulses and the data are automatically printed on adding machine tape and also punched in the 5-channel paper tape. Two banks of keys connected to push-button extensions are available on each adding machine so that manually coded information can be entered as desired separately for each lane of traffic.

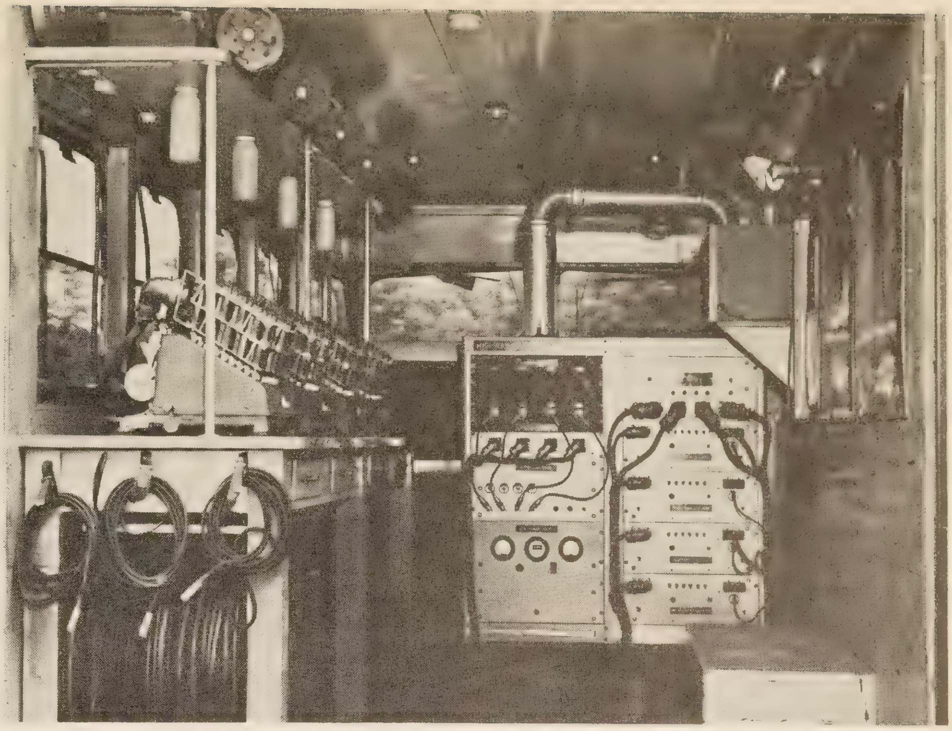

Figure 3.—An interior view of the mobile traffic analyzer vehicle.

Immediately behind the cab of the vehicle, the electronic data collecting and system-control equipment is mounted in a double relay rack cabinet. A specially fabricated cable connects the equipment in this cabinet with the four adding machines. An air conditioner, mounted above and to the right of the equipment cabinet, is necessary to dissipate the heat generated in the electronic circuitry and to cool the truck interior.

The data which are automatically recorded for each vehicle are speed, lateral placement referenced to a designated traffic lane, and precise time of day each vehicle passes the point of observation. Vehicle speed is recorded as travel time in hundredths of a second over the known distance between the speed detectors; lateral placement is recorded as a direct measurement of both the right and left wheel positions with respect to the right edge of the traffic lane, by the segmented detector; and time of day is continuously measured in intervals of one ten-thousandth of an hour. All of the data are recorded the instant that the front axle of each vehicle passes over the second speed detector.

These recorded data are subsequently taken into the office and interpreted through the use of an electronic digital computer. Vehicle speed is calculated from the travel time and the distance between detector tubes; the position of the center of the vehicle is computed from the wheel placements; and time spacings between vehicles are determined and reduced to headway distances measured in feet. The high speed computer also is used to determine the speed and the lateral and longitudinal positions of each vehicle relative to all other vehicles which are ahead, behind, or adjacent to it.

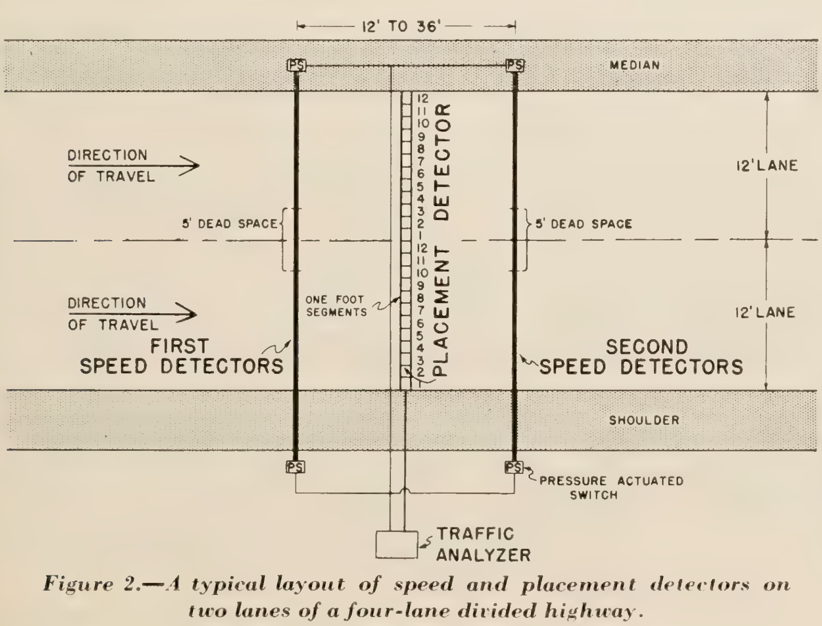

Figure 2.—A typical layout of speed and placement detectors on two lanes of a four-lane divided highway.

Electronic Design

The time base for the vehicle speed measurements, shown in figure 4, is a 100-cycles-per-second tuning fork. The fork and its associated amplifier and wave-shaping circuits is shown on the left. The tuning fork is electrically driven, self-starting, and is calibrated to the exact frequency of 100 cycles per second. A shutter attached to the tines of the fork, a light source above the shutter, and a photocell beneath it provide for an electronic signal output from the fork without affecting its natural frequency. The output of the time-base unit is a 100-cycle-per-second square wave of 20 volts amplitude to actuate the "one-shot" drivers of the decade scalers in the speed-timing unit. Four relay gates, one for each lane of traffic, are mounted under the time-base chassis, as shown on the right in figure 4. As they are actuated by the control relays for each lane, the gates, in turn, control the speed time pulses to be counted.

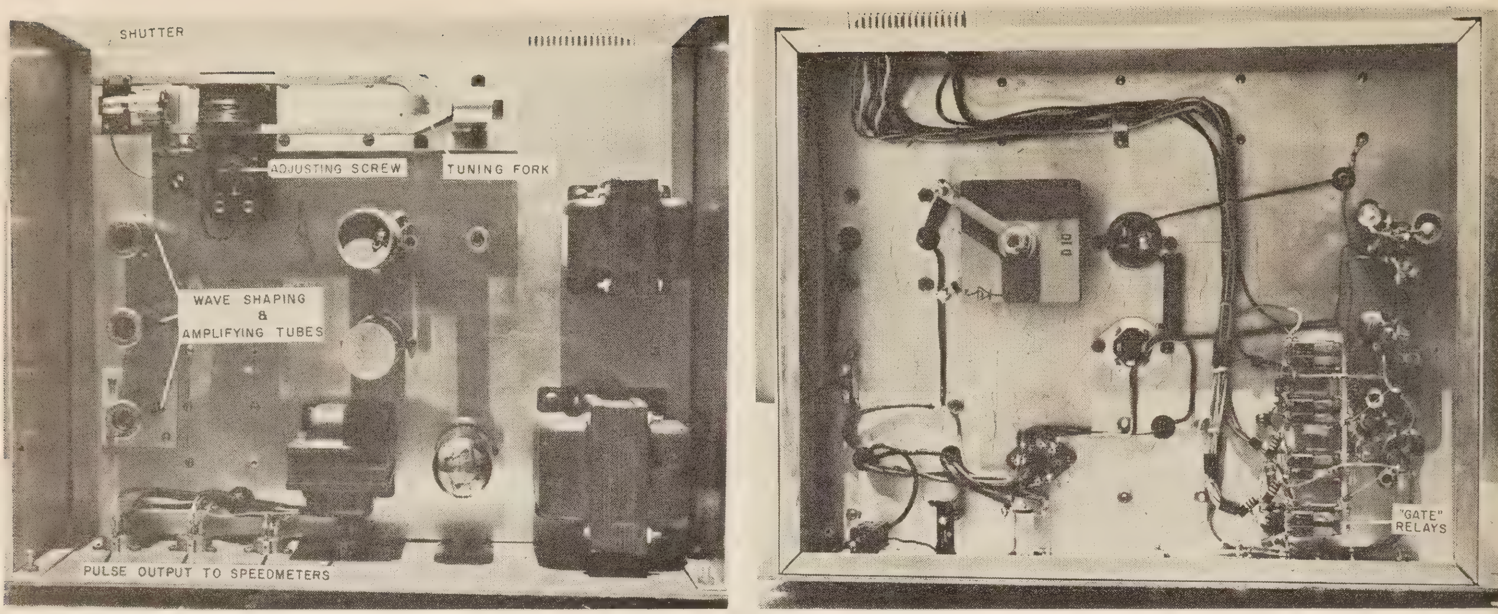

Figure 4.—Time base chassis (top view, left; bottom view, right).

The 4-lane electronic speedmeter, shown in figure 5, consists of four pairs of electronic decade scalers (on the left), each pair being capable of counting to 99. The pulse input connectors are located below each pair of scalers. As the speed-timing pulses (1/100th of a second) are received by any pair of these scalers, they are accumulated and the total held for recording. The circuitry of the speedmeter is shown on the right. The rectangular boxes in the middle of the chassis are the pulse-shaping one-shot multivibrator drivers to the decade scalers. Below these boxes are the vacuum-tube amplifiers necessary to actuate the relays in the binary to digital converter. Figure 6 is a rear view of the speedmeter, which contains the 52 vacuum tubes necessary to perform the proper functions.

The output of the decade scalers is a binary coded decimal. To record this on a digital printer a decoding relay matrix is actuated by the scaler output to provide the proper decimal number for recording. This unit is enclosed in the small panel seen immediately below the speedmeter in the interior view of the vehicle shown in figure 3.

Figure 7 shows a view of the chassis containing the placement and control relays for 1 lane of traffic. The 12 placement relays, which are actuated by the 12 contacts on the segmented placement detector, are shown in a row at the top of the figure. One power supply is needed to operate two of these relays, and the six power supplies needed are shown in the lower part of the figure. Each placement contact actuates the appropriate placement relay which, in turn, operates the proper solenoid on the adding machine. The two shift relays, shown just below the placement relays, permit automatic pickup of 3 feet of placements of the adjacent lanes to the right or left, a normal occurrence when vehicles straddle two traffic lanes. The three control relays, which are mounted on the panel, control the sequence of operation for the detection and recording of the data for the specific lane.

The time of day, accumulated in ten-thousandths of an hour, is provided by a decimal timer consisting of an 1,800-r.p.m. synchronous motor, a gear-reduction unit, and a breaker-point assembly shown to the left in figure 8. A 4-pointed cam closes an electrical contact each ten-thousandths of an hour to pulse the timing switches from the 12-volt d.c. power supply included on the chassis. These ten-thousandth-of-an-hour time units are accumulated in four 6-bank, 10-point spring-driven stepping switches. A count of 10 in one switch is carried over as a count of 1 in the next switch so that the decimal timer makes one complete timing cycle per hour. Four banks of each stepping switch provide the time information which is recorded in each of the four lanes. One bank controls the illuminated digital read-out on the timer panel, shown in figure 8 on the right, and one bank supplies the digit carry-over information to the next switch. Four push buttons on the front panel allow the timer to be preset for the start of a study.

The sequence of operation for a traffic lane being studied is initiated by a vehicle passing

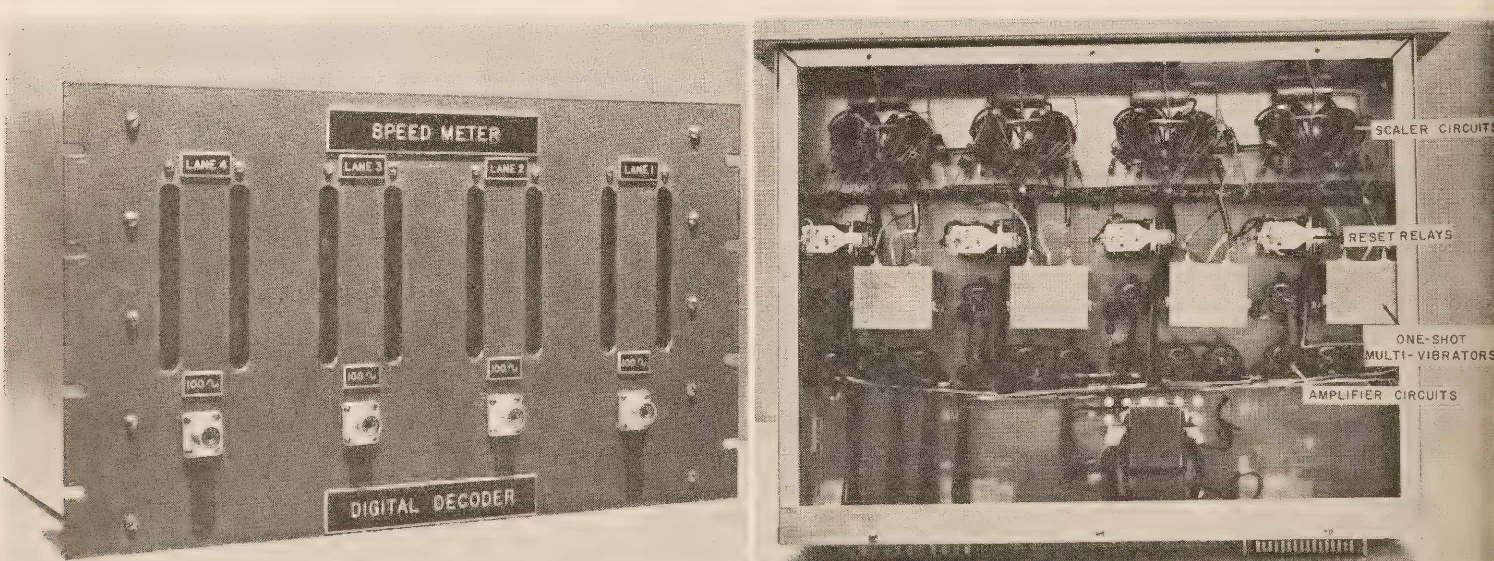

Figure 5.—Four-lane electronic speedmeter (front view, left; bottom view, right).

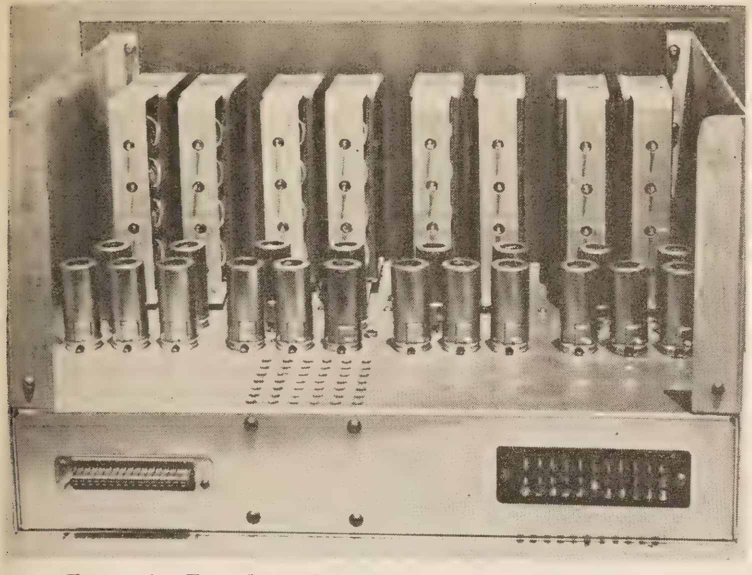

Figure 6.—Four-lane electronic speedmeter (rear view).

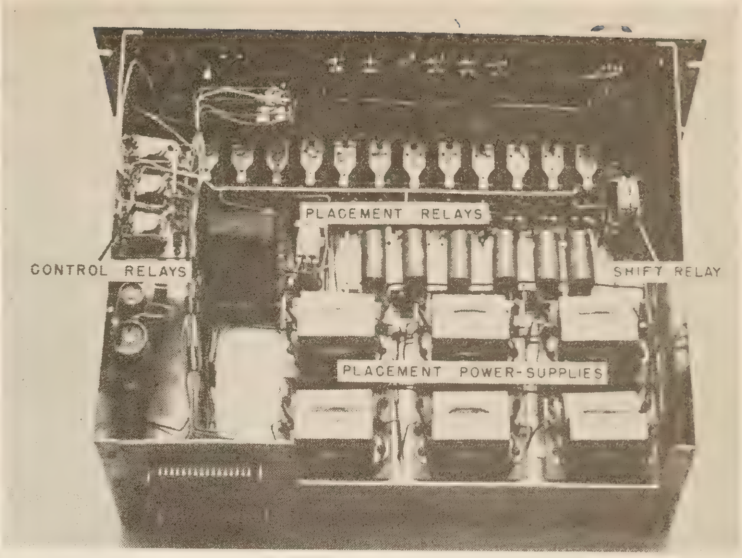

Figure 7.—Placement and control relay chassis (top view).

over the first speed detector. This electrical contact actuates a control relay which, in turn, opens the relay gate to the speedmeter and turns on the power to the placement detector for that lane. As the front wheels of the vehicle pass over the placement detector, the appropriate solenoids are actuated through the placement relays and the information is immediately entered in the adding machine recorder. When the front wheels of the vehicle pass over the second speed detector, the speedmeter gate is closed, the speed timing (in one-hundredths-of-a-second units) is entered on the recorder, the decimal timer reading (time of day in ten-thousandths of an hour) is transferred to the recorder, and a control signal causes the adding machine to cycle and print these data. During the printing cycle, the decade scalers in the speedmeter are reset to zero. The vehicle classification and any other desired information is usually set up by the observer in the two manually controlled columns in the recorder before the front axle of the vehicle closes the first positive contact detector; but it may be entered at any time before the printing cycle starts. Figure 9 shows a sample of the data recorded.

The built-in read-out to the 5-channel paper tape punch retains the necessary data after the printing cycle until the sequential operation of the punch is complete. Meanwhile, the keyboard of the adding machine will accept new data for the next recording.

Uses and Applications

The first extensive use of the original 2-lane digital recording equipment took place in 1947 on the San Francisco-Oakland Bay Bridge in California. Information was urgently needed to evaluate the driver behavior characteristics and the capacity of the bridge. Data for over 50,000 vehicles were recorded during one month at 11 locations. Because the field data were automatically printed on the adding machine tapes, it was possible to start punching machine tabulating cards after the first day of field observations. Summary tabulations showing averages and distributions of speeds, placements, and headways for all study locations were available within 2 weeks after field studies were completed. These results were very effectively used to justify specific recommendation for the improvement of traffic operations. A detailed analysis of these data also yielded invaluable criteria for lane capacity determinations discussed in the *Highway Capacity Manual*.[3]

For a 42-day period in 1948 a series of driver-behavior studies were conducted in conjunction with a study of time and gasoline consumption in motor truck operation.[4] For this purpose the equipment was used to record speeds, placements, and traffic volumes on level tangent sections, on grades, on curves, and in tunnels. The results of this study have been applied to the determination of speeds and travel time in conjunction with cost analysis of traffic operation on highways having varying horizontal and vertical alinement and in tunnels.

Since 1948, the traffic analyzer has been employed in a large number of studies in cooperation with at least 24 State highway departments, city and county traffic author-

[3] *Highway Capacity Manual*, practical applications of research, Bureau of Public Roads, 1950.

[4] *Time and gasoline consumption in motor truck operation*, as affected by the weight and power in vehicles and the rise and fall in highways, by C. C. Saal, Highway Research Board, Research Report No 9-A, 1950.

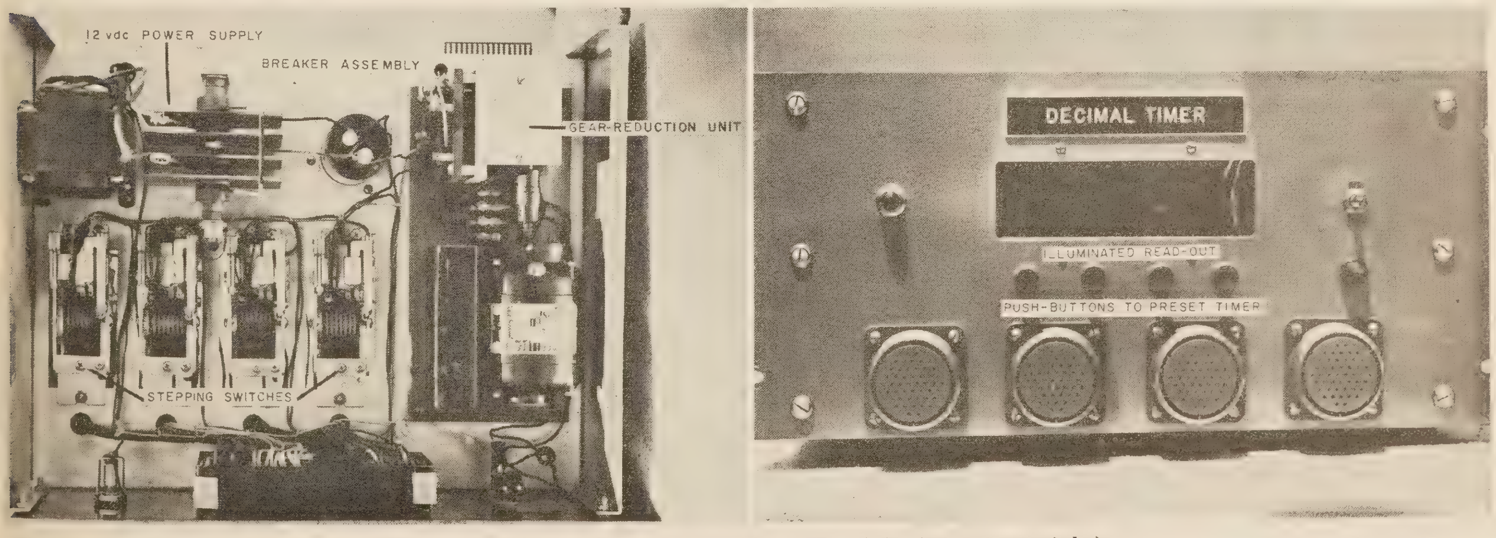

Figure 8.—Decimal timer chassis (top view, left; front view, right).

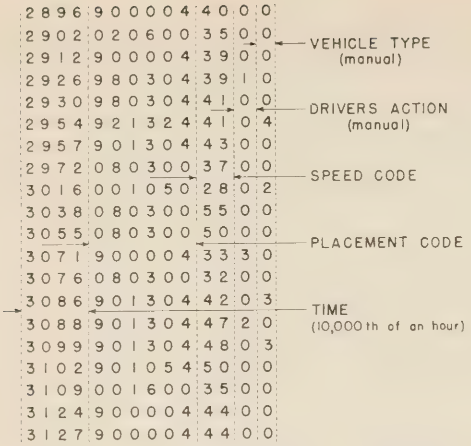

Figure 9.—A typical recording sample from the traffic analyzer.

ities, and a number of universities. The areas of study covered ranged from simply obtaining speeds of all vehicles simultaneously in four lanes carrying extremely heavy traffic volumes to very comprehensive studies involving weaving and merging vehicles such as on the Congress Street Expressway in Chicago, the John Lodge Expressway in Detroit, the Los Angeles Freeway system in California, and several expressways in Texas.

While every study made during heavy volume conditions has provided valuable highway capacity data, some studies have been undertaken primarily for this purpose. For example, in 1959 the analyzer was efficiently used to determine criteria for forecasting impending congestion on the Outer Drive and other locations in Chicago. The results of this study were of great value in the consideration of employing automatic traffic recording monitors for traffic surveillance on the Congress Street Expressway, a cooperative study by the City of Chicago, Cook County, the Illinois Division of Highways, and the Bureau of Public Roads.

The traffic analyzer has also been utilized for special purpose studies. In 1959, the Bureau of Public Roads and the Connecticut State Highway Department, in a cooperative study, used the equipment to evaluate the effectiveness of roadside delineation, pavement markings, and a combination of delineation and markings under various conditions of highway illumination.[5] Two comparable sites, an access ramp and an exit ramp, were studied.

Speed, placement, and headway data were obtained for a total of 183,000 motor vehicles for 9 different conditions of delineation and illumination during day and night. Because 2 sets of detectors were used at each ramp, there were, in effect, a total of 72 different study conditions. A high speed electronic computer was employed to analyze the multitude of data for the various conditions and a report was completed by November 1959, or about 4 months after the completion of the field work.

[5] *Traffic operations as related to highway illumination and delineation*, by A. Taragin and B. M. Rudy, Public Roads, vol. 31, No. 3, Aug. 1960, pp. 59–66.

Other areas of study for which the analyzer equipment has been used include: the effect on traffic operation of various shoulder widths and types, the effect of edge markings on traffic operation, lateral placement guides for the AASHO Road Test, effect of median dividers on driver behavior and highway capacity, and the truck equivalent factor on various highways. Presently, the analyzer is being utilized to determine the relative space that small cars occupy in the traffic stream.

Evidence of the reliability and accuracy of the mobile traffic analyzer unit is the fact that traffic researchers throughout the country, when faced with the problem of verifying proposed study procedures, are beginning to rely upon it as "the standard measure" in its field. It is quite apparent that one of the major future uses of the equipment will involve checking of manual, photographic, and other traffic recording techniques. Additional units that embody rather radical changes in design are now under development.

The Effects of Enforcement on Traffic Behavior

(*Continued from page 113*)

routes and was, therefore, an extremely complex section of highway, varying considerably in its geography, intersection characteristics, roadside development, and traffic composition. The interaction of such factors could well lead to a highway system open to a high degree of variability from time to time. In so large a system as 208 miles of highway, a significant change might well occur, independent of any imposition of police patrol. The conclusion from this speculation would then be that test route No. 4 was not influenced by enforcement and the change in variance was due to heterogeneity of the traffic and of the route.

Reliability of speed measurements

A second consideration concerns the reliability of the speed measurements. It was generally assumed in this study that the spot speeds measured on each of these routes were independent samples drawn from a single population of speed and, therefore, these speed distributions were representative of all the highway and all the traffic over all time. A recent study indicated that such an assumption is invalid (*5*). On the contrary, vehicle speed appears to depend upon a wide variety of factors, all of which appear to be time-varying. The inescapable conclusion is that spot speed data are unreliable. Therefore, the meaning of the significant F ratios is severely compromised, for the significance may be due simply to the inflated sample size and not the effect of enforcement.

A third consideration is the nature of drivers' reactions to their awareness of police. From the data it is possible to draw only primitive inferences. Certainly an individual driver's response will be far more complex than what appears in the measurement of either speed or accident data. It will be conditioned upon his physical situation, his attitudes, and the alternatives he perceives to be available to him. These are certainly dynamic influences whose effects under varying traffic conditions are highly unpredictable. To speak, then, of only speed behavior hardly approaches the complex responses inherent in driving or the complex responses of drivers to the presence of police.

Restrictions on the data

The limitations on the interpretation of the data in this study are indicative, for they demonstrate some basic restrictions inherent in the general type of field study. First, they suggest the limited efficiency of many of the measures used in traffic behavior studies. This is especially obvious when the purpose of such studies is to generalize about driver behavior or discriminate between treatments aimed at modifying that behavior. Second, the freedom of response available to drivers is so great that the variability in driver behavior is excessive. Consequently, measurements taken from the roadside on a mass of motorists are often so unreliable that definitive inferences are possible only in very limited situations. Third, the time-varying characteristics of the highway system prevent the establishment of any real experimental control in the field situation. Too many factors are operating to continually modify traffic activity. These factors cannot be controlled by the experimenter with sufficient precision to allow him to draw reliable generalizations about traffic behavior. The present study, then, demonstrates how basically restricted are many types of field studies of traffic behavior.

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(*4*) *The Federal role in highway safety*. H. Doc. 93, 86th Cong., 1st sess., March 1959, pp. 72–73.

(*5*) *Variability of fixed point speed measurements*, by Robert P. Shumate and Richard F. Crowther. The Traffic Institute, Northwestern University, Evanston, Ill., 1959, 101 pp.

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