Effect of Small and Compact Cars On Traffic Flow and Safety

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Time-headways between regular, small, and compact vehicles were used to study the effect of the latter on maximum traffic flow and therefore on highway capacity. Time-lapse photographic recording was the method used. From the records at each location, four complete 5-min samples were read to determine the normal complete distribution of time-headways. The film was then searched for small and compact cars and, for each of these, 4-car groups were recorded to give headways before and behind the smaller vehicle and a comparison headway between two regular vehicles ahead.

Records were made for peak and off-peak periods for six locations. Four of the locations were on Detroit expressways and two were on divided highways in Lansing, Mich.

Statistical analysis included comparison of the expected number of small vehicles with the actual number observed in the lower 15 and higher 15 percent of the time-headway distribution. Chi-square comparisons indicated no statistically significant differences from the expected number.

After eliminating stragglers, time-headway averages for the three different types of cars were compared by means of Fisher's t-function for lanes 1 and 2 at each location, combining lanes 1 and 2 and combining the three locations at which headways were similar. Time-headway differences between the different types of vehicles occurred in the different samples. However, these were not consistent in direction (headways between regular vehicles were not consistently larger or smaller than those including a small or compact vehicle). The differences were not statistically significant.

It was concluded that drivers of both the smaller vehicles and the surrounding standard automobiles operated in both peak and off-peak traffic in a way similar to operation of standard cars. Therefore, no consistent increase or decrease of traffic headways or of highway capacity is to be expected from inclusion of small and compact vehicles in the traffic stream.

There was some indication that time-headways may be of greater significance than distance-headways for certain purposes.

•IN THE LAST four or five years the increasing number of small low-powered European cars and the compact cars developed by U.S. automobile companies appearing on the roads in greater numbers have raised various problems. One of the claims for these cars is greater gasoline economy. Some of those interested in taxation problems have indicated concern about possible effects on gasoline tax income for highways. The questions have been raised, therefore, whether the smaller vehicles use a smaller, equal, or larger share of the highway because of their operating characteristics and the reactions of their own drivers and drivers of standard-size vehicles in the traffic stream.

As the proportion of smaller vehicles increases, it would be desirable to know enough about their effect on traffic flow to be able to predict whether they will increase, decrease, or leave unaffected the maximum capacity of highways, especially of the more expensive, free-flowing freeway design type of highways.

In addition to these questions, some have expressed opinions that the smaller vehicles introduce greater accident hazards on highways because of reduced visibility from within, and greater difficulty by other drivers in seeing the vehicle or seeing through it to other vehicles in the traffic stream. On the other hand, others have held that the small vehicles are as safe, or safer, because of greater maneuverability and because other drivers can see over them to other vehicles in the traffic stream. If either of these opinions represent an influence strong enough to affect the driving behavior of those operating the smaller vehicles or of the regular vehicles surrounding them, this should be reflected in vehicle spacings or headways while operating in traffic.

METHOD

If the small and compact vehicles are using more or less than their share of highway, a study of vehicle spacing and time-headways at different speeds should indicate this. The especially critical times for the problem would be those during the peak traffic flow when capacity of the highway is being taxed to the utmost. However, it is possible that in the off-peak periods any possible visibility hazard from the small cars felt by their own or other drivers might be indicated by headways during the lighter traffic hours.

Therefore, as a means of investigating the problem, a study of time and distance-headways was carried out using data from four expressway locations in Detroit and two divided highway locations in Lansing, Mich. Traffic flow was recorded for a minimum of eight hours on each of two days at the four Detroit locations from 7:00 to 11:00 AM and from 2:00 to 6:00 PM (with minor variations occasioned by different conditions). Thus, both morning and afternoon peak flow as well as off-peak flow were recorded.

The two Lansing locations were on divided highways near the downtown business section, using afternoon outbound traffic to get as heavy a flow as possible. It was found that only the peak hours from about 3:00 to 6:00 PM gave high enough volumes for the recorded headways to be of significance in reflecting driver judgments. Therefore, from three to four such periods were recorded. Some off-peak flow was also recorded but was so sparse that an analysis was not worthwhile. At both of these locations a traffic signal at a preceding intersection served to group or bunch up traffic so that it flowed through the experimental zone in close formation. (Distance from preceding signal to first marker was approximately 650 ft at Saginaw and 900 ft at S. Cedar locations.) These locations were used to see whether any markedly different relationships in the headways would be shown in such traffic.

Recording was accomplished by time-lapse photography from an overhead bridge, using a method reported previously (1). Three pairs of reference marks were painted on the gutter and curb of one side of the divided highway. A 16-mm camera with electronic timer was positioned on a bridge at the selected locations, each of which used straight and nearly level highway where possible. (Where a grade was present, corrections for it were included when the analysis grid was calculated.) Measurements for three pairs of reference marks at 100-ft intervals on the pavement edge and the distance and the elevation to the camera were surveyed in. Each reference mark was a white painted stripe about 2 ft wide and from 2 to 4 ft long. It did not extend into the roadway much beyond the gutter section. This is of importance to prevent drivers from feeling that something special is going on at this particular location and, therefore, altering their driving behavior. The short stripes on either side of the roadway were hardly noticeable from a car unless given special attention. In attention, the camera was always located on the far side of the bridge in the direction of flow so as to record the rear of the vehicles as they progressed away from the bridge. This, again, reduced driver attention to the camera equipment.

A few people coming in the opposite direction and using the cross-street stopped to ask what was going on. When told that "this was a traffic survey," they usually did not tarry.

EXPERIMENTAL LOCATIONS

Of the four freeway locations in Detroit, three were outbound (at Grand Boulevard, eastbound; Seward, northbound; and Addison, westbound) and one was inbound (at the Lonyo overpass which is near Edison Street). Thus, for the most part, traffic was flowing in such a direction as to disperse rather than back up because of congestion in downtown areas ahead. At one location on the Edsel Ford Freeway, there was both an inbound and an outbound location close together (Lonyo and Addison).

The Detroit Expressway records were made on two weekdays at each location during August and September 1960. Recording at the Lansing locations was during the winter of 1960 and spring of 1961. In each case, traffic flow was recorded only during clear, dry weather to eliminate possible effects from wet pavement and other weather conditions.

ANALYSIS OF RECORDS

Measurements from Film Record

The film records consisted of time-lapse photographs taken at 1-sec intervals for a total of 8 hr on each of two days at the Detroit locations. This totaled approximately five 100-ft rolls of 16-mm pictures each day for two days at each of four locations. Thus, a total of 4,000 ft of time-lapse photographic records resulted. At the Lansing locations, a total of five 100-ft rolls at each location, or 1,000 ft of photographic record, were obtained.

From these records, distances and speeds were obtained from the film by the method of Forbes and Fairman (1). In this method, a grid is calculated which eliminates the parallax error as the picture is projected to determine distances on a grid. By placing the grid on a darkroom floor, the photographic records were projected with considerable elongation so as to improve the accuracy of reading. With proper care in construction of the grid and lining up the projected pictures with the painted reference marks, vehicle positions at each 1-sec interval can be read to plus or minus 1-ft accuracy, as shown previously. Accuracy was checked for each location by means of a test vehicle using a fifth wheel and calibrated recorder.

Three positions of each vehicle were read, giving an average speed accurate to about plus or minus 1 mph. The time at which each vehicle passed an arbitrary zero point was calculated from the position and speed of each vehicle. The time-headway between each vehicle and the vehicle ahead was then obtained for the zero location. (see Fig. 1).

Four teams of students working in pairs recorded the vehicle positions. One man controlled the film advance using the remote control of a perceptoscope projector. The second student recorded the frame count and vehicle positions.

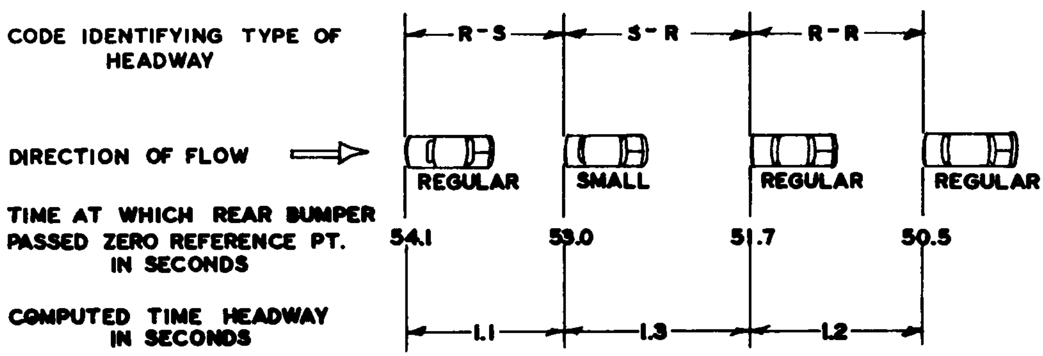


Figure 1. Time-headways within a four-car group.

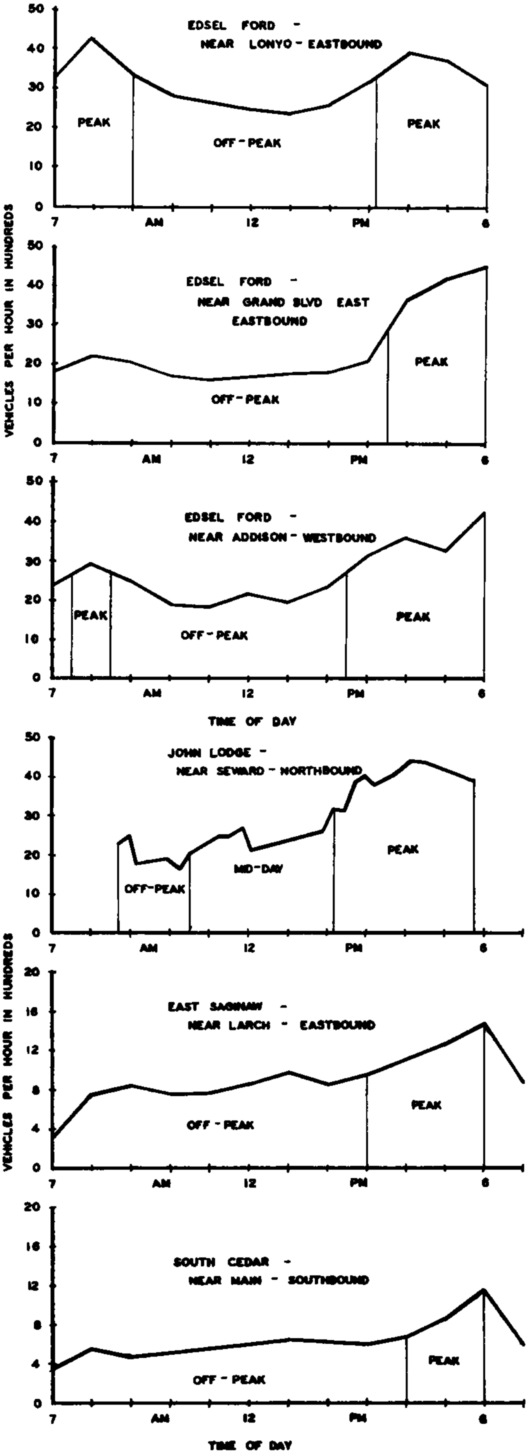


Figure 2. Traffic volumes by hours showing times of peak samples.

Continuous Samples

Vehicles in lane 1 (nearest the median) and lane 2 only were recorded, because the outermost lanes of the six- or eight-lane expressway at Detroit locations were more likely to involve weaving and other disturbances to traffic flow from outgoing or incoming vehicles.

At one location, one complete 5-min sample was read from each 15-min interval (the camera was ordinarily operated for 10 min of each 15, thus allowing a 5-min break for changing of film when necessary and making other checks of camera and timer operation). At other locations, two complete 5-min samples were recorded from peak hours and two from off-peak hours. For the two Lansing locations, four complete 5-min samples were recorded from peak-hour flow only. Figure 2 shows traffic volume curves and times of day from which peak and off-peak samples were selected.

The 5-min samples were used to establish a base distribution for later comparisons. Lanes 1 and 2 were read separately to avoid possible confusion in calling off position of cars in the two different lanes; i.e., after lane 1 was completed, lane 2 was read.

Four-Car Groups

In addition to the continuous samples, the complete film record for the Detroit locations and the complete record for the 3:00 to 6:00 period at the Lansing location were searched systematically for small and compact cars. For this purpose, the classification of the U.S. Department of Commerce Bureau of Public Roads for small and compact vehicles was used.

When a small or a compact vehicle appeared as the film was stepped along by means of the single-frame control, its position, the position of the cars immediately ahead and behind it and the position of a second standard vehicle ahead of it were recorded. This resulted in data from which speed, time-headway, and distance-headway were calculated between small and regular car ahead (S-R), regular following small (R-S), and between two standard-size cars (R-R) leading the small vehicle. A similar set of data resulted for each compact vehicle and the standard-size vehicles ahead and behind it.

A program was developed for a digital computer to carry out these routine calculations on the data recorded from the film. The correctness of the program was checked against some samples of data in which calculations were carried out by hand as a double-check.

ASSUMPTIONS AND HYPOTHESES

To obtain from the data answers to the questions posed in the problem statement, it was necessary to set up and test statistically certain hypotheses. Before this could be done, however, certain assumptions were necessary.

Assumptions

Necessary assumptions included the following:

1. Traffic flow and characteristics such as speed and headways between vehicles would be different under peak traffic conditions from that under off-peak lighter volume conditions.
2. Traffic flow characteristics would be generally similar within off-peak and within peak traffic periods (excluding any period during which actual stagnation and self-blocking of traffic was beginning to occur).
3. Driver reactions to vehicles ahead will affect speeds and time-headways when vehicles are operating close together under maximum volume conditions and/or in groups or "platoons."
4. Under heavy traffic volume conditions, at least, and to some extent in lighter volume conditions, the 85 percentile time-value determined from the distribution for a complete sample will furnish a division point beyond which vehicles may be considered as straggling between platoons. Such a method of determining platoons proved sufficiently valid for practical purposes in a previous study (2).

Hypotheses to Be Tested

The hypotheses required were the following:

1. A sample of four-car groups taken throughout the film wherever a small car or a compact car is found will give distributions generally similar to those from a continuous sample (but with equal numbers of each type of headway).
2. If small or compact vehicles use less or more than their share of the roadway, the average time-headway or distance-headway will be smaller or greater than that for a sample of standard-size vehicles taken at the same time and location as the small or compact car headways. Differences must be statistically significant (i.e., greater than chance expectancy) and also consistent in direction to be meaningful.
3. If visibility or other factors related to smaller vehicles present a hazard felt by drivers, then time and distance-headways used by those drivers should be longer as a result of their automatic and possibly unconscious reaction to such a feeling of hazard.

ANALYSIS OF DATA

The basic analysis was in terms of time-headways, because these represent an important index of driver response and involve both distance-headways and speed.

Continuous 5-Min Samples

Continuous 5-min samples were analyzed to show (a) range of time-headways; (b) expected proportion of vehicles at short and long (headway) ends of the distributions; and (c) whether small and compact vehicle-headways occurred at the two ends of the distribution consistently more or less frequently than expected.

For each continuous 5-min sample, time-headway distributions were tabulated by 0.2-sec intervals for regular cars (R-R) and each of the other combinations of small and compact cars (S-R, R-S, C-R, R-C). The time-headways between regular vehicles constituted the largest distribution because of the greater number of such cars in the stream. From each continuous distribution, the 85 percentile time-value was determined and also the 15 percentile time-value. Using these time-values, the expected number of small or compact cars in each end of the distribution was determined, using the headways between small and compact cars in these same distributions. A comparison was made by means of the χ^2 technique of the number of small car and compact car headways above the 85 percentile and below the 15 percentile time-value as compared to the expected number.

Four-Car Group Headways

The time-headways from the four-car group samples were analyzed to show (a) whether the samples so obtained differed from the continuous distributions significantly at either the short or long (headway) end of the distribution; and (b) whether, after elimination of stragglers, small and compact car average headways differed consistently from those between standard cars at the same time and place to a statistically significant extent.

From the four-car groups, time-headway distributions were tabulated by 0.2-sec intervals of R-R, S-R, and R-S headways. In each such distribution, the number falling below the 15 percentile and above the 85 percentile of the appropriate complete 5-min distribution of R-R headways was compared with the expected number based on continuous distribution for the same location and type of traffic flow. Differences were tested for greater than chance occurrence by the χ^2 technique.

Stragglers between platoons were eliminated by using as a cut-off point the 85 percentile time-headway of the appropriate continuous 5-min samples. Each of the four-car group samples was then scrutinized for all groups in which the S-R and R-S headways were both greater than the appropriate 85 percentile time-value. Where both were greater it was assumed that the small car was neither leading nor ending a platoon but was actually between platoons. Therefore, the two headways involving it and the accompanying R-R headway were all eliminated from the comparisons. Similarly, stragglers in the four-car groups involving compact cars were eliminated, because the drivers would not be judging position on the car ahead.

Next, each set of four-car headways for each location separately by peak and off-peak traffic periods was compared by Fisher's t-test to determine whether the average time-headways between S-R, R-S, and their corresponding R-R vehicle pairs showed statistically significant differences.

Time-Headways, Distance-Headways and Speed

For certain samples, time-headways, distance-headways and speeds were analyzed graphically to determine (a) relationships of each type of headway to speeds; and (b) whether time and distance-headways showed any markedly different relationships to each other or to speeds.

Time-headways and distance-headways for certain of the four-car groups were plotted against each other and the corresponding vehicle speed lines were drawn in on these plots. In this way, it was possible to see whether the two kinds of headway showed any noticeably different relationships and how both types of headways were related to vehicle speeds.

In addition, for several of the peak-hour, continuous 5-min samples, average values of speed, time-headway and distance-headway were computed for individual platoons. The time-headway and distance-headway values were then plotted by platoons, identifying those platoons in which small cars appeared. Thus, it was possible to see whether the inclusion of a small or compact car within a platoon resulted in any major difference in headway values or whether platoons containing such cars were in any way different from the others in the sample.

RESULTS

Continuous 5-Min Samples

The continuous 5-min samples gave a basis for evaluating the validity of other samples and of determining cut-off points for stragglers, as indicated under description of statistical analysis. Distributions were developed for three Detroit locations thrown together and for a fourth which differed from these. Other distributions were developed for the time-headways at the two locations in Lansing. Such distributions were developed both for peak-hour traffic and for off-peak traffic.

The most frequent time-headways under peak traffic conditions were consistently in the 1.0- to 1.35-sec range. In Lansing, where traffic was lighter, there was more straggling toward the long headways than in the heavier volume traffic in Detroit.

From these distributions, the percentage of small and compact cars in the samples were determined (Table 1). These proportions in Detroit ranged from 1.8 to 3.8 percent. At the Lansing locations during peak hours these proportions ranged from 0.6 to 5.0 percent. Off-peak traffic at these locations was relatively light, and this analysis was not carried out, but proportions were probably similar.

Small and Compact Cars in Ends of Distribution

From the continuous distributions, the expected number of small cars vs those actually occurring in the distribution was compared. The expected number below the 15 percentile and above the 85 percentile point was determined from the distribution of standard car headways. Table 2 shows that χ^2 analyses indicated no differences large enough to invalidate the hypothesis that the occurrence of the small and compact cars was similar to that of the standard car headways in the distribution.

TABLE 1

SUMMARY OF PROPORTION OF SMALL AND COMPACT CARS IN 5-MIN SAMPLES, LANES 1 AND 2 COMBINED

City	Street	All Cars	Peak Traffic				All Cars	Off-Peak Traffic[a]				All Cars	Total Traffic and Peak			
			Compact		Small			Compact		Small			Compact		Small	
			No	%	No	%		No	%	No	%		No	%	No	%
Detroit	Seward	658	20	3 03	15	2 28	293	7	2 39	7	2 39	951	27	2 84	22	2 31
	Lonyo	425	10	2 4	16	3 8	329	9	2 7	7	2 1	754	19	2 5	23	3 1
	Grand Blvd	611	11	1 8	21	3 44	235	8	3 4	6	2 56	846	19	2 24	27	3 20
	Addison	525	13	2 5	11	2 1	216	7	3 2	4	1 9	741	20	2 7	15	2 0
	Total	2,219	54	2 43	63	2 84	1,073	31	2 89	24	2 24	3,292	85	2 58	87	2 64
Lansing	Cedar	498	11	2 2	3	0 6										
	Saginaw	564	16	2 8	28	5 0										
	Total	1,062	27	2 54	31	2 92										

[a]For Lansing, traffic was light, therefore, not analyzed

TABLE 2

SMALL AND COMPACT VEHICLES IN ENDS OF DISTRIBUTIONS OBSERVED VS EXPECTED IN 5-MIN SAMPLES

Street	Type of Distribution	Number	Obs	Exp	χ^2	Significant at α = 0 01	Significant at α = 0 05
Seward, Grand Blvd and Lonyo[1]	Below 15%						
	C-R	41	8	6	0 78	No	No
	R-C	41	6	6	0	No	No
	S-R	48	11	7	2 67	No	No
	R-S	52	11	8	1 33	No	No
	Above 85%						
	C-R	41	4	6	0 78	No	No
	R-C	41	10	6	3 12	No	No
	S-R	48	11	7	2 67	No	No
	R-S	52	11	8	1 33	No	No
Saginaw	Below 15%						
	C-R	16	1	2	0 57	No	No
	R-C	15	4	2	2 31	No	No
	S-R	28	3	4	0 29	No	No
	R-S	27	4	4	0	No	No
	Above 85%						
	C-R	16	4	2	2 29	No	No
	R-C	15	1	2	0 58	No	No
	S-R	28	5	4	0 29	No	No
	R-S	27	7	4	2 64	No	No
Addison and S Cedar[2]							

[1]Individual location frequencies per cell too small for valid χ^2
[2]Frequencies per cell too small for valid χ^2

TABLE 3

SMALL AND COMPACT VEHICLES IN ENDS OF DISTRIBUTION—4-CAR GROUPS, NUMBER OF SMALLER VEHICLES OBSERVED IN 4-CAR SAMPLES VS NUMBER EXPECTED FROM 5-MIN SAMPLES[1]

Street	Period	Lane	Headway Type	15 Percentile					85 Percentile			
				N	E	O	χ^2	Signif Level	E	O	χ^2	Signif Level
Seward	Peak	1	R-R (all)	312	47	43	0.40		265	245	10.02	0.01
			R-R (small)	120	18	16	0.26		102	94	4.19	
			S-R	120	18	19	0.07		102	99	0.59	
			R-S	120	18	16	0.26		102	103	0.07	
			R-R (compact)	192	29	27	0.16		163	151	5.85	0.05
			C-R	192	29	33	0.65		163	152	4.91	
			R-C	192	29	28	0.04		163	151	5.85	0.05
	Peak	2	R-R (all)	313	47	23	14.42	0.01	266	266	0	
			R-R (small)	121	18	8	6.55	0.05	103	104	0.07	
			S-R	121	18	9	5.29	0.05	103	100	0.59	
			R-S	121	18	4	12.76	0.01	103	97	2.35	
			R-R (compact)	192	29	14	9.14	0.01	163	163	0	
			C-R	192	29	12	11.73	0.01	163	160	0.37	
			R-C	192	29	10	14.66	0.01	163	175	5.84	0.05
	Off-peak	1	R-R (all)	73	11	10	0.11		62	60	0.42	
			R-R (small)	26	4	3	0.30		22	22	0	
			S-R	26	4	4	0		22	22	0	
			R-S	26	4	4	0		22	23	0.30	
			R-R (compact)	47	7	6	0.17		40	38	0.67	
			C-R	47	7	7	0		40	43	1.51	
			R-C	47	7	8	0.17		40	42	0.67	
	Off-peak	2	R-R (all)	83	12	15	0.98		71	70	0.10	
			R-R (small)	33	5	6	0.24		28	26	0.94	
			S-R	33	5	4	0.24		28	29	0.24	
			R-S	33	5	7	0.94		28	28	0	
			R-R (compact)	50	8	9	0.15		42	44	0.60	
			C-R	50	8	8	0		42	44	0.60	
			R-C	50	8	6	0.60		42	46	2.38	
Lonyo	Peak	1	R-R (all)	308	46	41	1.49		262	284	12.35	0.01
			R-R (small)	153	23	17	1.84		130	145	11.53	0.01
			S-R	153	23	27	0.82		130	144	10.04	0.01
			R-S	153	23	18	1.38		130	137	2.51	
			R-R (compact)	155	23	24	0.05		132	139	2.50	
			C-R	155	23	20	0.46		132	140	3.27	
			R-C	155	23	20	0.46		132	135	0.46	
	Peak	2	R-R (all)	338	51	53	0.09		287	291	0.37	
			R-R (small)	176	26	28	0.180		150	153	0.406	
			S-R	176	26	33	2.21		150	153	0.41	
			R-S	176	26	25	0.05		150	154	0.72	
			R-R (compact)	162	24	25	0.048		138	138	0	
			C-R	162	24	31	2.40		138	133	1.22	
			R-C	162	24	26	0.20		138	136	0.20	
	Off-peak	1	R-R (all)	105	16	13	0.66		89	98	5.96	0.05
			R-R (small)	45	7	4	1.52		38	40	0.68	
			S-R	45	7	7	0		38	39	0.17	
			R-S	45	7	2	4.24		38	37	0.17	
			R-R (compact)	60	9	2	6.40	0.05	51	53	0.52	
			C-R	60	9	6	1.18		51	55	2.09	
			R-C	60	9	9	0		51	56	3.27	
	Off-peak	2	R-R (all)	169	25	38	7.93	0.01	144	154	4.69	
			R-R (small)	80	12	17	2.45		68	71	0.88	
			S-R	80	12	18	3.53		68	71	0.88	
			R-S	80	12	11	0.09		68	71	0.88	
			R-R (compact)	89	13	21	5.77	0.05	76	83	4.42	
			C-R	89	13	23	9.02	0.01	76	85	7.29	0.05
			R-C	89	13	12	0.09		76	79	0.81	
Grand Blvd	Peak	1	R-R (all)	216	32	25	1.80		184	207	19.41	0.01
			R-R (small)	121	18	15	0.59		103	115	9.40	0.01
			S-R	121	18	21	0.59		103	117	12.79	0.01

			R-S	121	18	22	1 05		103	115	9 40	0.01
			R-R (compact)	95	14	10	1 34		81	92	10.13	0 01
			C-R	95	14	11	0 75		81	92	10 13	0 01
			R-C	95	14	16	0 34		81	92	10 13	0 01
	Peak	2	R-R (all)	185	28	50	20 36	0 01	157	162	1 05	
			R-R (small)	91	14	23	6 84	0 05	77	82	2 11	
			S-R	91	14	24	8 44	0 01	77	74	0 76	
			R-S	91	14	27	14 26	0 01	77	79	0 34	
			R-R (compact)	94	14	27	14 88	0 01	80	80	0 00	
			C-R	94	14	22	5.37	0.05	80	81	0 03	
			R-C	94	14	20	3 02		80	75	2 10	
	Off-peak	1	R-R (all)	219	33	36	0 32		186	201	8 03	0 01
			R-R (small)	120	18	19	0.07		102	109	3 20	
			S-R	120	18	31	11.05	0 01	102	112	6 54	0 05
			R-S	120	18	21	0 59		102	108	2.35	
			R-R (compact)	99	15	17	0 32		84	92	3 32	
			C-R	99	15	22	3.85		84	92	5 03	0.05
			R-C	99	15	12	0.71		84	89	1 97	
	Off-peak	2	R-R (all)	221	33	22	0 04		188	208	14.25	0.01
			R-R (small)	132	20	20	0 00		112	129	17 03	0.01
			S-R	132	20	19	0 06		112	115	0 53	
			R-S	132	20	23	0.53		112	121	4 77	
			R-R (compact)	89	13	12	0 09		76	79	0 80	
			C-R	89	13	20	4 41		76	76	0.00	
			R-C	89	13	20	4 41		76	82	3 24	
Addison	Peak	1	R-R (all)	308	46	53	1.25		262	251	3 09	
			R-R (small)	157	24	26	0 20		133	127	1 77	
			S-R	157	24	23	0 05		133	131	0.20	
			R-S	157	24	26	0.20		133	126	2 41	
			R-R (compact)	151	23	27	0 82		128	124	0.82	
			C-R	151	23	33	5 13	05	128	120	3 28	
			R-C	151	23	16	2 15		128	126	0.20	
	Peak	2	R-R (all)	176	26	22	0 72		150	147	0.42	
			R-R (small)	98	15	14	0 08		83	82	0 08	
			S-R	98	15	9	2 83		83	75	5 04	0 05
			R-S	98	15	15	0		83	82	0 08	
			R-R (compact)	78	12	8	1 57		66	65	0 10	
			C-R	78	12	6	3 54		66	63	0 89	
			R-C	78	12	6	3 54		66	62	1 57	
	Off-peak	1	R-R (all)	86	13	9	1 45		73	74	0 09	
			R-R (small)	32	5	5	0.00		27	28	0 24	
			S-R	32	5	4	0.24		27	29	0 95	
			R-S	32	5	2	2.13		27	31	3 79	
			R-R (compact)	54	8	4	2 35		46	46	0 00	
			C-R	54	8	5	1 32		46	50	2.35	
			R-C	54	8	8	0		46	53	7 18	0 05
	Off-peak	2	R-R (all)	71	11	8	0 97		60	65	2 69	
			R-R (small)	41	6	6	0 00		35	36	0 20	
			S-R	41	6	2	3.13		35	39	3 13	
			R-S	41	6	3	1 76		35	37	0 77	
			R-R (compact)	30	4	2	1 15		26	29	2 60	
			C-R	30	4	4	0.00		26	26	0.00	
			R-C	30	4	2	1 15		26	25	0.29	
Cedar	Peak	1	R-R (all)	63	9	11	0.519	0 05	54	62	8.28	0 01
			R-R (small)	23	3	2	0.383		20	22	1 83	
			S-R	23	3	2	0.383		20	21	0 383	
			R-S	23	3	1	1 53		20	18	1.53	
			R-R (compact)	40	6	9	1 315		34	40	7 06	0 05
			C-R	40	6	7	0.22		34	36	0 86	
			R-C	40	6	7	0 22		34	34	0	
	Peak	2	R-R (all)	75	11	11	0		64	71	5.22	0.05
			R-R (small)	32	5	3	0.95		27	30	2.10	
			S-R	32	5	5	0		27	28	0.24	
			R-S	32	5	3	0.95		27	26	0.24	
			R-R (compact)	43	6	8	0.77		37	41	3.10	
			C-R	43	6	5	0.19		37	36	0.19	
			R-C	43	6	4	0.77		37	30	9 50	0.01

[1] No off-peak pictures analyzed.

Small and Compact Vehicles in End of Distribution in 4-Car Groups

To test roughly whether the 4-car groups produced a total sample similar to the continuous samples, the number of time-headways falling above and below the 15 percentile time value determined from the continuous samples was submitted to χ^2 comparison. Table 3 shows that when these comparisons were made by lane for each of the locations a few significant differences were found in nine sets of comparisons, but these were not consistent within each lane, type of headway, and location nor between locations. The remainder were not statistically significant.

This inconsistency and lack of statistical significance leads to the conclusion that there were some variations between the distributions derived from the 4-car samples and the continuous distributions but that they were not consistent nor great enough to invalidate use of the samples derived from the 4-car groups. Therefore, it seemed that no great violence would be done by using these samples and by using a cut-off point for stragglers determined by means of the 85 percentile time-value from the continuous distributions.

Comparison of Averages for Headway Types

After eliminating stragglers, as described earlier, comparison of averages for time-headways at each location by lane for each type of vehicle combination was carried out by means of Fisher's t-function. A summary of the results is given in Table 4. These results indicate that although some of the differences in mean time-headways were on the order of 10 to 15 percent, others were negligible, and very few were significant at the 0.01 probability level. The values for lanes 1 and 2 were then combined in the summary table which shows that in the combined comparisons one was significant at the 0.01 level and three between this and the 0.05 level. Furthermore, the direction of the differences, as shown by plus and minus signs, was not consistent in the different samples. Therefore, time-headway differences between different types of vehicles were not great enough nor consistent enough in direction to indicate a true difference (greater than might be obtained by chance).

Over-All Time-Headways

To summarize concisely and show how similar the peak-hour time-headway values were, over-all averages were computed as shown in Table 5 for peak-hour, 4-car group samples (stragglers eliminated). The number of headways from which each average was determined is shown in the R⟶R columns. Averages for small car headways and headways between standard cars taken immediately following the small car headways are shown on the left side part of the table. A similar set of time-headway averages is shown for compact cars and the comparison standard car headways for each of the compact cars on the right side of the table. Here again, the direction of differences varies in the different samples but the average value ranges from 1.67 to 2.22 sec in the peak-hour traffic in Detroit. The peak-hour traffic at the Lansing locations showed greater variability, which would be expected from the more dispersed characteristic and the lighter volume at these locations.

Off-Peak Time-Headways

Average time-headways for the off-peak traffic have not been given in the over-all average table nor in the preceding comparison of averages. These average time-headways were more variable and differences between types showed less consistency and statistical significance than the peak-hour headways. Therefore, no statistically significant differences between headways involving standard and smaller vehicles were shown in off-peak traffic.

Time, Distance and Speed by Platoons in Continuous Samples

To investigate relationships between time-headway and distance-headway in relation to platoon speeds, average values were calculated and plotted.

TABLE 4

COMPARISON OF AVERAGES FOR HEADWAY TYPES t - VALUES, FOUR-CAR GROUPS, PEAK TRAFFIC, LANES 1 AND 2 COMBINED

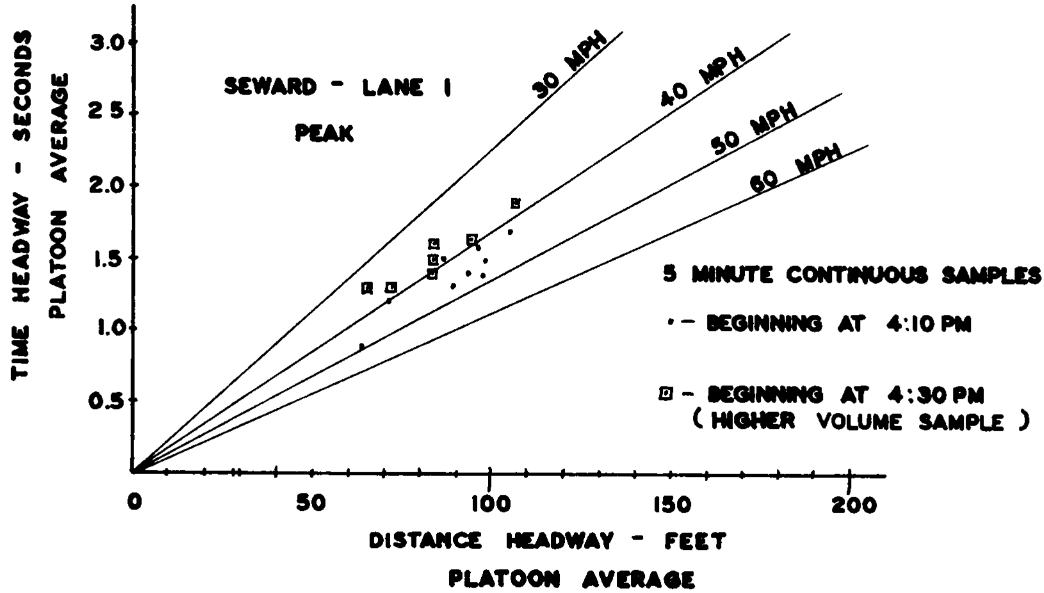
Street	Headway Type	$\bar{X}_1$	$\bar{N}_2$	X_2	N_2	$\bar{X}_1-\bar{X}_2$	t	Signif. Level
Seward	(S-R) vs (R-S)	1.774	232	1.794	232	-0.020	-0.186	
	(S-R) vs (R-R)	1.774	232	1.894	232	-0.120	-1.063	
	(R-S) vs (R-R)	1.794	232	1.894	232	-0.100	-0.906	
	(C-R) vs (R-C)	1.850	372	1.690	372	+0.160	+1.824	0.05
	(C-R) vs (R-R)	1.850	372	1.964	372	-0.114	-1.074	
	(R-C) vs (R-R)	1.690	372	1.964	372	-0.274	-2.881	0.01
Gr. Blvd.	(S-R) vs (R-S)	1.791	206	1.676	206	+0.115	+1.105	
	(S-R) vs (R-R)	1.791	206	1.727	206	+0.064	+0.629	
	(R-S) vs (R-R)	1.676	206	1.727	206	-0.051	-0.578	
	(C-R) vs (R-C)	1.909	187	1.752	187	+0.157	+1.375	
	(C-R) vs (R-R)	1.909	187	1.672	187	+0.237	+1.841	0.05
	(R-C) vs (R-R)	1.752	187	1.672	187	+0.080	+0.672	
Lonyo	(S-R) vs (R-S)	1.972	325	2.168	325	-0.196	-1.530	
	(S-R) vs (R-R)	1.972	325	2.050	325	-0.078	-0.629	
	(R-S) vs (R-R)	2.168	325	2.050	325	+0.118	+0.866	
	(C-R) vs (R-C)	2.092	310	2.158	310	-0.066	-0.523	
	(C-R) vs (R-R)	2.092	310	2.220	310	-0.128	-0.853	
	(R-C) vs (R-R)	2.158	310	2.220	310	-0.062	-0.407	
Seward, Gr. Blvd. and Lonyo	(S-R) vs (R-S)	1.863	763	1.921	763	-0.058	-0.826	
	(S-R) vs (R-R)	1.863	763	1.915	763	-0.052	-0.753	
	(R-S) vs (R-R)	1.921	763	1.915	763	+0.006	+0.084	
	(C-R) vs (R-C)	1.949	869	1.870	869	+0.079	+1.229	
	(C-R) vs (R-R)	1.949	869	1.993	869	-0.044	-0.577	
	(R-C) vs (R-R)	1.870	869	1.993	869	-0.123	-1.667	0.05
Addison	(S-R) vs (R-S)	2.226	237	2.107	237	+0.119	+0.712	
	(S-R) vs (R-R)	2.226	237	2.311	237	-0.085	-0.376	
	(R-S) vs (R-R)	2.107	237	2.311	237	-0.204	-0.928	
	(C-R) vs (R-C)	2.169	215	2.346	215	-0.177	-0.535	
	(C-R) vs (R-R)	2.169	215	2.213	215	-0.044	-0.168	
	(R-C) vs (R-R)	2.346	215	2.213	215	+0.133	+0.440	
S. Cedar	(S-R) vs (R-S)	5.109	54	5.380	54	-0.271	-0.228	
	(S-R) vs (R-R)	5.109	54	3.728	54	+1.381	+1.190	
	(R-S) vs (R-R)	5.380	54	3.728	54	+1.652	+1.524	
	(C-R) vs (R-C)	3.672	79	5.867	79	-2.195	-1.985	0.025
	(C-R) vs (R-R)	3.672	79	4.333	79	-0.661	-0.846	
	(R-C) vs (R-R)	5.867	79	4.333	79	+1.534	+1.329	

TABLE 5

SUMMARY OF OVER-ALL AVERAGE TIME-HEADWAYS, SMALL, COMPACT AND REGULAR CAR HEADWAYS, FOUR-CAR GROUPS, PEAK TRAFFIC, LANES 1 AND 2, TOTAL OBSERVATIONS

City	Street	Time-Headway (sec)			No. of Observ.	Time-Headway (sec)			No. of Observ.
		R→R	R→S	S→R		R→R	R→C	C→R	
Detroit	Seward	1.894	1.794	1.774	232	1.964	1.690	1.850	372
	Grand Blvd. E	1.727	1.676	1.791	206	1.672	1.752	1.909	187
	Lonyo	2.050	2.168	1.972	325	2.220	2.158	2.092	310
	Above 3 locations	1.915	1.921	1.863	763	1.993	1.870	1.949	869
	Addison	2.311	2.107	2.226	237	2.213	2.346	2.169	215
Lansing	S. Cedar	3.728	5.380	5.109	54	4.333	5.867	3.672	79
	Saginaw[a]								

[a]No 4-car group sample.



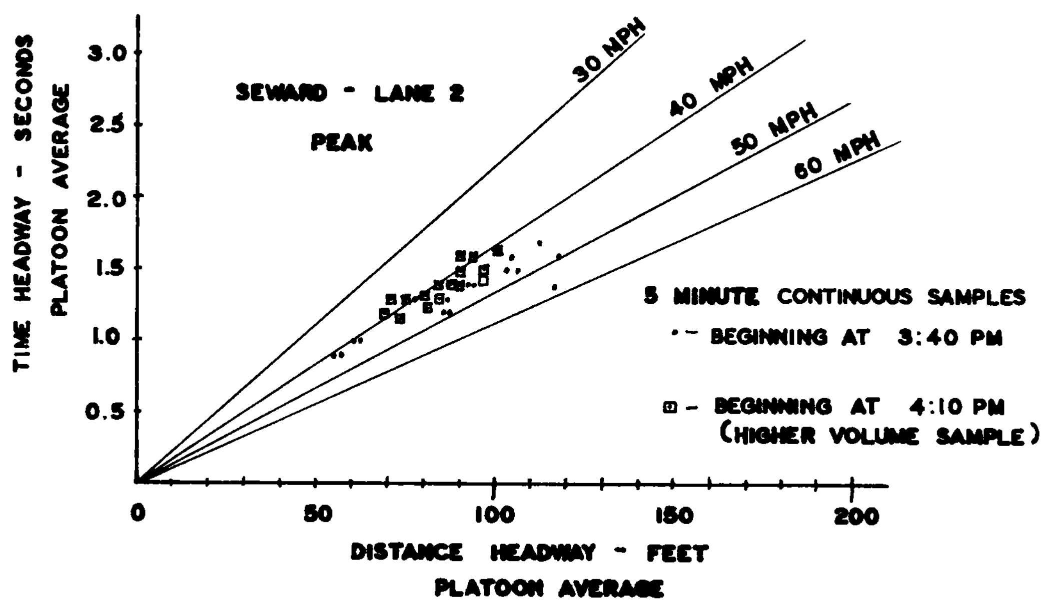
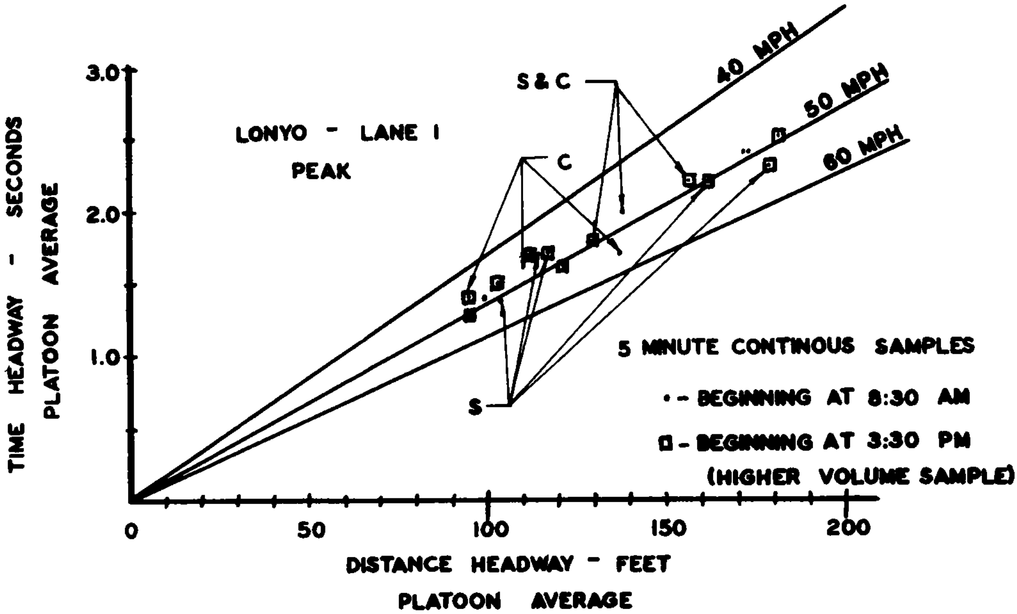


Figure 3. Average headways and speeds by platoons—John Lodge Expressway at Seward (outbound).



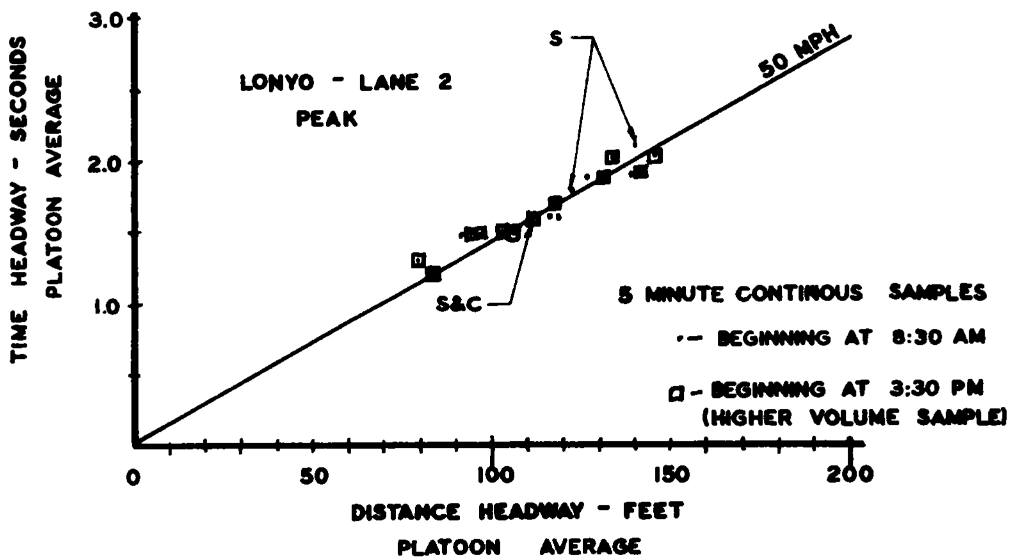
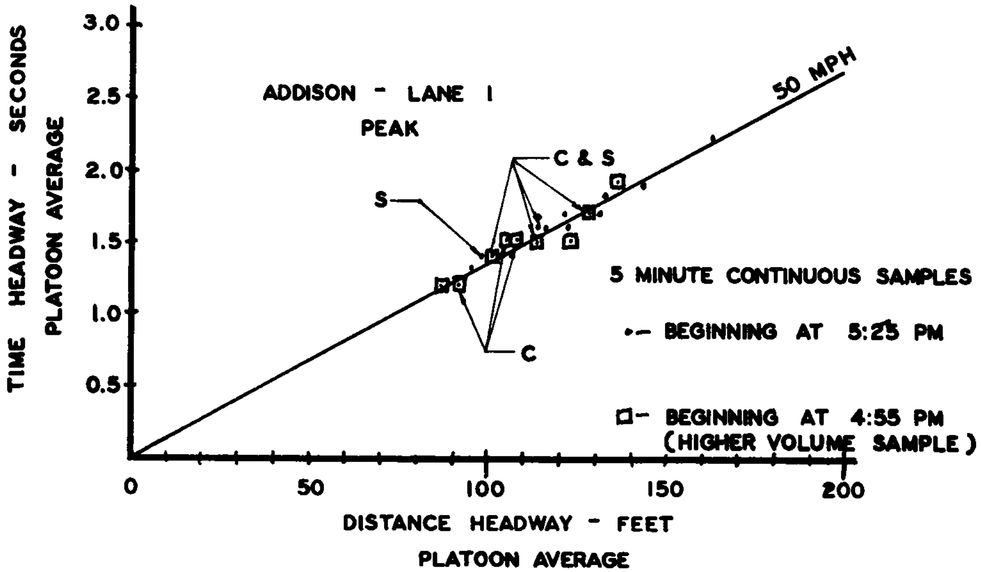


Figure 4. Average headways and speed by platoons—Edsel Ford Expressway at Lonyo (inbound), 5-min continuous samples.



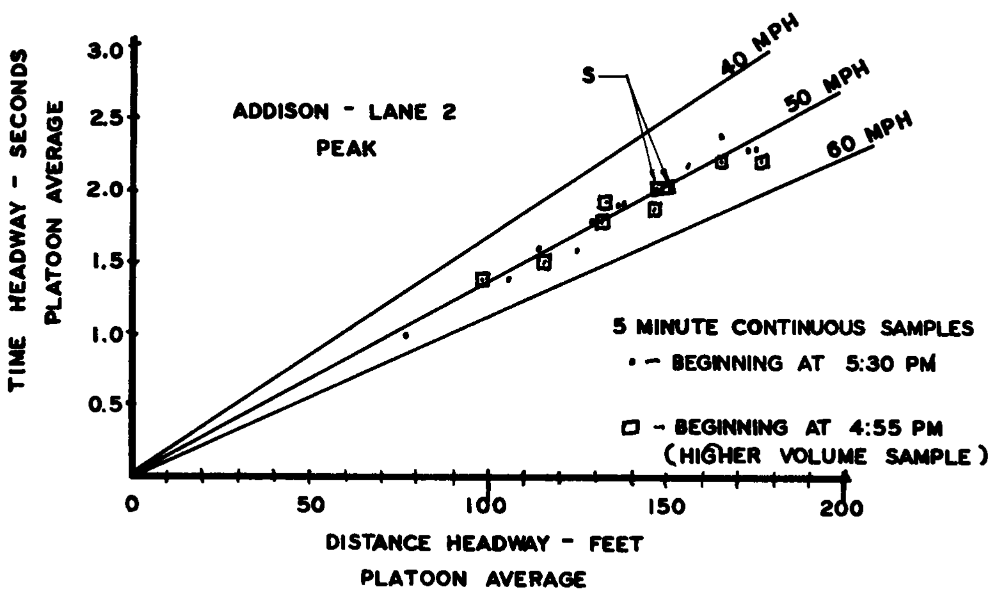


Figure 5. Average headways and speed by platoons—Edsel Ford Expressway at Addison (outbound), 5-min continuous samples.

Figures 3, 4, and 5 show plots of time-headways vs distance-headways by platoons in two 5-min samples at three Detroit locations. The lines radiating from the origin in this plot represent 40-, 50-, and 60-mph speeds and platoons including small and compact cars have been identified.

A linear relationship between average distance-headway and average time-headway for the platoons is shown at two of the locations. The plotted points cluster closely around the 50-mph speed line. At the third location (Seward) more slowing occurred, as shown by the tendency for plotted points to range between the 50- and the 30-mph line. However, there was very little indication of a curvilinear relationship, except possibly in the plot for the Seward Avenue bridge from which northbound large expressway traffic was recorded.

Time, Distance and Speed Analysis for Cars in 4-Car Groups

To determine briefly in graphic fashion the relationship between individual time-headways, distance-headways, and speed of the vehicles, two types of headways for the three combinations of vehicles (R-R, R-S, and S-R) were tabulated. Figure 6 shows the plot of average ordinates (time-headways) for given distance-headway values. The lines radiating from the ordinate again show speeds of 40, 50, and 60 mph, and the headways between the different types of vehicles are indicated by the three different symbols. It is clear that, for this location at least, there was a wide range of headways with only slight tendency toward curvilinearity representing a shorter time-headway relative to distance-headway as speeds increased; and the relationship was very similar for each type of headway.

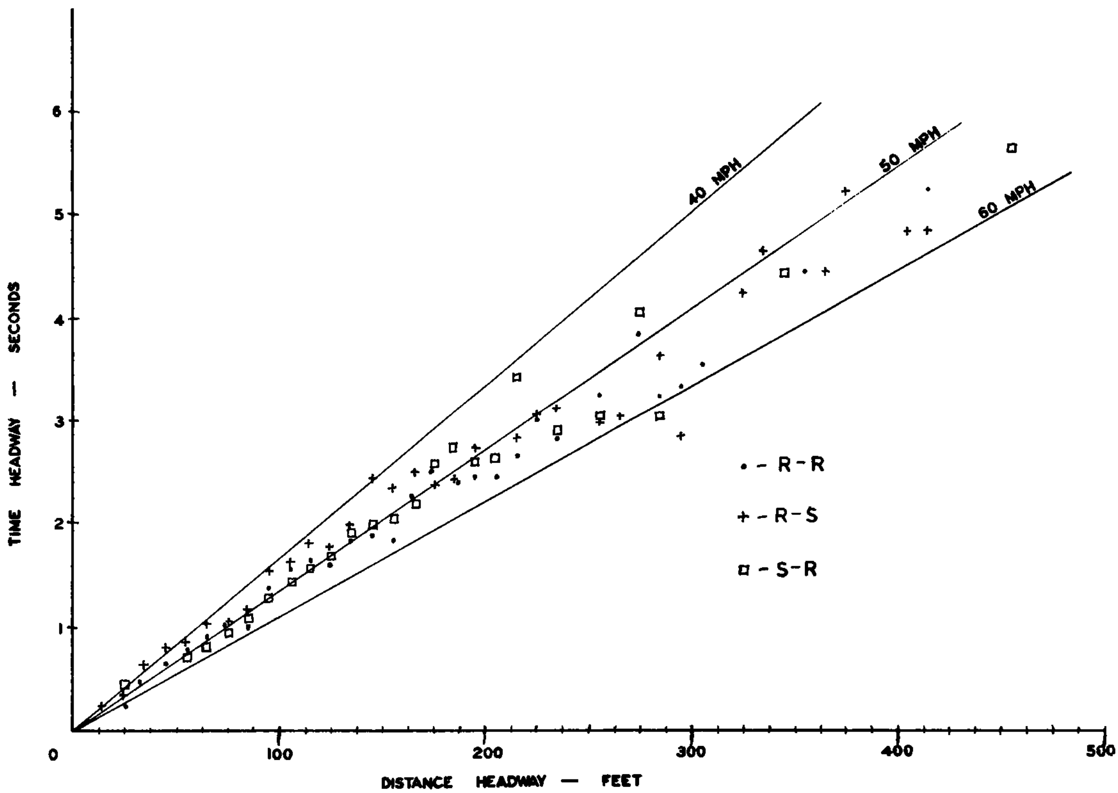


Figure 6. Time-headways, Distance-headways and speed in 4-car groups; average time-headways for 10-ft units of distance-headways, peak traffic, Ford at Addison.

Comment

The lack of significant differences or of consistent direction of differences indicates that small and standard car drivers operate their vehicles pretty much alike in heavy traffic. The greater variability found in lighter traffic and in the more dispersed traffic in Lansing is to be expected.

The very slight tendency toward a curvilinear relationship between time-headways and distance-headways of platoons at lower speeds may be of significance. However, it was not definite in the samples plotted. Facilities did not allow further analysis of samples which included marked slowing.

The definite linearity between time and distance headways for platoons and for individual cases in 4-car groups is of special interest when it is recalled that the most frequent time-headways cluster between 1.0 to 1.35 sec. It is suggested that time-headways may be more fundamental than distance-headways.

CONCLUSIONS

The following conclusions may be drawn from these samples of small and compact cars in relation to continuous samples in Detroit and Lansing.

1. The proportion of small and compact cars ranged from 1.8 to 3.2 percent in 5-min samples during peak hours in Detroit and 0.6 to 5.0 percent at one of the Lansing locations.
2. Distributions of time-headways obtained from 4-car groups did not differ markedly or consistently from continuous distributions taken at the same locations. Samples from 4-car groups could therefore be used for investigating the problem.
3. When stragglers between platoons were eliminated (drivers who would not be making judgments on other cars), the differences in average time-headways involving standard cars only and involving small and compact cars were not consistent in direction nor statistically significant.
4. Some of the differences were as large as 10 or 15 percent. Because average time-headways are the inverse of volume, this might mean a considerable effect on traffic capacity. However, these differences were not greater than could be expected by chance. These comparisons, therefore, indicate that small and compact cars added to standard cars in traffic flow when freeways were approaching capacity did not affect the capacity of the highway.
5. Platoon average time-headways and distance-headways and speeds indicated no consistent effect where platoons include small or compact cars. Also, relationships between the two types of headway were linear and followed closely around the 50-mph line in two samples analyzed. There was some possible curvilinearity at low and at highest speeds but the data analyzed were insufficient to determine a trend.
6. The individual car headways in the sample analyzed showed essentially the same relationships for R-R, R-S, and S-R headways.
7. Because average time-headways are the inverse of volume in vehicles per hour, and because other studies have reported a curvilinear relationship between volume and density, it appears that the present type of analysis (Figs. 3 to 6) may have certain advantages in throwing light on the characteristics of traffic flow.

Although the relationships shown are essentially linear, it may be that more curvilinearity would be shown if samples had been analyzed just preceding the occurrence of traffic stoppages. It was not possible to do that in this particular project. Platoon averages, however, showed internal densities on the order of 80 to 100 cars per mile, ranging downward to 50 to 60 cars per mile. The latter figure was found for 1-min averages in a previous study (3).

8. Time-headways may be more fundamental than distance-headways. Time-headways and distance-headways can be measured for individual cars whereas traffic volumes and densities must involve a large number of vehicles or a projected estimate from a number of vehicles. Time-headways involve the second (following) driver's combination judgment of distance and speed under conditions of the traffic stream. It may well be of significance that average time-headways in Figures 3 to 5 were more

similar than distance-headways and that a linear relationship resulted in the close spacing end of Figure 6.

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