Entering Headway at Signalized Intersections in a Small Metropolitan Area

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The entering headway is a parameter of fundamental importance to traffic engineers. It has major applications in intersection capacity and signal timing. However, the attention given to this matter appears to be inadequate. It was indicated by a literature review that past efforts tended to be infrequent, fragmented, and limited in scope. No studies were found using data from small cities or investigating factors that affect entering headways. This study, aimed at measuring entering headways in a small city and examining six factors, was conducted on sites in Lawrence, Kansas. Entering headway values from a total of 1,899 traffic queues were recorded by using video camera equipment. From the data, mean entry headways of vehicles 1 through 12 were found to be 3.80, 2.56, 2.35, 2.22, 2.16, 2.03, 1.97, 1.94, 1.94, 1.78, 1.64, and 1.76. Of the six factors studied, the following were also found: the signal type and the time of day have little influence on vehicular entering headways; vehicles in the inside lane of an intersection approach have lower entering headways than vehicles in the outside lane; vehicles in an intersection approach with lower speed limits have higher entering headways; vehicles in intersection approaches of streets with lower functional classifications have higher entering headways; and longer queue lengths appear to produce shorter entering headways for vehicles. However, because of data limitations, findings on the factors studied shall be viewed as only preliminary.

The entering headway, that is, the time between successive stopped vehicles entering a signalized intersection after the signal turns green, is of fundamental importance to traffic engineers. The values of several important parameters regarding signalized intersection operation—such as saturation flow rate, starting delay, and lost time—are often derivatives of measurements of the entering headway.

Greenshields et al. used a 16-mm camera to study traffic flow behavior at intersections in New York City and New Haven, Connecticut, in 1947 *(1)*. It was one of the earliest efforts in the United States to quantify vehicle flow characteristics on approaches to intersections. Entering headway was one of the major items investigated. Their data indicated that an average of 3.8 sec was necessary for the first stopped vehicle to enter the intersection after the traffic signal turned green. The successive mean headways for the following vehicles entering an intersection from a stopped queue were found to be 3.1, 2.7, 2.4, 2.2, and 2.1 sec.

Bartle et al. investigated starting delays and average time spacings of approaching vehicles at signalized Los Angeles area intersections in 1956 *(2)*. The mean releasing headway for the first vehicle studied ranged from 2.91 to 4.40 sec, and the average releasing headway of the remaining vehicles studied ranged from 0.95 to 1.63 sec at 13 intersection approaches. Furthermore, a significant difference in starting delay values was noted among approaches of different intersections and among different approaches of the same intersection. [Starting delay has been defined by Greenshields et al. as the additional delay caused by stop-and-start of vehicles due to traffic signals *(1)*].

Gerlough and Wanger completed a study on queue discharging behavior in 1967 utilizing field data collected from the Los Angeles metropolitan area *(3)*. They found that entering headways collected from the field were 3.85, 2.81, 2.51, 2.47, 2.37, 2.36, 2.40, 2.31, 2.24, 2.34, 2.29, 2.26, 2.19, 2.34, 2.38, 2.22, 2.26, 2.32, 2.31, and 2.28 sec from vehicles 1 to 20.

Carstens studied starting delays and headways with manual counts, stop watches, and time-lapse photographs in Ames, Iowa, in 1971 *(4)*. The elapsed time following the start of a green indication for various lengths of queues of stopped straight-through passenger cars to cross the stop line was: first car, 2.64 sec; second car, 5.13 sec; third car, 7.62 sec; fourth car, 9.91 sec; after the fourth car, add an additional 2.29 sec for each succeeding car.

King and Wilkinson used a manual input method to study the relative effectiveness of various signal configurations and lens sizes in dissipating queues in 1976 in Brookline, Massachusetts; San Francisco; Sacramento; and Huntington, New York *(5)*. The research indicated that except for lens size of the signal, no class of the signal configurations could be considered better than any other class in shortening the entering headway.

Lu used a time recorder and stop watches to collect left-turn discharging headways at an unprotected and a protected signalized intersection in Austin, Texas, in 1984 *(6)*. The average discharging headways for a protected left-turn maneuver were found to be 2.43, 2.62, 2.10, and 2.09 sec for the first four vehicles. This study should not be compared directly with other studies reviewed because it deals only with left-turning vehicles. However, it is interesting to note that left-turn vehicles were observed to have lower entering headway values.

An overall review of the studies suggests that past efforts were fragmented in terms of study methods, location characteristics, and technical objectives. Therefore, comparison of these studies is limited to a general observation that their results do not entirely agree. It is also noticed that by far the most comprehensive study was that reported by Greenshield et al. conducted 40 years ago; it is questionable whether the results could represent current traffic characteristics. In addition, the limited depth of the studies does not allow a clear identification of factors that can affect entering headway values. Furthermore, most of the studies were conducted in relatively large cities; whether the values can be applied to smaller cities remains a question to the engineer concerned with small-city traffic problems.

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OBJECTIVE AND SCOPE OF THIS STUDY

To address some of the issues discussed earlier, the main objective of the study was an attempt to measure entering headways at signalized intersections in a small city. It was also intended to collect as much information as possible so that major factors affecting entering headways could be identified. However, because of limitations on data collection sites and their associated condition variables, this part of the study was limited to examining only a few selected factors, including signal types (actuated versus pretimed signals); time of day (morning peak versus afternoon peak); lane (inside lane versus outside lane); approach speed (speed limits of various ranges); types of street (major versus minor arterials); and queue lengths.

DATA COLLECTION AND REDUCTION

All data collection sites were located in Lawrence, Kansas. Lawrence, with a population of approximately 55,000, is the county seat of Douglas County and is one of the smallest Standard Metropolitan Statistical Areas (SMSA) in the United States. The current corporate limits of Lawrence encompass approximately 14,000 acres and more than 70 percent of the area has been developed. The main campus of the University of Kansas with an enrollment of 24,500 is located in Lawrence. Some 30,000 automobiles and 12,000 trucks are registered in Douglas County.

Sixteen signalized intersections along four major streets (Iowa Street, 23rd Street, 6th Street and Massachusetts Street) in Lawrence were selected for study. These intersections and their associated characteristics examined in this study are summarized in Table 1. Massachusetts Street between 6th and 11th Streets is located in the central business district of Lawrence and has angle parking on both sides. Both 6th and 23rd Streets are similar; they are two of the major east–west thoroughfares in Lawrence and have extensive commercial development on the roadsides. Both are four-lane streets with no parking and most of the intersections studied have protected left-turn lanes. Iowa Street is a semi-controlled access north–south major arterial in Lawrence with four lanes for traffic and protected left-turn lanes.

For all selected intersection approaches, vehicle movements were recorded by using a portable video camera system that has a built-in timer with 0.1-sec accuracy. All field videotaping of traffic movements was conducted from June to September 1984. The actual filming at each intersection included 2 hr each day with 1 hr each for a.m. and p.m. peak hours. Within the filming period, half an hour was spent on one approach and the other half for the opposite approach of the major streets.

In all, more than 32 hr of traffic data were recorded on videotapes. They represent records of approximately 5,000 single-lane traffic platoons entering the intersections. The tapes were first examined in the laboratory to screen out the cases that were not suitable for this study, including the following: platoons within which vehicles did not stop before entering an intersection; platoons with trucks; platoons with turning vehicles; and platoons in which the movements of cars were impeded by pedestrians, cross traffic, or turning vehicles. In other words, only platoons containing unimpeded, straight-through passenger cars stopped before entering an intersection

TABLE 1 DATA COLLECTION SITE CHARACTERISTICS

Intersection	Signal Type	Approach	Speed Limit	Lane
Harvard & Iowa	2-phase fully actuated	Northbound Southbound	40 mph 40 mph	Inside & Outside
15th & Iowa	4-phase fully actuated	Northbound Southbound	40 mph 40 mph	Inside & Outside
19th & Iowa	3-phase fully actuated	Northbound Southbound	40 mph 40 mph	Inside & Outside
23rd & Iowa	4-phase fully actuated	Northbound Southbound	40 mph 40 mph	Inside & Outside
27th & Iowa	3-phase fully actuated	Northbound Southbound	40 mph 40 mph	Inside & Outside
23rd & Louisiana	4-phase fixed-timed	Westbound Eastbound	35 mph 35 mph	Inside & Outside
23rd & Massachusetts	3-phase fixed-timed	Westbound Eastbound	35 mph 35 mph	Inside & Outside
23rd & Barker	3-phase fixed timed	Westbound Eastbound	35 mph 35 mph	Inside & Outside
23rd & Haskell	2-phase semi-actuated	Westbound Eastbound	45 mph 35 mph	Inside & Outside Inside & Outside
8th & Massachusetts	2-phase fix-timed	Northbound Southbound	20 mph 20 mph	Single Lane
9th & Massachusetts	2-phase fix-timed	Northbound Southbound	20 mph 20 mph	Single Lane
10th & Massachusetts	2-phase fix-timed	Northbound Southbound	20 mph 20 mph	Single Lane
19th & Massachusetts	3-phase fix-timed	Northbound Southbound	30 mph 30 mph	Inside & Outside
6th & Maine	2-phase fix-timed	Westbound Eastbound	35 mph 35 mph	Inside & Outside
6th & Michigan	2-phase semi-actuated	Westbound Eastbound	35 mph 35 mph	Inside & Outside
6th & Kasold	2-phase full actuated	Westbound Eastbound	40 mph 40 mph	Single Through

TABLE 2 STATISTICS OF ENTERING HEADWAY DATA COLLECTED

Veh	Valid Case	Mean	Std. Err	Std. Dev.	Median	Mode	Variance	Max.	Min.
1	1899	3.802	.019	.845	3.700	3.500	.714	7.800	1.600
2	1252	2.555	.018	.640	2.500	2.200	.410	5.500	1.200
3	822	2.352	.021	.612	2.300	2.100	.375	5.000	1.100
4	526	2.214	.026	.587	2.100	1.900	.345	4.400	0.900
5	327	2.163	.035	.629	2.100	1.800	.395	5.000	0.900
6	191	2.026	.040	.550	1.900	1.700	.302	4.500	1.000
7	127	1.972	.047	.527	1.900	1.600	.277	3.500	1.000
8	78	1.938	.054	.475	1.850	1.500	.225	3.900	1.100
9	44	1.941	.086	.573	1.850	1.500	.328	3.500	1.200
10	24	1.783	.074	.363	1.750	1.600	.132	2.400	1.100
11	13	1.638	.109	.393	1.600	1.300	.154	2.700	1.200
12	7	1.757	.092	.244	1.700	1.600	.060	2.100	1.500

were considered valid cases for the study. The valid cases, totaling close to 2,000 traffic queues, were later viewed on a television screen to extract the entering headway values.

For the first vehicle of a queue, its entering headway was taken to be the time elapsed between the start of a green indication and the time at which the car's rear bumper cleared the stop line. For the remaining cars in the queue, the entering headway values were taken to be the elapsed time, rear bumper to rear bumper, as the successive vehicles passed an intersection stop line.

DATA ANALYSIS AND MAJOR RESULTS

From the data reduction phase, a total of 1,899 single-lane vehicular platoons were found to be valid for this study, and the number of vehicles in the queues varied from 1 to 12. Queues with more than 12 vehicles were rare occurrences in Lawrence and were not included in the study. Entering headway values from these platoons were coded into a Honeywell 60/66 computer, and a Statistical Package for the Social Sciences was used for the statistical analyses needed.

The first step in the analysis was to derive the basic statistics out of all the entering headway data collected. The mean entering headways (in seconds) for vehicles 1 through 12 are as follows: 3.80, 2.56, 2.35, 2.22, 2.16, 2.03, 1.97, 1.94, 1.94, 1.78, 1.64, and 1.76. These and other statistics are summarized in Table 2. The first seven headways were also compared with values reported in previous studies. The comparison is shown in graphic form in Figure 1.

It is interesting to note that all the entering headways from various studies appear to follow a similar pattern except for the first two vehicles. It was suspected that studies with the first vehicle having a low entering headway may have used a different definition of entering headway than the others. The surprise, however, was that the entering headway measured in this study was lower than in almost all other studies. This was

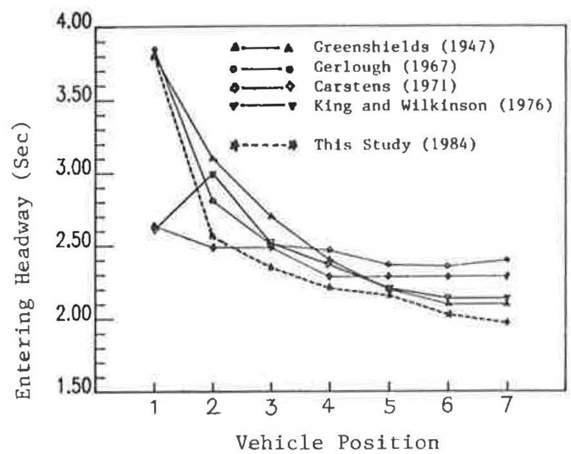

FIGURE 1 Comparison of entering headway patterns from various studies.

not expected because it was commonly assumed that small-city drivers tend to be less aggressive, which would result in higher entering headways.

A second look appeared to suggest that there are logical reasons for the observation that the entering headway measured in this study was lower than in almost all other studies. First, this study was the only one of the studies in the comparison that was conducted after the driving public felt the full impact of the 1973 energy crisis. Cars are smaller now and have better acceleration characteristics. It is also believed that in this study a large proportion of headway data may have been collected from lanes with higher approaching speeds than in the other studies. As will be revealed later, speed appears to have a significant effect on entering headways. These points not only help explain why the observed entering headways were low in this study, but also tend to suggest that entering headways can be affected by many factors, and city size may not be one of the important ones.

The second part of the analysis focused on finding out whether several factors selected were influencing entering headways. Because the variety of conditions existing in Lawrence intersections is limited, the factors that could be examined included only signal types, time of day, lane type, approach speed, type of street, and queue length. Because most of these factors could not be expressed in continuous numerical terms, factor analysis or regression analysis could not be attempted. Therefore, a simple comparative approach was engaged.

In this approach, the factors were analyzed one at a time. For each factor analyzed, the overall headway data were grouped into categories or levels for which that particular factor is normally expressed. For example, signal types were categorized into fixed timed signals, semiactuated signals, and fully actuated signals. Thus, when analyzing the influence of signal types, the entering headways were first grouped by their associated signal types. For each group, standard statistical computations were performed to find out averages, standard deviations, and other basic statistics. After this was done, a statistical test was performed on two selected groups to see if the average entering headways of the two groups were significantly different from each other. If the difference was significant, it would be concluded that this particular factor has significant influence on entering headways.

However, the nature of the entering headway data is such that conventional statistical test methods appeared to be inappropriate. For example, assume that Signal type i has mean entering headway values for the first vehicle h_{i1}, second vehicle h_{i2}, third vehicle h_{i3}, and so on, and signal type j has mean entering headways h_{j1}, h_{j2}, h_{j3}, . . . , and so forth. Although h_{i1}, h_{i2}, h_{i3} . . . and h_{j1}, h_{j2}, h_{j3} . . . are sequential events, each mean headway within a sequence is statistically independent of other mean headways. Therefore, treating h_{i1}, h_{i2}, h_{i3} . . . as coordinates of a continuous distribution curve and comparing with a curve connecting h_{j1}, h_{j2}, h_{j3} . . . by using a χ^2-test would not be correct. On the other hand, it would also be incorrect to compare the corresponding entering headways of different groups such as $h_{i1} : h_{j1}$, $h_{i2} : h_{j2}$, $h_{i3} : h_{j3}$ . . . , and so forth and combine them by using several nonparametric pairing test techniques such as a sign test or a rank order test because one pair is actually independent of other pairs.

However, one thing that is clear is that if Group i and Group j data do not significantly differ from each other, the corresponding entering headways of different groups should not be significantly different from each other, or at least the chances of such happening are small. After consultation with mathematical statisticians at the University of Kansas, a test scheme was utilized for this study.

TABLE 3 MEAN ENTERING HEADWAY OF DIFFERENT SIGNAL TYPES AND NUMBER OF OBSERVATIONS

	TYPE OF SIGNALS								
Veh.	All fix.	All act.	2-phase fix.	3-phase fix.	4-phase fix.	2-phase full act.	2-phase semi-act.	3-phase full act.	4-phase full act.
1	3.83 (927)	3.78 (972)	3.87 (555)	3.86 (251)	3.57 (121)	3.76 (216)	3.94 (306)	3.72 (259)	3.62 (191)
2	2.61 (618)	2.50 (634)	2.66 (358)	2.52 (162)	2.57 (98)	2.47 (146)	2.63 (159)	2.56 (160)	2.36 (169)
3	2.43 (382)	2.28 (440)	2.50 (207)	2.37 (100)	2.32 (75)	2.38 (97)	2.32 (84)	2.32 (113)	2.17 (146)
4	2.29 (225)	2.16 (301)	2.37 (117)	2.14 (56)	2.26 (52)	2.07 (67)	2.09 (36)	2.26 (79)	2.16 (119)
5	2.31 (114)	2.08 (213)	2.35 (53)	2.26 (26)	2.30 (35)	2.10 (43)	2.18 (20)	2.19 (50)	2.01 (100)
6	2.10 (49)	2.00 (142)	2.20 (24)	2.09 (8)	1.97 (17)	2.01 (29)	1.93 (7)	2.09 (36)	1.96 (70)
7	2.10 (30)	1.93 (97)	2.14 (13)	2.05 (4)	2.08 (13)	1.93 (16)	1.87 (3)	2.10 (25)	1.86 (53)
8	2.13 (13)	1.90 (65)	2.30 (5)		2.03 (8)	1.78 (8)	1.50 (1)	1.97 (20)	1.90 (36)
9	2.10 (3)	1.93 (41)	2.10 (1)		2.10 (2)	2.10 (6)		1.74 (15)	2.02 (20)
10		1.78 (24)				1.68 (4)		2.03 (7)	1.68 (13)
11		1.64 (13)				1.30 (1)		1.70 (4)	1.65 (8)
12		1.76 (7)						1.90 (2)	1.70 (5)

Note: The number of observations is given in parenthesis.

TABLE 4 RESULTS OF T-TEST ON SIGNAL TYPES

Signal Type		Vehicle position in a queue											
		1	2	3	4	5	6	7	8	9	10	11	12
All fix-timed	vs. All Actuated	X	O	O	X	O	X	X	X	X	—	—	—
2-phase fix.	vs. 2-phase full act	X	O	X	O	X	X	X	X	X	—	—	—
2-phase fix.	vs. 2-phase semi-act	X	X	X	X	X	X	X	X	—	—	—	—
2-phase full act.	vs. 2-phase semi-act	X	X	X	X	X	X	X	X	—	—	—	—
3-phase fix.	vs. 3-phase full act	X	X	X	X	X	X	X	—	—	—	—	—
4-phase fix.	vs. 4-phase full act	X	X	X	X	O	X	X	X	X	—	—	—

Note: X = no significant difference; O = significant difference; and — = lack of data.

The scheme is to use a standard t-test for each corresponding entering headway pair of the groups such as h_{i1} and h_{j1}, h_{i2} and h_{j2}, h_{i3} and h_{j3} . . . , and so forth at a (10/n) percent significance interval in which n is the total number of pairs tested. The whole two groups are declared different if any pairing is shown to be statistically different. The scheme would be comparable to testing two means by using a t-test with a 10 percent level of significance.

By using the approach just described, the factors selected were analyzed. Table 3 gives a summary of entering headways grouped by signal types, and Table 4 gives the results of the t-test. Tables 5 and 6 give results of a similar analysis for a.m. and p.m. peak-hour observations. Tables 7 and 8 give the results for lane types. Tables 9 and 10 give the results for approach speeds using speed limits as representing parameters. Tables 11 and 12 give the results for different types of streets for the four streets that were involved in this study. The last analysis conducted was the effect of queue length on entering headways; the results are presented in Table 13.

Before an overall interpretation of the results was made, the information presented in Table 1 was examined. It became obvious that because of the limited variety of intersections in Lawrence, it would be difficult to draw definite conclusions about the effects of entering headways on the factors investigated in this study. For example, there are three intersections along Massachusetts Street that are different from the other study locations. They all have only one lane for approaching vehicles, have a speed limit of 20 mph, have parking on both sides, are located in a business environment, and are controlled by two-phase fixed time signals. Because of these conditions and perhaps a combination of them, the entering headways collected were significantly higher than at other sites studied. However, because a limited variety of sites existed in Lawrence, the individual impacts of the factors could not be isolated by using statistical methods. Therefore, results would be exaggerated if a particular group contained a large amount of data collected at these three intersections.

It is important to be cautious in interpreting the results of this study. With this in mind, the following summary was made.

- Signal types have no significant influence on entering headways. The apparent difference of entering headways between intersections with actuated signals and those with fixed timed signals is mostly contributed by higher headways at intersections along Massachusetts Street. Those higher headways are mostly affected by other contributing factors, notably, approach speeds.
- Time of day, signified by a.m. and p.m. peak hours, does not appear to have any influence on entering headways.
- Regarding lane type and entering headways, the inside lane of an intersection approach appeared to have slightly lower entering headways than those of the outside lane and the difference is significant. Two-lane approaches appeared to have

TABLE 5 MEAN ENTERING HEADWAY OF THE A.M. AND P.M. PERIODS AND NUMBER OF OBSERVATIONS

Veh	Time of Day	
	AM	PM
1	3.78 (950)	3.82 (949)
2	2.58 (573)	2.54 (679)
3	2.36 (344)	2.35 (478)
4	2.29 (209)	2.16 (317)
5	2.15 (122)	2.17 (205)
6	2.00 (69)	2.04 (122)
7	2.06 (45)	1.92 (82)
8	2.14 (21)	1.86 (57)
9	2.07 (9)	1.91 (35)
10	1.90 (6)	1.74 (18)
11	2.30 (2)	1.52 (11)
12	1.70 (1)	1.77 (6)

TABLE 6 RESULT OF T-TEST ON A.M. AND P.M. PEAK-HOUR PERIODS

Time of Day	Vehicle position in a queue											
	1	2	3	4	5	6	7	8	9	10	11	12
AM Peak Hour vs. PM Peak Hour	X	X	X	X	X	X	X	X	X	X	O	X

Note: X = no significant difference; O = significant difference; and – = lack of data.

TABLE 7 MEAN ENTERING HEADWAY OF DIFFERENT LANE TYPES AND NUMBER OF OBSERVATIONS

Veh	Lane Types				
	Inside Lane	Outside Lane	Single Lane	Single Through Lane	Inside & Outside Lane
1	3.71 (742)	3.76 (784)	4.10 (297)	3.95 (76)	3.74 (1526)
2	2.48 (507)	2.51 (525)	2.84 (181)	2.74 (39)	2.50 (1032)
3	2.25 (338)	2.33 (376)	2.79 (89)	2.56 (19)	2.29 (714)
4	2.09 (231)	2.23 (238)	2.76 (66)	2.12 (11)	2.16 (469)
5	2.02 (160)	2.21 (147)	3.11 (17)	2.33 (3)	2.11 (307)
6	1.98 (100)	2.04 (83)	2.57 (7)	1.70 (1)	2.01 (183)
7	2.00 (66)	1.90 (56)	2.53 (4)	1.80 (1)	1.95 (122)
8	1.84 (40)	2.02 (36)	3.40 (1)	1.40 (1)	1.93 (76)
9	1.87 (23)	2.04 (20)		1.50 (1)	1.95 (43)
10	1.68 (13)	1.95 (10)		1.40 (1)	1.80 (23)
11	1.54 (8)	1.80 (5)			1.64 (13)
12	1.70 (4)	1.83 (3)			1.76 (7)

TABLE 8 RESULTS OF T-TEST OF LANE TYPES

Lane Types	Vehicle position in a queue											
	1	2	3	4	5	6	7	8	9	10	11	12
Inside Lane vs. Outside Lane	X	X	X	O	O	X	X	X	X	X	X	X
Single Lane vs Single Through Lane	X	X	X	O	X	X	X	X	—	—	—	—
Outside Lane vs Single Through Lane	X	X	X	X	X	X	X	X	O	X	—	—
Inside & Outside Lane vs Single Lane	O	O	O	O	O	O	X	O	—	—	—	—

Note: X = no significant difference; O = significant difference; and – = lack of data.

TABLE 9 MEAN ENTERING HEADWAY OF DIFFERENT SPEED LIMITS AND NUMBER OF OBSERVATIONS

Veh.	Speed Limit of Approach				
	20 mph	30 mph	35 mph	40 mph	45 mph
1	4.10 (297)	3.89 (133)	3.76 (719)	3.70 (666)	3.77 (84)
2	2.84 (181)	2.58 (82)	2.53 (475)	2.46 (475)	2.62 (39)
3	2.79 (89)	2.46 (49)	2.30 (315)	2.28 (356)	2.29 (13)
4	2.76 (46)	2.32 (25)	2.14 (185)	2.17 (265)	1.88 (5)
5	3.11 (17)	2.31 (12)	2.14 (102)	2.07 (193)	2.67 (3)
6	2.57 (7)	1.73 (3)	2.04 (45)	2.00 (135)	1.50 (1)
7	2.53 (4)	1.90 (1)	2.03 (28)	1.93 (94)	
8	3.40 (1)		1.98 (13)	1.91 (64)	
9			2.10 (3)	1.93 (41)	
10				1.78 (24)	
11				1.64 (13)	
12				1.76 (7)	

TABLE 10 RESULTS OF T-TEST ON SPEED LIMITS

Speed Limit	Vehicle position in a queue											
	1	2	3	4	5	6	7	8	9	10	11	12
20 mph vs. 30 mph	X	O	O	O	O	X	X	—	—	—	—	—
20 mph vs. 35 mph	O	O	O	O	O	O	X	O	—	—	—	—
20 mph vs. 40 mph	O	O	O	O	O	X	X	O	—	—	—	—
20 mph vs. 45 mph	O	X	X	O	X	X	—	—	—	—	—	—
30 mph vs. 35 mph	X	X	X	X	X	X	X	—	—	—	—	—
30 mph vs. 40 mph	X	X	X	X	X	X	X	—	—	—	—	—
30 mph vs. 45 mph	X	X	X	X	X	X	—	—	—	—	—	—
35 mph vs. 40 mph	X	X	X	X	X	X	X	X	X	—	—	—
35 mph vs. 45 mph	X	X	X	X	X	X	—	—	—	—	—	—
40 mph vs. 45 mph	X	X	X	X	X	X	—	—	—	—	—	—

Note: X = no significant difference; O = significant difference; and — = lack of data.

TABLE 11 AVERAGE HEADWAY OF DIFFERENT TYPES OF STREETS AND NUMBER OF OBSERVATIONS

Veh.	Streets			
	Iowa	23rd	Mass	6th
1	3.67 (590)	3.71 (522)	4.03 (430)	3.88 (357)
2	2.43 (436)	2.53 (332)	2.76 (263)	2.59 (221)
3	2.26 (337)	2.34 (206)	2.67 (138)	2.28 (141)
4	2.17 (254)	2.17 (127)	2.60 (71)	2.06 (74)
5	2.07 (190)	2.21 (74)	2.78 (29)	2.07 (34)
6	2.01 (134)	2.01 (30)	2.32 (10)	2.04 (17)
7	1.93 (93)	2.09 (18)	2.40 (5)	1.89 (11)
8	1.91 (63)	2.00 (9)	3.40 (1)	1.84 (5)
9	1.94 (40)	2.10 (3)		1.50 (1)
10	1.80 (23)			1.40 (1)
11	1.64 (13)			
12	1.76 (7)			

significantly lower entering headway values than did approaches with only one lane. However, the data collected in this study may be biased and this statement should be regarded as preliminary.

- When approach speeds, represented by speed limits, were considered, lower speed limits in general produced higher entering headways than did higher speed limits. The difference appeared to be most significant when the lower speed limit is approximately 20 mph and the higher speed limits are above 30 mph. However, when the compared approach speed limits are all above 30 mph, the influence of speed on entering headways decreases.
- The type-of-street factor appears to be a combination of other factors studied. Massachusetts Street—because of its low speed limits, single-lane approach configurations, and roadside frictions—produced significantly higher entering headway values when compared with the other streets.
- When queue length is considered, decreasing entering

TABLE 12 RESULTS OF T-TEST ON TYPES OF STREETS

Streets Compared	Vehicle position in queue											
	1	2	3	4	5	6	7	8	9	10	11	12
Iowa St. vs. 23rd St.	X	X	X	X	X	X	X	X	X	—	—	—
Iowa St. vs. Mass. St.	O	O	O	O	O	X	X	O	—	—	—	—
Iowa St. vs. 6th St.	O	O	X	X	X	X	X	X	O	X	—	—
23rd St. vs. Mass. St.	O	O	O	O	O	X	X	O	O	—	—	—
23rd St. vs. 6th St.	O	X	X	X	X	X	X	X	X	—	—	—
Mass. St. vs. 6th St.	X	O	O	O	O	X	X	O	—	—	—	—

Note: X = no significant difference; O = significant difference; and – = lack of data.

TABLE 13 MEAN ENTERING HEADWAY OF DIFFERENT QUEUE LENGTHS AND NUMBER OF OBSERVATIONS

	Queue Length (number of vehicles)											
Veh	1	2	3	4	5	6	7	8	9	10	11	12
1	3.86 (647)	3.89 (430)	3.75 (296)	3.78 (199)	3.66 (136)	3.67 (64)	3.75 (49)	3.68 (34)	3.43 (20)	3.28 (11)	3.50 (6)	3.40 (7)
2		2.65 (430)	2.59 (296)	2.49 (199)	2.48 (136)	2.40 (64)	2.45 (49)	2.30 (34)	2.48 (20)	2.26 (11)	2.32 (6)	2.80 (7)
3			2.38 (269)	2.44 (199)	2.34 (136)	2.27 (64)	2.25 (49)	2.17 (34)	2.07 (20)	2.25 (11)	2.38 (6)	2.29 (7)
4				2.25 (199)	2.21 (136)	2.22 (64)	2.22 (49)	2.10 (34)	2.29 (20)	2.08 (11)	1.87 (6)	2.03 (7)
5					2.24 (136)	2.16 (64)	2.11 (49)	2.14 (34)	2.00 (20)	2.01 (11)	2.28 (6)	1.79 (7)
6						2.12 (64)	2.03 (49)	1.95 (34)	1.86 (20)	2.05 (11)	1.97 (6)	1.97 (7)
7							2.07 (49)	1.95 (34)	2.11 (20)	1.87 (11)	1.58 (6)	1.69 (7)
8								2.09 (34)	1.71 (20)	2.09 (11)	1.68 (6)	1.83 (7)
9									1.96 (20)	2.06 (11)	1.63 (6)	1.99 (7)
10										1.79 (11)	2.03 (6)	1.56 (7)
11											1.52 (6)	1.74 (7)
12												1.76 (7)

headway with increasing queue length appeared to be the general trend. This might have been expected because longer queues are generally associated with heavier volumes, which in turn might be associated with higher types of streets, higher speed limits, more phases in a signal setting, and a greater likelihood for drivers to be in a hurry.

CONCLUSIONS AND RECOMMENDATION

In responding to the objectives of the study, there are two major findings resulting from the study. The first finding is that from 1,899 traffic queues observed in Lawrence, Kansas, the average headways in seconds for vehicles 1 through 12 entering a signalized intersection after the light turned green were as follows: 3.80, 2.56, 2.35, 2.22, 2.16, 2.03, 1.97, 1.94, 1.94, 1.78, 1.64, and 1.76.

The second finding is that out of the six factors examined, it can be stated with some confidence that

- Signal types have little influence on entering headways at signalized intersections.
- Time of day (a.m. or p.m. traffic) has little influence on entering headways.
- The inside lane of an approach has slightly lower entering headways than does the outside lane.
- The entering headways at approaches with speed limits of 20 mph are significantly higher than those at approaches with higher speed limits (≧ 30 mph). For approaches with speed limits higher than 30 mph, the influence of speed limits on the entering headway is not noticeable.
- In general, streets that have higher speed limits and less roadside frictions have lower entering headway values.
- When queue length increases, the general observation is that the entering headway values decrease.

It is to be noted that because the study locations are limited in their variety of conditions, the results on which these statements are based may be biased. Therefore, the second-part findings should be interpreted as only preliminary.

An overall review of this and previous efforts appears to indicate that although the entering headway is a basic parameter in traffic engineering, the attention received has been infrequent, fragmented, and limited in scope. All studies appear to point out that entering headways are affected by many factors. An attempt was made to examine a few of them in this study, but it appeared that the study only scratched the surface. There are numerous geometric and traffic factors that should be studied. Because the Transportation Research Board's 1985 *Highway Capacity Manual* adopts the saturation flow concept for signalized intersection capacities, a comprehensive headway study encompassing all factors appears to be urgently needed *(7)*. The ever-changing vehicle characteristics and fleet mixes on streets also indicate that the dynamics of the entering headway require more frequent attention than has been given to this matter.

From the discussion just presented it is recommended that a systematic framework of research needs on entering headways be drawn that specifies frequency, location, and factors to be studied in a coordinated and comprehensive manner. This framework would then be made known to universities and other research institutions so that research efforts to advance the state of the art on entering headways could be guided in an organized and useful manner.

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Traffic Operation on Busy Two-Lane Rural Roads in The Netherlands

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In the framework of updating standards for describing the quality of traffic flow on two-lane rural roads, research into the behavior of the traffic flow on relatively high-volume roads was carried out. Presented in this paper are findings about the relation between the volume and traffic composition as explanatory factors for speeds, headways, and platooning. It was found that mean speed was only marginally influenced by volume and truck percentage, whereas the standard deviation of speeds decreased substantially with increasing volume. An exponential tail model for headways, large enough to be relevant for passing opportunities, was used and its parameters were successfully related to volume. This model fits reality much better than the assumption that headways have a negative exponential distribution, which leads to severe underestimation of passing opportunities. Simple models were developed that relate the proportion of vehicles following in a platoon and the maximum platoon length in 5 min to volume and truck percentage. A comparison is made with results in the proposed Chapter 8 on Two-Lane Highways of the 1985 *Highway Capacity Manual.*

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In The Netherlands, as in many other countries, traffic engineers have used information from the 1965 *Highway Capacity Manual* (HCM) to a considerable extent. However, it was increasingly believed that the procedures and data in the HCM were not always applicable. Some factors were clearly different in the United States and The Netherlands, for example, capabilities of automobiles and trucks. Moreover, some data in the HCM appeared to be outdated, as was probably realized first in the United States.

As part of determining and updating standards for design of all types of rural roads, the Transportation and Traffic Engineering Division of the Dutch Ministry of Transport and Public Works has given attention to two-lane rural roads for motor vehicles, that is, roads without bicycles or low-speed motorbikes (mopeds) on the carriageway. Given in this paper are some results of research into the behavior of the traffic flow at relatively high volumes. This behavior is relevant for determining the service volumes that define the levels of service.

As is generally accepted, speed is no longer the only most suitable criterion on which to base level of service because speeds do not depend on volume that much any more. Speed was replaced by a general criterion that can best be described as