Vehicle Delay at Signalized Intersections as a Factor in Determining Urban Priorities

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One of the pertinent factors in rating urban sections on the state highway systems in the Tennessee Planned Construction Program Procedure is vehicle delay occasioned by traffic signals. The objective is to compare one urban section with another as to the average total delay occasioned by the signals in 24 hours.

Based on data contained in the "Highway Capacity Manual," together with some reasonable assumptions, average seconds of delay per vehicle were computed for an intersection operating at possible capacity (by definition) and various percentages of operation above and below this capacity. A percentage distribution of vehicles delayed less than one cycle, and those delayed one, two, three, etc., full cycles was determined for each condition of operation.

The average daily traffic is related to the geometrics of the signalized intersection under study to determine the percentage of practical capacity. Once this determination has been made, the average delay for vehicles for the highest hour and each successive hour in the day can be determined. The total delays for all signalized intersections within the section under study are then totaled. The average delay per mile for one route section can then be compared with another for this particular factor in the total program study.

●AFTER THE comprehensive study of highway needs in Tennessee was completed in November 1955, the Tennessee Department of Highways and Public Works decided to put into operation the study's proposals relative to the state highway system. A cooperative research project was undertaken by the department and the Automotive Safety Foundation first, to formulate an initial 5-year short-range program to remedy the system's most critical deficiencies and, second, to formulate criteria, techniques, and procedures necessary to establish a continuing construction program to meet future deficiencies as they accrue.

The fundamentals of the Tennessee Planned Construction Program Procedure were presented at the 36th Annual Meeting of the Highway Research Board. P. M. Donnell, in his paper, tells of Tennessee's experience after this plan has been in operation.

Ratings for rural and urban type sections are made separately. The three basic concepts of structural ability to support loads, traffic capacity to move the loads and safety are retained in each case. The factors used in the determination of section ratings vary slightly from rural to urban. The ability to move traffic on a rural section is measured in terms of rapid travel by individual vehicles with a wide latitude in a choice of speed. Satisfactory criteria have been developed and are available for this phase. For urban section this choice of speed by individuals is influenced by a variety of conditions superimposed upon one another such as traffic signals, speed zones, parking and turning movements. Collectively then, the movement of traffic on urban sections is dependent upon the degree of congestion or delay. Criteria were not available but had to be developed for this phase. This paper is confined to only one part of the development of techniques to measure vehicle delays—those incurred at signalized intersections.

A comparison of congestion on one urban section with another could be made in several ways. One method that has been used with some success is the "floating car." Tests indicate that five to seven runs are necessary to obtain stability and they are usually made in peak hours only. Tennessee has nearly 700 miles of urban extension on its state highway system to which the rating procedure will be confined. The use of the "floating car" method would be prohibitive in terms of cost and manpower and would be confined to certain hours of the day. Several more runs would need to be made to determine averages in the off-peak hours.

Tennessee chose to obtain comparisons of delay by an office procedure based upon field notes. Factors influencing delays are traffic signals, speed zones, parking, turns and railroad grade crossings. Traffic signal delay is the major factor in the rating procedure and this paper is confined to the computation thereof.

The original intent was to obtain the signal timing for each signal by the field inventory. At the same time a determination would be made if the signal was isolated, fixed time, interconnected with some progression, traffic actuated and the presence of a pedestrian interval. In the larger places some or all of this information would be obtained from a responsible official, such as the traffic engineer.

Field trials definitely indicated that obtaining this data resulted in inaccuracies of timing and determination of type of signal system and was a big deterrent to the progress of the inventory.

What is desired in this one phase of the study is a comparison of one urban section with another of the vehicle delay occasioned by traffic signals. It was believed that the objective could be reached by computation founded on some basic realistic assumptions.

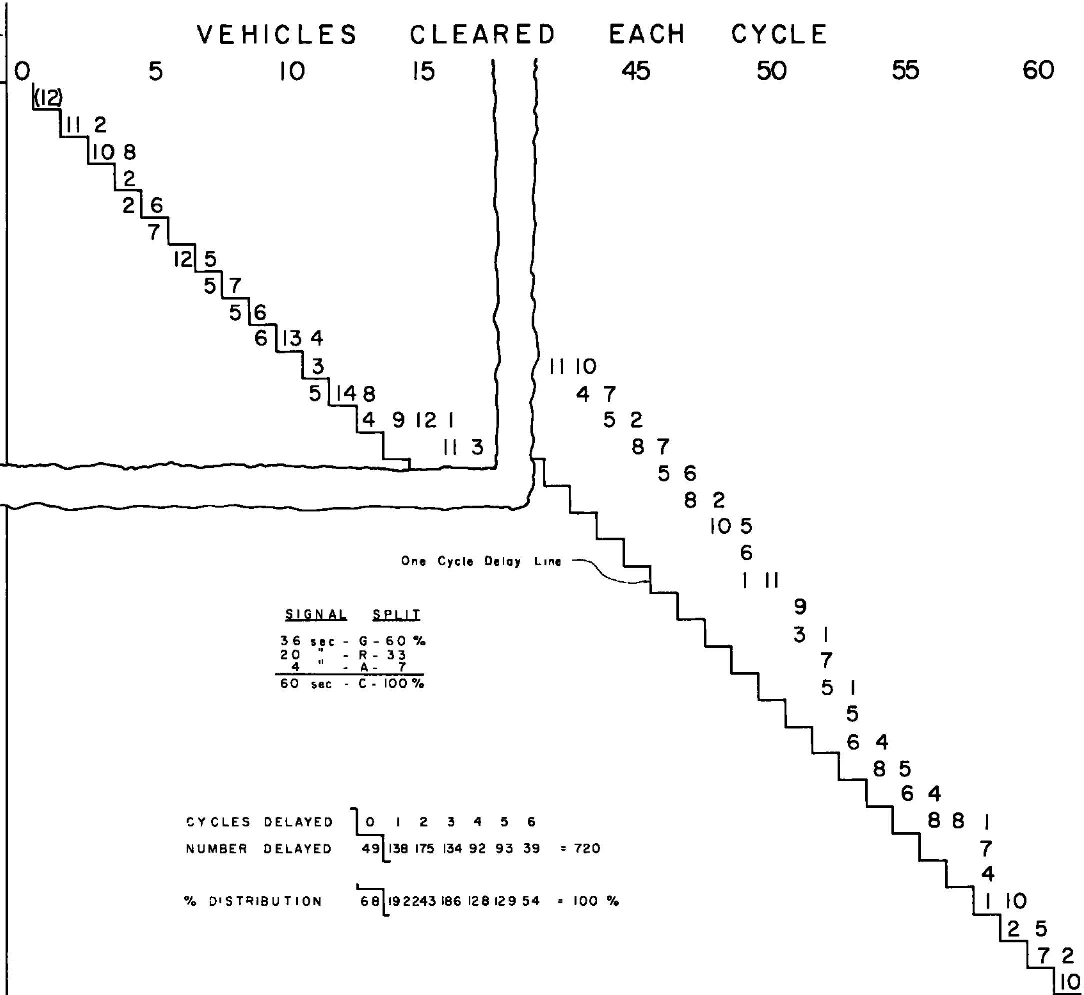
The state has a measure of the ADT on all the urban extensions of the state highway system and all the cross streets. A desirable signal timing could be computed for each signalized intersection from the estimated traffic. A signal cycle of 60 seconds could be assumed. The computation of average delay per vehicle proved to be more involved.

The only data readily available from which average delay time could be computed were those given in the Highway Capacity Manual on pages 72 and 73. These are examples of the vehicles approaching, clearing, and accumulating, or backlog, at a signalized intersection operating at possible and practical capacities by definition. The data are based on a 60-second cycle (60 percent green, 33 percent red and 7 percent amber) for a complete hour's operation.

The operation at possible capacity was used as the base. A distribution of the vehicles approaching was made for each cycle of operation to determine the number and percent that (a) cleared the signal on the approach, (b) were delayed 1, 2, 3 and etc. full cycles. The method is illustrated in Figure 1. This illustrates the definition of possible capacity of an intersection approach. Under the operating conditions, 720 vehicles approached and 720 were discharged—the maximum number that could be accommodated. There was a continual backlog and only a few vehicles had to wait as many as six cycles. For each cycle, the horizontal summary of the number of vehicles equals those that approached; the vertical summary equals those discharged; and the sum of all the vehicles to the right of the delay line equals the backlog. Similar distributions were made for seven other conditions when the intersection was assumed to be operating a percentage above or below possible capacity. For example, at 80 percent possible capacity (practical capacity), 80 percent of the approach vehicles (including beginning backlog) were used. The vehicles discharged did not exceed the maximum that were discharged at possible capacity for the given cycle of operation. A total distribution of the vehicles by cycles of delay was then computed for each percent of intersection operation above or below possible capacity. A conversion to practical capacity as the base (practical capacity = 100 percent) was made to conform with other standards in the Tennessee study.

A measure of average delay per vehicle was then computed after several false starts and with some assumptions. It was assumed the vehicles approached uniformly spaced. The time of entering the cycle was assumed mid-way of the interval (I), the interval being the cycle length divided by the average number of vehicles discharged per cycle. In the case of operation at possible capacity, 720 vehicles entered and departed the intersection within one hour or an average of 12 per 60-second cycle operation. The "I" for this condition is five seconds. Similar intervals were computed for four other conditions of intersection operation with a 60-second cycle and 60 percent green time, namely 100 percent, 75 percent, 50 percent and 25 percent of practical capacity. An acceleration time of 2.5 seconds per average vehicle was assumed. Figure 2 illustrates

CYCLE NO	TOTAL VEH APPR	MAX VEH DISC'D	BACK-LOG
-1			12
1	13	12	13
	18	11	20
	2	12	10
	8	12	6
5	7	13	0
	17	12	5
	12	10	7
	11	12	6
	23	12	17
10	3	13	7
	27	12	22
	26	14	34
13	14	12	36
43	15	14	65
	6	12	59
45	12	10	61
	9	12	58
	4	14	48
	7	12	43
	6	12	37
50	5	11	31
	10	12	29
	13	13	29
	10	12	27
	17	12	32
55	7	11	28
	4	12	20
	11	8	23
	7	13	17
	9	12	14
60	10	12	12
		(13)	
	720	720	



CYCLES DELAYED	0	1	2	3	4	5	6	
NUMBER DELAYED	49	138	175	134	92	93	39	= 720
% DISTRIBUTION	68	192	243	186	128	129	54	= 100 %

Figure 1. Distribution of vehicles at signalized intersections operating at possible capacity.

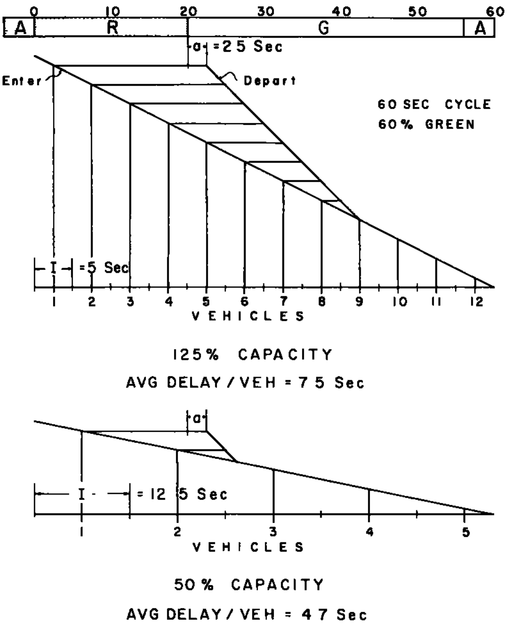


Figure 2. Average delay per vehicle for vehicles delayed less than one cycle.

the method. Vehicles delayed more than one cycle would experience the less-than-one-cycle delay plus 1, 2, 3, etc., full cycles of 60 seconds. Separate computations were made for assumed distribution of "green time" within the cycle, these being for 65, 60, 55, 45, 35 and 25 percent green time of the 60-second cycle. Average seconds delay per vehicle for percent of green time other than for those computed can be estimated from Figure 3.

In order that the information may be readily usable, it was summarized in a graph. Some eight points ranging from 25 to 150 percent capacity operation were computed and connected by a curve. Separate curves resulted for each distribution of 65, 60, 55, 45, 35 and 25 percent green time of the 60-second cycle.

Those of 25 percent and 65 percent "green time" are shown in Figure 4.

The application to known basic data involved additional computations. The length of time an intersection operates

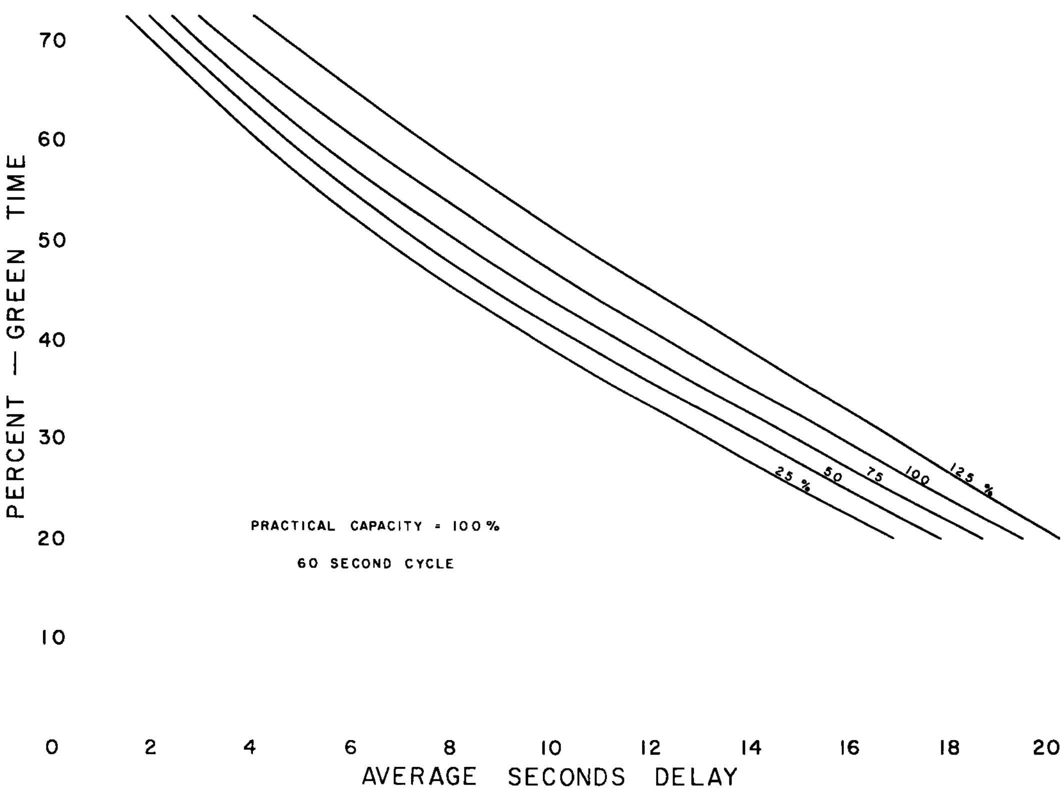


Figure 3. Average seconds delay per vehicle for vehicles with less than one full cycle delay.

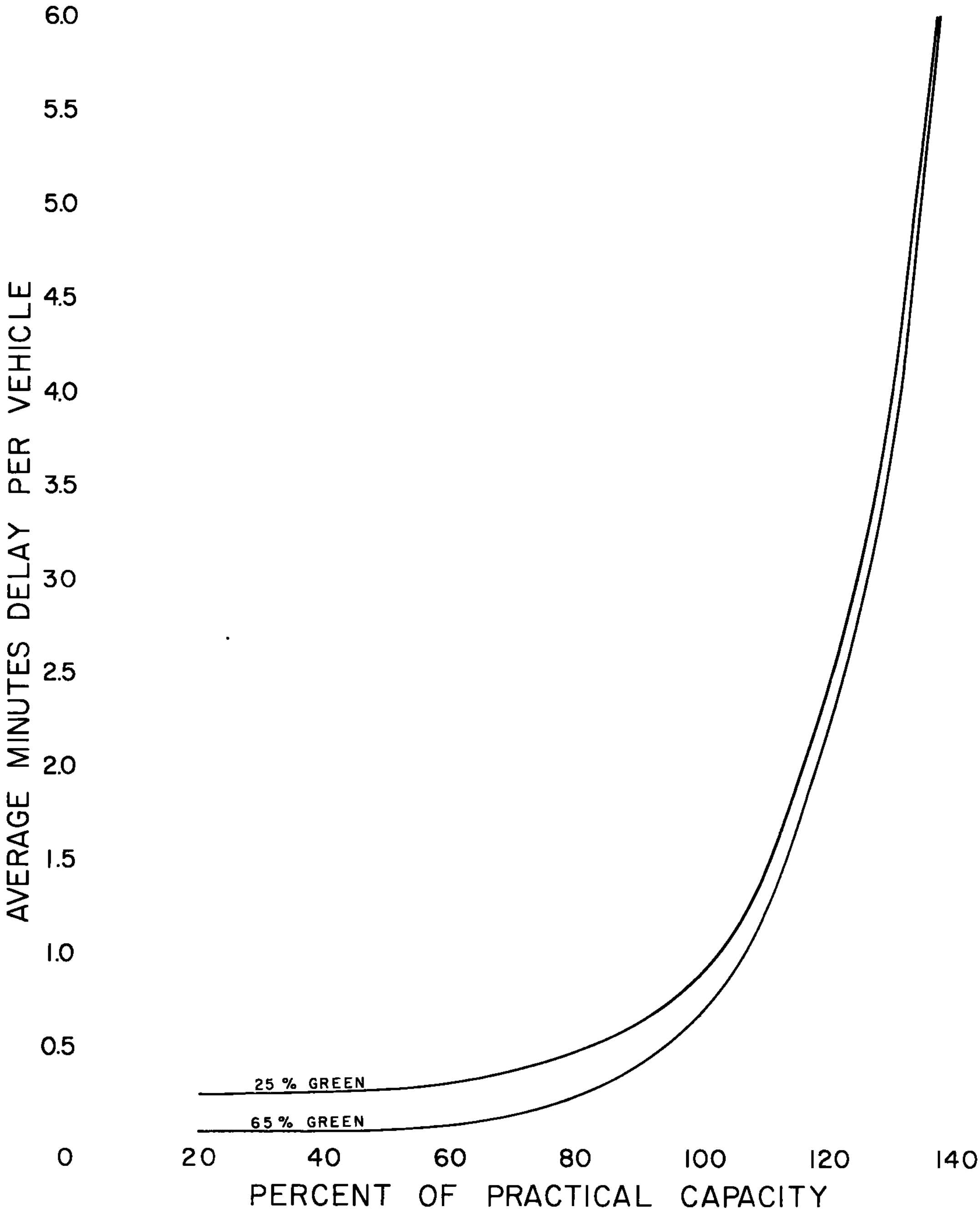


Figure 4. Average minutes delay per vehicle for intersections operating at various percentages of practical capacity.

at a percent of capacity had to be determined. Intersections do not operate at the same capacity for 24 hours or even for one hour in most cases. However, one hour interval is normally the basic unit for expressing capacities.

Tennessee has several permanent hourly traffic recorders located throughout the state in cities of all sizes of population. Yearly patterns of traffic distribution could be combined and summarized into four population groups of under 5,000; 5,000-25,000; 25,000-100,000; and over 100,000. The relationship between the higher hourly flows and the average daily traffic for the population group "over 100,000" is shown in Figure 5.

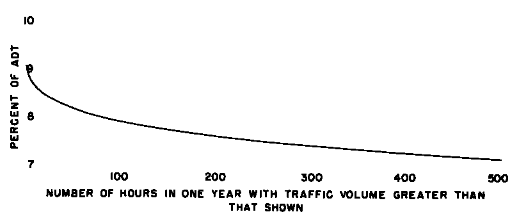


Figure 5. Tennessee urban population group over 100,000.

If it was known for any given hour in the yearly traffic pattern at what capacity the street was operating, then the seconds of delay per vehicle could be computed for that hour. Similarly, all other hours in the pattern could then be computed as a percentage above or below the known hour's operation. Any hour in the yearly pattern could be selected and the computation made on the basis that the selected hour operated at several percentages of capacity. The computation time for this procedure is prohibitive without the aid of some high speed electronic computer. This piece of equipment was available in Tennessee. The 300th hour was selected as the assumed condition although any hour could have been chosen. The 300th hour is well within that portion of the curve in Figure 5 where the change of slope is more uniform; there are only 299 hours in the year operating above this hour; values for all hours as interpreted from Figure 4 would be in the middle portions and more discernible; and the resulting Table 1 would not be more extensive than it is.

The 300th hour was assumed to be operating at increments of 5 percent capacity for the range from 20 percent through 150 percent. Computations were made for each of the 5 percent increments for each of the five percentages of green signal time and each of the four population groups. The result is shown in Table 1.

The geometrics for any urban street section are determined from the field inventory notes. They are then translated into hourly capacities through the use of a series of tables included in the manual of procedure. The capacity tables as developed, included such factors as: type of area, distribution and composition of traffic, type of street operation, parking, amount of green signal time, width of street, and turning movements.

As Tennessee has the ADT on each section of urban extensions of the state highway system, and the relationship of any hour's operation by population groups to the ADT, the 300th hour can be expressed in volume. With the known volume and capacity, the percent of operation in terms of capacity can be computed. From Table 1 the average seconds of delay per vehicle can be determined and applied to the ADT. The signal delay is then combined with delays computed for speed zones, turns, parking, and railroad grade crossings to obtain a time delay index expressed in seconds of delay per mile.

TABLE 1

WEIGHTED AVERAGE SECONDS OF DELAY PER VEHICLE OF ADT OCCURRING AT TRAFFIC SIGNALS

Percent Capacity in 300th Hour	Over 100,000 Population				
	Percent Green				
	25	35	45	55	65
20	15.12	11.52	8.22	5.52	3.06
25	15.17	11.55	8.25	5.53	3.06
30	15.26	11.62	8.32	5.55	3.06
35	15.39	11.72	8.42	5.58	3.06
40	15.53	11.84	8.53	5.63	3.08
45	15.71	12.02	8.68	5.74	3.19
50	15.95	12.26	8.88	5.91	3.38
55	16.28	12.59	9.20	6.17	3.69
60	16.73	13.04	9.66	6.55	4.15
65	17.30	13.62	10.27	7.10	4.75
70	18.05	14.39	11.08	7.85	5.53
75	19.03	15.36	12.13	8.83	6.52
80	20.28	16.59	13.44	10.10	7.77
85	21.85	18.17	15.11	11 74	9.39
90	23.85	20.19	17.21	13.81	11 44
95	26.49	22.83	19.92	16.52	14.11
100	29.98	26.30	23.40	20.05	17.57
105	34.64	30.95	28.02	24.74	22.17
110	40.75	37.04	34.10	30.89	28.23
115	48.87	45.14	42.19	39.03	36.29
120	59.31	55.57	52.60	49.47	46.66
125	72.61	68.88	65.91	62.81	59.92
130	88.98	85.25	82.28	79.23	76.26
135	108.94	105.20	102.24	99.24	96.17
140	132.60	128.84	125.82	122.92	119.75
145	159.35	155.59	152.44	149.65	146.46
150	188.88	185.12	181.83	179.14	175.95

The method herein described is only a part of the total Planned Construction Program Procedure successfully in use in Tennessee. The method is based upon very limited data but is workable and affords a comparison of signal delay occasion on one urban state highway with another. It must be remembered that the construction program procedure is in use and at the same time it is in the research stages. The methods employed had to be invented as there were no precedents in most cases. Certainly as the work progresses in Tennessee, improvements toward accuracy and simplification of method will be forthcoming. It is earnestly hoped the other states will employ similar methods or devise new ones which will improve procedures to attain the ultimate objective of a workable and usable planned construction program.

Considerable time and effort were given toward the development of this phase by the personnel of the Tennessee Highway Planning Survey Division, O. K. Normann of the Bureau of Public Roads, and C. F. McCormack and R. H. Winslow of the Automotive Safety Foundation. This cooperation is sincerely appreciated.