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Traffic Signal Warrants—A Bibliography

An NCHRP staff-prepared presentation of the annotated bibliography compiled as part of the final report from NCHRP Project 3-20, "Traffic Signal Warrants," by E. B. Lieberman, G. F. King, and R. B. Goldblatt, of KLD Associates, Huntington, New York. The original bibliography was prepared by J. L. Barker and J. W. Perry of Transportation Systems Center, LFE Corporation, and G. F. King.

THE PROBLEM AND ITS SOLUTION

The purpose of traffic signal warrants should be to determine when the improvement of intersection performance, whether measured by operation or safety criteria, should include the installation of a traffic control signal. Existing traffic signal warrants, as presented in the "Manual on Uniform Traffic Control Devices for Streets and Highways," may not consider all of the factors that should go into a determination of need for traffic signal control. Or the factors may be considered, but only in general terms. As a result, in practice, it is often necessary to so temper the numerical warrants with judgment that the warrants may appear discredited. This is not to say that engineering judgment should be precluded in the decision, but better warrants should lead to more consistency in the application of traffic signal installations.

The objectives of this project were, therefore, to evaluate the adequacy of existing warrants in meeting current needs for determining whether a traffic signal should be installed and to determine the need for revised or additional warrants. Among the research tasks stipulated as means of achieving these objectives was the compilation of an annotated bibliography of relevant literature pertaining to traffic signal warrants.

FINDINGS

The literature review made in preparing the bibliography was restricted for the most part to materials published since 1967. This restriction reflects the availability of a comprehensive bibliography compiled at that time by Box and Assoc. (reported herein as entry number 24). A second restriction on the bibliography scope is that its subject is limited to traffic signal warrants for isolated intersections.

The bibliography has been assembled in two parts. The first, containing 152 entries, covers the general subject area; the second, containing 29 entries, includes supplementary material on accident occurrence and costs. Entries are listed by author in alphabetical order. Where no authors are cited, the appropriate agency name has been used as the entry.

APPLICATIONS

To aid users of the bibliography, the entries have been classified by subject in the tables that follow. In most cases, the subject terms apply both to traffic flow and performance and to accidents. A number of extremely general entries occur, many of which are existing warrants that have been successfully employed. These are included for their obvious reference value.

Lane Signs	Ped Signals	Cost Analysis	Control Type	Control Effect		Surveys		Predictors	Ped Behavior
20	2	7	8	66	134	8	72	14	21
57	11	24	18	93	139	9	96	24	45
	16	31	22	103	142	22	120	31	91
	24	52	24	108	144	32	122	90	98
	62	90	30	113	147	53	127	101	
	63	111	31	116	148	58	128	120	
	77	129	33	123	150	64			
	92	130	34	126	152				
	100	139	53	133					

Geometry		Severity		Sensitivity Measurements	Gap Acceptance		Queue	Capacity		Saturation	Headways
7	101	27	99	4	10	72	6	3	69	5	6
9	102	32	102	35	12	86	37	13	70	6	19
22	109	44	104	36	24	107	42	17	82	51	24
25	110	64	108		43	118	50	19	83	68	107
47	115	77	119		49	137	54	24	85	87	
58	135	81	128		71	146	68	29	87	112	
60	139	84	129				74	41	88	140	
65	143	90	130				95	47	107		
78	146						109	48			
90	150										

Delays Ped		Simulation		Stop and Delay Vehicles		Flow		General	
11	72	5	72	1	69	1	72	17	72
16	91	10	75	4	89	24	85	24	73
24	92	15	82	24	92	41	92	28	79
56	114	26	83	30	94	36	102	38	80
70	132	34	84	37	95	69	121	39	88
71	136	40	94	40	112	70	145	46	97
	142	41	106	41	121	71		55	105
		49	107	42	131			61	117
		50	131	49	142			67	124
		59	137	52	146			69	125
		68	151	59				70	141
									145

PART I

1. A Tentative Peak Hour Delay Warrant. Smith (Wilbur) and Associates, New Haven, Conn. Prepared for the West Virginia Dept. of Highways. March 1973.
A tentative peak-hour delay warrant is developed based on a review of existing warrants of this type and on traffic flow and delay data collected at three sites in West Virginia. The warrant is expressed in terms of intersection type, number of minor street approach lanes, minor street volume, total intersection volume, and minor street total delay. The warrant must be met or exceed for 1 hr of an average weekday or during 5 hr on a typical weekend. The warrants were tested at six locations, three in West Virginia and one each in Texas, Connecticut, and California and were found to give reasonable results.

2. AAA Special Survey on Pedestrian Signals. Pedestrian Safety Report, American Automobile Association, Washington, Vol. 1, No. 3, January 1971.

3. Allsop, R.E. Estimating the Traffic Capacity of a Signalized Road Junction. Transportation Research, Vol. 6, No. 3, Sept. 1972, pp. 245-255.
This paper describes a new method that applies to nearly all junction layouts and signal cycles and that reduces to Webster and Cobbe's method in cases where that method is directly applicable. The results apply to both isolated traffic signals and systems. The calculations result in an analysis of practical capacities that are dependent on assumed values of saturation flows on each approach and acceptable degrees of saturation on the most heavily loaded approaches.

4. Allsop, R.E. Sensitivity of Delay at a Fixed Time Traffic Signal to Small Errors in the Observations Used for Calculating the Signal Settings. Traffic Flow and Transportation, Proceedings of 5th International Symposium on the Theory of Traffic Flow and Transportation, Berkeley, 1971. Elsevier Publishing Co., New York, pp. 253-267.
A rigorous mathematical analysis of the effect of errors in input data (average flow and saturation flow) on the computation of delay at signalized intersections computed according to Webster's method (see entry 145). The author shows that although individual errors in input data have a rather small effect, these errors are apt to occur in multiples and to reinforce each other.
These results are important in assessing the sensitivity of any signal warrant based on vehicular delay. They will also have application in determining whether traffic flow rates are sufficiently stable over time to permit accurate delay predictions for even optimally timed fixed-time traffic signals.

5. Ancker, C.J., Jr. and Gafarian, A.V. A Simple Renewal Model of Throughput at an Oversaturated Signalized Intersection. Transportation Research, Vol. 1, No. 1, May 1967, pp. 57-65.
The effect of random headways on throughput at an oversaturated signalized intersection is studied. The model assumes an infinite queue of vehicles at the beginning of the green phase. The entry time of the first car is assumed to be a random variable X, and all successive entry-time headways (minus a minimum time T) are assumed to be the random variable X.

All random variables are assumed to be mutually independent. Expressions are derived for the mean and variance of the number of vehicles that pass through the intersection. Some calculations and curves are given for the specific case of an Erlangian distribution function of the random variable X. It is shown that a deterministic model is quite accurate for mean value calculations but that variability in headways does cause significant variance in throughput.

6. Ancker, C.J., Gafarian, A.V., and Gray, R.K. The Oversaturated Signalized Intersection—Some Statistics. Transportation Sci., Vol. 2, No. 4, Nov. 1968, pp. 340-361.

   A report on the investigation of an oversaturated intersection. With no turning permitted, it was found that queue discharge headways could be fitted to a shifted Erlang density function and that all vehicles from the third place and back can be considered as members of the same population with different means. The mean headway is constant from the seventh vehicle and back. The measured headways decrease monotonically from 2.72 sec for the first vehicle to 1.70 sec for the seventh.

7. Anderson, K.W. Traffic Engineering to Reduce Accidents. Traffic Engineering, Vol. 39, No. 12, Sept. 1969, pp. 48-53.

   This article carries a methodology on accident analysis, correction measures, and a benefit/cost analysis. An example is worked out for accident correction changes at a signalized intersection. The importance of correlating the location, traffic operation, and accident records in the determination of corrective treatment at intersections is detailed. This then is used to set up a hazard elimination and its cost versus the probable accident reduction over some finite period and its associated dollar benefit. The author emphasizes the need for continuing high-hazard reduction procedures throughout the highway system.

8. Andreassend, D.C. Another Look at Traffic Signals and Accidents. Proceedings, Australian Road Research Board, Paper No. 601, Vol. 5, Part 3, 1970, pp. 304-318.

   This paper contains a before and after analysis of 41 newly signalized intersections, 19 intersections where previously installed signals had been modernized, and 25 intersections at which flashing beacons had been installed. The analysis period was four years, two years before and after each change. All signals installed were justified under the signal warrants of the State of Victoria, which are identical to the MUTCD (1971) warrants. The figure of merit used for comparison was the number of accidents per intersection. No checks were made on possible changes in traffic patterns between the two analysis periods.

   The data presented showed an average reduction of 31.9 percent in total number of accidents and a reduction of 71.6 percent in right-angle accidents. On the other hand, rear-end accidents increased by 12.7 percent and right-turn accidents (which would be left-turn accidents under U.S. driving rules) increased by 157.0 percent. All of these changes, with the exception of rear-end accidents, are significant at 0.0001 level.

The signal reconstruction work consisted of installing actuated equipment including an all-red interval and enhancing signal-head visibility and target value. The respective changes in accident rates, in the same order as above, were -29.2 percent, -49.8 percent, +10.1 percent, and +6.3 percent.

Flashing signals, yellow for the main street and red for the side street, were installed at 25 locations. The average reduction in accidents was 42.2 percent and the reduction in right-angle accidents was 50.4 percent. No data are given on rear-end or turn accidents for this case.

9. Antrim, J.D. An Investigation of Traffic Accident Locations in South Carolina State Highway Dept., Dist. No. 3. Clemson Univ., Rept. No. 081, June 6, 1969.

Investigations were conducted to determine how engineering knowledge can be applied to reduce the number of traffic accidents at those intersections and roadway sections having high accident rates. The investigations were confined to those 1962-66 traffic accidents in South Carolina State Highway Department District No. 3 that had been reported on SCSHD Form 310 by officers of the South Carolina State Highway Patrol. High-accident locations were identified by considering only those sites that experienced five or more accidents during 1966 and that had an accident rate of three or more accidents per million vehicles passing the site during 1966. The resulting fourteen high-accident intersections and sixteen high-accident half-mile roadway sections were then studied in depth to determine which design features, if any, were wholly or partly responsible for causing any of the accidents. Recommendations regarding corrective measures are presented for each of the thirty high-accident sites and future design considerations are discussed. Also discussed are the deficiencies in the present system of accident reporting.

10. Ashworth, R. A Note on the Selection of Gap Acceptance Criteria for Traffic Simulation Studies. Transportation Research, Vol. 2, No. 2, June 1968, pp. 171-175.

A mathematical model has been constructed to demonstrate the bias that is introduced in the collection and presentation of gap acceptance data at a stop-sign-controlled intersection. For the purpose of the model, it is assumed that traffic on the major road is randomly distributed and that driver gap acceptance characteristics follow a normal distribution curve with standard deviations. The model shows that the resulting gap acceptance curve is of the original form but displaced by an amount qs^2, where q is the major road volume (vps). This result has been confirmed by simulation studies carried out with traffic volumes ranging from 300 to 1,500 vph. It is considered that the existence of this bias necessitates care in the collection and combination of gap acceptance data at different levels of traffic volume and also requires a careful appraisal of the procedure used to simulate traffic movements at the intersection in order to ensure that the observed gap acceptance data are reporduced in the simulation model.

11. Ashworth, R. Delays to Pedestrians Crossing a Road. Traffic Eng. Control, Vol. 13, No. 3, July 1971, pp. 114-115.

The point at which a grade-separated pedestrian crossing is justifiable should be determined not only in terms of safety but also in terms of pedestrian time saved.

12. Ashworth, R. The Analysis and Interpretation of Gap Acceptance Data. Transportation Sci., Vol. 4, No. 3, Aug. 1970, pp. 270-280.

This paper considers various methods of collecting and analyzing gap acceptance data. The existence of a bias is shown for the case where all accepted and rejected gaps are taken into account. The paper advocated the use of a correction factor to eliminate this bias from the computed mean of the gap acceptance distribution.

13. Ashworth, R. The Capacity of Priority-Type Intersections with a Non-Uniform Distribution of Critical Acceptance Gaps. Transportation Research, Vol. 3, No. 2, July 1969, pp. 273-278.

This analysis determines the capacity of a minor road at a stop-controlled intersection that has a gap acceptance function (a) replaced by a distribution of critical gaps. These values will give a better indication of intersection capacity than will the use of a constant value for delay because of the variation of the individual driver's response to gaps in the main stream.

14. Baker, W.T. An Evaluation of the Traffic Conflicts Technique. Highway Research Record 384, June 1972, pp. 1-8.

The traffic conflicts technique (see entry 101), as developed by General Motors Research Laboratories, was evaluated by the Federal Highway Administration in cooperation with the State Highway Departments of Washington, Ohio, and Virginia. In addition to a field test of the technique, an attempt was made to find whether there is a statistical relation between traffic accidents and traffic conflicts. Conflicts were counted at 392 intersections before improvements were made and 173 intersections after construction of the improvements. It appears that those characteristics of intersections that contribute to accident causation can be more readily exposed by using conflicts than by using conventional accident analysis techniques. This may be especially true at low-volume rural intersections. Because of the ability to provide more precise information, lower cost remedial actions should result. Correlation coefficients were calculated for bivariate populations of number of conflicts, and number of corresponding accidents are associated.

15. Barnes, J.W. and Crisp, R.M. Simulation of the Four-Way and Two-Way Sign Controlled Intersections. Proceedings, Winter Simulation Conf., 1971.

A report on the development and implementation of two simulation models for stop-controlled intersections. The models utilize previously published results for arrival, gap acceptance, start-up, delay, and crossing time distributions. The models also assume perfect obedience to the priority rules and a constant speed for all free-moving vehicles. The writers conclude, on the basis of exercising the model with a number of different approach flow levels, that the total intersection delay is less for two-way stop control than it is for the four-way case.

16. Bayley, J.M. Pedestrians and Traffic Signals. Traffic Eng. Control, Vol. 8, No. 5, Sept. 1966, pp. 311-312+.

Melbourne's preplanned coordinated fixed-time system of signals rather than a vehicle-actuated system gives added weight to pedestrian crossing needs.

17. Bayley, J.M. Some Aspects of Traffic Signal Control. J. Australian Road Research Board, Vol. 2, No. 3, March 1965, pp. 23-39.

18. Bennett, G.T. Accidents at Urban Junctions. J. Inst. Highway Eng., Vol. 18, No. 7, July 1971, pp. 23-28.

19. Berry, D.S. and Gandhi, P.K. Headway Approach to Intersection Capacity. Highway Research Record 453, 1973, pp. 56-60.

This paper develops a method for computing the capacity of signalized intersections from measurements of headways, starting delays, and utilization of the yellow and presents some preliminary data on its application. The mean measured starting delay for dry, daylight conditions was 2.48 sec. For the same conditions, the mean discharge headway was 1.085 sec with a standard deviation of 0.049 sec. Significant differences in these values were found to exist for all other roadway and atmospheric conditions investigated.

20. Berry, D.S., Wattleworth, J. and Schwar, J.F. Evaluating Effectiveness of Land-Use Control Devices at Intersections. Proceedings, Highway Research Board, 1962, pp. 495-528.

Field studies were made at several high-volume signalized intersections in the Chicago area to evaluate the effectiveness of different designs of roadside and overhead traffic signs for controlling multiple turns (double left turns or double right turns). The comparative effectiveness of different roadside double-turn signs was also studied in the laboratory by measuring response times and accuracy of responses to questions asked of groups of subjects concerning their interpretations of test signs when shown in relation to simulated driving situations. Slides were used to display the driving situations and the test signs.

It was found that effectiveness of multiturn controls could be evaluated in the field by studying changes in the use of the second, or optional, lane for turns coupled with observations of violations of lane-use controls. In the laboratory the questions on accuracy of response appeared to provide the most useful information for evaluation of effectiveness of double-turn control signs.

It was concluded that the regulatory lane-use control signs in the 1961 edition of the Manual on Uniform Traffic Control Devices should be satisfactory for control of multiple turns until refinements are developed from further research.

21. Biehl, B.M., Older, S.J. and Griep, D.J. Pedestrian Safety. Organisation for Economic Cooperation and Development, Paris, 1970, 70 pp.

Summary of past research on pedestrian behavior and accidents and recommendations for future research on an international basis.

22. Box, P.C. Intersections. Traffic Control and Roadway Elements-Their Relationship to Highway Safety, Chapt. 4, Revised. Highway Users Federation for Safety and Mobility, 1970, 11 pp.

Statistics show that intersectional accidents are a national problem in highway safety. About 24 percent of fatal accidents listed in a national tabulation were classified as occurring at intersections. In urban areas, approximately 41 percent of total accidents and 39 percent of fatal accidents were reported as intersectional. In rural areas, the data showed that 27 percent of total accidents but only 17 percent of fatal accidents were at intersections. Intersection elements that can be related to intersection accident rates include geometric layout and traffic controls. The basic intersection configurations include the L, Y, T, offset (JOG), and

cross-type. In a comparison of uncontrolled intersections in limited-access subdivisions, the cross-type was found to have 14 times the accident frequency as the T-type. Accident frequency for cross-type intersections in gridiron subdivisions was 41 times that of T-type. The intersection shape was also found to be an important element at rural locations. Many studies are reported on the effect of traffic signals on traffic operations. Studies on flashing beacons and directional signing are described.

23. Box, Paul C. Traffic Control at Minor Intersections. Municipal Signal Eng., Vol. 31, No. 1, January - February 1966, pp. 21-25.

24. Box (Paul C.) and Associates. Assembly, Analysis and Application of Data on Warrants for Traffic Control Signals. Prepared for Signal Comm., National Joint Comm. on Uniform Traffic Control Devices. March 1967. Unpublished. Abridged version published in 3 parts. Traffic Eng., Vol. 38, No. 2, Nov. 1967, pp. 32-41; No. 3, Dec. 1967, pp. 22-29; No. 4, Jan. 1968, pp. 14-21, 56.

This report is an extensive and valuable analysis of existing and proposed warrants. It includes an extensive annotated bibliography (273 items).

The volume, as used as a warrant in the Manual on Uniform Traffic Control Devices, 1961 edn., has been analyzed with regard to hourly peaking characteristics. An analysis is made relative to the need for study of lower ADT specifically on intersections in urban areas, the need for additional data for the interruption-type warrant, and the need for extension of the volume warrants for rural intersections.

The authors present an excellent study of gap availability and acceptability. Results indicate strongly the need for defining the gap availability with respect to urban/rural, two-lane/four-lane, etc. Relative to gap acceptance as a warrant there appears so much variability due to physical, traffic, vehicle, and driver characteristics that the use of gap acceptance as a control device warrant is not recommended. This input would require actual field measurements that are not simple and available to local traffic engineers.

Delay is discussed as it might be used as a primary warrant and how it actually is the important factor in volume warrants. An analysis of the material and studies by several investigators is made of delay at stop signs, fixed-time control, and actuated control. The results seem to indicate that delay may be higher at low volume levels for signal control than realized. The paper points out the value of simulation models to perform delay warrant analysis. A suggested form of simple field delay study is shown. The merit of using both delays and volumes to various degrees is suggested as a warrant.

Pedestrian warrants are analyzed as they relate to street width, number of pedestrians, and volumes on the street to be crossed, etc. Reference is made to accident warrants for pedestrian control.

The authors cover several investigators' work on the effects of different types of control devices and volumes on accidents. These are related to the type and number of accidents. Basic conclusions are that changing from two-way or four-way stop control to signalization if applied on valid warrants will (a) reduce right-angle accidents (severe), (b) increase rear-end accidents (less severe), and (c) generally increase total number of accidents. The authors point out that for stop control, the minor street volume is the sensitive parameter and not the major street volume.

Suggested warrants are discussed by the authors with the general conclusion that the peak-hour factor (PHF) and peak-hour delay are most probable factors in setting up warrants for signalization. Volumes, turns, number of lanes, and geometry are complicated. As stated throughout the paper, simulation properly applied may be the answer to this problem. The warrant for system signalization of two or more major routes has been suggested as a simple requirement of 800 entering vehicles during the peak hour or 5 hours of a Saturday or Sunday.

A simplified warrant for school crossing control is stated as requiring only 30 adequate gaps per peak 30-min period if pedestrian volumes are 60 per hour and that this happens at least twice per weekday. A similar but somewhat more complicated warrant is proposed for ordinary pedestrian (not school) crossings which involve pedestrian delay. The accident warrant accommodation is left wide open with no recommendation.

25. Bruzelius, N.G. Safety at Intersections: Relations Between Accidents and Layout and Control. International Road and Traffic Safety Rev., Vol. 13, No. 2, 1965, pp. 7-12, 14, 26.

26. Buckley, D.J. Road Traffic Counting Distributions. Transportation Research, Vol. 1, No. 2, Aug. 1967, pp. 105-116.

This paper reviews the existing literature on counting distributions in road traffic. The author derives the counting distribution for the mixture of several Poisson processes. He considers the displaced Erlang distribution as the probability density function of headways and derives, in detail, two types of counting distributions. A result for the counting distribution of the Erlang semi-Poisson model is stated.

27. Cantilli, E.J. Statistical Evaluation of Traffic Accident Severity. Highway Research Board Bull. 208, 1959, pp. 29-34.

The study was an attempt to create a scale of numerical values to be applied to traffic accidents. A scale was set up based on monetary damage values and American standard injury classifications. Accident severity was compared with accident rate on the basis of weather, road, and light conditions. It was found that (a) severity as a monthly, daily, or hourly pattern did not, in general, follow the movements of accident frequency or accident rate; (b) severity of accidents increased with a decrease of natural light; and (c) severity increased with poor road conditions and also with bad weather.

28. Carstens, R.L. Some Parameters at Signalized Intersections. Traffic Eng., Vol. 41, No. 11, Aug. 1971, pp. 33-36.

This work deals with the analysis of intersection capacity as it applies to unusual intersections where the Highway Capacity Manual may not be appropriate. A detailed analysis is made of the headways as observed at the stop line and it is shown how actual measurements can justifiably be used to modify signal timing as compared to the use of average headways. The work further points out the value and suggests a method to refine the "passenger car equivalent" value to turning vehicles and various vehicle classifications.

29. Chang, Y., and Berry, D.S. Examination of Consistency in Signalized Intersection Capacity Charts of Highway Capacity Manual. Highway Research Record 289, 1969, pp. 14-24.

This study was undertaken to determine possible inconsistencies in the 1965 Highway Capacity Manual and some capacity differences when changes are made in parking conditions and in the width of approaches. The major problems are that (1) the curves for capacity on two-way and one-way streets with parking need revision relative to the amount of left-turn traffic percentage, (2) the capacity curves for one-way streets when parking is allowed on both sides appear to be too high, and (3) the total effects on capacity and level of service for changes in widths, lane markings, parking, turns, and opposing flows should be evaluated and refined.

30. Clyde, M.N. Michigan Study Indicates Signals Increase Accidents. Traffic Eng., Vol. 35, No. 2, Nov. 1964, p. 32.

A before and after study at 52 newly signalized intersections in Michigan indicated an increase in total accidents and a significant shift in accident-type distribution.

	Before		After	
	No.	%	No.	%
Total Accidents	621	100	830	100
Rear End	259	41.7	514	62.0
Right Angle	242	39.0	134	16.2
Left Turn	35	5.6	58	7.0
Other	85	13.7	124	15.0

An increase in injury accidents and a decrease in fatalities were noted. However, the statistical significance of these changes is not established.

A parallel study at 75 locations with newly installed flashers indicated significant decreases in total accidents, injury accidents, and fatalities.

	Before	After	% Decrease
Total Accidents	578	434	25
Injuries	566	290	49
Fatalities	63	25	60

Decreases were noted in all types of accidents.

31. Cribbins, P.D., Bennett, J.W., and Walton, C.M. Evaluation of Traffic Control Improvements on Low-Volume Highways. North Carolina State Univ. Highway Research Program, ERD 110-68-5, June 1969, 94 pp.

Overhead flashers and signals were measured for their effectiveness in reducing accidents at low-volume, high-speed rural intersections. Accidents for at least one year periods prior to and after installation of the devices were compared on the basis of exposure rates and severity indices. A category defined as Equivalent Property Damage Only (EPDO) accidents was found to be the most reliable and significant indicator of accident consequences. Differences in EPDO rates between before and after periods were evaluated by the Student T test, which revealed an association between the installation of flashing beacons, and a reduction in EPDO rates. Results of the analysis for traffic signals were not highly significant. In the flashing beacon cases, there was a significant reduction in EPDO rates for all sites and for the four-leg, three-leg intersections; the EPDO increase in the after-period at non-channelized intersections was not significant. The severity index for all accident groups decreased except at non-channelized intersections.

32. Cribbins, P.D., and Walton, C.M. Traffic Signals and Overhead Flashers at Rural Intersections: Their Effectiveness in Reducing Accidents. Highway Research Record 325, 1970, pp. 1-14.

This paper reports on a before and after study made in North Carolina encompassing 14 flashers and 19 signals at low-volume high-speed rural intersections. The statistics on which the authors place primary reliance in making the before and after comparison is equivalent property damage only (EPDO). This is a weighted average of accident severity as expressed in the five standard classes. Statistically significant reductions in EPDO were noted for flasher installations. The over-all reduction in EPDO was not statistically significant for the traffic signal installations. When, however, one outlier showing a large increase was eliminated, the reduction in EPDO for the other 18 locations proved to be significant.

A striking change in accident distribution by type is shown by analysis of the data used in the study. Rear-end and left-turn accidents are increased while right-angle collisions are sharply reduced. On the other hand, no significant change in accident distribution is caused by the installation of flashers.

33. Crossette, J.G. Traffic Control Measures Improved Safety. Traffic Eng., Vol. 39, No. 4, Jan. 1969, pp. 18, 20, 21.

34. Dare, C. The Traffic-Actuated Speed Signal Funnel. Traffic Eng., Vol. 40, No. 2, Nov. 1969, pp. 18-28.

High-speed signalized intersections are hazardous from the standpoint of causing rear-end collisions between vehicles. The signal funnel system developed in Germany appears desirable at these locations since it substantially reduces the number of vehicles forced to stop. However, the signal funnel has not been incorporated with the semi-actuated traffic signal that is often used at intersections on major throughfares in the United States.

The objectives of this investigation were to design and evaluate a signal funnel system capable of functioning effectively with semi-actuated control. Two computerized simulation models were developed in order to fulfill the objectives. The first model involved a conventional semi-actuated system and it was validated by comparing its output to field data obtained at a signalized intersection in a 45 mph zone. The second model was similar to the first but included a main route speed advisory signal and a series of three detectors on the side approach. Data from the signal funnel simulation were compared to the data from the first model, thus evaluating the proposed control system.

From the traffic volume studies, the signal funnel system stopped an average of only 2 percent of the main route traffic while the conventional system halted 20.9 percent. Furthermore, the signal funnel stopped 2.8 cars during 15 typical signal cycles, compared to 25.8 stopped during 15 cycles with the semi-actuated controller. The results indicate the traffic-actuated speed signal funnel has the potential for reducing the frequency of rear-end collisions since the number of vehicles stopped for each red phase is considerably reduced.

35. deSmit, J.H.A. The Transient Behavior of the Queue at a Fixed Cycle Traffic Light. Transportation Research, Vol. 5, No. 1, April 1971, pp. 1-14.

The Beckman et al (1956) model for a fixed-time signal is studied. Expressions are derived for the distribution of waiting time and queue length particularly as these results lead into nonstable conditions under peak and oversaturated conditions. A number of curves are shown that give an insight into the behavior of the system under critical flow conditions.

36. DiPietro, C.M., and King, L.E. Pedestrian Gap-Acceptance. Highway Research Record 308, 1970, pp. 80-91.

Statistical tests were utilized to investigate relationships between size of gap accepted by pedestrians at unmarked mid-block crossing and time waited at curbside, speed of approaching vehicle, volume of traffic, number of persons waiting at curbside, and walking speed of the pedestrian.

37. Dorfwirth, J.R. Wartezeit und Rückstau von Kraftfahrzeugen an nicht signalgeregelten Verkehrsknoten, Eine Anwendung der Theorie stochastischer. (Delay and Queuing of Motor Vehicles at Uncontrolled Intersections.) Prozesse für den Verkehrsablauf an nicht signalgeregelten Kreuzungen. Forschungsgesellschaft für das Strassenwesen, Forschungsarbeiten aus dem Strassenwesen, New Series, No. 43, Bad Godesberg, 1961, 40 pp.

38. Drew, D.R. Traffic Flow Theory and Control. McGraw-Hill, 1968, 467pp.

This textbook covers the subject matter in a rather precise and mathematical manner but still maintains definite practical considerations. The energy model and acceleration noise parameter are indicated as relating to intersection performance and accident rates. The text covers queuing processes, traffic flow parameter distributions of various types, simulation fundamentals, and other subjects directly related to the approach needed to develop traffic signal warrants.

39. Dunne, M.C. A Mathematical Investigation of the Control of Traffic at an Intersection. Ph.D Thesis, Univ. of Adelaide, 1966.

40. Dunne, M.C. Traffic Delay at a Signalized Intersection with Binominal Arrivals. Transportation Sci., Vol. 1, No. 1, Feb. 1967, pp. 24-31.

Delay formulas are derived for vehicles at an isolated intersection at which the vehicle arrivals are supposed generated by a binominal process, the departure rates are assumed constant, and the control strategy is to switch the lights when the favored queue empties. The mean delay is calculated using a discrete analog of a method used for the case of random arrivals. Later, a probability-generating function for delay is developed yielding, in particular, the variance of the delay.

41. Dunne, M.C., and Buckley, D.J. Delays and Capacities at Unsignalized Intersections. Proceedings, Australian Road Research Board, Vol. 6, Part 3, 1972, pp. 345-362.

A theoretical investigation is made of the operating characteristics of unsignalized intersections. Some useful approximate formulas are developed for average delay and capacity in the case of two conflicting streams of traffic. The theoretical analysis is extended to the case of a simple T-junction and a comparison is made between the priority rule (i.e. the major road/minor road system) and the yield-to-right rule using as criteria throughput, capacity, and average delay. It is shown that the throughput is greater under the priority rule but that the yield-to-right rule is superior with respect to both capacity and average delay.

42. Dunne, M.C. and Potts, R.B. Control of Traffic at an Intersection. Proceedings, Austrialian Road Research Board, Vol. 2, Pt. 1, 1964, pp. 265-273.

This paper represents an extension of Webster's work (see entry 145) to the case of traffic-actuated signals. The type of signal controller considered is one that responds to queue lengths on competing approaches. A linear control algorithm is derived that, with the choice of the proper control constraints, will yield reasonable minima for both average delay and maximum individual delay in the unsaturated case.

43. Ehle, B.L. On Gap Utilization. Traffic Eng., Vol. 38, No. 1, Oct. 1967, pp. 36-41.

It is the responsibility of the traffic engineer to determine where traffic lights are needed and, just as important, when they are needed. Careful study of changing traffic patterns should allow him to act before a traffic problem exists rather than simply react to problems after they are a fact. If, however, the traffic engineer is to act rather than react he must have tools that allow him to pinpoint problems before they become problems. This paper attempts to sharpen one possible tool the traffic engineer might use to determine the placement of traffic lights. The problem is to determine if a warrant for traffic signal control can be established for the intersection of a main street and a minor street by using the relationship between the availability of gaps in the traffic stream on the main street and the lag and/or gap acceptance by drivers on a minor street. As a basis for such a warrant, the gap utilization at the intersection is determined. It was believed that the easiest way to present the method for determination of gap utilization is by means of several examples. Four examples are treated in this paper, the first three of which are artificial.

44. Failmezger, R.W. Relative Warrant for Left Turn Refuge Construction. Traffic Eng., Vol. 33, No. 7, April 1963, pp. 18-20, 50.

An index of hazard (I.H.) is developed to provide an overall number that takes into account the major factors at an intersection contributing to the magnitude of the problem associated with left-turn movements for the eight maximum hours of the day. The equation for the index of hazard is:

$$I.H. = V_L \; I.H. \; = \; V_L V_O (1 + F_C + F_E + F_{SA} + F_{SO} + F_S + F_M)$$

in which

V_L = the average of the eight maximum hours of left-turn movements as abstracted from a standard 16-hour manual vehicle count to include all left-turn movements from the through highway traffic stream.

V_O = the through movement in opposition to the left-turn movement for the same eight-hour period averaged for one direction.

F_C = the clearance width (i.e., more than 1 lane).

F_E = the escape width (i.e., room for another through vehicle to pass to right-or left-turn vehicle).

F_{SA} = the sight distance ahead of left-turn vehicle.

F_{SO} = the sight distance for the overtaking car behind left-turn vehicle.

F_S = the through-vehicle speed.

F_M = the miscellaneous factors (i.e., intersection angle, etc).

The factors are readily measured at the intersection and have been assigned values for use in the equation. The author considers the value of the index of hazard that would exist if a redesign is made at the intersection to include a refuge pocket for a left-turn vehicle or other geometrics. From this a relative warrant is developed that includes as factors the cost of the reconstruction and the number of accidents that would have been prevented if the construction had been installed. The index of hazard computed for a number of intersection can be used to set up a priority list for intersection treatments to be considered. The relative warrant computed for a number of intersection modifications are reported to give realistic comparative values.

45. Fleig, P.H., and Duffy, D.J. A Study of Pedestrian Safety Behavior using Activity Sampling. Traffic Safety Research Review, Vol. 11, No. 4, Dec. 1967. pp. 106-111.

Study of behavior of pedestrians at New York City street crossing before and after the installation of pedestrian traffic signals.

46. Forwood, A.V. and Pretty, R.L. A Comparison of Right of Way Rules at Intersection. Proceedings, Australian Road Research Board, Paper No. 449, Vol. 4, pt. 1, 1968, pp. 616-632.

This paper defines the right-of-way rules of unsignalized intersections throughout the world. The cases considered would be, under U.S. conditions, analogous to the intersection types such as (1) uncontrolled with priority to the right, (2) uncontrolled with priority to the left, (3) two-way stop, (4) four-way stop, and (5) yield. Results are taken from previous studies (in Australia, New Zealand, Sweden, England, and the USA), some simple mathematical models developed and some calibration data for these models developed.

The various right-of-way rules are compared in terms of intersection capacity and delay. Certain intransitive situations (i.e., situations with no clear-cut priority are defined for each major case. Most of these involve turning movements. The relative ranking of the four major types studied which are applicable to U.S. conditions, in terms of both capacity and delay, shows that uncontrolled with priority to the right ranks best followed, in order, by four-way stop, yield, and two-way stop. Delay due to left-turning vehicles was not considered,and safety considerations were not included in the study.

47. Frick, W.A. The Effect of Major Physical Improvements on Capacity and Safety. Traffic Eng., Vol. 39, No. 3, Dec. 1968, pp. 14-20.

48. Gandhi, P.K. Effect of Adverse Weather and Visibility on Capacity of a Signalized Intersection Approach. M.S. Research Rep., Northwestern Univ., Dec. 1972.

49. Gazis, D.C., Newell, G.F., Warren P., and Weiss, G.H. The Delay Problem for Crossing an n Lane Highway. Vehicular Traffic Science. Proceedings, 3rd International Symposium on the Theory of Traffic Flow, New York, 1965. Elsevier Publishing Co., New York, 1967, pp. 267-279.

This paper presents a theoretical analysis of the delay encountered at a minor street stop-controlled approach to a multilane uncontrolled highway. The first two moments of the distribution of waiting times are derived. It is shown that the multilane problem can be approximated by a single-lane-crossing formulation with suitable transformations of the arrival and gap acceptance distributions.

A series of simulation experiments showed that the theoretical distribution can be satisfactorily represented by a Pearson Type III (Gamma) distribution.

50. Grace, M.G., Morris, R.W.S. and Pak-Poy, P.G. Some Aspects of Intersection Capacity and Traffic Signal Control by Computer Simulation. Proceedings, Australian Road Research Board, Vol. 2, Pt. 1, 1964, pp. 274-304.

A digital computer simulation of various types of signal controllers. Salient findings of this first stage of a major effort include the following points:

1. There is an optimum timing for actuated controllers based on both flow rates and queue lengths.

2. The variance of delay, as well as its magnitude, for fixed-time signals increases greatly as the degree of saturation exceeds 0.8. This value of degree of saturation is, therefore, equivalent to practical capacity.

3. Properly timed vehicle-actuated signals have a greater capacity than fixed-time signals and provide a significantly better level of service for the same volume conditions.

51. Grant, E., and Simpson, A.D. Traffic Signals Saturation Flow and Lost Time.

Traffic Eng. Control, Vol. 9, No. 7, Nov. 1967, pp. 344-345.

This paper describes methodologies for the collection of data at an intersection, which will yield saturation flow, lost time, green and cycle times, turning movememts, and vehicle classifications. The use of event chart recorders to reduce the field data collection manpower requirement is stressed.

52. Gurnett, G. Intersection Delay and Left Turn Phasing. Traffic Eng., Vol. 39, No. 9, June 1969, pp. 50-53.

Technical article compares the advantages and disadvantages of providing separate traffic control signal phase indications for left-turn vehicles. In cases studies, left-turn slots or refuges had been installed both before and after the installation of the left-turn signal phases. The following conclusions were drawn:

1. Intersection delay per vehicle substantially increased (from 22 percent to 121 percent after left-turn phasing was installed.

2. Peak hour delay may increase over 100 percent after left-turn phasing is installed on all approaches of the intersection.

3. Left turn delay is not substantially reduced by left-turn phasing.

4. Normally, intersection delay costs outweigh accident reduction savings, but accident savings should be considered for each individual intersection.

The author comments, "Nevertheless most drivers appear willing to accept an additional 3 to 5-sec delay at an intersection for safety and convenience of a left-turn phase" in the signal control cycle.

53. Heany, J.J. 4-Way Stop: A Highly Effective Safety Device. Philadelphia Bur. of Traffic Eng., 1970. (Mimeo).

An unpublished report on the before and after accident experience at 57 4-way-stop locations in Philadelphia. An over-all reduction of 87 percent in all accidents, 92 percent in personal injuries, and 100 percent in fatalities was noted. No intersection showed an increase in accidents. The 57 locations showed a range of total daily traffic volume of 1,000 to 8,100 and, according to the paper, none of them met the minimum volume requirement of the MUTCD. The sample also included nine locations with a traffic demand split of 70/30 or greater.

On the basis of this study, the City of Philadelphia adopted a warrant for 4-way-stop control, which provides for the installation of this type of control at any location that shows an accident rate one standard deviation above the city-wide mean. Apparently this includes all accidents and does not call for the classification required by the MUTCD. The upper boundaries on the warrant are the capacity limitations of this type of control stated on p. 158 of the Highway Capacity Manual. Ten of the intersections included in the sample did not meet the accident warrant.

In the general discussion part of the report it is postulated that 4-way-stop control would show smaller vehicular delay than traffic signals with ADT's below 10,000. However, no delay figures are given in the report.

54. Herman, R., Lam, T., and Rothery, R.W. The Starting Characteristic of Automobile Platoons. Traffic Flow and Transportation, Proceeding, 5th International Symposium on the Theory of Traffic Flow and Transportation, Berkeley, 1971. Elsevier Publishing Co., New York, 1972, pp. 1-17.

This paper reports on a series of studies of the General Motors Research Laboratory dealing with the response of platoons of passenger cars. The acceleration and velocity profile of the last (sixth) vehicle in the platoon was determined as a function of the acceleration, velocity, and target velocity of the lead car. The changes in platoon length during the acceleration phase was also measured.

This research presents a methodology and some initial data that can be used to evaluate the time required to clear a waiting platoon from a signalized intersection and, consequently, the expected delay.

55. Highway Capacity Manual. Highway Research Board, Special Report 87, 1965, 397 pp.

56. Hoel, L.A. Pedestrian Travel Rates in Central Business Districts. Traffic Eng., Vol. 38, No. 4, Jan. 1968, pp. 10-13.
The effect of environmental factors (time of day, external influences, temperature) on pedestrian travel rates.

57. Hoffman, M.R., Alashari, N. and Lampela, A.A. Evaluation of Traffic Lane-Use Control Signs. Traffic and Safety Division, Michigan Dept. of State Highways, Rept. TSD-SS-112-69, 1969.
An evaluation was made of over head lane-use control signs and how their installation on one-way traffic sections of US 12 in advance of six intersections in the City of Wayne, Wayne County, affected accident rates. The installation of the signs (costing $6,602 for six overhead sign suspension assemblies) contributed to the reduction in the total number of accidents by 44 percent (88 to 49) in a one-year period. During the same period, the incidence of accidents caused by turning from the wrong lane was reduced by 58 percent (31 to 13). This accident reduction, according to National Safety Council criteria, resulted in savings of $47,900 to the motoring public.

58. Hoffman, M.R., Suboski, L.V., and Scarcella, F.R. An Evaluation of a Federal Aid Safety Project. Michigan Dept. of State Highways, June 1968.
An evaluation is presented of a Federal Aid Safety Project in Lansing, Michigan, which had a trunk-line accident reduction of 65 to 33 from the year before the improvement to the year after the improvement, respectively. The project consisted of widening the business loop of I-96 from four to five lanes to provide a center lane for left turns and the construction of roadside control. This business loop is developed industrially and commercially from the downtown area south through an intersection connecting with I-96. Each of the four legs of this intersection previously carried four lanes of two-way traffic. Previous to the improvement, this intersection had one of the highest accident rates in the city. This spot improvement project relieved operational problems and improved safety at the intersection. The safety project reduced accidents, especially the type which involved the left-turn operation. It also increased the efficiency of lane usage at the intersection, because since motorists in the left through-lane no longer needed to slow down for left-turning vehicles.

59. Huddart, K.W. The Importance of Stops in Traffic Signal Progressions. Transportation Research, Vol. 3, No. 1, Apr. 1969, pp. 143-150.
This paper deals with the relative timings of traffic signals to ensure optimum progression of platoons of vehicles in a road network. Previous work, which is quoted, has described means of producing such progressions which either maximize the time for which a particular traffic flow will not be stopped (bandwidth) or minimize the delay to all traffic. A short description is given of a computer program based on minimizing delay. A new parameter, stop penalty, is included in the program to achieve an approach to maximum bandwidth while still allowing for varying street width and a variety of networks. The paper analyzes the effect of stop penalty and its interaction with cycle time, travel time between signals, and the complexity of the

network. For single junctions, an analytical approach shows the similarity between stop penalty and extended intergreen times. For more complex networks, the computer program has been used to analyze an arterial road and a closed loop in a network. This analysis shows how networks vary in sensitivity to stop penalty and how the inclusion of stop penalty discourages the selection of progressions in which the heads of traffic platoons are stopped at the signals.

60. Intersection Design. Final Report. Bureau of Safety and Traffic, New Jersey Dept. of Transportation, 1969, 301 pp.
Thirty intersections and interchanges representing several design types are included in the study. The physical features as signing, travel time, accident and traffic volume data are included in the presentation of each intersection. Each site has been studied and compared, and specific comments on the design accident experience and travel time are offered. The aim of the study is to provide better engineering tools to the highway engineer.

61. Jacks, M. The Feasibility of Establishing Warrants for Signal Systems. Traffic Eng., Vol. 39, No. 8, May 1969, pp. 46-47.
It is generally agreed that a key factor in the solution of traffic congestion problems on urban surface streets is the efficient operation of traffic signal systems. Recent technological advances have resulted in the formation of a variety of system configurations, which in turn has created a question regarding the feasibility of establishing warrants for the utilization of specific types of signal systems and the application of digital computer equipment. It is that question to which this article is addressed. The state of the art of traffic signal system operation is such that the establishment of warrants for utilization of specific types of signal systems is not presently feasible. However, for a given situation, an analysis that considers all qualitative factors, costs, and capabilities of the various systems can provide a logical basis for system determination.

62. Jacobs, G.D. The Effect of Zebra Crossing Installations on Pedestrians and Vehicles. Surveyor and Municipal Eng., Vol. 126, No. 3816, July 24, 1965, pp. 23-24, 27.
Describes effects on vehicle speeds, pedestrian delay times, crossing times and crossing locations.

63. Jacobs, G.D., Older, S.J., and Wilson, D.G. A Comparison of X-way and other Pedestrian Crossings. Great Britain Road Research Laboratory Rept. LR 145, 1968, 46+ pp.
X-way crossings compared with zebra and normal signal-controlled crossings in terms of efficiency (i.e., delay to pedestrians and vehicles) and risk.

64. Jacobs, G.D., and Wilson, D.G. A Study of Pedestrian Risk in Crossing Busy Roads in Four Towns. Great Britain Road Research Laboratory Rept. LR 106, 1967, 23 pp., 5 figs.
Comparison of the number of pedestrians crossing the road and the number of pedestrian casulties on lengths of a busy road in four British towns.

65. Johnston, B. Highway Improvements Suggested by Accident Analysis. Proceedings Western Association of Canadian Highway Officials. April 1965.
Records of all traffic accidents indicating cause, location and accident rate should be kept on file. A comprehensive analysis of this data enables the highway engineer to ascertain what improvements must be undertaken to increase the safety margin of a particular highway or section. These records are being

kept in Manitoba and a safety-oriented improvement program has shown encouraging results. While, singly, accident records are of no value, they assume high importance when linked to statistics such as traffic volume and flow, design standards, and pavement shoulder widths. Four examples of road improvements resulting from accident analyses are given. Three were intersection modifications and one, the resurfacing of a slippery pavement.

66. Kassan, A.L. and Crowder, T.F. Improved Signal Visibility Reduces Accidents. Traffic Eng., Vol. 19, No. 7, June 1969, pp. 42-44.

Accident history comparison for 68 Los Angeles intersections indicates that improvement in signal visibility reduces the most predominant types of intersection accidents and thus has a high payoff in relation to the relatively low cost of improvement. Signal modernization cost less than $5,000 per intersection.

67. Knox, D.W. and Waldron, R.J. Traffic Signal Warrants and Priorities. Proceedings, Australian Road Research Board, Vol. 6, Part 3, 1972, pp. 144-159.

Warrants for the installation of traffic signals at intersections have been developed during an extensive period, particularly in North America. The available references are reviewed briefly in this paper, and further consideration is given to the subject of traffic accidents within the context of establishing warrants. The results of previous research have shown that significant reductions in accidents are obtained after installation at locations where there was a history of right-angled collisions.

A graphical warrant is developed to relate traffic accidents represented by an annual accident rating with a traffic conflict factor derived from peak-hour traffic counts. The graph also indicates zones where traffic signals are not justified, but less restrictive means of traffic control can be applied at an intersection.

The data collected in establishing warrants can also be applied to develop priorities among a group of locations where traffic signals are expected to be required. The application of ranking methods is indicated to determine a list of priorities for intersections where warrants have been established.

68. Kyprianou, E.K. The Quasi-Stationary Distributions of Queues in Heavy Traffic. J. of Applied Probability, Vol. 9, No. 4, Dec. 1972, pp. 821-831.

A queueing-theory analysis of the distributions of waiting time and of queue lengths for heavy traffic conditions ($\rho \to 1$) for those cases where the arrival distribution or the service time distribution is not purely exponential.

It is shown that these distributions can be approximated by gamma distribution with two degrees of freedom whose means are functions of the mean and variance of both the inter-arrival and service time distributions.

69. Lee, C.E. and Vodrazka, W.C. Evaluation of Traffic Control at Highway Intersections. Center for Highway Research, Univ. of Texas, Austin, Research Rept. 78-1F, 1970, 291 pp.

This study covers, in quite extensive detail, field methods and data reduction procedures to acquire stops and delay measurements at device-controlled intersections. A total of 124 individual studies were made at 19 different intersections totaling approximately 240 hrs of observed data. Intersection control devices studies were two-way stop, four-way stop, fixed-time, and actuated. Dial settings were changed on the signal controllers to secure the effects on delay and stops over reasonable volume ranges and traffic splits. An analysis was run to determine the optimum measurement period over which the resultant delays and stops might be made to compromise the loss of sensitivity if too long periods are used versus too much variance for short periods. Their results show the efficacy of 15-min periods.

Extensive development has been made of regression equations to develop fits and models for two-way and four-way stop control. These are not completely generalized, but do show clearly the break points or critical volumes versus delay curves which develop around 200 to 250 vehicles per 15 min (approximately 750 vph at intersection) for two-way stops and around 250 to 300 vehicles per 15-min (approximately 900 vph at intersection) for four-way stops. The rate of delay per vehicle is about four times greater above critical.

Recommended warrants for two-way and four-way stops are developed using average delay per stopped vehicle as the fundamental parameter. This average stopped delay is then required to exist over two two-hr periods (probably one in the morning and one in the evening). Required field measurements by the traffic department at an intersection are thereby kept to a minimum, namely, volumes and determination of peaking factors. A strong recommendation is made to use flashing beacons if the stop-sign warrants are not met since both accidents and delay are considerably lower with flashing beacons.

Some generalized results are made of studies of stopped-time delay at pretimed, semi-actuated, and full-actuated control. Semi-actuated control was indicated where the actuated street carried 40 percent or less of the total traffic and full-actuated indicated at intersections where the ratios of volumes were closer to 50:50 percent. The use of actuated control versus pretimed resulted in less delay for a reduced volume (450 vehicles per 15-min) warrant for signalization.

The methodology of field data collection and equipment is covered.

70. Leisch, J. Capacity Analysis Techniques for Design of Signalized Intersections. Public Roads, 2 pts., Vol. 34, No. 9, Aug. 1967, pp. 171-209; No. 10, Oct. 1967, pp. 211-226.

This report presents a graphic procedure for the capacity analysis of most street and highway signalized intersections. Reference should be made to Leisch "Effect of Control Devices on Traffic Operations" (see entry 71) where the same procedures are applied to two- and four-way stop control. The methodology simplifies the work required in using the basic theory and data presented in the Highway Capacity Manual (see entry 55). The report covers different types of intersection (one-way, two-way) flows, parking conditions, turn considerations, area considerations, approach widths and so forth by means of twenty nomographs. The resultant greentime/cycle time (G/C) is developed as a factor in the final compilation of design capacity. The author has presented a number of typical problems and solutions to aid in the understanding of the use of the nomographs.

71. Leisch, J.E., Barry, W.A. (Jr.), Pfefer, R.C., DeLeuw, C.E. (Jr.) and Klaesi, E.F. Effect of Control Devices on Traffic Operations—Interim Report on Project 3-6. Highway Research Board, NCHRP Rpt. 11, 1964, 107 pp.

A thorough analysis is made relating to the performance of yield- and stop-sign control at intersections. Factors related to warrants for control devices, data gathering, and analysis techniques are described. Studies

were made at urban intersections with low volume totals of all approaches (approximately 550 vph or less) and low speed limits (23 to 30 mph). Significant results are (a) drivers at yield control will accept an initial lag of less size than those drivers at stop control; (b) intersection dependent factors such as sight distances, parking, street width, and the like cause as much variation in gap and lag acceptance characteristics as the type of control; and (c) gap and lag acceptance characteristics tend to vary between peak and off-peak periods.

Flow charts are presented for computer programs used in data reduction and analysis of photographically recorded data for (a) gap and lag acceptance and (b) speed, volume, and delay. This subject is further reported (see entry 72).

72. Leisch, J., Pfefer, R. and Moran, P. Effect of Control Devices on Traffic Operations, Final Report on Project 3-6. Highway Research Board, NCHRP Rept. 41, 1967, 83 pp.

Report specifically covers results of study at 71 urban intersections with regard to the effects of yield, two-way stop, and four-way stop control. Graphical solutions for annual expected accidents are provided that utilize, as input parameters, average daily traffic (ADT) of same street, ADT of cross street/ADT of same street, ADT of cross street, average approach speed, cross street width, safe approach speed right and left, average speed/safe approach speed, area considerations, and classification of streets. Graphical solutions for delay on approaches are provided which utilize, as input parameters, volume/10-ft width on cross street, volume/10-ft on main street, percent left-turn vehicles on main street approaches, percent right-turn and percent left-turn vehicles on cross street, volume cross street/volume main street, average approach speeds, safe approach speeds, geographical area, classification of streets, and distance to nearest signals.

73. Leong, H.J.W. Some Aspects of Urban Intersection Capacity. Proceedings, Australian Road Research Board, Vol. 2, Pt. 1, 1964, pp. 305-338.

74. Little, J.G. Jr. Queuing of Side-Street Traffic at a Priority Type Vehicle Actuated Signals. Transportation Research, Vol. 5, No. 4, Dec. 1971, pp. 295-300.

The queuing of side-street traffic at a semi-actuated signal is studied. The effect of the length of the minimum artery green periods is studied as it relates to the side-street traffic flow. A discrete model is formulated, and the steady-state distribution and mean value of the side-street queue length at the end of the cycle, and the steady-state distribution of the side-street red period length are found. Numerical results are shown for the analysis as applied to two one-way streets.

75. Lombard, D. An Analytic Study of Left-Turning Vehicles at Signalized Intersections. M.S. Thesis, Northwestern Univ., Oct. 1970.

76. Mackie, A.M. and Jacobs, G.D. Comparison of Road User Behaviour at Panda, Zebra and Light-Controlled Crossings. Traffic Eng. Control, Vol. 6, No. 12, April 1965, pp. 714-718, 732.

77. Mackie, A.M. and Older, S.J. Study of Pedestrian Risk in Crossing Busy Roads in London Inner Suburbs. Traffic Eng. Control, Vol. 7, No. 6, 1965, pp. 376-380.

78. Malo, A.F. Signal Modernization. Highway Research Board Special Rept. 93, 1967, pp. 96-116.

This paper reports on several studies comparing the before and after accident experience at intersections where signals have been modernized for improved visibility, and it includes:

1. Detroit - 20 intersections. Overall reduction of 47 percent in number of accidents. Biggest reduction was 75 percent in right-angle collisions.

2. Wayne County - 3 intersections. Overall reduction of 41 percent in number of accidents. Reduction of 46 percent in right-angle collisions.

Similar results have been found in studies made in Phoenix, Arizona; Los Angeles, Calif.; and Helena, Montana.

79. Manning, J.R. Accidents at Controlled Junctions. Gt. Brit. Road Research Laboratory, Note RN 2133, 1954, 6 pp.

80. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Admin. U.S. Government Printing Office, 1971, 377 pp.

81. Marks, H. Control of Right Angle Collisions at Intersections of Two Minor Streets. Traffic and Lighting Div., Los Angeles County California Road Dept., November 1955, p. 10.

82. May, A.D. and Gyamfi, P. Extension and Preliminary Validation of a Simulation of Load Factor at Signalized Intersections. Traffic Eng., Vol. 40, No. 1, Oct. 1969, pp. 46-52.

This investigation into the load factor proposed in the 1965 Highway Capacity Manual utilized the basic signalized intersection program first reported in the February 1968 issue of the same journal. The program was modified to allow the use of the composite exponential headway distribution and measured field headways. Amber phase decisions were based on Olson and Rothery and discharge queue headways were based on Greenshields' 1947 work. The results from simulation runs were "quite close" to the field measurements. Discrepancies were found between the simulation, field work, and the 1965 Highway Capacity Manual. Very general conclusions were drawn. The authors proposed a new level of service distribution.

83. May, A.D. and Pratt, D. A Simulation Study of Load Factor at Signalized Intersections. Traffic Eng., Vol. 38, No. 5, Feb. 1968, pp. 44-49.

Technical article pointed toward the objective of developing a simple computer simulation model that will allow a qualitative investigation of the effect of service volume on load factor and to relate load factor to delay. A second objective is to question the present MUTCD qualitative values of load factors as related to the road volume-width diagrams and levels of service designations. A conclusion might be drawn that, if load factor is to be used as an independent variable in the development of traffic control device warrants, further correlation of load factor to effectiveness measures should be researched.

84. Mayne, A.J. The Problem of the Careless Pedestrian. Proceedings, Second International Symposium on the Theory of Road Traffic Flow, London, 1963. Paris, Organisation for Economic Cooperation and Development, pp. 279-285.

Calculates the probability that an inattentive pedestrian will be hit by a vehicle at a given velocity while he crosses a one- or two-lane road.

85. McInerney, H.B. and Petersen, S.G. Intersection Capacity Measurement Through Critical Movement Summations: A Planning Tool. Traffic Eng., Vol. 41, No. 4, Jan. 1971, pp. 45-46, 50-51.

The traffic engineer engaged in planning frequently must evaluate the impact of generated traffic distributed over a new or expanded street system. Capacities must be determined, and this generally concerns intersection capacity because, at least in urban considerations, intersection conditions usually fix the capacity of the street system. By means of what can be called a critical movement method, intersection capacities can be developed easily.

While the Highway Capacity Manual (1965) and Public Roads (Vol. 34, Nos. 9 and 10, 1967) cover the procedure for making capacity determinations of at-grade intersections, when traffic engineers are dealing with future conditions, overly conscientious involvement with estimates of street widths, G/C ratios, peak-hour factor adjustments, and percentages of turns and trucks is often beyond the accuracy of the base data. The critical movement method, on the other hand, provides results reasonably consistent with those which could be obtained through conventional capacity analysis. The only data requirement is an estimate of the traffic that will be using an intersection in some future year, turning movements, and the number of lanes available.

86. Miller, A.J. Nine Estimators of Gap-Acceptance Parameters. Traffic Flow and Transportation, Elsevier Publishing Co., New York, 1972, pp. 215-235.

An excellent survey of previously advocated methods for analyzing gap acceptance data. Accurate estimates of the parameters of the gap acceptance distribution are required for the analysis of nonsignalized intersections and of signalized intersections with opposed turning and pedestrian movements.

The author analyzes nine different methods, giving the theoretical basis, the assumptions mode and the bias, if any, of the computed results. Each of these methods is then applied to 100 sets of artifical data in a simulation exercise and the computed values of the parameter compared. It is concluded that the method of maximum likelihood is most precise and shows a satisfactorily small bias. It is, however, computationally complex and somewhat dependent on an a priori assumption of the distribution of the critical gaps. A method advocated by Ashworth, although somewhat less precise, is suitable for use with desk calculators and can also be used for obtaining quick rough estimates by plotting on log-probability paper.

87. Miller, A.J. The Capacity of Signalized Intersections in Australia. Australian Road Research Board, Bulletin 3, March 1968, 95 pp.

New approximations have been derived for the probability of clearing the queue and for the average number of vehicles left in the queue at the end of the phase at fixed-time signals.

Saturation flows have been measured in seven Australian cities. These are expressed in through-car units (tcu's). This method saves the need to estimate the distribution of commercial vehicles and turning vehicles between lanes.

The following equivalents, in terms of through cars, have been found.

	Car	Commercial Vehicle
Left turn	1 1/4	2 1/2
Through or unopposed right turn	1	2

A formula is presented for the equivalents for opposed right-turning cars and commercial vehicles. Average equivalents are 2.9 and 3.9 for right-turning cars and commercial vehicles, respectively.

Saturation flows have been found to be almost constant for lane widths between 10 ft. and 13 ft. A table is given of average saturation flows as a function of the type of lane and the locality within the city.

At approaches with three or more lanes, it has been found that about 40 percent of the available curb lane capacity is utilized when parking is banned. This increases to 60 percent when stopping is banned and this is enforced by police.

It is recommended that the average lost time per change of phase should be taken as either: (a) the intergreen time minus 1/2 sec, or (b) 2 1/2 sec plus the travel time through the intersection of the last vehicle, whichever is the longer.

88. Miller, A.S. Australian Road Capacity Guide - Signalized Intersections. Australian Road Research Board, Bull. 4, June 1968, pp. 5-42.

Methods are given for estimating the capacities and operating characteristics of signalized intersections. Saturation flows, that is the rates at which vehicles can cross the stopline during the period that a green signal is showing, are calculated in terms of the number and types of lanes. Saturation flows are expressed in terms of through-car units (tcu's) per hour of green. Adjustments are given for curb lane usage, lane width, gradient, parking, and the effect of buses.

The y value for any approach or movement is the ratio of the arrival flow to the saturation flow for that approach or movement. It is recommended that the sum of y values for an intersection should not exceed 0.7, where the sum of y values must contain one and only one y value for each phase in the cycle.

Numerical examples are given to illustrate each type of calculation. A method of measuring saturation flows is described.

This report represents the codification and application of the research results reported in Australian Road Research Board, Bulletin 3 (see entry 87).

89. Morris, R.W.J. and Pak-Poy, P.G. Intersection Control by Vehicle Actuated Signals. Traffic Eng. Control, Vol. 9, No. 6, Oct. 1967, pp. 288-293.

This paper presents an analysis of traffic control at an intersection where the signal phase variable is controlled by detectors activated by vehicles approaching the intersection. In this analysis the mathematical model describes a two-way intersection with flow approaching the intersection from two orthogonal directions. The flows conjugate to these two directions are assumed to be zero. The results based on this simplified model provide reasonable starting points for analyses of more complex intersections and control devices.

90. Mulinazzi, T.E. and Michael, H.L. Correlation of Design Characteristics and Operational Controls with Accident Rates on Urban Arterials. Purdue Univ. and Indiana State Highway Comm. Joint Highway Research Program Rept. No. 35, Dec. 1967.

The report discusses design and control factors which were found to be correlated, by means of regression analysis and case study approaches, with accidents on urban arterials. Traffic accident studies on the urban arterial street systems in Indiana led to the following conclusions. (1) Where one or more certain conditions occur, traffic accidents per mile on urban arterials will most likely decrease if reductions are made in parking, the number of

traffic signals per mile, the number of high-volume intersections per mile, traffic volume, the number of heavily used driveways, the number of friction points per mile (sum of the number of approaches to the arterial, intersections and driveways); and if the quality of signing and pavement markings is improved, (2) traffic accidents per 100 million vehicle miles will also most likely decrease, (3) the importance substantiates control of access as an accident reduction tool, (4) intersections or major driveways are the most usual sites of most accidents on urban arterials, and (5) the multiple linear regression equations developed to predict accidents per mile should be useful in evaluating possible safety benefits from proposed design and control changes.

91. Navin, F.P.D. and Wheeler, R.J. Pedestrian Flow Characteristics. Traffic Eng., Vol. 39, No. 9, June 1969, pp. 30-33, 36
This study of pedestrian flow, concentration, and speed was made in terms of pedestrian travel on sidewalks. The results, however, appear to be applicable to pedestrian warrants. Pedestrian speeds were found to average 4.3 feet/second with a S.D. of 0.62 for a primarily college-age subject population.

92. Nesselrodt, J. and Yu, J. Pedestrian Effect on At-Grade Intersection Flow. Highway Research Record 355, 1971, pp. 26-36.
This work objective was to identify and relate measurable variables at an intersection relating to the effect of pedestrians on vehicle flow. The variables considered were: number of pedestrians involved with pedestrian-vehicle friction, number of pedestrians violating the signal display, parking as it effects narrowing of the roadway, total vehicle volume on all legs for a given interval, total pedestrian count in a given interval, percent left-turns, percent right-turns, maximum red interval, and street width. The dependent variable was delay or the measure of loss of flow through the intersection. The measured delay was the vehicle seconds the vehicles were delayed, i.e., the product of the number of vehicles in the queue and the time they were delayed. Statistical multiple-regression techniques were used to develop models to relate the independent variables to the dependent variable. Three regression models were developed to cover the intersection types studied, namely, combinations of one-way and two-way streets. The work indicates that pedestrian delays to vehicles can and probably should be included in intersection control device warrants.

93. New Type Stop Sign Cuts Accidents. Michigan Roads and Construction, Vol. 55, No. 15, April 1958, p. 6.

94. Newell, G.F. Statistical Analysis of the Flow of Highway Traffic Through a Signalized Intersection. Quarterly of Applied Mathematics, Vol. 13, No. 4, Jan. 1956, pp. 353-369.
The paper is a report on some calculations of the statistical distribution of delay times due to a fixed-time traffic signal on a single-lane highway. A model of a traffic light is proposed leading to a set of dynamical equations describing a relationship between the times at which cars leave the light in terms of the times at which they arrive. Some equations are derived for the conditional probabilities that a car will leave at any specified time if it enters at some given time. For this, it is assumed that the time intervals between incoming cars form a set of independent random variables and that one seeks only the equilibrium solution for which the arrival time of any individual car has a constant probability density.

A procedure for obtaining approximate solutions to these equations is derived which actually gives exact solutions for the case in which the cars arrive at equally spaced time intervals. This procedure is also applied to obtain first and second approximations in the special case in which cars arrive with the maximum disorder in spacing possible for this model.

It is found that, to a first approximation, it makes very little difference what statistical assumptions are made if one wishes to calculate the average delay.

95. Newell, G.F. and Osuna, E.E. Properties of Vehicle-Actuated Signals; Pt. 1, One-Way Streets; Pt. 2, Two-Way Streets. Transportation Science, Vol. 3, No. 1, Feb. 1969, pp. 30-52; No. 2, May 1969, pp. 99-125.

An analysis of the expected delay at intersections under fixed time and under vehicle-actuated control with a number of different strategies.

96. Older, S.J. Accident Comparisons at Halt or Stop Junctions. Traffic Eng. Control, Vol. 2, No. 11, March 1961, pp. 655-657, 665.

This field study involved the comparison of traffic control by stop signs only as compared to the same control but with appropriate signing by markings on the road surface. Statistically good sample sizes were used in the study and the results sum to be statistically significant in showing approximately 40 percent reduction in accident rate where additional roadway marking is employed.

97. Othman, Z. and Rapino, F. Evaluation of Drivers Utilization of the Amber Time Used on Pre-Times Traffic Signals. MS Research Rept., Northwestern Univ., July 1971.

98. Pedestrian Response to Red Lights. National Committee on Uniform Traffic Laws and Ordinances, Traffic Laws Commentary, 69-3, Washington, Sept. 3, 1969, 13 pp.

Debate concerning value of prohibiting pedestrians crossing on a red light.

99. Peleg, M. Evaluation of the Conflict Hazard of Uncontrolled Junctions. Traffic Eng. Control, Vol. 9, No. 7, November 1967, pp. 346-347.

This paper approaches the hazard at an intersection through two basic assumptions: (1) there are a fixed number of conflict points at any intersection and this number multiplied by the total flow will produce a so-called "conflict factor"; (2) the conflict factor multiplied by the average kinetic energy of the flow (speed squared) will produce a so-called "damage factor" for the intersection.

From the damage factor, a priority rating can be generated for treatment of a number of intersections on a logical basis.

100. Pelican Pedestrian Crossings; How they Work and Will They Work? Pedestrian, 1969.

Great Britain institutes a two-step crossing with an elongated island and push-button signals at the curbs and central refuge.

101. Perkins, S.R. and Harris, J.I. Traffic Conflict Characteristics - Accident Potential at Intersections. Highway Research Record 225, 1968, pp. 35-43.

Traffic conflict characteristics are measures of traffic accident potentials. A traffic conflict is any potential accident situation. Over twenty objective criteria for traffic conflicts (or impending accident situations) have been defined as to specific accident patterns at intersections. Essentially, these conflicts are defined by the occurrence of evasive actions, such as braking or weaving, that are forced on a driver by an impending accident situation or a traffic violation. A method of systematically observing an intersection for traffic conflicts has been devised. In three 12-hr observation sessions, it is possible to evaluate completely an intersection. The information obtained is much more comprehensive than that normally available from accident histories. Further, the initial causes of the incidents, which accident records often fail to reveal, are uncovered. Traffic conflict studies use objective criteria to obtain significant quantities of data in short observation periods.

102. Priest, R.V. Statistical Relationships Between Traffic Volume, Median Width and Accident Frequency on Divided-Highway Grade Intersections. Highway Research News, No. 13, June 1964, pp. 9-20.

103. Radelat, Guido. Accident Experience as Related to Regular and Flashing Operation of Traffic Signals. D.C. Dept. of Highways and Traffic, June 1966, 12 pp.

104. Ray, J. Identify Your Most Critical Traffic Problems. Traffic Eng., Vol. 42, No. 1, October 1971, pp. 30-32, 68.

This article describes procedures for rapidly identifying specific problem intersections and establishing priorities for implementing the solutions. The procedures are not intended to produce finite results, but will indicate the relative degree of congestion and travel danger at individual locations. Weighting factors are assigned to problem identification factors such as: low speeds, high number of accidents, signal timing, and parking. These are readily available inputs. From the weighting factors a composite weighted value is assigned to an intersection, street, or area to select those of higher value which warrant detailed study.

105. Ray, J.C. Experience With Right-Turn-On-Red. Proc., Inst. of Traffic Eng., 1956, pp. 111-116.

The research included a questionnaire study, an investigation of accidents at signalized intersections, and a study of delays to right-turn-on-green traffic. The results show that right-turn-on-red does not add any significant hazard at signalized intersections and, in fact, has many advantages that tend to decrease delay and increase capacity.

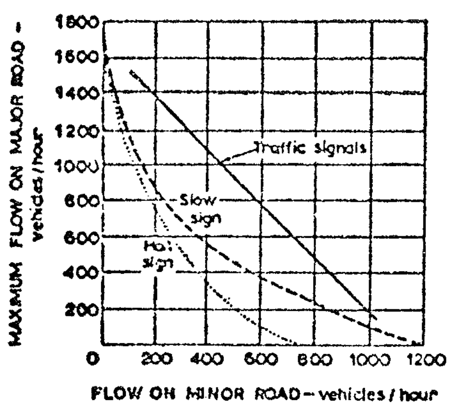
106. Reid, D.H. Some Problems of Inference Arising from the Fitting of Mathematical Models to an Unsignalised Priority Intersection. Fourth International Symposium on the Theory of Road Traffic Flow, Karlsruhe, 1968, Bundesministerfür Verkehr, Abt. Strassenbau, Bonn, pp. 130-134.

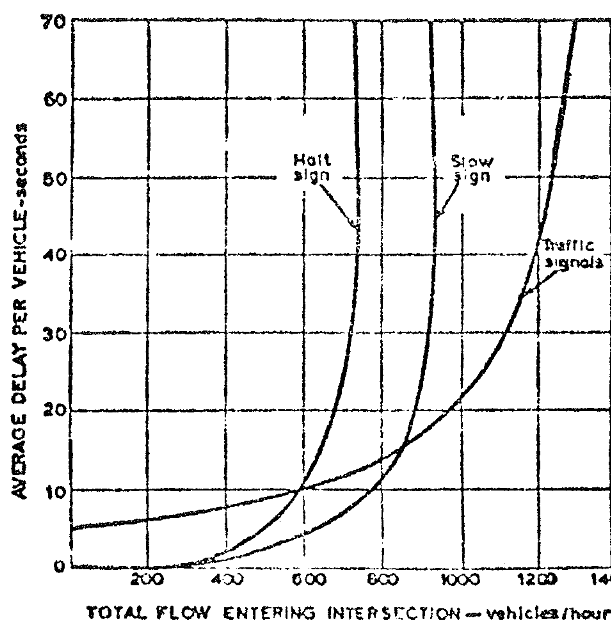
107. Road Research - 1962. Gt. Brit. Dept. of Scientific and Industrial Research, London, HMSO, 1963, 166 pp.

One of the studies reported on pages 18-19 in this annual report of the British Road Research Laboratory deals with the capacity and delay at a hypothetical intersection under a variety of controls. The analysis was made using the following parameters:

Average discharge headway:	
Signal control	3 in.
Stop control	5 in.
"Slow" control	3 in.
Minimum main street headway	2 in.
Side street accepted gap	8 in.

The results of the study are summarized in the figures shown below. It can be seen that "capacity" is usually higher for signal control. Comparison of capacity: some particular hypothetical cases of traffic signals, halt signs, and slow signs. Comparison of delay: some particular hypothetical cases of traffic signals, halt signs, and slow signs.





108. Roer, P. and McLaughlin, W.A. Safety Aspects of Intersection Control Devices. Waterloo Univ., Ontario Dept. of Highways Rept. RR 164, Oct. 1970, 17 pp. and apps.

The objective of this research was to develop an intersection accident exposure index and to determine relationships between this index and various intersection control devices. Major findings to date indicate no statistically significant relationship between the number of collisions and the intersection control device. A collision exposure function was developed.

109. Rorbech, J. Determining the Length of the Approach Lanes Required at Signal-Controlled Intersections on Through Highways. Transportation Research, Vol. 2, No. 3, Sept. 1968, pp. 283-291.

It is often with great misgivings that traffic signals are installed on roads carrying high-speed traffic. That is because the speed differences within the stretch of road influenced by the signals may be very great and may, in conjunction with sudden braking and with merging and diverging, make exacting demands on the geometrical design of the junction.

This paper is concerned with the braking of a flow of motor cards as a result of a shock wave which, at the beginning of the red period, moves from the stop line backwards along the road against the incoming traffic, reducing the speed of the latter. It is suggested that the length of a queue should be defined by that part of the incoming traffic which is affected by the shock waves. On th-s basis, a method is proposed for determining the length of the approach lanes required.

110. Rowan, N.J. and Williams, T.G. Channelization. Texas Transportation Inst., Research Rept. 19-4 (final), 1966, 59 pp.

The approach-end treatment of channelization is studied with particular emphasis placed on driver vision under conditions of night-driving in adverse weather. Studies were conducted to determine the relative visibility and serviceability of marking materials for delineating channelization islands. Raised markings constructed with a slurry mixture were the most satisfactory of the devices tested. They provided stripes of sufficient height to cause an adequate vehicle rumble and presented a convenient surface texture for visibility purposes. Other studies were performed to evaluate the relative visibility and legibility of signs used to direct traffic around the approach-ends of channelizing islands. Eight different signs were used. They were similar in geometric configuration but differed in the types of materials used and the methods of illumination. The most satisfactory signs tested had prismatic reflectors or reflective sheeting on a black background. The safety aspects of channelization were investigated by comparing traffic accident data before and after channelization was installed on an arterial street. The results of the analysis indicate a favorable effect of channelization on traffic accidents. A computer program was developed to translate design data into a perspective view of the road-way; in order to help the designer in controlling the approach profile to improve the visibility aspects of the intersection.

111. Rushing, J.B. Selecting Locations for Accident Prevention. Traffic Eng., Vol. 40, No. 10, July 1970, pp. 26-29.

The SLAP (Selecting Locations for Accident Prevention) program uses a statistical analysis of intersections, their type of control, and number of accidents in a given time period, in an attempt to show the traffic engineer where he can make improvements other than those involving major investments of time and money. It can also show him where he can find problems that other similar intersections are not experiencing.

112. Sagi, G.S. and Campbell, L.R. Vehicle Delay at Signalized Intersections - Theory and Practice. Traffic Eng., Vol. 39, No. 5, Feb. 1969, pp. 32-36, 38-40.

This paper begins with a discussion of certain problems associated with an index of operation for intersections called load factor. The discussion identifies the following two problems conventionally associated with the measurement of delay. Models for traffic flow at an intersection are not generally applicable to the periods of interest to traffic engineers, for example, during rush hour conditions. Conventional methods of field measurement of vehicle delay generally require microscopic observation of the traffic streams and are thus very expensive.

113. Schoene, G.W. and Michael, H.L. Effects of a Change in the Control Device on Intersection Accidents. Purdue Univ. and Indiana State Highway Comm. Joint Highway Research Program Rept. No. 21, Dec. 19, 1966.

Factual information was collected by means of before and after studies about changes in accident characteristics when a traffic signal replaced two-way-stop control. Sample intersections whose accident histories were available for two years before and after the date of signal installation were chosen. The intersections had no other control device or railroad crossing within two blocks of the intersection, no major construction conflict, four approaches, the driver's view of the control device unobstructed and the intersection not on or near a significant vertical or horizontal curve. The traffic volume and control device were important characteristics of each intersection which changed during the study period. The installation of traffic signals at an intersection did not usually result in fewer accidents occurring at that intersection. For those intersections which did have a change in the number of accident types, the change was usually an increase in total, rear-end and miscellaneous accidents and a decrease in right-angle accidents.

114. Schwarz, H. The Influence of the Amber Light on Starting Delay at Intersections. MS Thesis. Northwestern Univ., May 1961.

115. Seyfried, R.K. The Effect of Approach and Lane Widths on Initial Delay and Average Headways at Signalized Intersections. MS Thesis. Northerwestern Univ., Jan. 1970.

116. Simons, F. The Installation of STOP and YIELD Sign Control for Two-Lane Roads. National Institute for Physical Planning and Construction Research, Dublin, Ireland. Rept. RT. 109, 8 pp.

This report contains an analytical derivation of a decision criterion for the choice between Stop and Yield control at unsignalized rural intersection. The criterion depends on the safety of the crossing/merging maneuver as determined by approach speeds and sight distance considerations. Volumes are not taken into account.

117. Simons, F. Warrants for the Installation of Pedestrian Crossing Facilities. National Inst. for Physical Planning and Construction Research, Dublin, Ireland. Rept. RT. 36, 1970, 74 pp.

An extensive report dealing with the development of warrants for the installation of pedestrian facilities. The proposed warrants are based on previous work and on empirical data collected at 23 different locations with varying degrees of pedestrian crossing protection.

The recommended warrants are delay based and presuppose an average pedestrian delay of not more than 30 sec. The warrants are presented in terms of design charts which incorporate pedestrian and vehicular volumes, street width, and approach speed as input parameters. The time frame of the proposed warrants is stated in terms of two half-hour periods of an average weekday.

118. Sinha, K.C. and Tomiak, W.W. Section Gap Acceptance Phenonmenon at Stop-Controlled Intersections. Traffic Eng., Vol. 41, No. 7, April 1971, pp. 28-33.

The authors first define "section gap" as the time interval between any vehicles crossing some reference line. This eliminates the semantic confusion with gap as it more often is used to define the time headway of vehicles in the same directional stream of traffic. A method was developed to make field studies for measuring section gap acceptance times at intersections. Field results showed significant increases in the section gap acceptance for minor street vehicles with increases of major street speeds; left-turning vehicles required larger gaps, some effect from vehicles stopped on the opposing minor leg, and some evidence of vehicle type influencing the section gap acceptance value.

119. Smith, W.L. Probability Study of High Accident Locations in Kansas City, Missouri. Traffic Eng., Vol. 40, No. 7, April 1970, pp. 42-49.

The goal was to provide a relevant analysis of hazardous intersections. To accomplish this goal, this study was developed with the use of probability theory and a series of input-output systems. A secondary goal was the development of easily used nomographs for the determination of intersection accident probability and statistical analysis of the effects of intersection improvements on the accident probability. Through the development of easily used nomographs, it is hoped that this study technique can be more easily made a part of a continuing network accident analysis.

120. Snyder, M.B. and Knoblauch, R.L. Pedestrian Safety: The Identification of Precipitating Factors and Possible Countermeasures. Operations Research, Inc., Silver Spring, Md. Final Report prepared for U.S. National Highway Traffic Safety Admin., Contract No. FH-11-7312. Jan. 1971, 2 Vol. (PB197749-50).

Data collected for 2,000 pedestrian accidents in 13 major cities studied to identify causes and countermeasures.

121. Sofokidis, H., Tilles, D.L. and Geiger, D.R. Evaluation of Intersection-Delay Measurement Techniques. Highway Research Record 453, 1973, pp. 28-48.

This report covers some recent work by the office of Traffic Operations, Federal Highway Administration, relating to the evaluation of level of service and performance at intersections. Specifically two normally used field methods of delay measurement are tested—the Sagi-Campbell method and the Berry-Van Til. As a base for the study, lapse-time movies and TV video recordings were made in addition to some use of a traffic flow meter. The report indicates the need for possible refinement of delay-measuring techniques if consistent and direct relationships between volume and delay are to be developed.

122. Statistics Report - Traffic Accidents in the City of Montreal in 1967. Montreal, Quebec, Canada, 1969.

An annotated statistical report is presented on traffic accidents in the City of Montreal during 1967. The report contains tabulations showing variations in accidents with month, time of day, weather conditions, road surface conditions, and the like. The location of accidents at intersections or mid-block are analyzed and dangerous intersections identified. The costs of traffic accidents are tabulated. The types of vehicles and other vehicle characteristics of involved vehicles are tabulated. The measurable attributes of persons involved are also shown. Figures comparing several accident statistics for the period 1950-67 are also presented. Some discussion of the implications of the data is included.

123. Stevens, D.F. Accident Reduction Through Directional Signing. Proceedings, Tenth Annual California Street and Highway Conference, 1958, pp. 89-90.

124. Stillman, I.L. Accident Sensing and Surveillance System. Cornell Aeronautical Laboratory, Rept. YB-1957-X1, Oct. 1965, 68 pp.

The purpose of this study was to determine the feasibility of an accident sensing and surveillance system to be used to record on video tape events leading up to and including a motor vehicle collision at urban intersections. A laboratory model of the system was designed and evaluated. The system consists of two virtually independent subsystems—a detection-discrimination system and a surveillance-storage system. The detection-discrimination system is designed to identify those sounds associated with motor vehicle crashes while disregarding other sounds common to urban intersection environments. The surveillance-storage system consists of a pair of continuously operating, narrow band-width television systems and two magnetic tape units. The television systems' video signals are continuously recorded on one tape unit containing a tape loop. When a detect signal is received from the detection-discrimination system, the information is read from the tape loop and re-recorded on a permanent storage tape for later analysis. The laboratory model of the system operating at 15 frames per second demonstrated a capability of televising and recording the image of an automobile 230 ft from the center of an intersection with a resolution permitting a measurement of its instantaneous position to within plus or minus 5 ft.

125. Stoffers, K.E. Scheduling of Traffic Lights - A New Approach. Transportation Research, Vol. 2, No. 3, Sept. 1968, pp. 199-234.

126. Stop Sign Below Light Cuts Accident Rate. Eng. News-Record, Vol. 160, No. 24, June 12, 1958, p. 65.

127. Stop Sign Report No. 1 for Arlington Heights. Prepared for Public Safety Comm., Eng. Dept., Arlington Heights, Ill., Jan. 1964, 15 pp., tables, maps and appendices.

128. Surti, V.H. Accident Exposure and Intersection Safety for At-Grade, Unsignalized Intersections. Highway Research Record 286, 1969, pp. 81-95.

The purpose of this study is to provide a method that will enable traffic and safety engineers to compare certain types of intersections relative to traffic safety. The method is based on determining an accident exposure index and could be utilized to identify the intersections that are prone to accidents. Four priority-type, unsignalized, at-grade intersections of varying geometrics were investigated. A fairly good correlation was found between the number of accidents and the accident exposure index. The index was calculated on the basis of the merging of the two traffic streams, and hence the single-vehicle accidents cannot be assumed to correlate with the index.

129. Tamburri, T.N., Hammer, C.J., Jr., Glennon, J.C. and Lew, Alan. Evaluation of Minor Improvements. Highway Research Record 257, 1968, pp. 34-79.

This report covers the effectiveness of a number of devices including flashing beacons, safety lighting, delineators of many types, and guard rails. With regard to traffic control devices warrants the following are reported:

1. Beacons, both advance warning and intersection delineation, are significant in reducing accidents and severity.

2. Beacon signals of 12-in. are more effective than 8-in. although there is some indication that nighttime brilliance should be kept the same as daytime.

3. Severity index (SI) is not as indicative a measure of accidents at a location as is equivalent property damage only (EPDO), which includes both fatal and personal injury using weighting factors. This is due to the fact that SI does not include the number of accidents occurring.

130. Tamburri, T.N. and Smith, R.N. The Safety Index: A Method of Evaluating and Rating Safety Benefits. Highway Research Record 332, 1970, pp. 28-43.

An index to evaluate proposed highway safety improvement projects on a safety cost-benefit basis. Numerically the safety index is the ratio (move decimal point two places to right) of construction, right-of-way, equipment, etc. costs for the improvement, divided by the anticipated prevented number of accidents times the cost of these accidents over the expected life of the improvement. The procedure involves determining the present accident rate and value before improvement and the anticipated rate and value of accidents after improvement. Both are explained, with examples, in the paper. A number of accident-reduction factors as related to the use or modifications of traffic control devices are listed.

131. Tanner, J.C. A Theoretical Analysis of Delays at an Uncontrolled Intersection. Biometrika, Vol. 49, Nos. 1 and 2, 1962, pp. 163-170.

A theoretical analysis of the average delay to minor street traffic for the case in which the major road has absolute priority. In United States practice this is equivalent to the determination of delay to traffic facing a yield sign.

A shifted exponential distribution, involving a minimum headway, is assumed for the major road while minor road traffic is described by a shifted exponential distribution with a minimum discharge headway.

Expressions are derived for the mean delay to side street traffic. This is found to be a function of the mean accepted gap, the two minimum headways, the two flow rates and the distribution of major street platoon lengths. Some special cases, including multilane major street flow, are analyzed and an expression derived for the capacity of the side street, i.e. side street flow rate as average side street delay approaches infinity.

132. Tanner, J.C. The Delay to Pedestrians Crossing a Road. Biometrika, Vol. 38, 1951, pp. 383-392.

This paper presents a mathematical analysis, based on probability theory, of several aspects of pedestrian crossing. A number of relationships are derived. Important among these is a method of evaluating P (T), the probability of a delay greater than T. The derivation is based on the assumption of random (i.e. Poisson) arrival of traffic. Numerical values for P (T), can be obtained using as inputs the required gap (i.e., street width divided by walking speed) and the mean traffic flow. This expression has been validated by field data except for extremely low values of T in which case a "hesitation" period distorts the results. An expression is also derived for the size of groups of pedestrians. The determination of the distribution of delay is extended to the case of crossing two streams of traffic under various assumptions concerning pedestrian behavior. (This paper is listed as No. 245 in the Box and Assoc. bibliography (entry 24) but not annotated therein.)

133. Taylor, W.C., Foody, T.J., Blackwell, H.R., Treiterer, J. and vandenBranden, B. The Effect of Flashing Traffic Control Devices on Accident Occurrence. Ohio Dept. of Highways, HPR 1-14820, Nov. 1967.

The effectiveness of various types of flashing devices was evaluated in reducing the total accident rate at intersections on the rural state highway system. Several other variables were considered while the relationship between type of flashing device and reduction in accident rate was being formulated. Cross-type intersections of Indiana county roads were found to experience an accident frequency four times that of T- and Y-types. Accidents were studied at low-volume rural intersections along Minnesota highways. Traffic volume was found to have the greatest effect on accident frequency at cross-type intersections. These studies point quite strongly to the desirability of using T-type intersections for local streets in both urban and rural areas. An important design element involves provision for vehicles to make left turns off major routes. Left-turn channelization was installed at 40 unsignalized urban and rural intersections along California highways, and accidents were found to be reduced significantly. The types of intersectional controls included in the discussion are yield, two-way stop, four-way stop, and the traffic signal. The yield sign is used to regulate traffic flow at low-volume intersections and at intersections where the accident rate is above the average of other intersections of the same type. Yield signs were found to be an effective measure at previously uncontrolled, isolated, urban, low-volume intersections in Berkeley, California, where accidents were reduced 44 percent at a total of 13 intersections; and in Seattle, Washington, a 52 percent reduction at a total of 30 intersections was achieved. The findings of various researchers indicate that yield signs can be an effective control under many low-volume conditions. Several studies are reported on two-way stop control. The studies indicate for two-way stops that accident rates increased as cross-street volume increased, and accident rate decreased as main street volume increased. For four-way stops, St. Paul and California studies support a conclusion that accident reduction can be effective under specified conditions. The results indicated that the reduction in intersection accident rate was optimized through the use of a particular type of flashing device in combination with the variables of intersection geometrics. It was also determined that the variables of intersection geometrics and total intersection volume place limiting constraints on this relationship. This research was conducted in two phases. The simulated study of flasher conspicuity and the determination of their luminance values was conducted by the Ohio State University, and the remainer of the study was conducted by the Ohio Department of Highways. This report was prepared jointly by these groups and represents the total project effort.

134. Terry, D.S. and Schneider, M.I. Semi-Actuated Signal Study: Preliminary Report. Los Angeles, Dept. of Traffic, Bur. of Traffic Research, R&D Rept. 2670, Jan. 15, 1971, 41 l.

A preliminary report on an investigation of the effect of control mode on system delay. Three arterial systems were investigated. Each system consisted of three adjacent signalized intersections along one artery. The two outer intersections remained under fixed-time signal control while the control mode at the middle intersection was varied from fixed time to two types of semi-actuated (pulse and presence). Stopped delay was measured by the Berry-Van Til method while a floating car was used for route speed determination.

The results seem to indicate that fixed-time control leads to smaller total system delay than either of the semi-actuated controls. System delay is defined as consisting of the sum of the delay at the four approaches to the middle intersection plus the interior arterial approaches to the two outer intersections. The largest differences were noted at the outer intersections. There appears to be some indication, from the data given, that the degradation of system performance with semi-actuated control can be related to the width of the through band possible with fixed time control.

135. Terry, D.S. and Wildy, D.S. Correlation of Painted Traffic Poles and Intersection Accident Rates. Traffic Eng., Vol. 40, No. 11, 1970, pp. 50-53.

A possible relationship between intersection accident rates and color treatment of traffic signal poles was investigated. Intersections having painted (yellow) and unpainted signal poles were selected and categorized according to land use. Within each category, traffic volume was used as a controlled variable in the selection of intersections. Considering only accidents which may have been influenced by poor signal visibility, accident rates for painted and unpainted categories were compared statistically. Although in most comparisons (by accident type within land-use category) the mean accident rate for intersections with painted poles was slightly lower, the difference was not statistically significant. Hence the authors conclude that "...the study does not show a correlation between yellow painted traffic signal poles and accident rates."

136. Thedèen, T. Delays at Pedestrian Crossings of Push-Button Type. Proceedings of the Fourth International Symposium on the Theory of Road Traffic Flow, Karlsruhe, 1968, Bonn, Bundesminister Für Verkehr, 1969, pp. 127-130.

137. Thomasson, N.J.N., Jr. and Wright, P.H. Simulation of Traffic at a Two-Way Stop Intersection. Traffic Eng., Vol. 37, No. 11, Aug. 1967, pp. 39-45.

This paper describes the development and exercising of a digital simulation model for a two-way stop-controlled intersection. The configuration tested consisted of the intersection of two bi-directional, two lane roadways. The simulation model is written in Algol Extended 60 and runs at 1/82 of realtime. Machine requirements are not specified.

The model was calibrated using empirical data collected at three intersections in Atlanta. The lag and gap acceptance distributions, based on 3,040 acceptance decisions was found to be log-normal with a mean of about 7 sec. The starting time distribution was found to be normal with a mean of 1.75 sec. The arrival distribution previously derived by Kell was used.

The model was exercised over a range of main street and side street volumes and turn percentages. Each run was made for a period of 1 hr of simulation time. The MOE used was average delay to side street vehicles. This was found to increase logarithmically with increases in main street volume. Increases in right turn percentages, at constant volumes, lead to decreases in average delay. The results were compared with those previously obtained by Lewis and by Kell and found to be comparable. The delay associated with minimum volumes required by MUTCD was found to be about 23 sec for the volume warrant and 20 sec for the interruption warrant.

138. Thorpe, J.D. Accident Rates at Signalized Intersection, Paper No. 51, Proceedings, Fourth Conference Australian Road Research Board, 1968, pp. 995-1004.

A comparison of accident rates at 124 signalized intersections and 16 unsignalized intersections in the Melbourne metropolitan area. Since reporting of most PDO accidents in the State of Victoria is not required by law, rates of equivalent personal injury accidents were used. Right angle, four-legged intersections only were studied. The square root of the product of entering AADT from the two cross streets was used as an index of exposure. This equals total flow through the intersection if the two flows are equal but understates the total flow otherwise. All signals were installed under State of Victoria warrants which are identical to the MUTCD (1971) warrants.

The average total entering traffic was approximately equal for the signalized and unsignalized group. The computed rates were 6.22 for the signalized case and 5.68 for the unsignalized case. There is no significant difference between these values.

139. Torres, J. The Effects of Street Geometrics and Signalization on Travel Time and Their Relationship to Traffic Operations Evaluation. Highway Research Record 211, 1967, pp. 54-75.

Emphasis in the study was on urban arterial streets under different types of signal control.

This paper discusses in some detail the use of a composite-type "measure of traffic performance" which includes travel time, driver discomfort, driving hazards, and vehicle running costs. Those factors that were examined over a broad number of intersections to provide the data base for the experiments include (1) the identification of the significant variance-producing geometrics and traffic control factors, (2) the classification and structuring of streets with respect to the most significant factors, (3) the validation of the hypothesis that representative correspondence relationships can be obtained for street classes, and (4) the determination of the general prediction relationships (coefficients versus street characteristics) for each of the driver satisfaction factors. Travel time was examined in the most detail and directly related to volumes thereby allowing a more efficient analysis of the effect of the intersection dependent factors. Good relationships are shown between signal installation per mile (signal density), type of signal, lanes, and the slope of the

delay versus volume relationship. For actuated signals the expected correlation of the cross-street volume or lighter flow was shown to be significant with regards to the slope of the delay versus volume relationships.

140. Traffic Control in Oversaturated Street Networks. Brooklyn Polytechnic Inst., Final Report NCHRP Project 3-18(2), Jan. 1973.

This report covers three areas relative to the oversaturated street-network problem: (1) a definition of the scope and magnitude of the problem, (2) determination of how best to use existing control techniques to combat the problem, and (3) the discussion of a systematic research program leading to improved operations of oversaturated streets and networks.

Specifically with respect to NCHRP Project 3-20 on warrants this report provides recent findings on significant parameters relative to congestion that have a direct value in structuring the use of the developed warrants. Land-use policies were seen as the primary cause; pedestrians ranked second; bus and commercial vehicle operations ranked about equally in third place. The report also deals with solutions that may be required when control devices are no longer effective to control traffic without congestion.

141. Uniform Traffic Control Devices for Canada. Council on Uniform Traffic Control Devices for Canada, Roads and Transportation Association of Canada. Second Edn. with revisions, May 1966, 1 vol. (looseleaf).

The manual is divided into three major areas: traffic signs, traffic signals, and markings. Regulatory signs, pedestrian signs, and warning signs are covered. The portion discussing traffic signals describes in detail the general aspects of traffic control signals, installation warrants for traffic control signals, operational requirements for traffic control signals, traffic control signals timing, traffic control signal head and detector locations, and miscellaneous traffic signals. Pavement and curb markings and hazard and delineation markings are described. Definitions of all major traffic engineering terms are given. These established standards for signs, signals, and pavement markings for Canada place emphasis on the use of the recommended symbolic traffic signs.

142. Vodrazka, W., Lee, C. and Haenel, H. Traffic Delay and Warrants for Control Devices, Highway Research Record 366, 1971, pp. 79-91.

This paper describes a complete methodology for gathering sufficient data at a number of intersections to provide a base from which a warrant for control devices may be statistically derived. The warrant used is volume and the effect of volume on delay is analyzed with regard to the effectiveness of the traffic control device. A set of minimum volume warrants are developed for installation of four-way stop sign control and these warrants provide a basis for validating a proposed set of volume warrants for the installation of actuated signal control.

A field-type recorder was developed to digitally record at an intersection the number of stopped vehicles on each lane, the traffic volumes, and the traffic signal indication. Observers of the stopped vehicles and vehicles entering the intersection simply operate coded pushbutton switches. Between six to eighteen observers are needed depending upon the number of lanes entering the intersection. The recorder directly punches the input data onto paper tape which is subsequently automatically transferred to magnetic tape for computer use.

143. Vuchic, V.R. Pedestrian Crossing Time in Determining Widths of Signalized Traffic Arterials. Transportation Science, Vol. 1, No. 3, Aug. 1967, pp. 224-231.

Widening of traffic arterials at signalized intersections is often done with the intention of increasing vehicular capacity of the intersection. An analysis of the impact of increased pedestrian crossing time resulting from the widening (particularly on undivided arterials) on capacity is presented. It is shown that when signal cycle length is fixed, pedestrian crossing time imposes an upper limit on vehicular capacity of the arterial, so that its widening yields diminishing increases in capacity. There is a width beyond which capacity decreases. Relatively simple formulas and diagrams for deriving maximum capacity taking the pedestrian factor into account are presented. Short of adjustments at other points of the street network, grade separations, and the like, provision of a protected pedestrian island in the middle of the arterial is suggested as the only acceptable solution to this problem.

144. Warinner, J.E. The Effectiveness of Flashing Beacons. Traffic Eng., Vol. 21, No. 4, Jan. 1951, pp. 128-132.

This early study included intersections in Connecticut and Virginia. Before and after speed studies, braking studies and accident records were analyzed. The flashing signal as a warning device is only as good as the response of the driver. The accident records at 6 intersections showed a reduction of 10 percent. The significant value is indicated primarily for night operation. Minor changes were noted in braking near the intersection; and no significant reduction in speeds after installation of flashing beacons.

145. Webster, F.V. and Cobbe, B.M. Traffic Signals. Gt. Brit. Road Research Laboratory. Road Research Technical Paper 56, 1966, 111 pp.

This publication has been included because it is referenced in this project where cycle length and splits at traffic signals are discussed with regard to signal warrants. This reference also describes the equivalent warrants and the approach used in Great Britain in regard to standards for traffic control devices.

146. Weiss, G.H. The Intersection Delay Problem with Gap Acceptance Function Depending on Speed and Time. Transportation Research, Vol. 1, No. 4, Dec. 1967, pp. 367-371

This paper is concerned with the distribution of the delay to a single car at an intersection, when the gap acceptance depends on the speed of the next car to arrive at the intersection. The Laplace transform of the distribution is obtained as a direct extension of the results derived earlier by Weiss and Maradudin (Operations Research, Vol. 10, 1962, pp. 74-104). The Laplace transform is then used to evaluate the mean delay. The numerical values thus obtained by the author demonstrate that when the traffic is light, the differences in the mean delay time when calculated with velocity dependence are small and probably negligible from the practical point of view.

147. Wenger, D.M. Accident Characteristics at Four-Way Stop Control Versus Two-Way Stop Control. Bureau of Highway Traffic, Yale Univ., 1958.

148. Where a Stop Sign Proved Better Than a Traffic Signal. American City, Vol. 66, No. 1, Jan. 1951, p. 13.

149. Wilson, D.G. and Older, S.J. The Effects of Installing New Zebra Crossings in Rugby and Chelmsford. Great Britain Road Research Laboratory Rept. LR358, 1970, 16 pp.

Study of the effect of doubling the number of zebra crossings on pedestrian delay at the curb, vehicle journey times, total pedestrian and vehicle flow, and pedestrian risk.

150. Wilson, James E. Minor Improvement Program. Traffic Digest and Review, Vol. 13, No. 6, June 1965, pp. 9-14.

151. Wright, P.H. Simulation of Traffic at a Four-Way Stop Intersection. Analysis and Control of Traffic Flow Symposium Society of Automotive Eng., Detroit, Conf. Proc. P-22, 1968, pp. 44-52.

A simulation model of a four-way stop intersection was developed and calibrated and validated at three intersections in Atlanta. The model differs somewhat from other simulation models in the manner in which operational traffic parameters are handled. Exercising of the model led to the conclusion that the capacity of a four-way stop intersection with one lane on each approach and symmetrical demand is about 1,300 vehicles per hour with delays increasing sharply beyond a volume of 800 vehicles per hour. Turning movement percentages had little effect on delay and queue lengths.

152. Young, T.E. New Traffic Signals: Their Effect on Street Utilization. Highway Research Board Special Rept. 93, 1967, pp. 84-95.

A report of a number of helps and after-studies of accident experience at newly signalized intersections in Cincinnati. The first study (152 intersections) showed that total accidents were likely to increase after the installation of signals, there would be no significant change in injury, and fatal accidents and pedestrian accidents were likely to decrease. The second study (32 intersections) showed somewhat more favorable results which may be attributable to improvements in signal and geometric design standards. This paper also makes the point that, although delay appears to increase as a result of signalization, motorists seem to accept higher average delay at signals than they do at stop signs.

PART II

153. Accident Facts. National Safety Council. Published annually.

154. Automobile Insurance and Compensation Study. U.S. Department of Transportation, 1970.

This is a comprehensive survey of the subject. Separate reports have been issued each covering a separate aspect of the survey. The subjects covered include economic consequences of accident injuries; compensation for motor vehicle losses in the metropolitan Washington, D.C., area; automobile personal injury claims; quantitative models for automobile accidents and insurance comparative studies in automobile accident compensation; and rehabilitation of auto accident victims.

155. Billingsley, C.M. and Jorgensen, D.P. Direct Costs and Frequencies of 1958 Illinois Motor Vehicle Accidents. Highway Research Record 12, 1963, pp. 48-76.

This Illinois study gives average accident invovlement costs for cars and trucks including both reported and unreported accidents.

156. Burke, D. Highway Accident Costs and Rates in Texas. Texas Transportation Institute, Texas A & M University, Research Rept. 144-1F, Dec. 1970, 107 pp.

A procedure is devised and implemented for estimating Texas accident costs using cost data developed by other states in previous studies.

157. Claffey, P.J. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. Highway Research Board NCHRP Rept. 111, 1971, 97 pp.

Motor vehicle running costs are presented for the categories of fuel, oil, tire wear, maintenance, depreciation and for motor-vehicle operating costs and on the relationship between highway accident costs and highway design.

158. Cost of Motor Vehicle Accidents to Illinois Motorists, 1958 - Rept. No. 7. Illinois Div. of Highways, Springfield, Ill., Dec. 1962, 159 pp.

159. Crash Damage to Automobiles. Allstate, Kemper, Liberty Mutual and State Farm Mutual Insurance Companies in cooperation with the American Mutual Insurance Alliance, Oct. 1972, 50 pp.

The research department of the American Mutual Insurance Alliance collected and analyzed detailed information on 89,060 crash repair estimates involving 1969, 1970, 1971, and 1972 model cars on a country-wide basis. This report presents the major findings on patterns of crash damage relative to point of impact and relative to the differences in repair costs among the cars studied.

160. Curry, D.A. and Anderson, D.G. Procedures for Estimating Highway User Costs, Air Pollution and Noise Effects. Highway Research Board NCHRP Rept. 133, 1972, 127 pp.

Procedures, based on user costs and air and noise pollution consequences, are given for selecting level of traffic service in planning and evaluating highway programs. Included is a procedure for estimating traffic accident costs using accident rate estimates and estimated costs per accident. The cost per accident are classified by severity.

161. Darrohn, S.D. Report on Pennsylvania's Automated Accident Analysis System. Proceedings, American Assoc. of State Highway Officials, Oct. 1969, pp. 146-150.

The system, begun in 1966, is based on state and municipal police reports and drivers' reports of vehicle accidents. Data on location is coded, edited, and filed in a computer. Using additional data on highway route length, classification, ADT, surface width and type, the system generates several types of reports. The three most widely used of these reports are the "cluster" report of highway accident locations, the "improbable rate" accident location report, and collision diagrams for an intersection.

162. Drake, G.L. and Kraft, M.A. Motor Vehicle Accident Costs in Washington Metropolitan Area, Highway Research Record 188, 1967, pp. 127-139.
A comprehensive study of traffic accident costs for a predominantly urban area. The cost of an accident includes the value of damages and losses to persons and property. This includes the present value of loss of future earnings for persons fatally injured or permanently disabled.

163. Economic Cost of Motor-Vehicle Accidents to Cargo Carrying Vehicles of Utah Registry, 1957. Utah Dept. of Highways, 1960, 3 Vols. Contents: v.1 Accidents and Incidents; v.2 Direct Costs; v.3 Involvements.

164. Evaluation of Criteria for Safety Improvements on the Highway. Jorgensen (Roy) and Associates, and Westat Research Analysts, Inc., Rept. to U.S. Bur. of Public Roads, Office of Highway Safety (PB 173822), 1966, 227 pp.
Methods are presented for determining hazardous locations forecasted accident reductions for various safety improvements and ways of determining the cost-effectiveness of proposed safety improvements. A discussion of accident records systems organizations is also included.

165. Hoch, D. Chicago Accident Experience on Arterials and Expressways. Traffic Quarterly, Vol. 14, No. 3, July 1960, pp. 340-362.

166. Insurance Facts. Insurance Information Inst. Published annually.

167. Kay, J.L. Signal System Studies: A New Approach. Traffic Eng., Vol. 40, No. 4, Jan. 1970, pp. 24-31.
A utility-cost method is presented for evaluating alternative signal systems.

168. Leininger, W.J., Bruce, R.G., Clinkscale, R.M., Heilbron, R.D., Lynch, E.A. (Jr.), McCoy, F.L., Purcell, R.N. and Reuzan, L.H. Development of a Cost-Effectiveness System for Evaluating Accident Countermeasures. Operations Research Inc., Silver Spring, Md., Tech. Rept. 505, 1968, 6 Vols.

169. Little (A.D.) Inc. Cost Effectiveness in Traffic Safety. New York, F. A. Praeger, 1968, 167 pp.
This study assesses the feasibility of using cost-effectiveness analysis in the evaluation of traffic safety as well as a survey of optimization techniques. In addition, a review of the adequacy of traffic safety data in various categories of programs and a set of measurement problem examples are described.

170. McCarthy, J.F. Economic Cost of Traffic Accidents in Relation to the Vehicle. Highway Research Board Bulletin 263, 1960, pp. 23-39.
Data are given on accident involvement costs for both reported and unreported accident involvements developed in Massachusetts study (1953-1955).

171. Personal Injury Evaluation Handbooks. Jury Verdict Research, Inc., 1968-1971.

172. Smith, R.N. and Tamburri, T.N. Direct Costs of California State Highway Accidents. Highway Research Record 225, 1968, pp. 9-29.

Estimates of the direct costs of accidents in California were developed using accident cost data from the 1958 Illinois accident cost study plus data on both the number of vehicle involvements per accident and the relative fraction of reported and unreported accidents determined for California in 1964. The average number of vehicle involvements (all vehicles) per accident in California in 1964 was 1.61 on rural nonfreeway routes, 1.55 on rural freeways, 1.91 on urban nonfreeway routes, and 1.81 on urban freeways. This is an average of 1-3/4 vehicles per accident. The percentages of total fatal, injury, and property-damage-only accidents for which accident reports were filed in California in 1965 were 100 percent (fatal), 94 percent (injury), and 37 percent (property damage only).

Accident costs have been categorized by severity, vehicle type, road type, and rural-urban dichotomy. In the discussion with the paper, a good review is covered relative to the merits of inclusion or exclusion of "possible future earnings" as costs for fatalities. The effect of including these earnings is to greatly increase this cost.

173. Societal Costs of Motor Vehicle Accidents - Preliminary Rept. U.S. National Highway Traffic Safety Admin., April 1972, 1 Vol.

Report presents quantitative estimates of costs to society resulting from motor vehicle accidents. The loss categories include property damage, medical costs, productivity losses, insurance administration, losses to other individuals, employer losses, pain and suffering and miscellaneous accident costs. Results are summarized by accident severity level, by availability and reliability of data for each severity level on which the estimates are based and by the appropriateness and applicability of the accident cost component as an economic loss to society. The appendices provide detailed information on assumptions, methodology, and calculations.

174. Summary of Pedestrian Accidents—1969. Washington State Department of Highways, Olympia, 1970.

This report gives statistics on pedestrian accidents in all communities in the State of Washington except Seattle, Spokane, and Tacoma.

175. Taylor, J.I., McGee, H.W., Sequin, E.L. and Hostetter, R.S. Roadway Delineation Systems. Highway Research Board NCHRP Rept. 130, 1972, 349 pp.

Included in a series of appendices is a general discussion of benefit-cost analysis procedures and an evaluation of these procedures relative to highway projects. Cost of time and accident costs from the Illinois and Washington, D.C., studies are compared. A method which considers intangible costs of total accidents is described.

176. Traffic Accident Experience in the United States. Insurance Information Institute, March 1972.

177. Utah Accident Cost Study, 1955 Passenger Car Data. Utah Road Commission, 1959, 1 Vol. Cover title: Cost of Passenger Car Accidents to Utah Motorists in 1955.

178. Widerkehr, R.R.V. A Methodology for Programming Highway Safety Improvement Projects. Second Cost-Effectiveness Symposium, Washington Operations Research Council, 1968.

179. Winfrey, R. Economic Analysis for Highways. International Textbook Co., 1969, 923 pp.

A comprehensive treatment of the economic aspects of highway transportation. The material covered includes engineering economy, transportation and road user costs, vehicle costs, traffic accidents, traffic operations, right-of-way land costs and the economic aspects of highway management and decision making. In the traffic accident section an important discussion of accident classification systems and enumeration of cost elements is given. A comparison and tabulation of the results of the 1958 Illinois accident study and the 1964-65 Washington, D.C., area study is included. The Cornell Aeronautical Laboratory study of the relationship of motor vehicle accidents to highway types and highway design elements is summarized.

180. Winfrey, R. and Zellner, C. Summary and Evaluation of Economic Consequences of Highway Improvements. Highway Research Board NCHRP Rept. 122, 1971, 324 pp.

The consequences and relationships of highway improvements to social and economic community changes are discussed. The report includes: an evaluation of a planning, programming and budgeting system, (PPBS), discussion of highway user costs and gains including accident costs and the related economic theory, techniques for evaluating alternative plans, and a presentation of decision making tools.

181. Wohl, M. and Martin, B.V. Traffic System Analysis for Engineers and Planners. McGraw-Hill, 1967, 558 pp.

A good fundamental reference on elements entering in, and procedures applicable to, the decision-making process as applied to alternate design or traffic control measures. Of special interest are Chapters 7, 8, and 9 which deal specifically with these methods of analysis.

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