REPORT NO. DOT-TSC-FHWA-78-2,III

SEVEN EXPERIMENT DESIGNS ADDRESSING PROBLEMS OF SAFETY AND CAPACITY ON TWO-LANE RURAL HIGHWAYS

Volume III: Experimental Design to Evaluate MUTCD and Other Traffic Controls for Highway Construction and Maintenance Operations on Two-Lane Highways

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FINAL REPORT

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16. Abstract This is Volume III. This report contains an experimental design to evaluate methods of providing safe and expeditious movement of traffic through or around construction and maintenance zones while providing safety for workers in these zones. Two types of construction/maintenance zones will be examined with different traffic control devices. A simulation model for single-lane, two-direction operation in a long construction zone is appended. This Technical Report consists of seven other volumes. They are:

Vol.	pp.	Title
I	38	Introduction, Description of Experiments and Common Elements
II	70	Develop and Evaluate Dynamic Aids for Narrow Bridges
IV	58	Develop and Evaluate Remedial Aids to Warn Drivers of Slow Moving Vehicles on a Grade
V	62	Vehicle Equivalency and Capacity Including Effects of Commercial and Recreational Vehicles on Rural Non-Controlled Access Highways
VI	54	Comparative Evaluation of Warning-Advisory and Regulatory Traffic Control Devices
VII	50	Develop and Evaluate Measures for Reducing Effects of Roadside Friction on Traffic Flow
VIII	70	Remedial Aids for Intersections with Inadequate Sight Distance

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1. INTRODUCTION

This report contains the Experimental Design for the "Evaluation of MUTCD and Other Traffic Controls for Highway Construction and Maintenance Operations on Two-Lane Highways"*. This is Volume III of an eight-volume report. Volume I contains background information and summaries of the seven experiments and discusses those aspects which are common to the seven experimental designs.

The present volume includes:

- Background and Objectives,
- A State-of-the-Art Review,
- The Experimental Design,
- A Bibliography.

1.1 Background

Construction and maintenance activities within, or immediately abutting, the traveled way of a highway represent both a physical discontinuity as well as an unexpected occurrence. Both of these violations of driver expectancy place increasing demands on the driving task (3) and are thus likely to increase the probability of catastrophic failure of the highway-vehicle-driver system; that is, lead to an increased accident potential.

Evidence is available to indicate that this potential is realized and that construction and maintenance activities create a definite hazard. This hazard applies to the driving public as well as to the crews engaged in the construction and maintenance action.

1.2 Objective of Experiment

The objective of this experiment is to evaluate methods of providing safe and expeditious movement of traffic through or around construction and maintenance zones on two-lane rural highways while also providing safety to the work force performing these operations.

The methods to be tested in this experiment emerge from a thorough literature search and state-of-the-art review which is summarized in the following section. Section 3, the final section, details the experimental design which tests the relative effectiveness of these methods.

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*This experiment is referred to as Experiment B in Volume I.

By far, the greatest proportion of the required information is received by the driver on the visual channel. Schmidt and Connolly (86) have prepared a comprehensive survey of all visual elements involved. Rockwell et al. (83) have addressed the specific problem faced by the driver at night.

The literature on the design and effectiveness of traffic control devices is particularly rich and comprehensive. All of the quoted references include extensive bibliographies on the subject. Section 2.2 below lists a number of basic studies which cover individual classes of traffic control devices. A good comparative study of various types of devices is reported by Markowitz et al (57).

2.2 Specific Traffic Control Devices

The standards for the design, location and use of all traffic control devices for the United States are contained in the Manual of Uniform Traffic Control Devices (MUTCD) (102) and the periodic revisions thereto that have appeared since the issuance of the present edition in 1971. Signs, signals, markings, barricades, delineators and other types of devices are all covered separately.

A considerable body of literature exists on the subject of signing. Forbes and his co-workers at Michigan State University have produced a number of general and specific studies on this subject. Of these, two are of special importance. One of these (17) deals with the general subject of traffic sign requirements while the other (23) presents a bibliography on the subject. Woltman (108) has reviewed the visibility factors involved in highway signing. Most of this work had dealt with fixed message signing. The principles involved in the use of variable message displays have been stated by Stephens (92). A specific sign problem, especially germane to the problem of construction/maintenance signing is the minimum letter size as a function of reading time, analyzed by Moore and Christie (65), by the British Road Research Laboratory (79) and by King (48). Allen et al (4,94) have shown that legibility distances decrease markedly when sign luminance drops below 20 foot-lamberts in a series of studies dealing with night visibility of both illuminated and non-illuminated signs.

A current study is concerned with all aspects of traffic signal design configurations. The recently issued Interim Report on the project (51) covers the design factors which affect the efficiency of traffic signal design configurations

2.3 Construction/Maintenance Traffic Control

Construction and maintenance activities can take a great number of different forms. An ASCE committee has prepared a useful summary of these activities (14). Recent developments in this area have concentrated on refining procedures so as to minimize interference with traffic (e.g., 10,91). The possibility of doing maintenance work at night is also receiving increasing consideration (25,53).

Currently, applicable United States Standards for all types of construction and maintenance traffic control are contained in the MUTCD (102) promulgated in 1971. A number of changes and interpretation in these standards have been made by the National Advisory Committee on Uniform Traffic Control Devices since that date. These have recently been assembled in a separate publication (103). A number of states, cities and other jurisdictions have issued their own manuals to supplement the Federal standards. A good, although incomplete, survey of the use of these local standards has been completed on behalf of the American Public Works Association (5). The National Safety Council has taken an active role in expanding and promulgating these standards (67,72).

The Wisconsin Manual (106) can be considered typical of those local manuals. The California (11) and Pennsylvania (73) Manuals, issued as separate publications covering only construction and maintenance traffic control, are particularly comprehensive. Pennsylvania makes extensive usage of high level warning devices (39). Particular note should be made of a Louisiana publication (100) which combines the roles of a standards and training manual. It also includes a unique decision tree approach to picking the correct type of traffic control. Also noteworthy is work done in Arizona (31) which includes exclusive tabular data on the placement details of the various devices. A number of States, of which Illinois is a good example, have undertaken a concerted effort to propagate information on these standards (24,40).

Current Canadian practices, as contained in the 2nd Edition of the Canadian Manual (16), closely follows U.S. practices.

A number of publications deal with construction/maintenance traffic control logistics. These cover such areas as planning, erection, maintenance inspection and removal of the pertinent items. A number of these also have the added purpose of publicizing the manual requirements and stressing the importance of adherence to these standards (26,27,28,60,77,81). The specific application of these items to utility operations within the highway has been considered by Adrian (2). Cummings (18) covers the traffic planning aspects of establishing maintenance or construction traffic control.

2.4 Safety Aspects of Construction/Maintenance Traffic Control

The safety implications of construction/maintenance work have been stressed by both NHTSA (104) and AASHTO (1). Here they are considered from two separate aspects:

- Safety of the traveling public
- Safety of the work force

Studies of the effect of construction/maintenance work on highway safety are complicated by the fact that this effect often extends a considerable distance beyond the defined physical limits of the construction/maintenance work. Detailed analysis will often show that accidents are caused, directly or indirectly, by construction/maintenance activities even though they occur some distance upstream, due to queue formation and shock wave propagation. Downstream accidents, due to overcompensation for lost time by motorists, are also possible. However, routine police accident reports seldom indicate the presence of construction/maintenance activity for these types of accidents. A survey of the safety aspects of construction/maintenance areas made by the Highway Safety Research Institute of the University of Michigan (66) gives statistical data on this type of accident for three states (Texas, Virginia and Wyoming) and also includes an annotated bibliography of 15 items.

A California study (44) analyzed the construction zone accident experience. After identifying this to be a serious problem, remedial measures, consisting of a detailed analysis of each construction site for potential accident hazards were

Table 1

California Construction Zone Accidents

	BEFORE CONSTRUCTION									DURING CONSTRUCTION									PERCENT CHANGE						
			NUMBER OF ACCIDENTS				ACCIDENT RATES					NUMBER OF ACCIDENTS				ACCIDENT RATES				NUMBER OF ACCIDENTS				ACCIDENT RATES		
PROJ. NO	NUMBER MONTHS	MVM	TOT.	FAT.*	INJ.	PDO	TOT.	F+I	FATALITY	NUMBER MONTHS	MVM	TOT.	FAT.*	INJ.	PDO	TOT.	F+I	FATALITY	MVM	TOT.	FAT.*	INJ.	PDO	TOT.	F+I	FATALITY
1	12	4.7	10	0	4	6	2.12	0.85	0	12	5.1	16	0	10	6	3.14	1.96	0	+8	+60	0	+150	0	+48	+131	0
2	5	8.7	44	0	21	23	5.07	2.42	0	5	9.2	41	0	18	23	4.45	1.95	0	+6	-7	0	- 14	0	-12	- 19	0
3	12	20.1	33	0	22	11	1.65	1.10	0	12	24.3	54	3(3)	23	28	2.23	1.07	12.50	+21	+64	+∞	+ 4	+154	+35	- 3	+∞
4	12	62.6	68	4(5)	21	43	1.08	0.40	7.99	12	62.0	118	5(5)	61	52	1.90	1.06	8.06	-1	+59	+25	+190	+ 21	+76	+165	+ 1
5	5	17.3	27	0	13	14	1.57	0.76	0	5	17.4	37	1(1)	27	9	2.13	1.61	5.75	+1	+37	+∞	+108	- 36	+36	+112	+∞
6	12	28.1	64	0	26	38	2.28	0.93	0	12	27.1	78	0	29	49	2.88	1.07	0	-4	+22	0	+ 12	+ 29	+26	+ 15	0
7	12	4.4	20	1(1)	11	8	4.55	2.73	22.73	9	4.4	25	0	11	14	5.73	2.52	0	0	+25	-∞	0	+ 75	+26	- 8	-∞
8	12	41.1	65	1(1)	33	31	1.58	0.83	2.44	12	47.2	74	8(9)	29	37	1.57	0.78	19.07	+15	+14	+700	-12	+ 19	- 1	- 6	+681
9	12	54.9	130	4(5)	58	68	2.37	1.13	9.09	12	63.9	188	9(11)	77	102	2.94	1.35	17.18	+16	+45	+125	+33	+ 50	+24	+ 19	+ 89
10	24	36.4	98	1(2)	42	55	2.68	1.18	5.50	12	44.5	114	2(6)	49	63	2.56	1.15	13.63	+26	+16	+100	+17	+ 14	- 4	- 3	+148
Total	118	278.3	559	11(14)	251	297	2.01	0.94	5.03	103	305.1	745	28(35)	334	383	2.44	1.19	11.47	+9.6	+33.3	+154.5	+33.1	+29.0	+21.4	+26.6	+128.0

DURING CONSTRUCTION:

PDO	accident rate increased	17.8%	(1.07 to 1.26 acc/mvm)
Injury	accident rate increased	21.1%	(0.90 to 1.09 acc/mvm)
Fatal	accident rate increased	132.4%	(3.95 to 9.18 acc/100 mvm)
TOTAL	accident rate increased	21.4%	(2.01 to 2.44 acc/mvm)

***Figures in parenthesis show the number of persons killed.**

Table 2

Accidents in Areas under Construction

A. TEXAS: Rural Motor Vehicle Accidents at Areas under Construction

Year	Fatal Accidents	Nonfatal Accidents
1960	60	1664
1961	40	1598
1962	50	1450
1963	56	1517
1964	53	2131
1965	30	2033
1966	53	2341
1967	54	2650

B. VIRGINIA: Accidents at Areas under Construction

Year	All Accidents	Fatal Accidents	Personal Injury	Property Damage
1960	574	4	NA	NA
1961	881	5	217	659
1962	971	15	247	709
1963	1109	7	272	830
1964	1319	9	307	1003
1965	1814	16	383	1415
1966	1763	13	394	1356
1967	1734	9	417	1308

C. WYOMING: Accidents at Areas under Construction

Year	Total No. of Accidents	Injuries	Fatalities
1962	127	76	3
1963	108	54	4
1964	NA	NA	NA
1965	100	91	3
1966	118	86	6

"The primary aim is to evaluate the effects of an advance warning traffic control system on traffic flow and driver alertness under various traffic and maintenance operations. The measured response will be in terms of traffic conflicts and vehicle speed in the critical zone. Dependent variables will include size, height of legend, reflectance of portable signs, and the combination of flashing lights and electronic signs. Data will be evaluated using ANOVA technique."

Also potentially applicable is a study by the Oregon State Highway Division, under Contract No. FHWA-RD-75-66, whose "objective is to develop preliminary design specifications for a speed advisory system to inform drivers of the optimum speed during periods of reduced visibility."

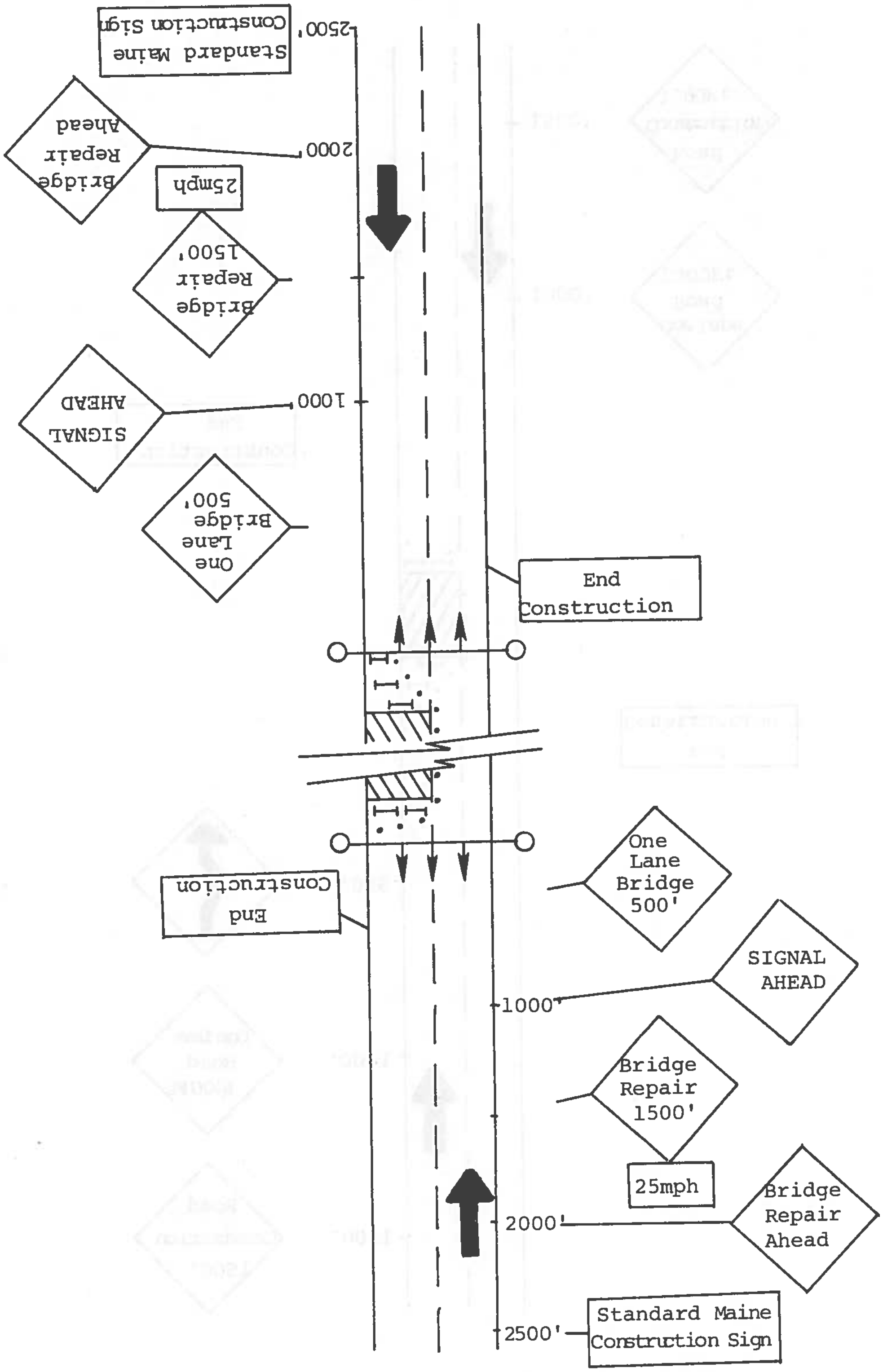

Figure 1: MUTCD - Long Section

be developed by the Traffic Engineering Section of Maine DOT so as to assure adherence with all current standards.

2. The same traffic control device configuration augmented with powered flashing devices and additional signs as shown in Figures 3 and 4.

3. A traffic control device configuration similar to No. 1 above but using symbol signing to the maximum extent possible. The configurations are shown in Figures 5 and 6.

The symbols shown are indicative in nature only. The exact symbols to be used shall be those adopted by the National Advisory Committee on Uniform Traffic Control Devices at its January 1977 meeting in Silver Springs, Maryland. In case no specific symbol has been adopted for a specific message, the recommendations of the NAC Subcommittee on Construction and Maintenance and of the Task Force on Symbol Signing of the NAC Subcommittee on Signs should be followed.

Supplementary, word message, plates should not be used unless the use of such plates, for a specific symbol, is recommended or suggested by NAC.

The configurations shown in Figures 1, 2, 5 and 6 should be supplemented with flashers, lanterns and similar illumination devices at night in accordance with current practices of the Maine Department of Transportation.

Another set of independent variables is associated with the conditions under which data is collected. Analysis of these independent variables will indicate the effect of environmental and traffic conditions on the relative effectiveness of the various traffic control configurations considered. The analysis will also indicate if any differences in reaction to the tested configurations can be distinguished between the different components of the traffic stream.

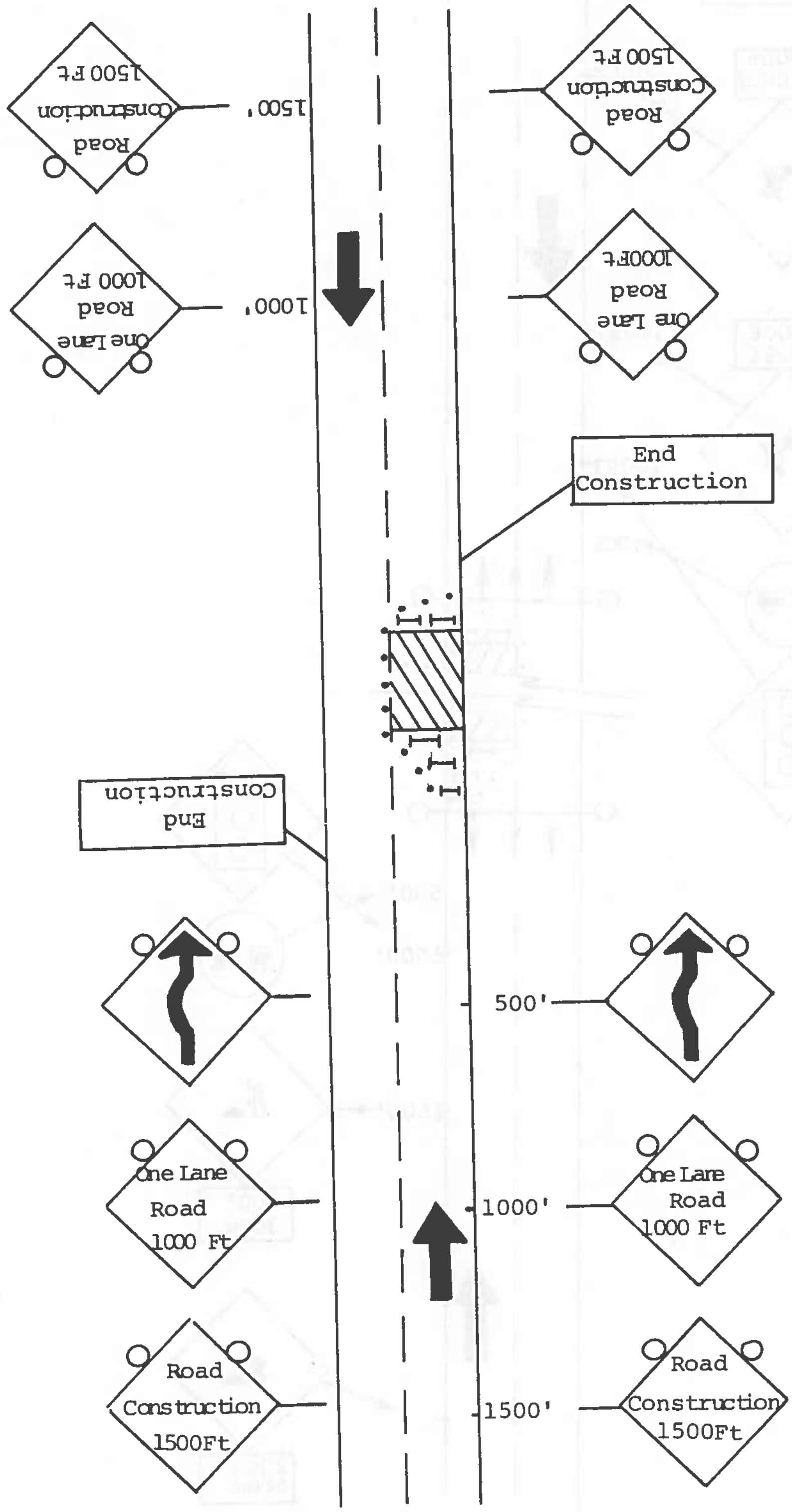

Figure 4: Augmented MUTCD - Short Section

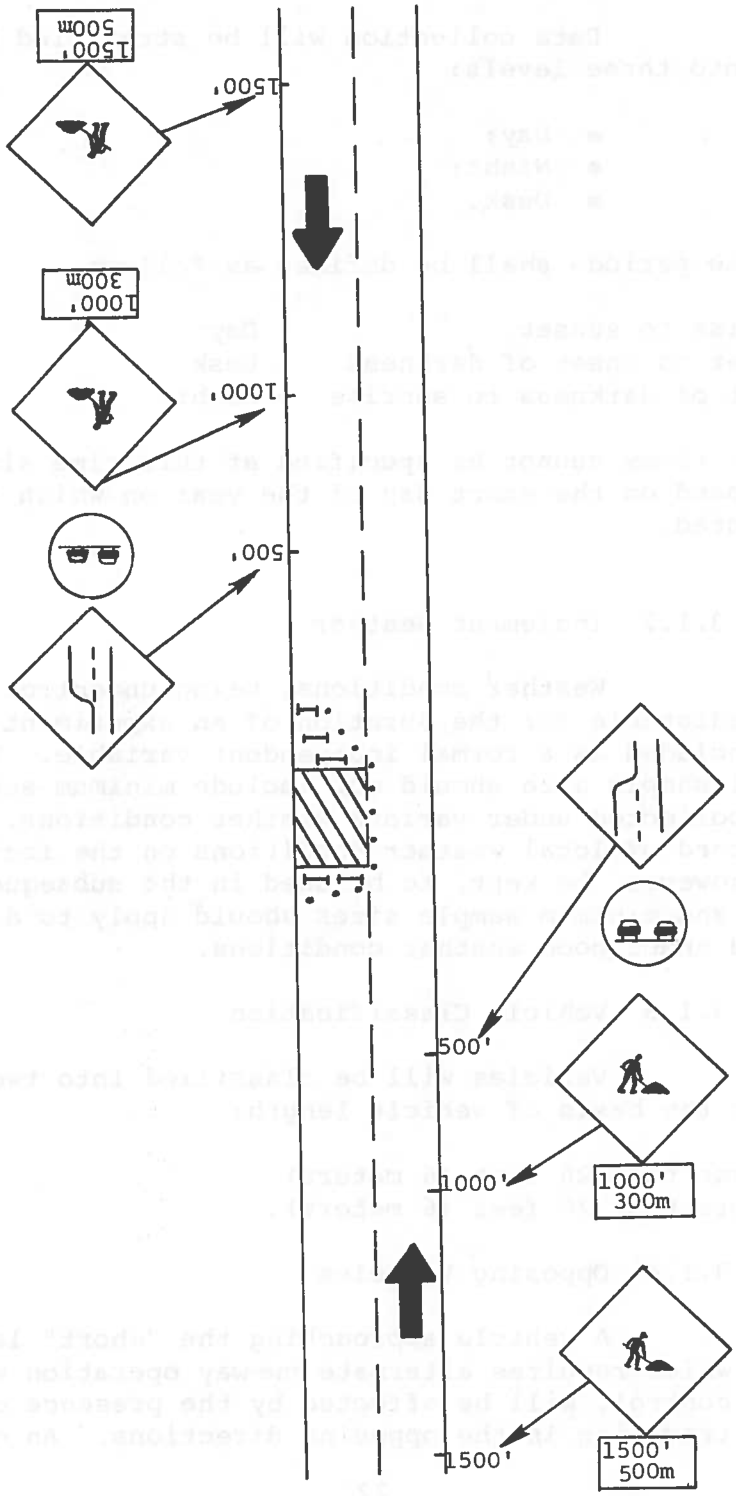

Figure 6: Symbol Signing - Short Section

vehicle will be defined as one which is twenty seconds or less travel time upstream of the lane closure in the opposite direction at the time the test vehicle passes the furthest downstream sign.

This variable therefore applies only to the "short" lane closure. Three levels would be optimum. However, sample size restrictions (see Section 4) may place a constraint on the number of levels that can be used.

- "Short" vehicle unopposed;
- "Short" vehicle vs. "short" vehicle;
- "Short" vehicle vs. "long" vehicle.

3.1.5 Presence of Queue

The presence of a queue at the signal controlled "long" closure may affect results in that motorists may react to the queue rather than to the traffic control devices. A queue will be defined as two or more vehicles facing a red signal indication and the presence and absence of such a queue will constitute the two levels of this variable.

3.1.6 Signal Status

Past studies at KLD (47) and elsewhere have shown that the instantaneous signal state exerts a direct influence on the speed and headway behavior of approaching motorists. Signal state will thus be considered as an independent variable with two levels as follows:

- Signal indication red
- Signal indication green and ten seconds or more after initiation of green.

The amber interval is too short to allow for meaningful sample sizes. Data collected during the amber interval should, therefore, not be included in the primary analysis. The initial portion of the green interval, approximately the first ten seconds, represents a transition marked by queue discharge and by a change from deceleration to acceleration. Data collected during this period should, therefore, also be excluded from the primary analysis.

Table 3

Summary of Independent Variables

Variable	Levels: Long Closure	Levels: Short Closure
Treatment	3	3
Time of Day	3	3
Vehicle Classification	2	2
Opposing Vehicle	-	3
Presence of Queue	2	-
Signal State	2	-

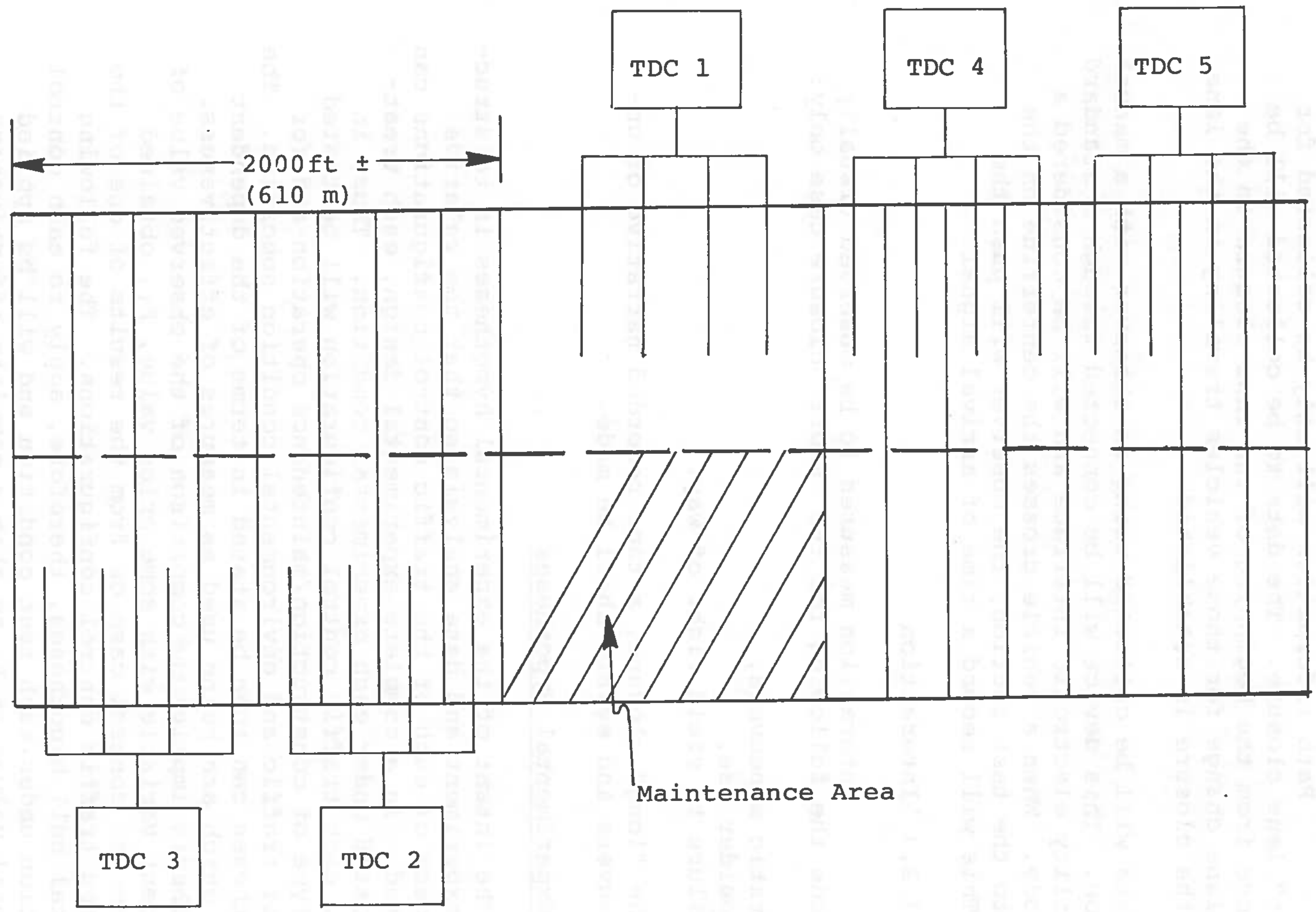

Figure 7: Detector Placement Schematic

- There has been no decrease in average speed through the construction maintenance zone;
- The average speed through the zone exceeds the maximum safe speed;
- The 85th percentile speed has increased;
- The speed variance has not decreased either over time or space;
- The deceleration exceeds a safe, comfortable rate;
- Average time headways between vehicles have decreased below minimum safe headways;
- The average queue discharge headway increased;
- The average number of avoidance maneuvers (sudden decelerations, lane encroachments, erratic path movements) has increased;
- The variance of the position at which vehicles crossed the roadway centerline has increased;
- The capacity of the restricted roadway has decreased.

These hypotheses are all one-sided and reflect the use of speed changes, interactions between vehicles, and capacity as measures of effectiveness in the analysis. Statistical tests will determine whether these hypotheses can be rejected and whether observed changes are statistically significant at a pre-specified confidence level--usually the 0.05 level.

An additional experimental hypothesis, of a slightly different form, asserts that there exists a regression relationship for capacity as a function of approach volume, length of maintenance section and volume split. A formal statement of the appropriate null hypothesis would be worded so that rejection of the null hypothesis implies the existence of such a relationship in which the independent variables, approach volume, length of maintenance section and volume split, do explain a significant portion of the variation in capacity.

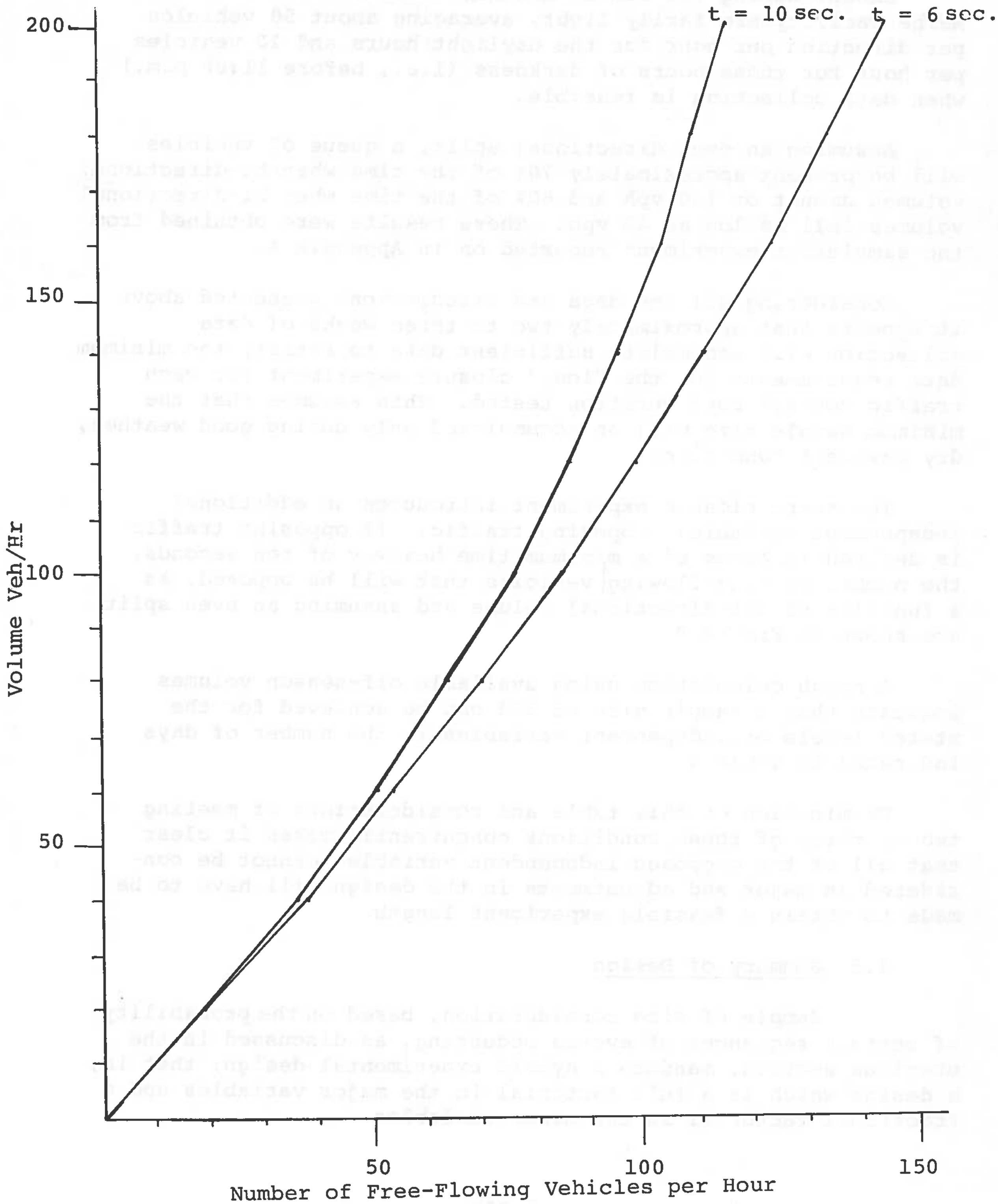

Figure 8: Free-Flowing Vehicles

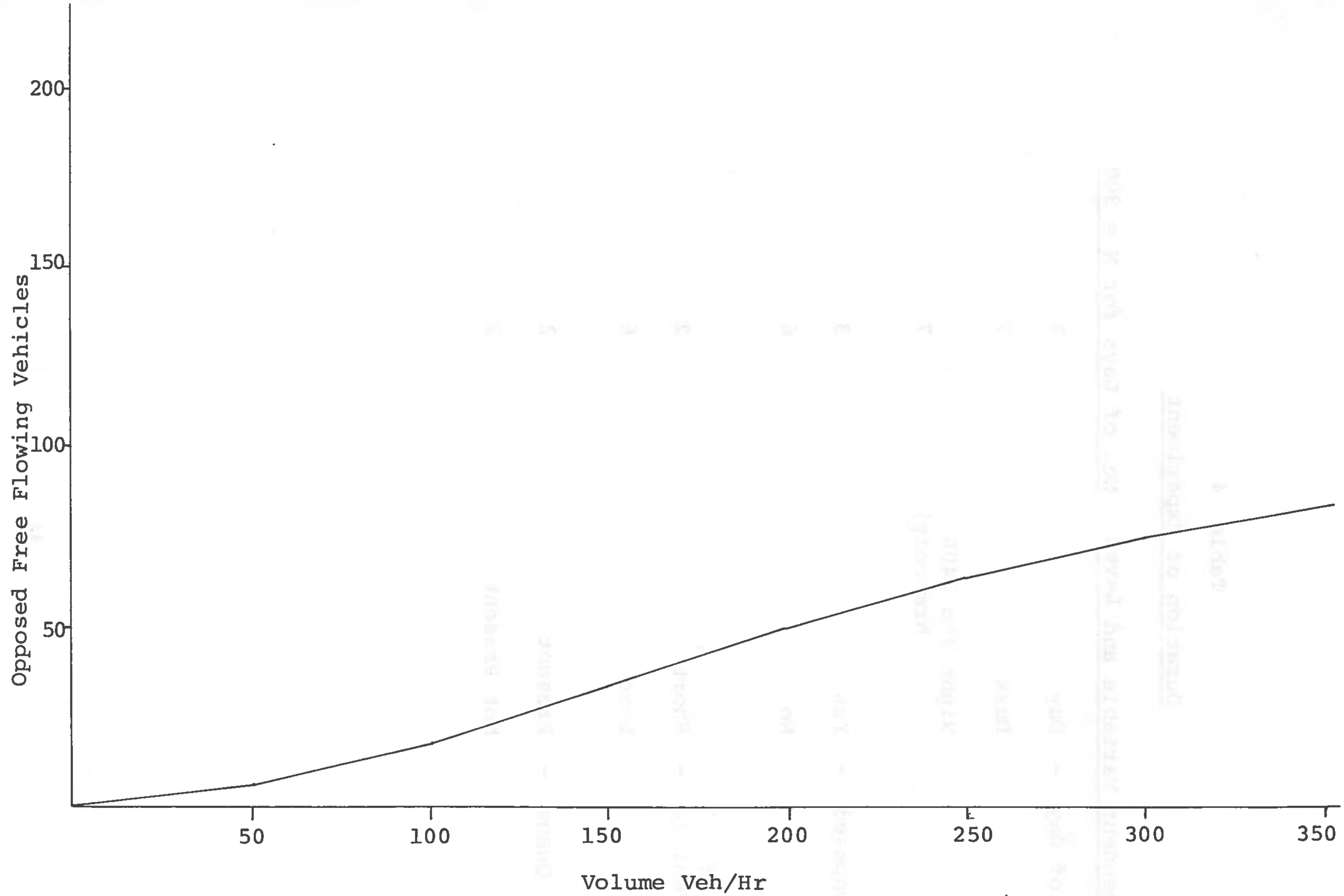

Figure 9: Opposed Vehicles

For purposes of design, the "long" and "short" closure experiments are to be considered as two separate experiments. Each of these experiments will include three types of traffic control device configurations. For each of these configurations, data collection should be continued until the minimum sample size has been reached for every cell of the design shown in Table 5. Minimum sample sizes apply to each direction of travel separately.

Based on past data, an initial sample size of 300 has been assumed. It is, however, recommended that, immediately preceding the initiation of the experiment, the true value of the standard deviation of speed be estimated from a sample of 500 vehicles using data from a permanent detector located in the middle of the approach zone. This sample size is approximately equal to one-directional daylight volume for an average day. The sample standard deviation should then be used to recompute minimum sample size.

It is estimated that, with a sample size of 300, data collection will take three calendar weeks for each treatment of the "long" closure experiment and two calendar weeks for each treatment of the "short" closure experiment. These estimates allow for some times when data collected does not contribute to the minimum sample size requirements due to adverse weather or wet pavement. These data should, nevertheless, be collected, identified, and retained for potential secondary analysis.

The estimated running time of the experiment is highly dependent on starting date due to seasonal variations in:

- Total volume;
- Proportion of long vehicles in the traffic stream;
- Distribution of the hours of the day, and therefore the total volume, among the three time-of-day levels.

3.7 Data Analysis Procedures

Speed and headway data on the approach to the construction/ maintenance sections will be analyzed both longitudinally and laterally.

- Longitudinal Analysis - analysis of the trajectories of individual vehicles through the entire instrumented section;

- Lateral Analysis - analysis of the distribution of speeds and headways at individual locations.

The analysis of speed related parameters is detailed herein. The headway analysis is analogous. It must be remembered that the minimum sample size was selected on the basis of free flowing vehicles and is geared towards speed analysis. Headway analysis will only be possible if data on sufficient vehicles with headways short enough to fall within the car following mode is obtained.

3.7.1 Trajectory Matching

The data collected will consist of the speed and time of arrival of vehicles at individual detector stations. $V_j(i)$ and $t_j(i)$ are the measured speed and clock time of arrival of vehicle i at detector station j. D_j is the distance from detector station j+1 to detector station j. Detector station numbers increase in a downstream direction. The initial step in data analysis consists of synthesizing the trajectories of individual vehicles. A trajectory match program reconstructs the trajectories by estimating the acceleration:

$$\hat{a} = \frac{V_{j+1}(k) - V_j(i)}{t_{j+1}(k) - t_j(i)}$$

computing the distance covered at this rate

$$\widehat{\Delta x} = V_j(i)\Delta t + \frac{1}{2}\, a(\Delta t)^2$$

queue presence, and signal state or opposing traffic as applicable.

- For variance of headways and variance of speeds, an analogous set of F-tests are made.

A treatment is considered "better" than another treatment for the specified set of conditions if:

- Mean speed is reduced and/or;
- Standard Deviation of speed is reduced.

Lack of significance in the comparison test on means may be due to the fact that the mean is a relatively insensitive indicator of speed behavior. If no significant difference in mean speed is found the following supplementary statistical tests should be performed:

- Comparison of 85th percentile speed using the Quantile Test (15);
- Comparison of the two cumulative speed distributions using the Kolmogorov-Smirnov Test (15).

In interpreting the results of these tests, a treatment will be considered "better" than another if the value of the test statistics is lowered significantly.

3.7.4 Trajectory Analysis

The purpose of this analysis will be to generate statistics on turbulence and hazard within the sections. This analysis should be implemented after examination of the results of the two analyses described above.

3.7.4.1 ΔV and A

The statistics ΔV and A may be considered, or more precisely,

3.7.4.2 Individual Trajectories

For individual vehicles (i) over the entire section, one can also compute

$$\sigma_i^2 = \frac{1}{T_i} \int_0^{T_i} [a_i(t)-\bar{a}_i]^2 dt = \frac{1}{T_i} \sum_{j=1}^{n-1} \left(\frac{\Delta V_j(i)}{\Delta t_j(i)} - \bar{a}(i) \right)^2 \Delta t_j(i)$$

where $T_i = [t_n(i) - T_1(i)]$ and $\bar{a}(i) = [V_n(i) - V_1(i)]/T_i$ and n = number of detection stations.

For each condition, one may compute the mean of this quantity, as well as this quantity normalized by

$$\bar{V} = \frac{1}{N} \sum_{i=1}^{N} \left\{ \frac{\sum_{j=1}^{n-1} D_j}{t_n(i) - t_1(i)} \right\}$$

Note that only complete trajectories can be used for this computation.

The computed means can be compared between different conditions using standard t-tests.

3.7.4.3 Hazard Analysis

Headways at, or approaching, the end of a queue may become so small that the following vehicle cannot stop safely in case of any abrupt stop by the leader. Table 6 depicts a desired summary for each daylight condition when a queue is present. The table is generated by estimating vehicle space headways from trajectory data and "stopping" the lead vehicle at the rate indicated just as the follower enters a given section.

One such summary is possible for each position except the last. The different conditions can be compared by tests on the percentages given in the individual tables (tests for significance of differences in proportions for individual cells or χ^2 tests for contingency tables). It should be recognized that this analysis is sensitive to the proper choice of a reaction time parameter. Furthermore, the analysis can only be implemented if sufficient short headway (i.e. car following mode) data is available.

In this analysis, improvement can be denoted by significant increases in the "can stop" percentages.

3.7.5 Queue Discharge Analysis

The purpose of this analysis is to generate statistics on queue discharge headway. It will only be implemented for the signal controlled long closure. The following results will be obtained:

- Mean discharge headway by queue position;
- Standard deviation of discharge headway by position.

These quantities should be computed for each experimental condition.

Comparisons between the conditions will be done by generating tables of t-test decisions (for means) and F-test decisions (for variances).

It has been shown that differences in queue discharge headway characteristics affect both delay and capacity. This analysis will, therefore, assist in the determination of the capacity and delay aspects of the construction/ maintenance lane closure.

Significant reductions in mean queue discharge headways would indicate increased in capacity and reductions in mean delay (50). Significant decreases in the standard deviation of queue discharge headway would indicate a decrease in the proportion of vehicles exposed to long delays.

The reduced data on queue discharge headway characteristics is also required for calibration of the simulation model.

The optimum value of D_{CL} is a function of approach geometry, approach speed and lane width. This optimum value should be the shortest distance that will allow for a comfortable lateral movement not requiring braking or abrupt steering maneuvers. Individual treatments can, therefore, be judged in relation to this optimum. A minimum variance of D_{CL} is desirable.

3.7.7 Interaction Analysis

Interaction measures will be reduced to proportions. Standard tests on the difference between proportions can then be made. A low value of this proportion is desirable.

3.7.8 Subsidiary Analysis

Depending on the availability of data, similar analyses can be implemented to evaluate the effect of adverse weather conditions and/or wet pavement. Other similar analyses can be made, insofar as the data permits, for defined conditions such as the absence of a work crew during daylight hours.

The individual data analyses, discussed in the preceding sections, are designed to determine if significant differences exist between the various traffic control treatments contained in the experiment. The effect of all other independent variables contained in the experiment is also to be determined. These analyses are summarized in Table 7.

3.7.9 Capacity Analysis

One of the purposes of the planned experiment is a determination of the capacity effects of construction/maintenance lane closures on two-lane rural highways. Since uni-directional, hourly volumes on the approaches to the construction/maintenance section cannot be expected to exceed 150 vehicles per hour during the experiment, capacity cannot, in all probability, be measured directly.

It is, therefore, suggested that the results of the experiment be used to calibrate and validate the simulation model described in Appendix A. This model can then be exercised so as to yield capacity.

Table 7 (Continued)

Summary of Data Analyses

Test Statistic	Discussed In	Experiment Level	Derived From	Direction of Improvement
S.D. (Queue Discharge Headway)	6.5	Long	Stop line sensor	Lower
$E(D_{ce})$	6.6	Short	Manual data	Towards Optimum
S.D. (D_{ce})	6.6	Short	Manual data	Lower
Interaction Measures	6.7	Both	Manual Data	Lower

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APPENDIX

SIMULATION OF A CONSTRUCTION SECTION

The purpose of this appendix is to present studies of various traffic control strategies used in conjunction with construction and maintenance activities on two-lane rural roads. A number of control strategies were evaluated using the UTCS-1 simulation model.

1. Simulation Model

The tool used to evaluate the control strategies was the UTCS-1 simulation model.* The model is widely used and accepted. It has the ability to track vehicles through a network on a second-by-second basis.

For the purposes of this simulation study, a simple network was designed to correspond to the area encompassing the Sibley Pond Bridge and its approaches along U.S. 2. Figure A-1 presents a schematic drawing of the study network.

This schematic allowed simulation of the lane closure situation on a two-lane road. This is shown in Figure A-2.

The simluation was accomplished by assuring that the test section was totally cleared of vehicles moving in one direction before traffic was allowed to proceed in the other direction. This was accomplished through the use of variable clearance intervals at the signals at node 1 and node 2. The signalization plan is given on the following page.

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*Network Flow Simulation for Urban Traffic Control System - Phase II. Report in 5 volumes. Washington, D. C. Peat, Marwick, Mitchell and KLD Associates, Inc., 1973 (NTIS-PB 230760, 230761, 230762, 230763, 230764/as).

Interval	Node 1 Approach (3,1)	Node 1 Approach (2,1)	Node 2 Approach (1,2)	Node 2 Approach (4,2)
1	G	R	G	R
2 (clearance)	R	R	G	R
3	R	G	R	G
4 (clearance)	R	G	R	R

The control logic dictated the length of intervals 1 and 3, whereas the length of the clearance intervals was dictated by the need to clear links (1,2) or (2,1) of vehicles.

2. Traffic Control Strategies

A total of two strategies were tested. The first represents a fixed time controller. The length of intervals 1 and 2 were determined using Webster's algorithm * to find the cycle length and split using V_1 and V_2 as the critical lane volumes.

The second strategy was to discharge one direction as long as the following conditions were met:

1) There is demand in the direction being serviced (queue length > 0)

2) Opposing queue length is less than 10 vehicles

3) The first vehicle in the opposing queue has been waiting less than 60 seconds.

After some initial testing, it was found that Strategy 2 would cause the signals to flip-flop if volumes were sufficient to cause long queues on both approaches to the construction area. The solution to this problem was to incorporate a minimum dwell time for intervals 1 and 3.

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*Webster, F.V. and Cobbe, B.E., "Traffic Signals," Road Research Technical Paper No. 56, London, HMSO, 1966.

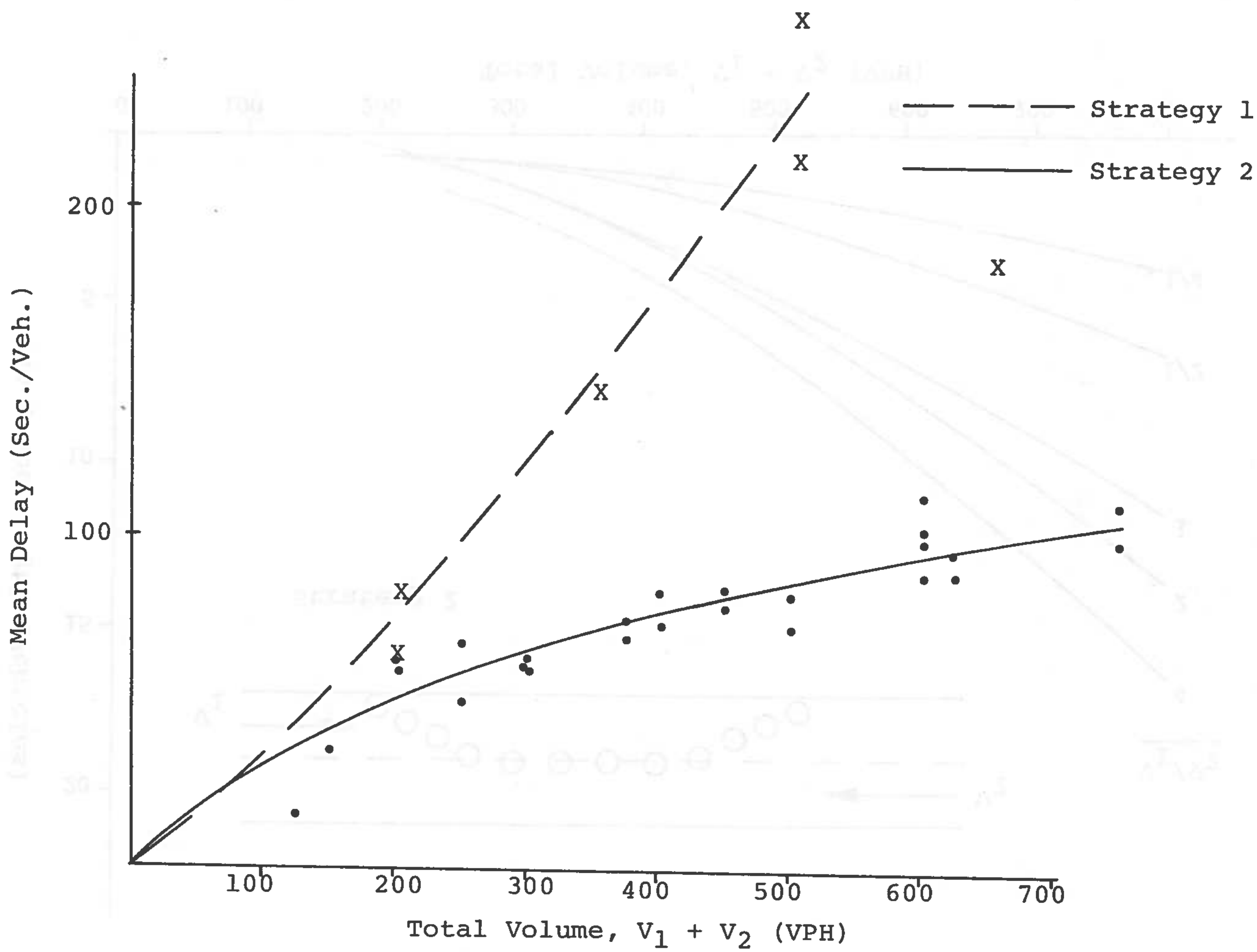

Figure A-3: Comparison of Traffic Control Strategies

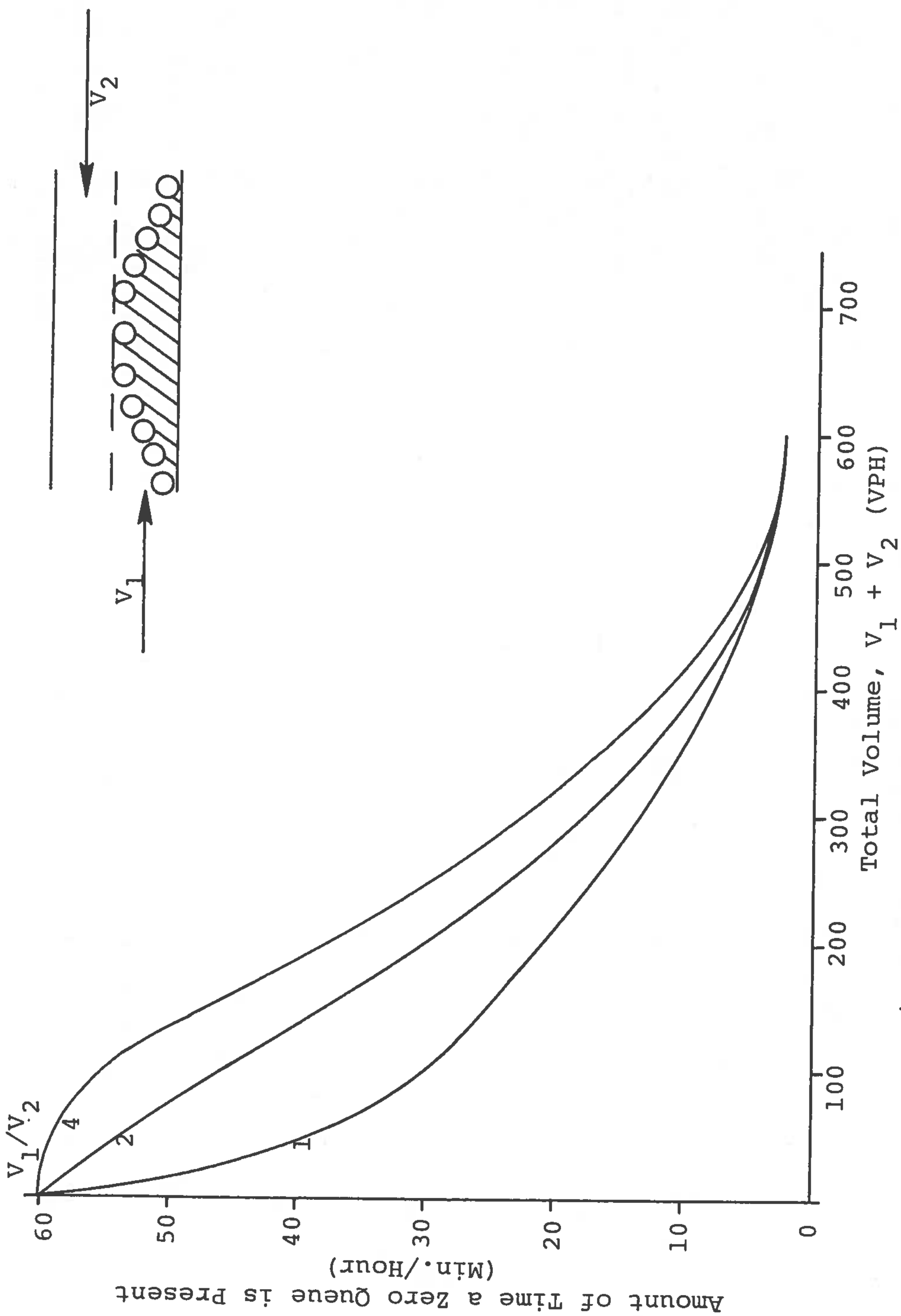

Figure A-5: Existence of a Zero Queue Length

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