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16. Abstract

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INVESTIGATION OF LANE OCCUPANCY AS A CONTROL VARIABLE FOR A SAFETY WARNING SYSTEM FOR URBAN FREEWAYS

by

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Research Report Number 165-6

Development of Urban Traffic Management
and Control Systems

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ABSTRACT

Lane occupancy was evaluated as a traffic variable for digital computer control of a safety warning system for urban freeways. Performance characteristics were studied of measured lane occupancy as an indicator of shock waves resulting from freeway incidents. A control strategy was developed, programmed, and evaluated for digital computer operation of the warning system. Comparisons were made with energy as a control variable. Based on the results of this research a new control algorithm was developed incorporating the best performance features of both energy and lane occupancy.

Key Words: Freeway control, traffic surveillance, safety, driver communications, traffic characteristics, shock waves, freeway incidents.

DISCLAIMER

SUMMARY

This report is concerned with an investigation of lane occupancy as a measured traffic variable for the detection of shock waves due to freeway incidents. Furthermore, results of this investigation were directed toward digital computer control of a freeway safety warning device described in an earlier project report (1). The function of the warning system is to increase freeway efficiency by alerting motorists to stoppage waves on freeway sections having restricted sight distance (i.e., overpasses).

The occupancy variable was computed based on one-minute data updated every 30 seconds. Computer logic was developed centered about critical occupancy as the control parameter. Studies were made regarding the responsiveness of the critical occupancy parameter to stoppage waves using both a one-lane control criterion and a two-lane control criterion.

The performance of the occupancy parameter was compared to that of energy as reported in reference 2.

The following specific findings may be drawn from the results of this research:

1. Critical occupancy parameters for shock wave detection were initially identified by regression analyses of occupancy and volume data but were found to result in numerous cases where the parameter did not respond in sufficient time to stoppage waves (Type I error), and erroneously indicated a stoppage (Type II error). A

sensitivity analysis resulted in adjusted occupancy parameters that had the minimum observed errors.

2. Performance evaluation of the resulting parameters using a one-lane detection criterion revealed detection of shock waves in 69 of 70 cases studied. Advance warnings ranged from -27 to 270 seconds. The one remaining case resulted in an untimely detection of the shock wave and represented an observed Type I error of 1.4 percent for the total sample. No false indications of a shock wave (Type II errors) were observed for the data studied under the one-lane detection criterion.

3. A two-lane detection criterion resulted in a greater observed Type I error than the one-lane criterion.

4. Control logic for the safety warning device was developed using the critical occupancy parameters. The logic was translated into an operational program for digital computer control of the warning system. Evaluation of the operation, simulated in real time, revealed that satisfactory control of the safety warning device was accomplished for incidents that occurred downstream (Case I) and upstream (Case III) of the subsystem.

5. The logic and processes involved were not able to provide for the detection of shock waves resulting from incidents within the subsystem (Case II). However, the low frequency of these incidents and the observation that response to such an incident would often be ineffective tend to minimize this problem.

6. A comparison of the occupancy parameters and energy parameters developed by Dudek (2) revealed that, on the average, occupancy was not as quick to respond to shock waves in comparison to energy. The average difference was 6.5 seconds. (Significant at the .05 level).

7. In comparison to energy, the occupancy control program provided a more stable operation of the warning system when major incidents occurred.

8. The energy program responds to slow moving vehicles (i.e., trucks, funeral processions, etc.) during the off-peak periods. The occupancy program, as it currently is structured, does not.

9. Although the occupancy parameters were selected based on minimizing Type I and Type II errors, high volume surges of traffic occasionally cause the warning system to activate erroneously.

Implementation

This research resulted in the development of an algorithm incorporating the best features of energy and lane occupancy for digital computer control of a safety warning system for urban freeways. The control logic is shown in Figure S-1. Although the combined control logic has not been used in practice as of this date, a careful evaluation of the control strategy indicates satisfactory performance. The following listing identifies the parameters presented in Figure S-1:

E_c = Critical Energy
E_{D1} = Energy at First Downstream Station
E_{D2} = Energy at Second Downstream Station
ϕ_c = Critical Occupancy
ϕ_u = Occupancy Upstream
Vol_c = Critical Volume (8 vph)
Vol_u = Volume Upstream
Vol_{D1} = Volume at First Downstream Station
Vol_{D2} = Volume at Second Downstream Station
U_t = Threshold Speed (30 mph)
U_{D1} = Average Speed at First Downstream Station
U_{D2} = Average Speed at Second Downstream Station

It is anticipated that an extension of the research reported herein will lead to techniques for automatic detection of incidents on urban freeways.

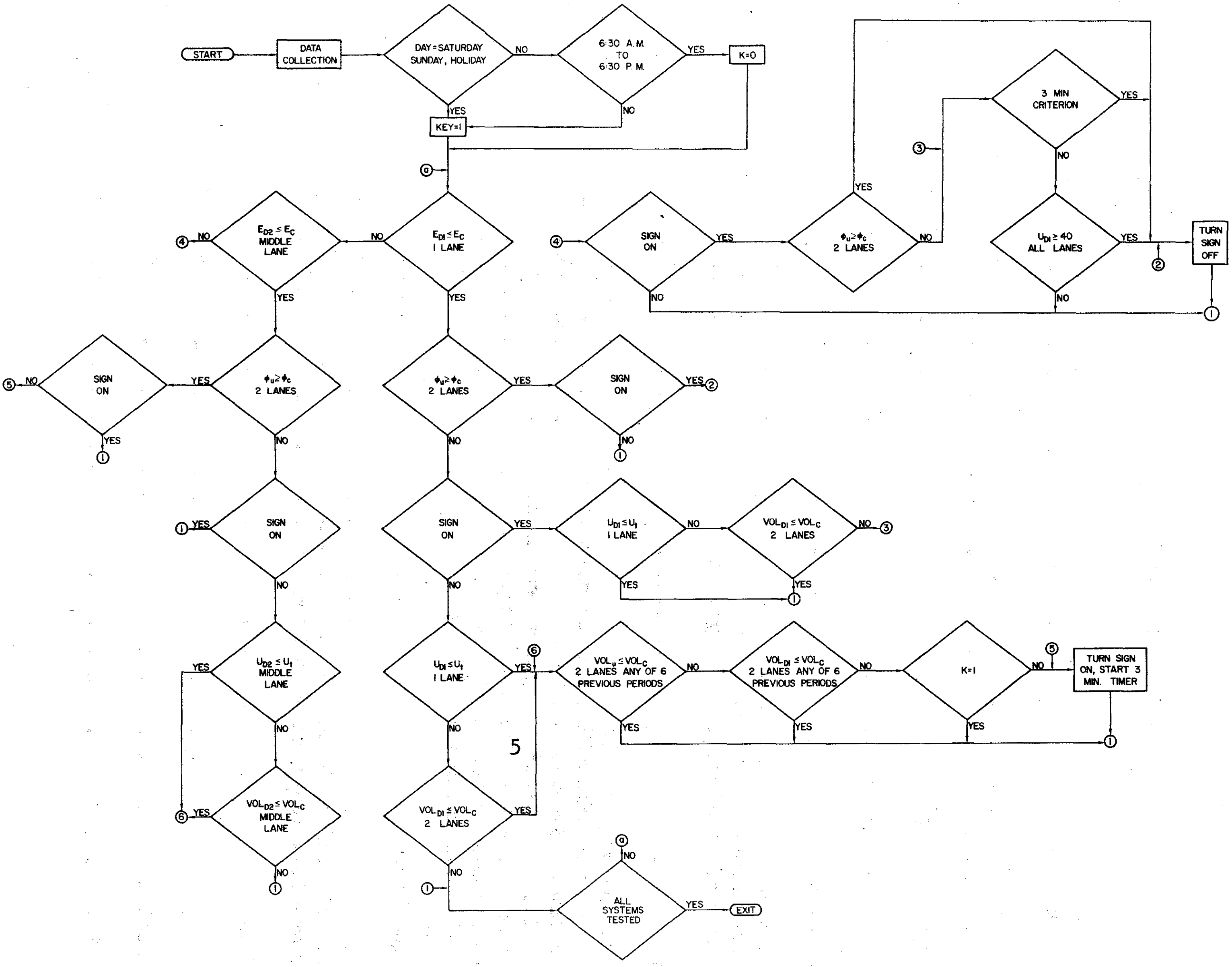

Figure S-1 - Safety Warning System Control Logic Using Energy (downstream) and Lane Occupancy (upstream)

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INTRODUCTION

General

A prototype safety warning system (Figures 1 and 2) has been installed on the Gulf Freeway to alert the freeway motorists of stoppage waves propagating downstream of overpasses (1). An earlier project report (2) described the development of a technique using traffic energy for digital computer control of the system. The system has been under computer control since April 3, 1972, and has been operating quite satisfactorily. The energy variable is a function of speed and volume and represents one method of detecting stoppage waves for operational control of the warning system. This report is an evaluation of occupancy as an alternate control variable. This latter variable can be measured by single loop detection per lane. As a result of previous research, lane occupancy is viewed as a traffic variable that may satisfactorily describe the range of operating conditions on a section of roadway and may have some practical advantages in representing the degree of concentration within a moving traffic stream. The required number of detectors, for example, could be reduced if a control technique using occupancy could be developed for the warning system.

Objectives

The objectives of this research are aimed at determining whether lane occupancy could be satisfactorily used for the control of the safety warning system. Specifically, the objectives are to:

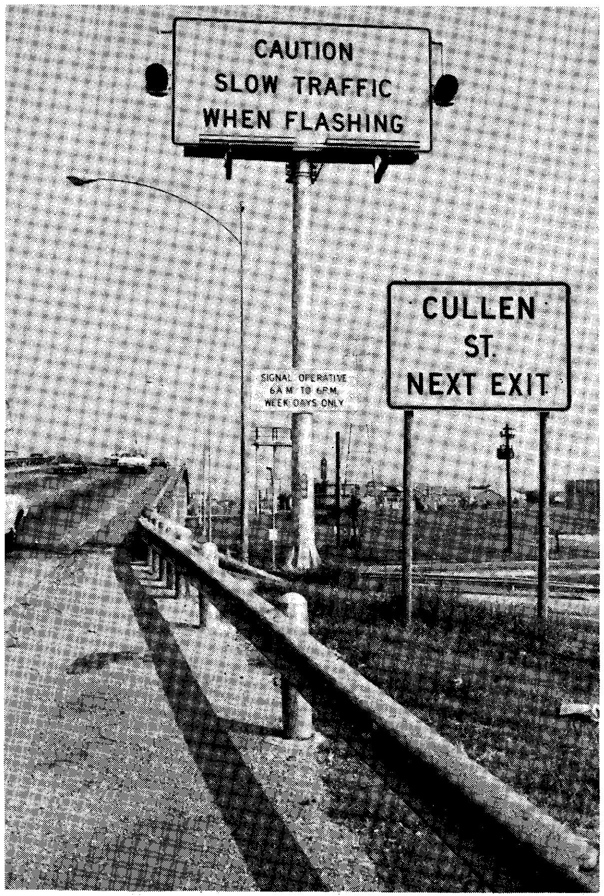

Figure 1 - Warning Sign with Flashers

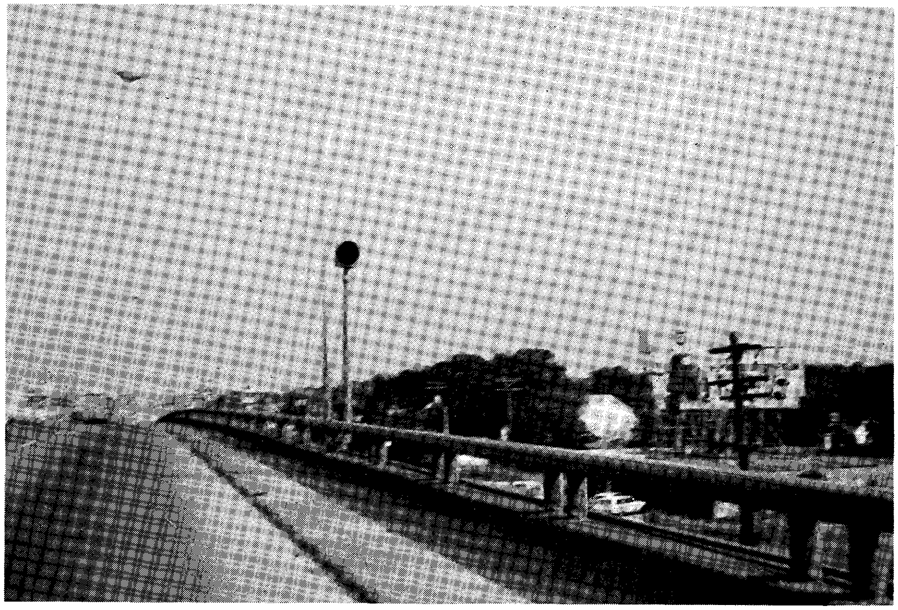

Figure 2 - Flasher Unit at Crest of Overpass

1. Determine the performance characteristics of measured lane occupancy as an indicator of shock waves resulting from freeway incidents.
2. Develop a control strategy, using occupancy parameters, that meet the control requirements of an on-freeway safety warning device.

THEORY OF OCCUPANCY

The Occupancy Variable

Lane occupancy is defined as the ratio of time that vehicles are present at a detector to the total time of sampling. For example, if during a one-minute sampling period, vehicles had occupied a detector for 20 seconds, the occupancy by definition would be 20/60 = 0.333 or, expressed as a percentage, 33.3 percent.

As shown in Figure 3, the occupancy relationship can be further developed by considering a number of vehicles, N, passing a detector in a given sampling period, T, with the speed of the i^{th} vehicle being S_i and the effective length of detection of the vehicle being L. Thus, the time, t_i, that the i^{th} vehicle is in the detection zone is L/S_i. The total time for N vehicles being in the detection zone is:

$$\sum_{i=1}^{N} t_i = \sum_{i=1}^{N} \frac{L}{S_i} = L \sum_{i=1}^{N} \frac{1}{S_i} \tag{1}$$

since it is being assumed that all vehicles have the same length. Thus, by definition, occupancy (ϕ) is:

$$\phi = \sum_{i=1}^{N} \frac{t_i}{T} = \frac{L}{T} \sum_{i=1}^{N} \frac{1}{S_i} \tag{2}$$

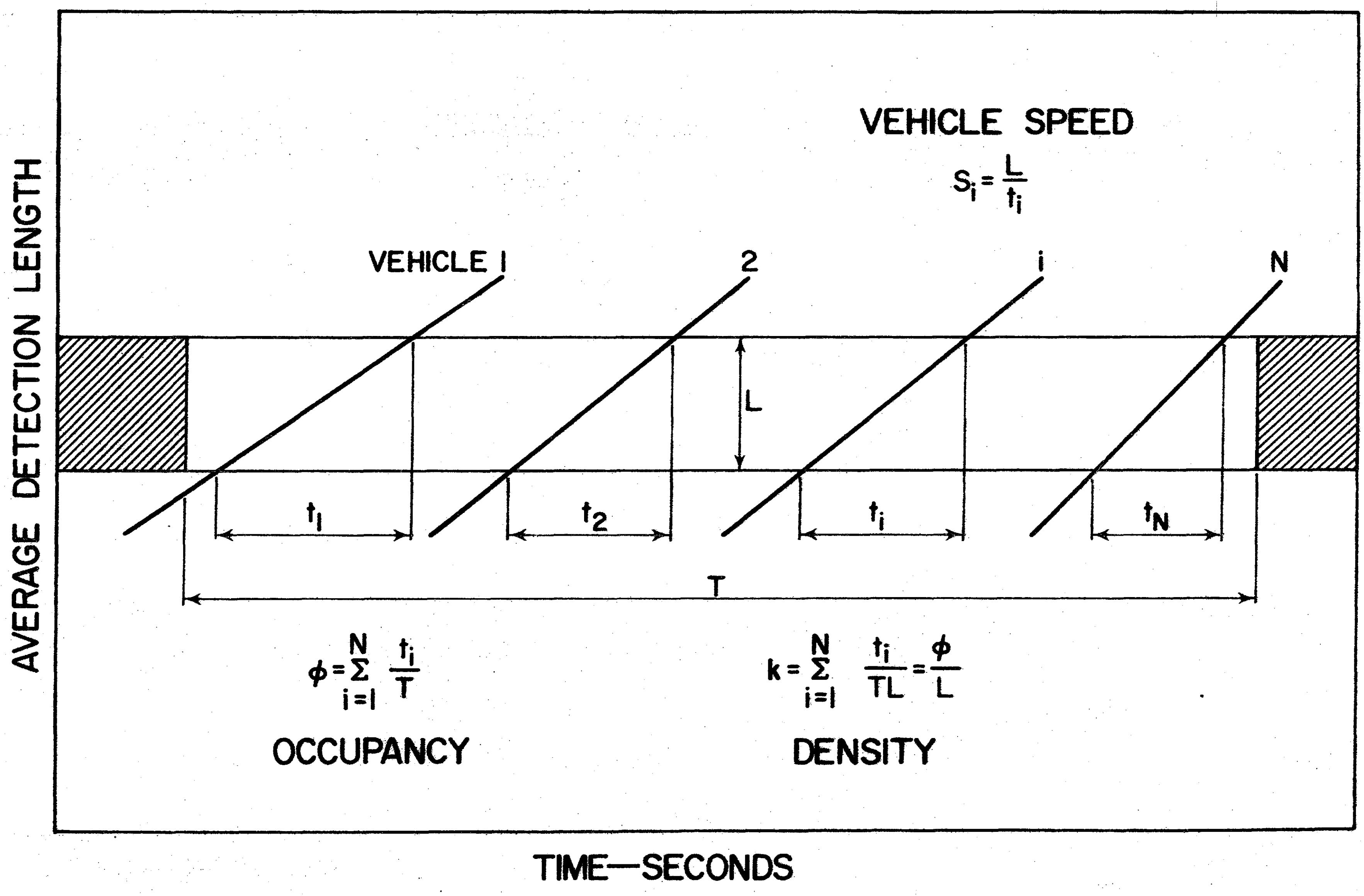

Figure 3 - Definitions of Occupancy and Density Measured by a Detector

Multiplying and dividing this equation by N to define it in terms of space mean speed and volume results in:

$$\phi = L \left[\frac{\sum_{i=1}^{N} \frac{1}{S_i}}{N} \right] \left[\frac{N}{T} \right] \tag{3}$$

where the first term, in brackets, is the inverse of space mean speed, 1/u, and N/T is volume, q. Therefore, substitution of these identities into Eq. 3 results in:

$$\phi = L \frac{q}{u} = Lk \tag{4}$$

since the quantity q/u represents density, k. Letting 1/L be a constant, C, we find the occupancy-density relationship:

$$k = \frac{1}{L} \phi = C \phi$$

If occupancy is expressed as a percentage and an average vehicle length is assumed, a value for C could be obtained. Athol (3), assuming an average vehicle length of 17.6 feet and converting to units of miles, arrived at a value of 3.0 for C.

$$C = \frac{5280 \text{ ft./mi.}}{(17.6 \text{ ft./veh.})(100\%)} = 3.0 \text{ veh./mi./\% occupancy} \tag{6}$$

Paesani (4) later developed this relationship with the additional consideration of the greater road requirement of trucks in the traffic stream that would require a greater average vehicle length.

Assuming a linear relationship between speed and density, a generalized equation for speed and occupancy can be written as:

$$u = Cu_f \quad (1 - \frac{\phi}{\phi_j}) \tag{7}$$

where ϕ_j represents occupancy during jammed traffic conditions.

The generalized occupancy-volume relationship can then be written as:

$$q = C\phi u_f \quad (1 - \frac{\phi}{\phi_j}) \tag{8}$$

since $q = ku = C\phi u$.

Differentiation of Eq. 8 with respect to ϕ and equating to zero results in the identity for critical occupancy - the occupancy at maximum flow, ϕ:

$$\phi_c = \frac{\phi_j}{2} \tag{9}$$

Examination of a generalized occupancy-volume curve shown in Figure 4 reveals that the parameter critical occupancy, ϕ_c, identifies a level of occupancy at capacity flow (q_c). Forced flow conditions, where traffic operation is typically stop-and-go, is indicated by lane occupancies above critical occupancy. Flows would be below capacity and the formation of vehicle queues would progress in the upstream direction. This effect, as previously described, is identified by a

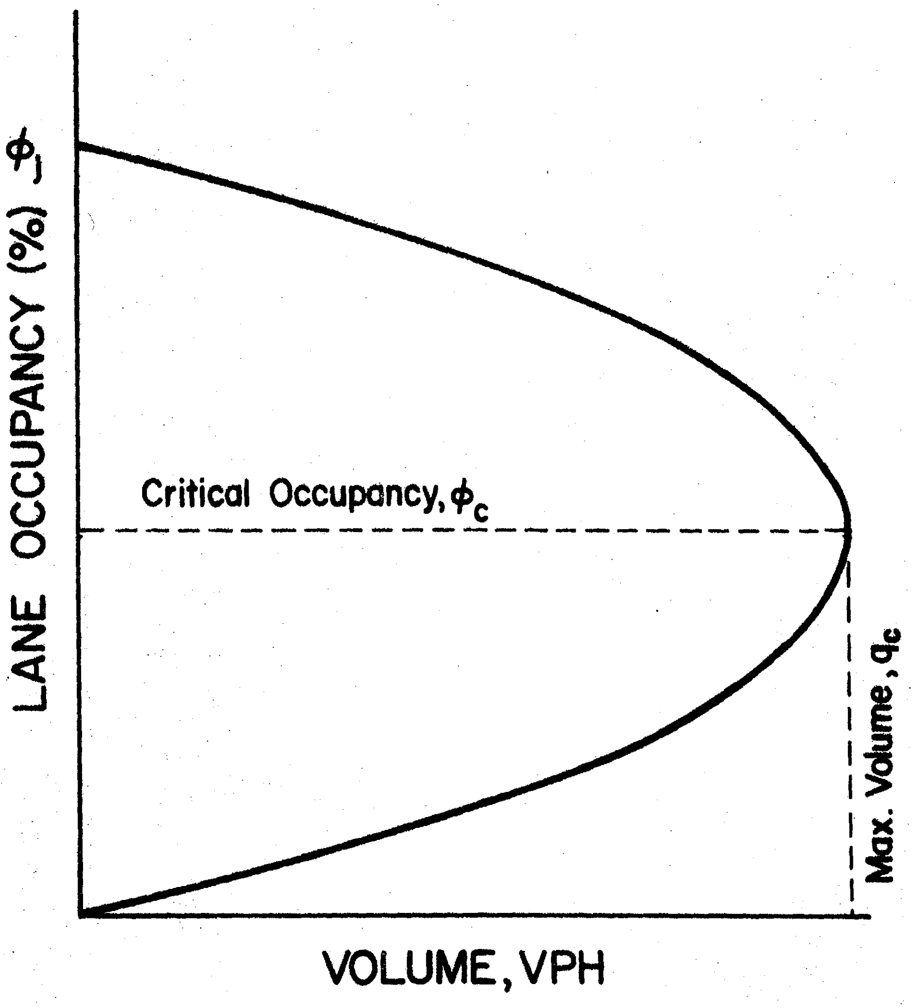

Figure 4 - Generalized Occupancy-Volume Relationship

traffic discontinuity termed a shock wave. Based on this theory and previous discussions, it would appear initially that shock waves could be detected by measured occupancy exceeding the critical occupancy at capacity flow (ϕ_c).

STUDY PROCEDURES

Equipment

Double-loop detectors are positioned on each lane of the inbound Gulf Freeway both upstream and downstream of three overpasses selected as the sites for the prototype safety warning devices. Information from these detectors is transmitted to an IBM 1800 digital computer located in the surveillance and control center. The information is then processed to compute traffic variables that can be used for control and then be stored on disk, printed, or punched on cards. The location of the three subsystems and their associated detectors are illustrated in Figures 5 and 6.

Data Collection and Reduction

Occupancy values can be computed for each of the three inbound lanes and can be analyzed separately or averaged together to form a composite value as desired. When an incident was observed on the study section, the computer stored the incoming data from the subsystem detectors on remote disk units for later analysis and processing. Simultaneously, a video tape recording system was activated which provided a visual record of traffic conditions during the incident. This provided the capability for later evaluation of traffic flow that could not be easily accomplished as it occurred.

Video tape recordings of incidents were examined and specific information on the origin of freeway shock waves and the time shock waves were observed to cross individual detectors were noted. The

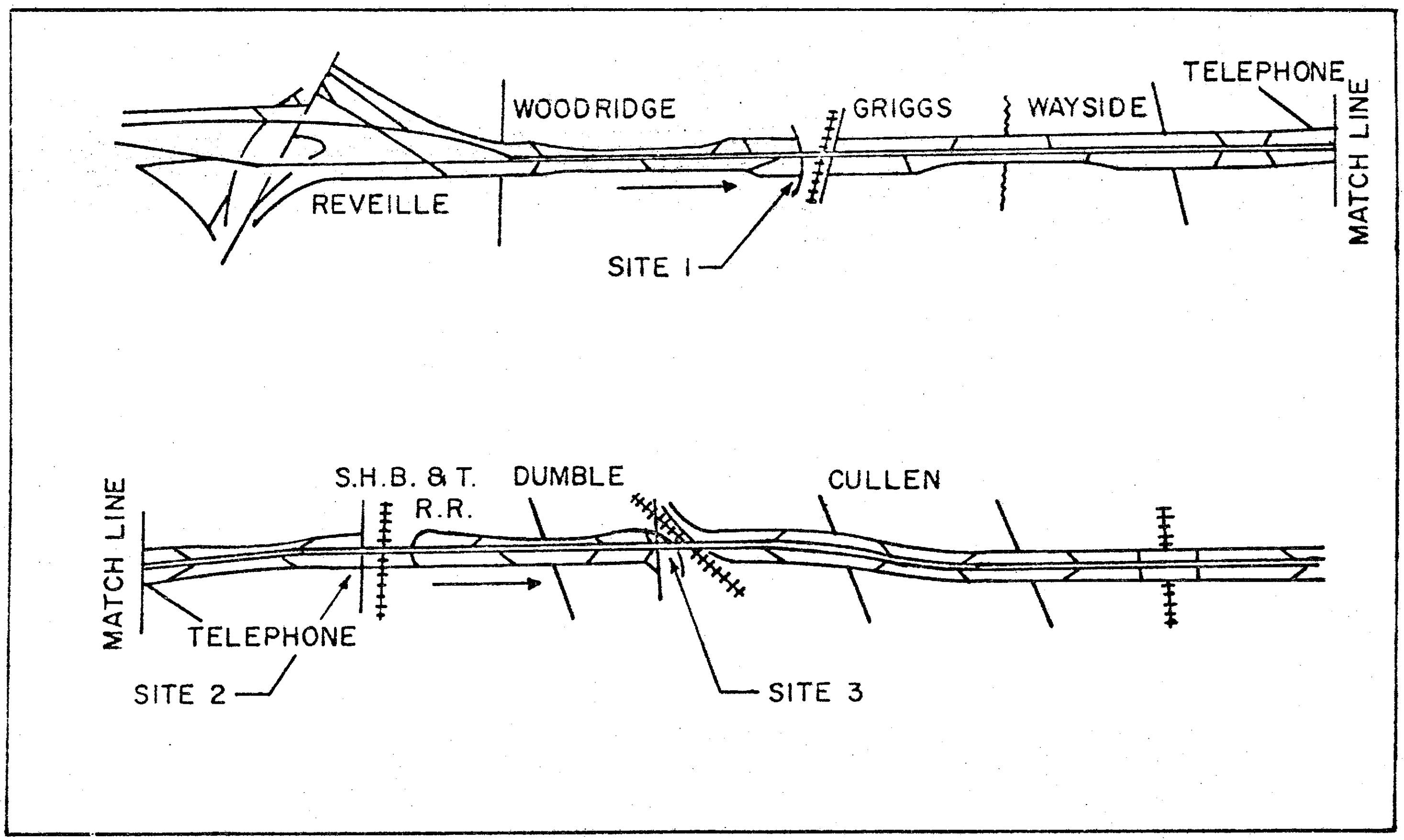

Figure 5

Installation Sites for the Warning Devices

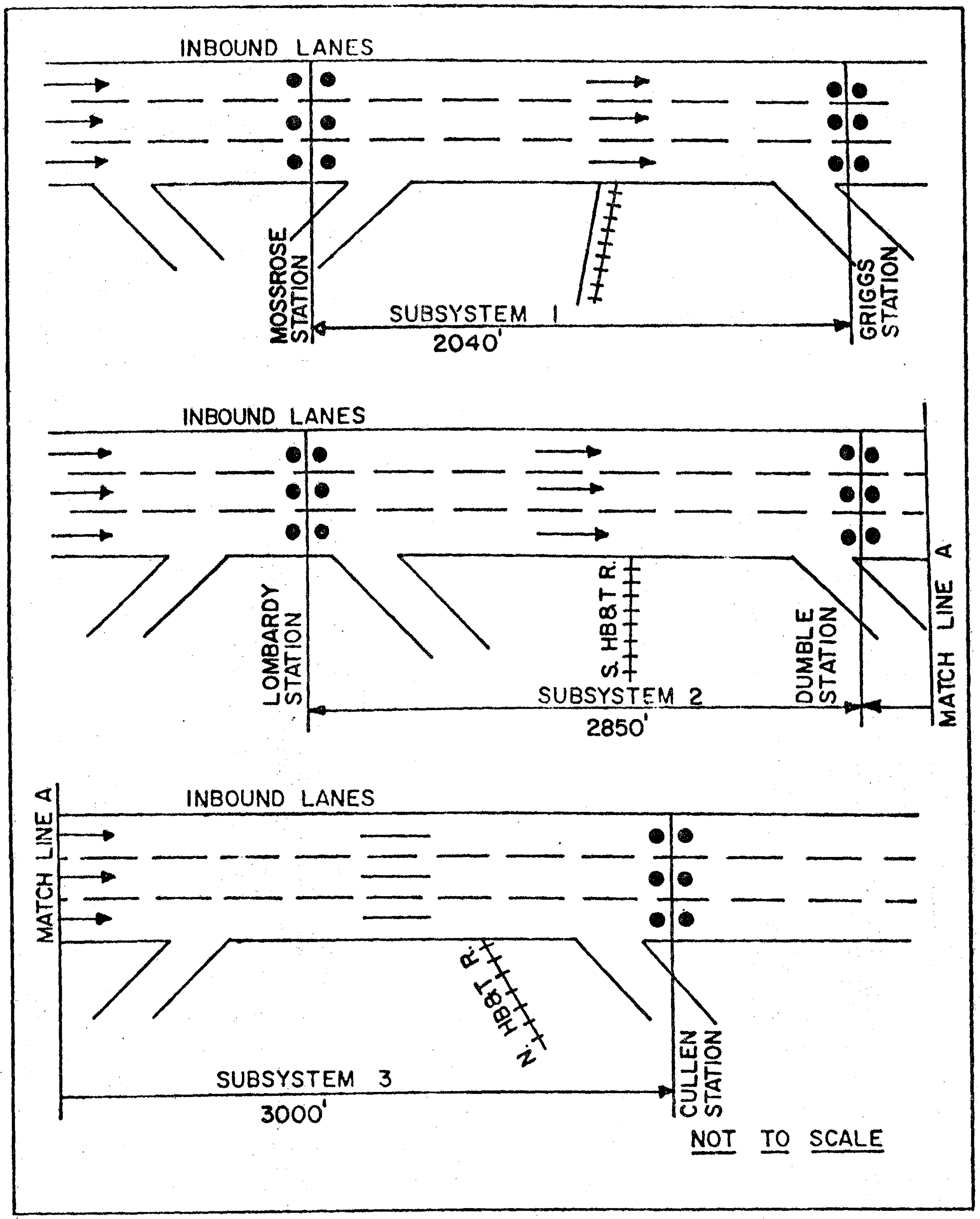

Figure 6 - Schematic of the Study Subsystems

origins of shock waves were categorized according to the following notation:

1. Case I - Downstream of subsystem
2. Case II - Within subsystem (between upstream and downstream detectors)
3. Case III - Upstream of subsystem

The quantitative computer data were examined and the traffic flow condition (light, moderate, or heavy, based on speeds and flow rates) prior to the shock wave passage was noted. The computer data and the video tape recording were synchronized in time, thus providing the capability to compare the two types of data.

Although the data acquisition equipment was on a standby basis during regular hours of operation, manpower and system requirements did not make it possible or practical to collect data for every incident that occurred. Also, the initial effects of an incident were sometimes not observed. Consequently, the data necessary for analysis were collected over a period of several months.

Determination of Critical Occupancy

A deterministic relationship between volume (or flow rate) and lane occupancy was given in Eq. 8. Expansion of Eq. 8 and combining constant terms results in the following relationship of volume as a function of occupancy:

$$q = A\phi - B\phi^2 \tag{10}$$

where A and B are coefficients.

Multiple regression analysis was the technique used to estimate these coefficients. Once the relationship for each lane of each subsystem was established, the individual critical lane occupancies were found by solution of the first derivative of Eq. 10 with respect to ϕ set equal to zero:

$$\frac{dq}{d\phi} = 0 = A - 2B\phi_c \tag{11}$$

or

$$\phi_c = \frac{A}{2B} \tag{12}$$

This permitted the estimation of critical lane occupancy values, or occupancy at capacity, which is the initial estimate of occupancy for detection of shock waves.

RESULTS

Critical Occupancy Concept

Determination of Critical Occupancy - Table 1 presents a summary of the regression analysis performed on lane occupancy-volume data to estimate the relationship between these two variables. Tests of significance were performed on the regression coefficients using the Student's t test and proved significant at the 0.01 level in all cases. The correlation coefficient, R, for each regression is a measure of the fit of the observed data to the regression relationship. These values are all above 0.950 thus indicating a good correlation.

The values of critical occupancy were computed from the results of the regressions by taking the first derivative of relationship with respect to occupancy and setting equal to zero (Eqs. 9, 12). These values and corresponding maximum hourly flow rates are presented in Table 2. Figure 7 illustrates the occupancy-volume relationship for one of the regressions with the relevant parameters identified.

Detection of Shock Waves - The ability of critical occupancy to reliably detect a freeway shock wave crossing a detector location was evaluated by comparing the clock time when the occupancy value exceeded the critical occupancy value, as determined by the computer, against the time the shock wave was actually observed to cross the detector location as recorded on video tape. These differences were calculated as seconds of advance warning. The results are presented in Figure 8 and Table A-1 of the Appendix. A positive advance warning indicates

Table 1

SUMMARY OF OCCUPANCY-VOLUME REGRESSIONS

	A	t	Sign.	B	t	Sign.	R
Mossrose							
Inside	167.10	52.54	**	3.223	28.48	**	.98343
Middle	170.56	52.63	**	3.795	27.78	**	.98861
Outside	146.94	56.60	**	3.098	24.77	**	.96827
Griggs							
Inside	212.68	38.78	**	5.290	21.69	**	.97391
Middle	170.84	57.91	**	3.770	28.14	**	.98987
Outside	189.56	41.85	**	6.149	16.30	**	.98666
Lombardy							
Inside	135.06	45.69	**	2.276	29.29	**	.98243
Middle	187.09	44.88	**	4.609	27.08	**	.98740
Outside	128.74	36.58	**	2.124	18.66	**	.98842
Dumble							
Inside	138.68	32.68	**	2.486	19.81	**	.96018
Middle	167.88	45.07	**	3.893	28.46	**	.98177
Outside	137.58	50.38	**	2.971	24.15	**	.98350
Cullen							
Inside	144.15	39.13	**	2.636	27.11	**	.97517
Middle	133.04	36.22	**	2.455	24.17	**	.96971
Outside	92.54	33.05	**	1.291	21.35	**	.95571

**Significant at the 0.01 level (t = 2.74, d.f. = 141)

Table 2

COMPUTED PARAMETERS

Location	Critical Occupancy (%)	Maximum Flow (VPH)
<u>Mossrose</u>		
Inside	26	1927
Middle	23	1916
Outside	24	1742
<u>Griggs</u>		
Inside	20	2138
Middle	23	1936
Outside	15	1461
<u>Lombardy</u>		
Inside	30	2004
Middle	20	1899
Outside	30	1951
<u>Dumble</u>		
Inside	28	1934
Middle	22	1816
Outside	23	1599
<u>Cullen</u>		
Inside	27	1965
Middle	27	1803
Outside	36	1692

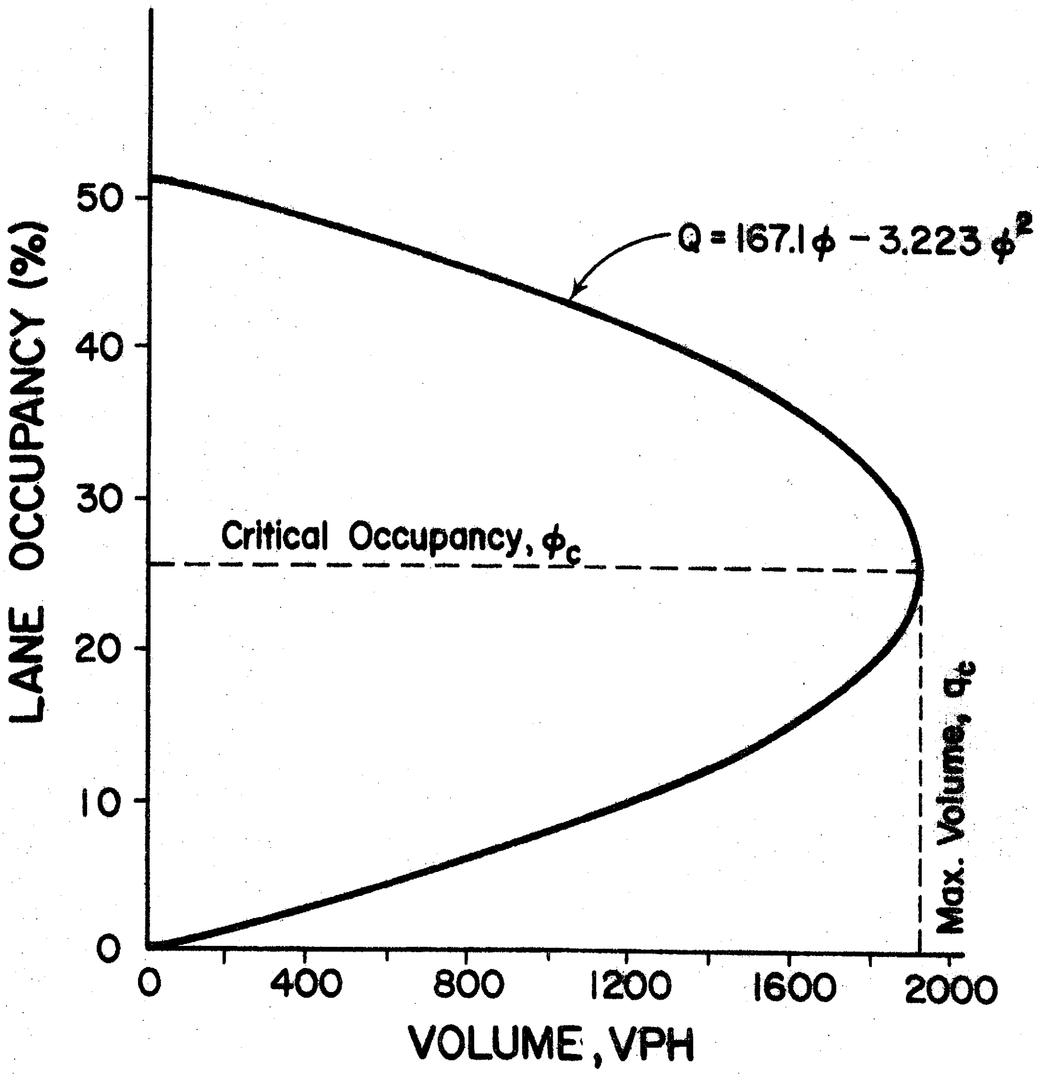

Figure 7 - Occupancy-Volume Relationship for Mossrose Inside Lane

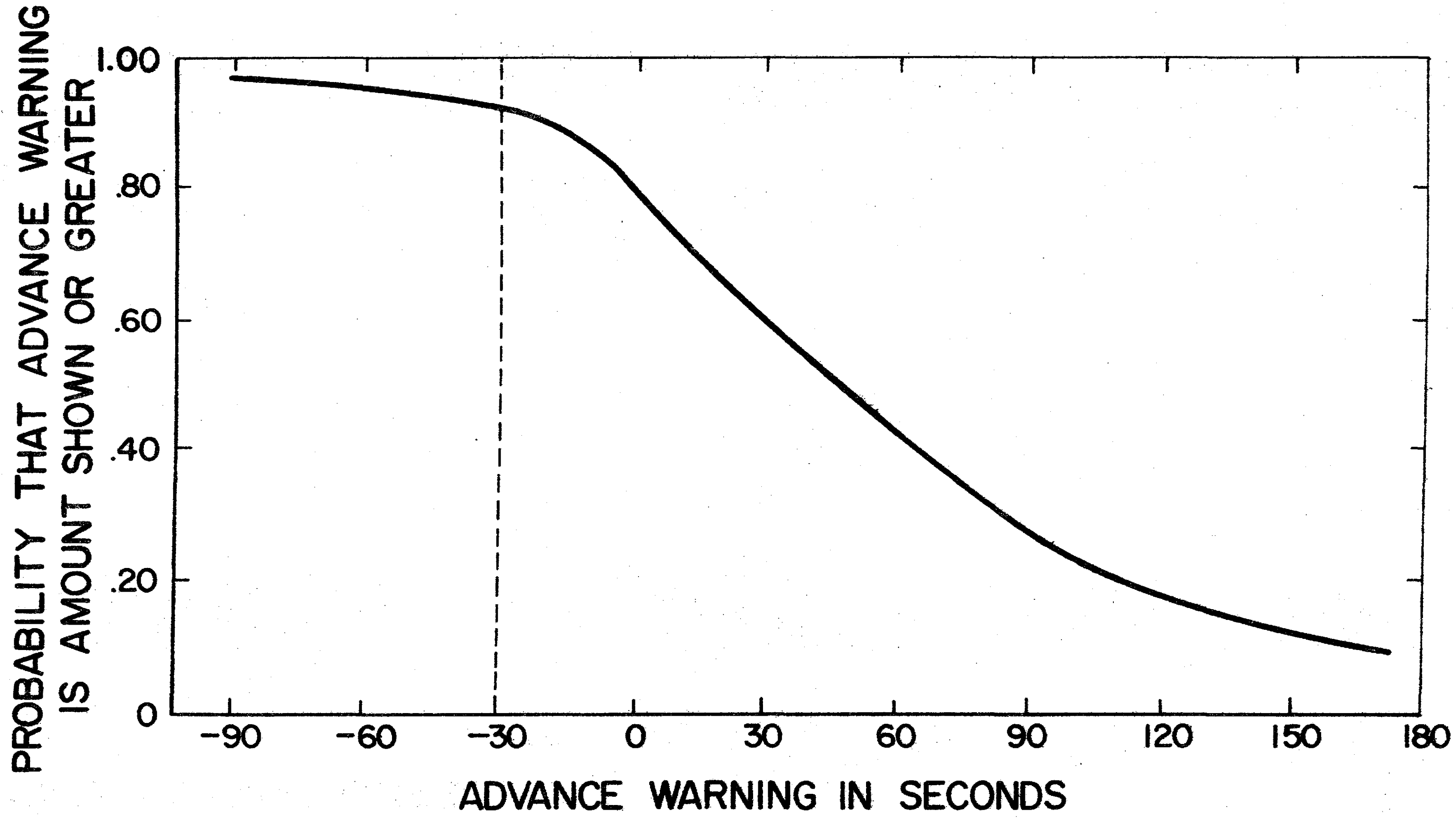

Figure 8 - Performance Curve - Individual Lanes

critical occupancy was exceeded before the shock wave was observed to pass. Conversely, a negative value indicates the shock wave was observed to cross before the occupancy parameter so registered.

Negative advance warnings constitute Type I errors, or late response to the presence of a shock wave. However, due to 30-second data updates by the computer, it is possible for a shock wave to cross the detectors as much as 30 seconds before critical occupancy is exceeded. Therefore, late responses as high as 30 seconds (-30 seconds advance warning) could occur. Inspection of Table A-1 reveals that there were 12 instances where the advance warning was less than -30 seconds or where critical occupancy was never exceeded although a shock wave was observed. This represents an aggregate Type I error of 6.7 percent for the 179 cases studied. However, 50 percent of the observed Type I errors occurred at the Cullen outside lane detection station.

Type II errors exist when critical occupancy is exceeded although no shock wave is present. In other words, non-critical conditions are characterized by measured occupancy exceeding critical occupancy thereby giving a false indication of a shock wave. This type of error was found to occur only when freeway conditions were at or near heavy flow.

Type I errors, late warnings, were generally observed to occur when freeway operating conditions were good (light to moderate flow). In such a case, an incident creating a shock wave may result in an abrupt increase in measured occupancy. However, the magnitude of the measurements may not reflect a passing shock wave if critical occupancy is not exceeded. Type II errors, false indications, were generally observed to occur in moderate to heavy flow conditions where a surge in flow caused an increase in occupancy that just exceeded ϕ_c for a moment.

Thus, it may be deduced that a lane location with several Type II errors is an indication that the value of critical occupancy is too low to detect accurately and reliably the passage of freeway shock waves. Likewise, a location with several Type I errors is an indication that the value of critical occupancy is too high. The problem, therefore, is to have a critical occupancy value for a location that minimizes both the Type I and Type II errors.

Sensitivity of Occupancy Measurements - Recognizing that there existed numerous Type I and Type II errors at several locations using the critical occupancy values, a sensitivity analysis of occupancy measurements was conducted. Figure 9 presents a probability plot of observed Type I and Type II errors for the Mossrose outside lane detection location. This figure illustrates that a range of occupancy values (23 to 26 percent) had no observed errors of either type. The critical occupancy value of 24 percent was included in this range although it appears that occupancy values of 23, 25, and 26 percent would also be suitable as the detection parameter. Figure 10 illustrates a similar plot for the Griggs inside lane location. Here critical occupancy was observed to have a large Type II error. Examination of

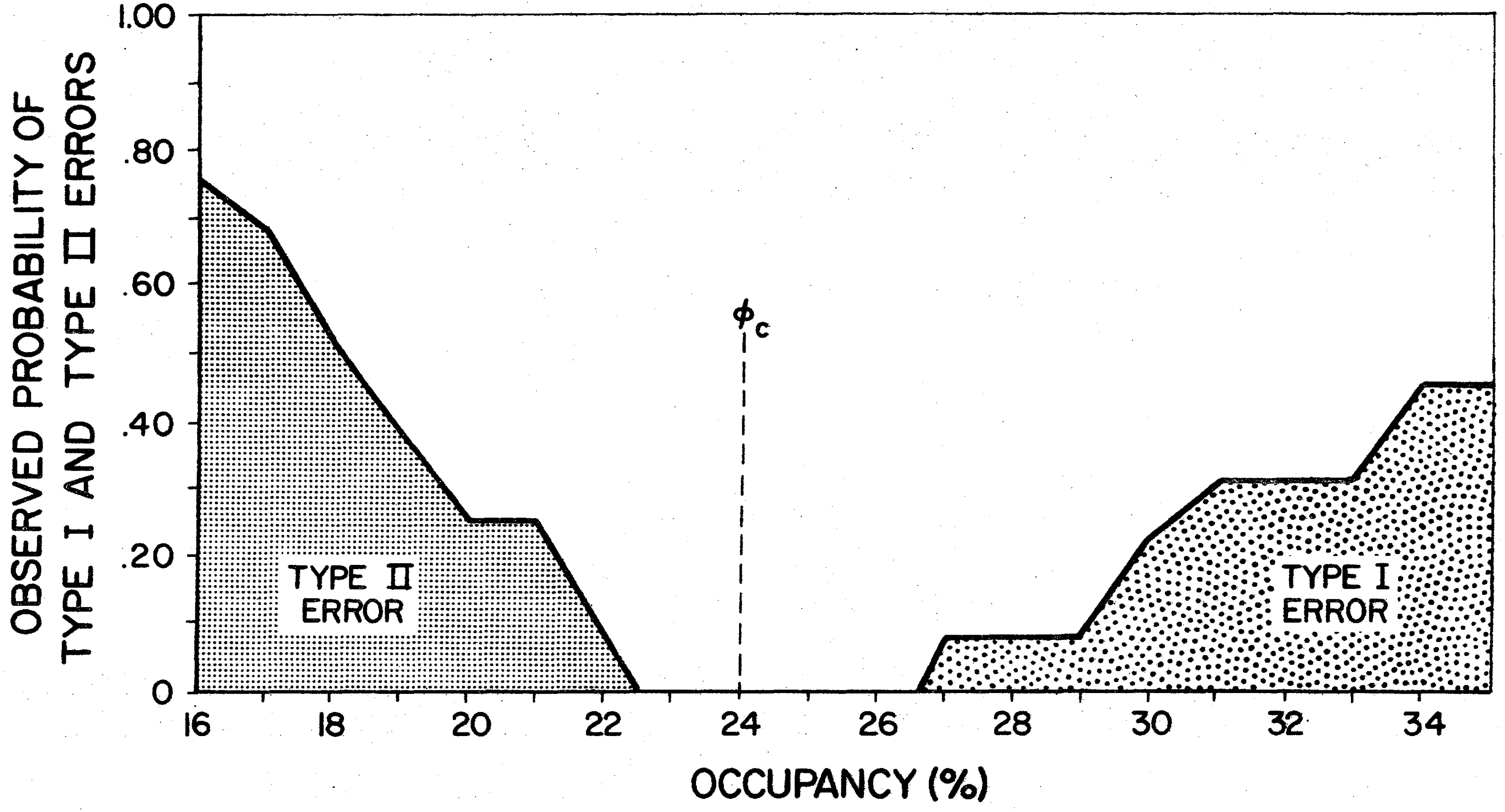

Figure 9 - Distribution of Observed Type I and Type II Errors as a Function of Measured Lane Occupancy - Mossrose, Outside Lane

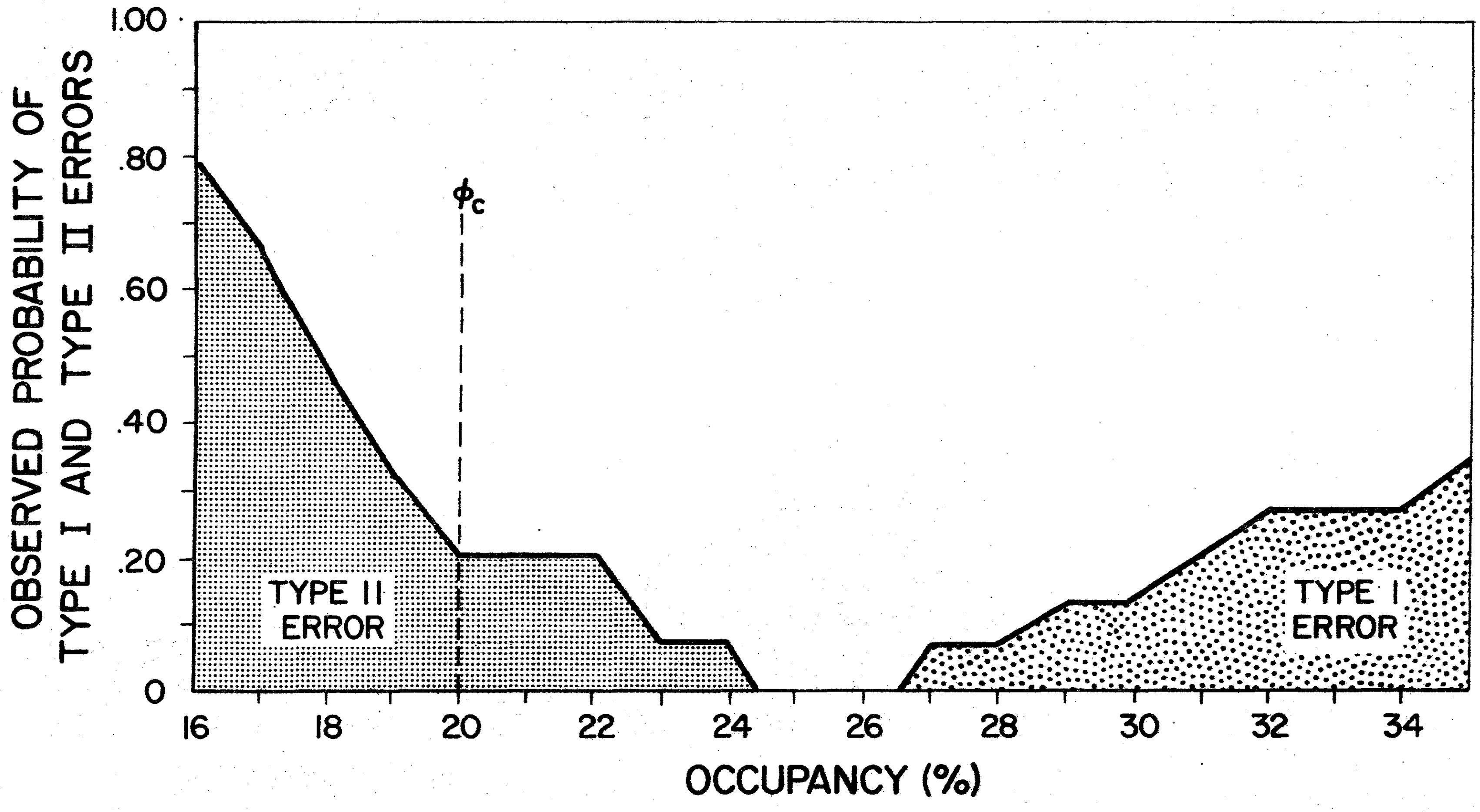

Figure 10 - Distribution of Observed Type I and Type II Errors as a Function of Measured Lane Occupancy - Griggs, Inside Lane

this figure reveals that occupancy values of 25 and 26 percent had no observed error. It would then be logical to consider an adjustment to the critical occupancy value at this location in order to minimize the error.

Adjustment to Critical Occupancy - An adjustment to the critical occupancy was considered for each lane at each location based on minimizing the observed errors. Table 3 presents the results of the adjustments compared to the previously computed values of critical occupancy. It is important to note that four of the five freeway locations did not require adjustment because ϕ_c was within the range of values having minimum errors. Occupancy values were adjusted upward at six detector locations and downward at five locations. The effect of an increase in a critical occupancy parameter was to lower the average advance warning at the location. Likewise, the effect of a decrease in a critical occupancy parameter was to raise the average advance warning time.

One-Lane Detection Criterion - Since detectors are located in each lane at each detection station, any one lane can provide the indication of a shock wave at that station. The ability of the adjusted occupancy parameters to detect shock waves was examined using such a one-lane detection criterion. Figure 11 and Table A-2 present the resulting advance warnings for each observation of a shock wave. These advance warnings constitute the difference between the time a shock wave was first observed to cross the detectors in any one of the three lanes and the time critical occupancy first registered the presence of a

Table 3

COMPARISON OF COMPUTED CRITICAL OCCUPANCY AND ADJUSTED CRITICAL OCCUPANCY VALUES

Location	Computed Critical Occupancy (%)	Adjusted* Critical Occupancy (%)
Mossrose		
Inside	26	26
Middle	23	24
Outside	24	24
Griggs		
Inside	20	25
Middle	23	24
Outside	15	16
Lombardy		
Inside	30	26
Middle	20	24
Outside	30	28
Dumble		
Inside	28	25
Middle	22	24
Outside	23	23
Cullen		
Inside	27	27
Middle	27	26
Outside	36	23

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*Based on minimum observed Type I and Type II errors

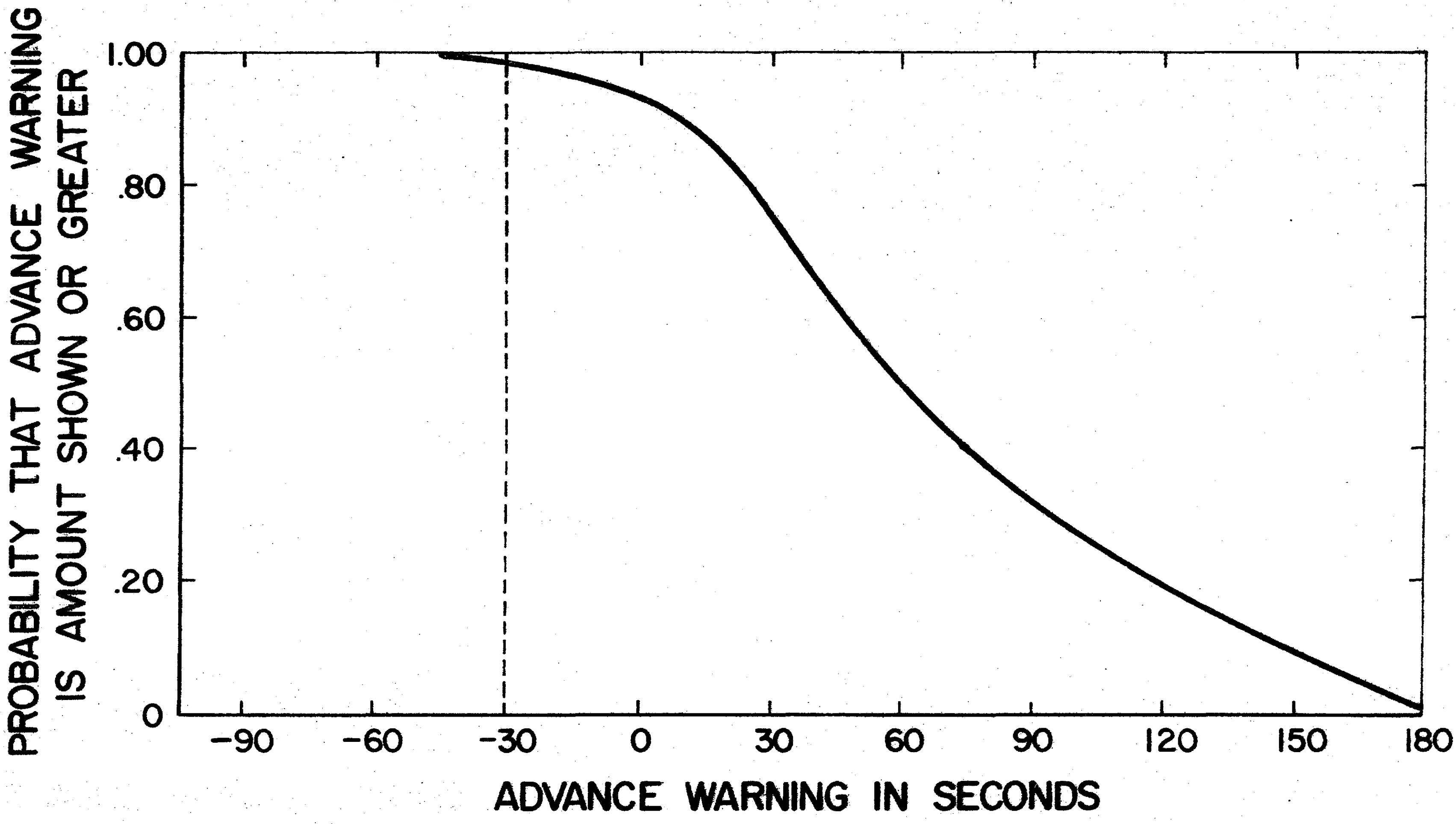

Figure 11 - Performance Curve of One-Lane Detection Criterion
(Critical Occupancy Concept)

shock wave in any one of the three lanes. Again, positive advance warnings indicate a shock wave was registered before it was actually observed to cross the detectors and negative values indicate late warnings. However, warnings as late as -30 seconds are allowable due to the data update time. The results show that there was only one observed case where the advance warning was less than the -30 second allowable and represents an aggregate Type I error of 1.4 percent for the 70 observations. No Type II errors were observed under the one-lane detection criterion.

Two-Lane Detection Criterion - A two-lane detection criterion was considered as a fallback system in case of a detector failure on one of the lanes (2). The two-lane criterion would require that any two of the three lanes register the presence of a shock wave before detection is assumed. The performance of critical occupancy to detect a shock wave under the two-lane criterion was compared to the performance for a one-lane criterion and is illustrated in Figure 12. It can be seen that the probability of a Type I error (advance warning less than -30 seconds) is less than two percent for the one-lane criterion whereas the observed probability of this error for a two-lane criterion is approximately 10 percent.

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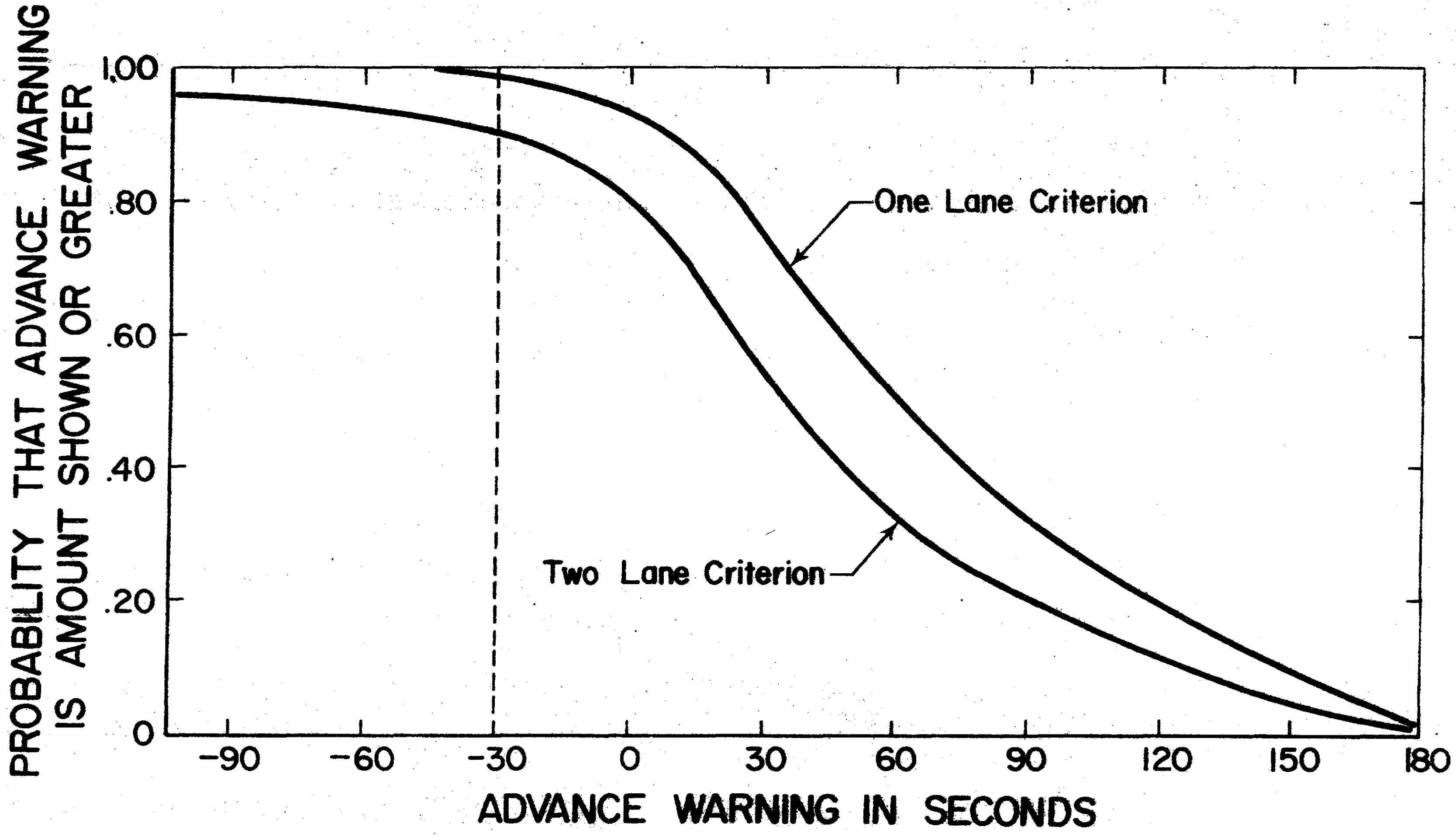

Figure 12 - Performance Curves of One-Lane and Two-Lane Detection Criteria (Critical Occupancy Concept)

CONTROL TECHNIQUE

General

Dudek (2) developed digital computer logic for control of the safety warning system using critical energy as a control parameter. The logic presented in Figure 13 follows the same pattern of control but incorporates critical occupancy as the control parameter. Minor modifications to the control logic have been made since some portions of the energy program that require certain checks to verify the conditions on the freeway are not necessary using the lane occupancy control parameter.

The control logic shown in Figure 13 is structured to operate during levels of service B, C, D, and E. It is designed to recognize shock waves resulting from incidents that occur downstream of the subsystem detectors (Case I), between the subsystem detectors (Case II), and upstream of the subsystem detectors (Case III).

Evaluation of Control Technique

The logic flow chart was transformed into a computer program that operated in real time in response to occupancy measurements from the detectors. The program was run during various periods from 6:30 a.m. to 6:00 p.m. for several weeks.

Evaluation of the logic was accomplished subjectively by comparison of actual freeway conditions to the simulated operation of the three safety warning devices. This operation was indicated by a bank of three lights, each light representing a single safety warning device.

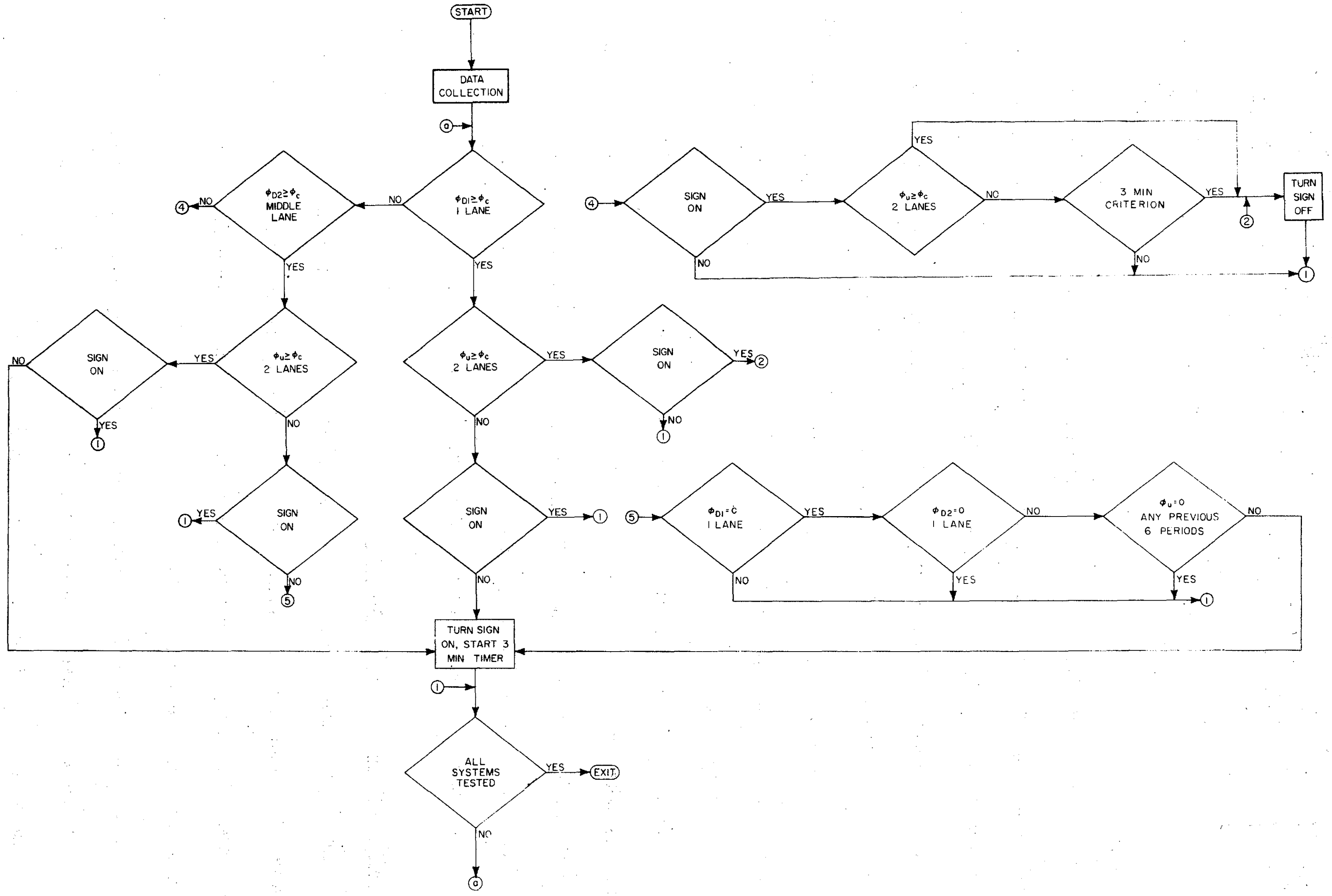

Figure 13 - Safety Warning System Control Logic Using Lane Occupancy

These were located in the television monitor room of the Gulf Freeway Surveillance Office. Activation or deactivation of the lights could be instantly compared to the freeway operation seen by the closed circuit television system. Computer data were also output as a record for both the simulated warning device operation and the freeway operation.

Study of this operation indicates that the control logic using the critical occupancy parameters provided a responsive and reliable system for the detector of freeway shock waves and thus, traffic congestion occurring at a downstream location. Although the critical occupancy concept and resulting logic cannot provide for the detection of Case II incidents, those few Case II incidents that were observed while the operation was simulated indicated that response would have been ineffective even if detected. This was due to the rapid upstream movement of the shock wave that crossed the upstream detectors or came into view of oncoming traffic in a very short time.

Occupancy vs. Energy Control Approach

An analysis was made to evaluate the performance of the occupancy concept for control in respect to energy. Performance curves for the occupancy approach and for energy, taken from reference 2, are presented in Figure 14. A comparison reveals that the energy approach appears to be less susceptible to Type I errors (late responses). However, it must be recognized that the approaches are compared based on separate data sets.

An additional 45 days of computer data were analyzed to establish operational characteristics for the same data set. One of the most

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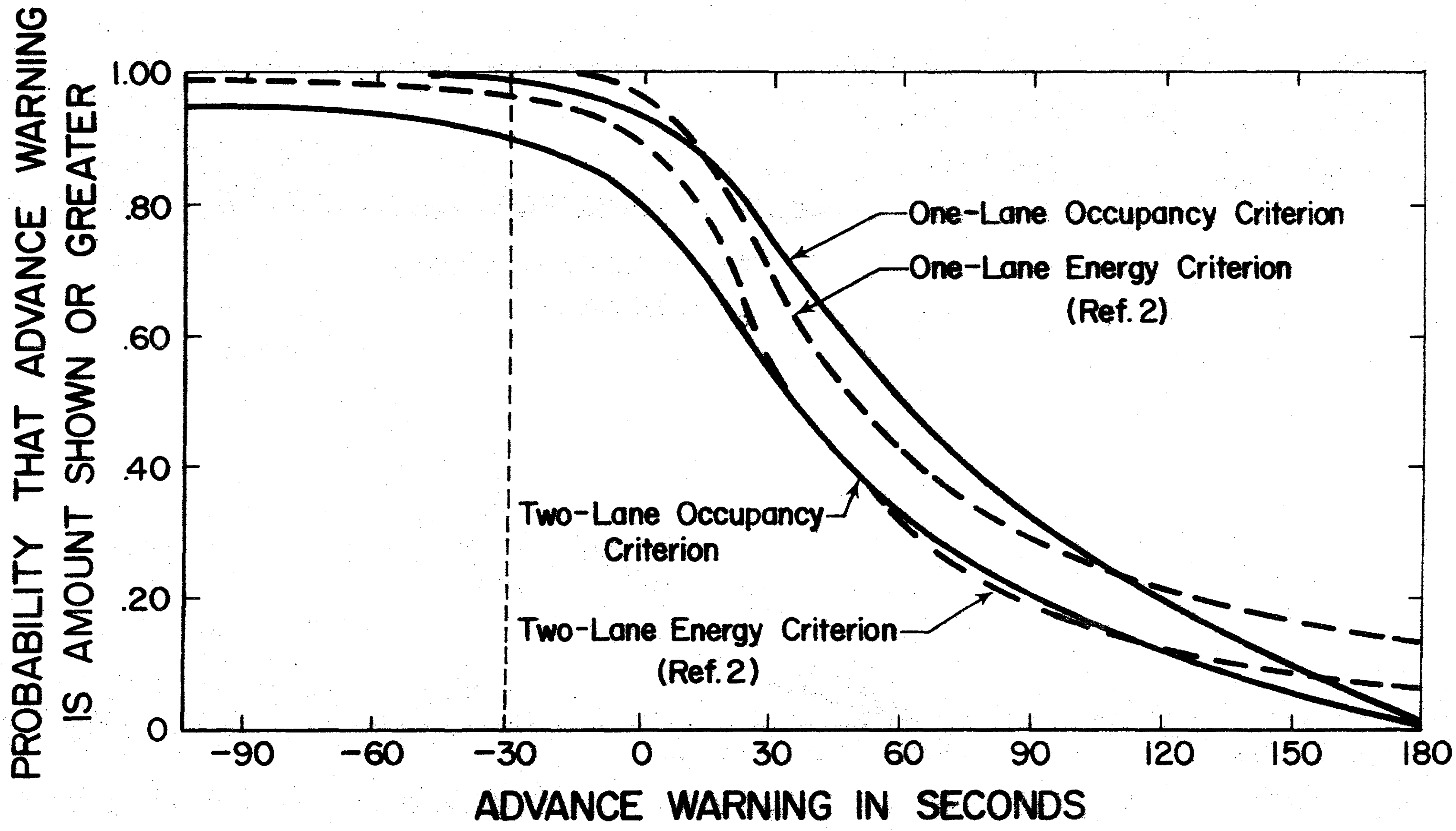

Figure 14 - Performance Curves of Occupancy and Energy Concepts

important considerations in the operation of the warning system relates to the response for the initial stoppage waves propagated as a result of an incident or bottleneck. The data were, therefore, analyzed to determine the relative response between the two approaches. During the 45-day period, a total of 127 initial waves were observed. A comparison of the relative response times are given in Figure 15.

The results show that, on the average, occupancy was slightly less responsive to shock waves in comparison to energy. The average difference was 6.5 seconds. Statistical analysis of the data revealed that the response difference was significant at the .05 level.

Although energy appears to provide an earlier (although slight) indication of shock waves, occupancy should not be regarded as ineffective. The results reported earlier support the fact that occupancy is responsive to waves and provides a high degree of reliability using a one-lane control criterion. The major advantage of occupancy, of course, is that it reduces the number of detectors required for the system.

The data collected during the 45-day study period were further evaluated to establish general trends or characteristics between the two variables for operation of the warning system. The following paragraphs summarize the results.

The occupancy program generally provides a more stable operation of the warning system when major incidents occur. After the initial shock wave, several other waves propagate upstream due to reduced capacity conditions resulting from incidents. Once congestion sets in

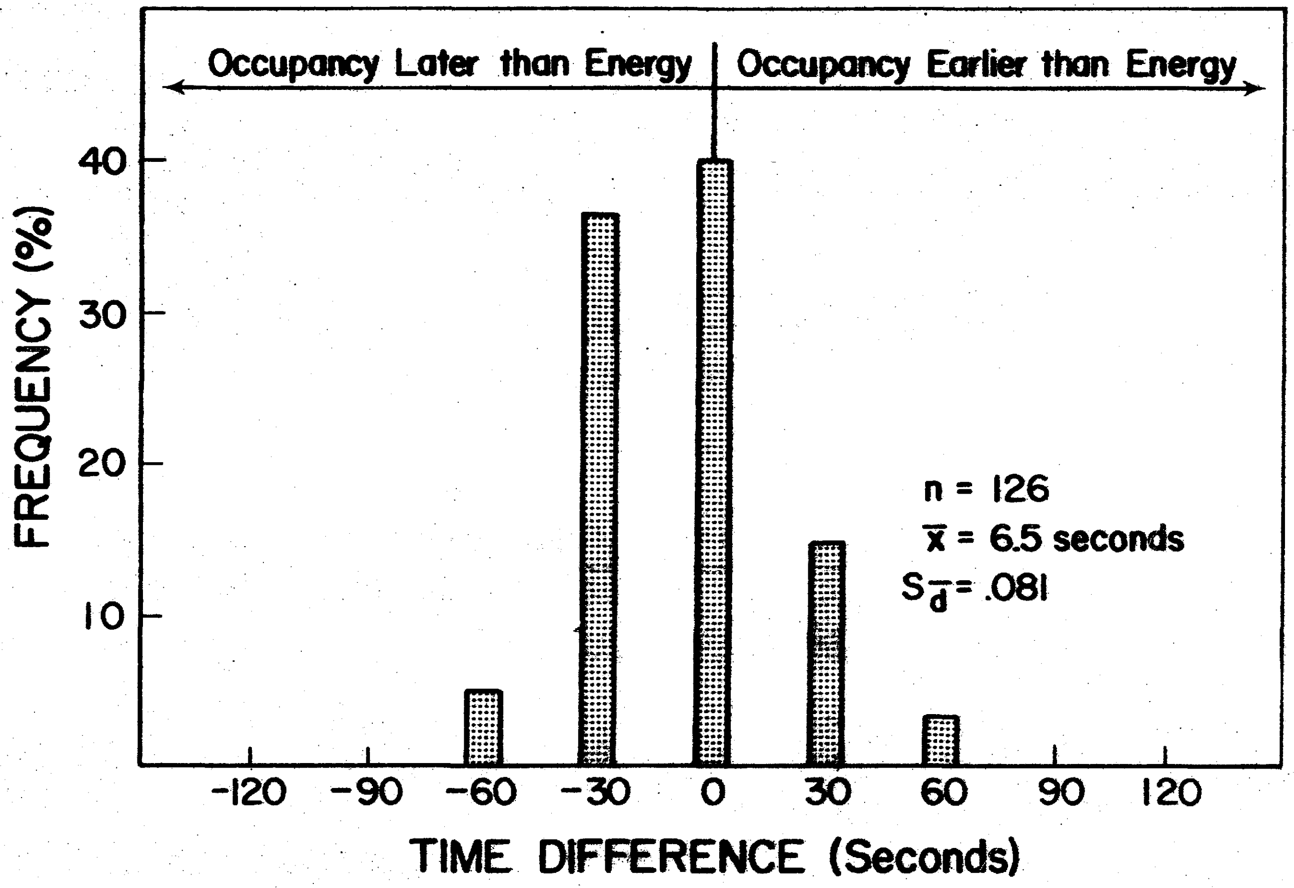

Figure 15 - Comparison of the Difference in Activation Times of Occupancy vs. Energy Control Parameters (One-Lane Control Criterion)

upstream of the warning device, the occupancy program generally reduces the frequency of on-off operations of the system due to secondary shock waves. This is due to the stability of the occupancy variable at the upstream detector station.

The energy program responds to slow moving vehicles such as trucks, funeral processions, etc., during the off-peak periods. The occupancy program as it currently is structured does not.

Although the occupancy parameters were selected based on minimizing the Type I and Type II errors, a high volume surge of traffic would occasionally cause the system to activate erroneously. One method of compensating for this problem is to increase the occupancy parameter value. However, this compensation also tended to increase the Type I error.

APPLICATION

The results presented in this report reveal that the occupancy criterion provides a favorable approach for control of the safety warning system. One disadvantage of using the occupancy variable is the lack of response to slow moving vehicles during the off-peak periods.

It seems desirable to select the good features of both the occupancy and energy control strategies and to combine them into one program. It is evident from the results that the energy variable is more desirable for measurement downstream of the crest, whereas, the occupancy variable performs more favorably at the upstream detector station. Thus, double-loop detectors would be recommended for the downstream station and single-loops upstream. The control logic incorporating this concept has been structured and is presented in Figure 16. Although the program has not been used in practice, a careful evaluation of its operation indicates that it will function satisfactorily. The following listing identifies the parameters presented in Figure 16:

E_c = Critical Energy
E_{D1} = Energy at First Downstream Station
E_{D2} = Energy at Second Downstream Station
ϕ_c = Critical Occupancy
ϕ_u = Occupancy Upstream
Vol_c = Critical Volume (8 vpm)
Vol_u = Volume Upstream
Vol_{D1} = Volume at First Downstream Station
Vol_{D2} = Volume at Second Downstream Station

U_t = Threshold Speed (30 mph)
U_{D1} = Average Speed at First Downstream Station
U_{D2} = Average Speed at Second Downstream Station

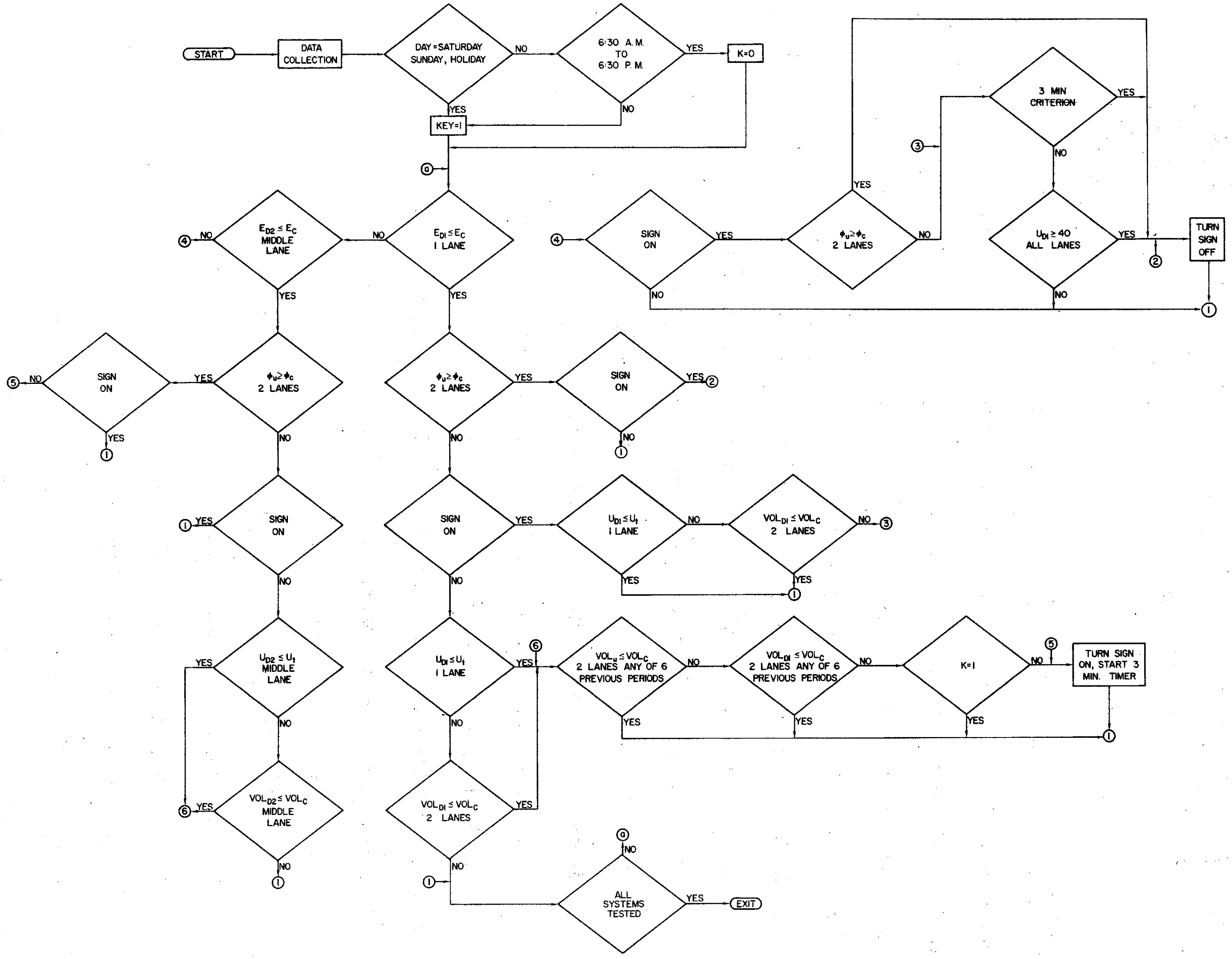

Figure 16 - Safety Warning System Control Logic Using Energy (downstream) and Occupancy (upstream)

FINDINGS

General

This report was concerned with an investigation of lane occupancy as a measured traffic variable for the detection of shock waves due to freeway incidents. Furthermore, results of this investigation were directed toward operation of a freeway safety warning device. The following constitute the specific findings of the study:

1. Critical occupancy parameters for shock wave detection were initially identified by regression analyses of occupancy and volume data but were found to result in numerous Type I and Type II errors. A sensitivity analysis resulted in adjusted occupancy parameters that had the minimum observed errors.
2. Performance evaluation of the resulting parameters using a one-lane detection criterion revealed detection of shock waves in 69 of 70 cases studied. Advance warnings ranged from -27 to 270 seconds. The one remaining case resulted in an untimely detection of the shock wave and represented an observed Type I error of 1.4 percent for the total sample. The advance warning for this case was -58 seconds which was beyond the allowable limit of -30 seconds. No

reason can be given for this single failure but it is viewed as an isolated instance with a much lower probability of occurrence than the sample indicated. No false indications of a shock wave (Type II errors) were observed for the data studied under the one-lane detection criterion.

3. A two-lane detection criterion resulted in a greater observed Type I error than the one-lane criterion.
4. Control logic for the safety warning device was developed using the critical occupancy parameters. The logic was translated into an operational program for digital computer control of the warning system. Evaluation of the operation, simulated in real time, revealed that satisfactory control of the safety warning device was accomplished for incidents that occurred downstream (Case I) and upstream (Case III) of the subsystem.
5. The logic and processes involved were not able to provide for the detection of incidents within the subsystem (Case II). However, the low frequency of these incidents and the observation that response to such an incident would often be ineffective tend to minimize this problem.

Table A-1

DIFFERENCES BETWEEN OBSERVED SHOCK WAVE PASSAGE AND MODEL INDICATION FOR HYPOTHESIZED CRITICAL OCCUPANCY CRITERIA (ADVANCE WARNING IN SECONDS)

Mossrose			Griggs			Lombardy			Dumble			Cullen		
In	Mid	Out	In	Mid	Out	In	Mid	Out	In	Mid	Out	In	Mid	Out
13	135	55	135	66	*	42	*	55	81	81	51	0	-	-
60	60	285	127	93	*	51	*	72	15	105	30	60	75	-10
-27	-18	17	0	0	10	-58	*	-51	15	30	110	240	120	-
114	30	220	45	40	-	60	xx	285	-15	255	-30	40	30	-195
0	90	30	75	20	*	150	125	165	105	60	-30	95	50	60
90	210	30	50	70	90	150	210	45	30	90	15	300	-	-
45	15	20	280	20	-	-60	xx	72	10	40	-	50	0	-
20	30	60	90	90	15	30	300	270	50	0	-	30	-15	-70
120	30	-	60	90	60	0	xx	120	-5	60	-	35	-55	-105
30	180	-	165	220	-30	20	xx	140	10	26	-	30	30	x
0	-	30	105	135	15	75	xx	-	-80	95	-5	15	15	x
150	180	210	205	155	100	x	-20	-				45	-15	-
280	xx	-20	40	xx	5	50	255	45				20	0	-50
85	80	55	xx	225	15							15	-	-
15	20	150	180	150	-							290	50	-

* = Defective detector
\- = Shock wave did not cross detector
x = Critical occupancy never exceeded (Type I error)
xx = False indication of shock wave (Type II error)

Table A-2

ADVANCE WARNING* FOR DETECTION LOCATION - ONE LANE DETECTION CRITERION

	Advance Warning in Seconds				
	Mossrose	Griggs	Lombardy	Dumble	Cullen
	133	45	132	81	0
	60	93	81	75	60
	-27	105	-58	15	205
	114	-30	240	0	10
	90	10	115	105	50
	90	50	165	15	120
	45	100	210	40	50
	50	90	270	50	15
	30	90	120	-5	35
	30	195	140	10	30
	30	75	135	40	15
	30	145	10		45
	80	40	50		20
	55	60			15
	15	150			50
					80
Avg. Adv. Warning (Sec.)	55.0	81.2	123.8	38.7	50.0

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*Difference between the time that a shock wave was first observed in any one of the three lanes and the time critical occupancy first registered the presence of a shock wave in any one of the three lanes.

PREVIOUS RESEARCH REPORTS OF STUDY

Research Report 165-1. "A Study of Accident Investigation Sites on the Gulf Freeway," by Mary Ann Pittman and Roy C. Loutzenheiser.

Research Report 165-2. "Evaluation of the Datamate Model D-16 as a Traffic Controller," by Gene P. Ritch.

Research Report 165-3. "Computer Control of the Wayside-Telephone Arterial Street Network," by Carroll J. Messer and Jim L. Gibbs.

Research Report 165-4. "Design of a Safety Warning System Prototype for the Gulf Freeway," by Conrad L. Dudek and Raymond G. Biggs.

Research Report 165-5. "Development of a Technique for Digital Computer Control of a Safety Warning System for Urban Freeways," by Conrad L. Dudek.