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Guidelines for Selecting Traffic Signal Control at Individual Intersections

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 3-27, "Guidelines for Selecting Traffic Signal Control at Individual Intersections," by Philip J. Tarnoff, Alan M. Voorhees & Associates, McLean, Va., and Peter S. Parsonson, Georgia Institute of Technology, Atlanta, Ga.

THE PROBLEM AND THE SOLUTION

The selection of the most appropriate form of traffic signal control for an individual intersection is a complicated process because of the many types of control that are available, the wide range of control equipment, and the varying site conditions. Each type of control (pretimed, semi-actuated, basic full-actuated, and volume-density) offers varying performance and cost characteristics depending upon the nature of the installation and existing traffic conditions. The proper choice of vehicle detector configuration and controller settings further complicates the selection and design process.

Procedures currently being used to select traffic control equipment are quite limited and lack uniformity. The available literature on the subject is voluminous, but provides little guidance on the complete set of costs and benefits associated with the selection of alternative forms of signal control at a specific site. Although traffic engineers recognize that each type of control has its appropriate use, selection of control type is generally determined without a comprehensive analysis because of the lack of guidelines and supporting reference data. To properly evaluate and determine the best type of traffic signal control to use at an intersection, some of the basic considerations that should be addressed are (a) maintenance requirements, (b) vehicle delays on the major and minor streets, (c) over-all traffic safety, (d) coordination adaptability, and (e) cost effectiveness.

In NCHRP Project 3-27, comprehensive guidelines were developed to help traffic engineers evaluate the costs and benefits of various control alternatives while taking roadway and traffic conditions into account. Although the emphasis of this project was on traffic control at isolated intersections, adjacent intersections were considered in regard to the need for coordinated operation.

More than 100 references were reviewed to determine the state of the art of traffic signal control and to identify data sources for use in this research. As part of the state-of-the-art survey, numerous traffic engineering organizations were contacted to identify current practices that would be appropriate for incorporation into the guidelines and to ensure that the guidelines will be applicable to the requirements of the traffic engineering community. Contacts were made with a sample of 43 state, county, and city traffic engineering agencies throughout the United States.

In this research, controller performance was evaluated in terms of delay per vehicle (in seconds/vehicle) and percent stops per vehicle. These measures of effectiveness were selected because they are frequently used in traffic engineering studies and can be directly related to traffic flow at individual intersections. The approach used in the development of the guidelines was to perform detailed analysis of controller effectiveness expressed in terms of stops and delays and then to develop additional relationships for vehicle emissions, fuel consumption, and accidents as a function of stops and delay.

Three complementary approaches were used to evaluate controller effectiveness:

1. Field data collection using observers to measure manually vehicle volumes and vehicle stops and delay.
2. Simulation using the NETSIM model developed under the sponsorship of FHWA to evaluate control system performance.
3. Analytical techniques developed by the research team and other agencies.

Initially, the field data collection phase of the research was intended to provide baseline data as a starting point from which simulation studies could be performed. The purpose of the simulation would have been to both extrapolate and interpolate the field data base. This approach was subsequently modified to include a greater reliance on simulation studies because of difficulties encountered in locating actual intersections having the full range of desired traffic and geometric characteristics. Consequently, the basic approach of this project was to use simulation to examine the performance of pretimed, semi-actuated, actuated, and volume-density controllers over a broad range of traffic and roadway conditions. The simulation activity was preceded by a field comparison of performance characteristics at selected intersections, and the simulation results were constantly cross-checked with the results of other studies to ensure their validity. The simulation studies were developed under the following conditions for the individual intersection: four, two-lane, right-angle approaches; two phase signals; approach speeds of 35 mph; and traffic volume for each approach evenly divided between the approach lanes.

FINDINGS

A review of the extensive literature related to this subject revealed that:

1. The vast majority of the literature deals with performance characteristics of controllers at isolated intersections. Within these references, vehicle delay is used almost exclusively as the measure of controller effectiveness.
2. A limited number of references offers criteria for the selection of control alternatives at individual intersections. These criteria are generally based on capacity considerations and do not include costs.

3. With the exception of manufacturers' literature, few documents address installation, operations, or maintenance issues. Most of the documents identified deal exclusively with procedures and do not contain data that would allow cost comparisons to be performed between alternative forms of control.

4. Numerous analytical studies have developed statistical relationships for various types of control. These studies often provide insight into operation of signal control alternatives; however, they have been conducted under assumptions too restrictive to permit their application to a specific set of guidelines.

In spite of these limitations, the researchers were able to arrive at some general conclusions:

1. Pretimed controllers operate most effectively when the shortest possible cycle length is used subject to the constraints of providing adequate intersection capacity and minimum green times for pedestrians and vehicle clearance intervals.

2. The delays produced by full-actuated controllers are extremely sensitive to the value of the extension that is used. In general, the shorter extensions reduce vehicle delays.

3. At low and moderate traffic volumes, when extensions of 2 or 3 sec are employed, the use of the full-actuated controller will produce reduced delays and stops over those that can be achieved using pretimed controllers. At higher volumes, the full-actuated controller will perform as a pretimed controller, producing comparable measures of vehicle flow.

4. The relative effectiveness of the various control alternatives depends on the quality of the signal timing employed. A poorly timed actuated controller will degrade traffic performance to as great an extent as a poorly timed pretimed controller.

Findings from the state survey indicate that in some jurisdictions, particularly in the northeast, there are certain barriers to the use of full-actuated control with large-area detection at isolated intersections. These barriers relate to difficulties in maintaining the controllers and detectors.

The researchers also found that controller maintenance has become difficult for many agencies throughout the country because of the multiplicity of makes and models that tend to be purchased under low-bid policies. Also, the continuing increase in sophistication of solid-state equipment dictates a transition in bench-repair staff from electrician to electronics technician. Limited budgets make this transition difficult. However, the controller industry is currently experiencing the same conversion to microprocessor technology that has revolutionized the calculator and wristwatch industries. The low cost and high reliability of microprocessors, coupled with their simple procedures for field troubleshooting, suggest that maintenance requirements might be eased in the future.

The detailed evaluation of controller performance conducted in this project employed simulation techniques validated from field data. The evaluation of both pretimed and full-actuated controller performance generally confirmed the relationships defined in previous studies.

Examples of the performance-controller relationships developed in this research are shown in Figures 1, 2, and 3. Before using these figures, the reader should obtain a copy of the agency's full report to understand the underlying assumptions and limitations.

Volume-density controllers were considered to provide the greatest benefit at intersections with high approach speeds where detector setbacks from the inter-

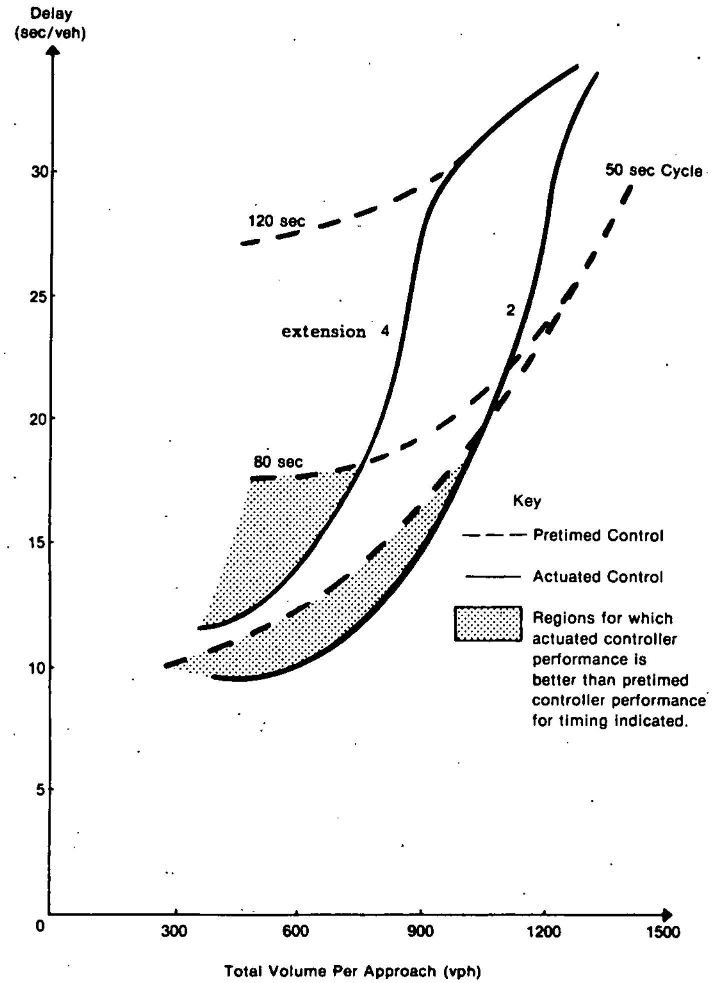

Figure 1. Comparison of pretimed and full-actuated controller delay.

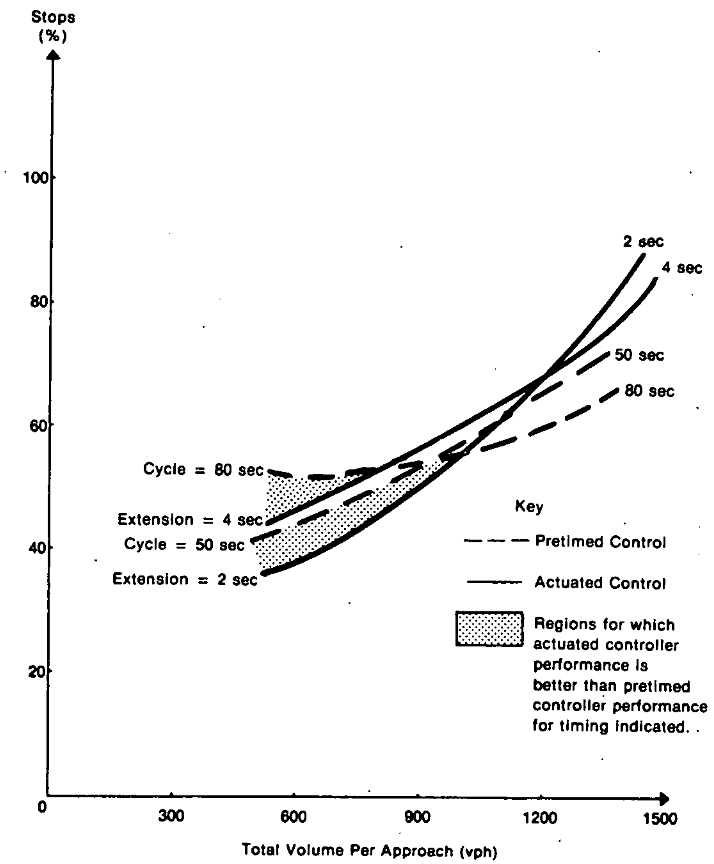

Figure 2. Comparison of pretimed and full-actuated controller stops.

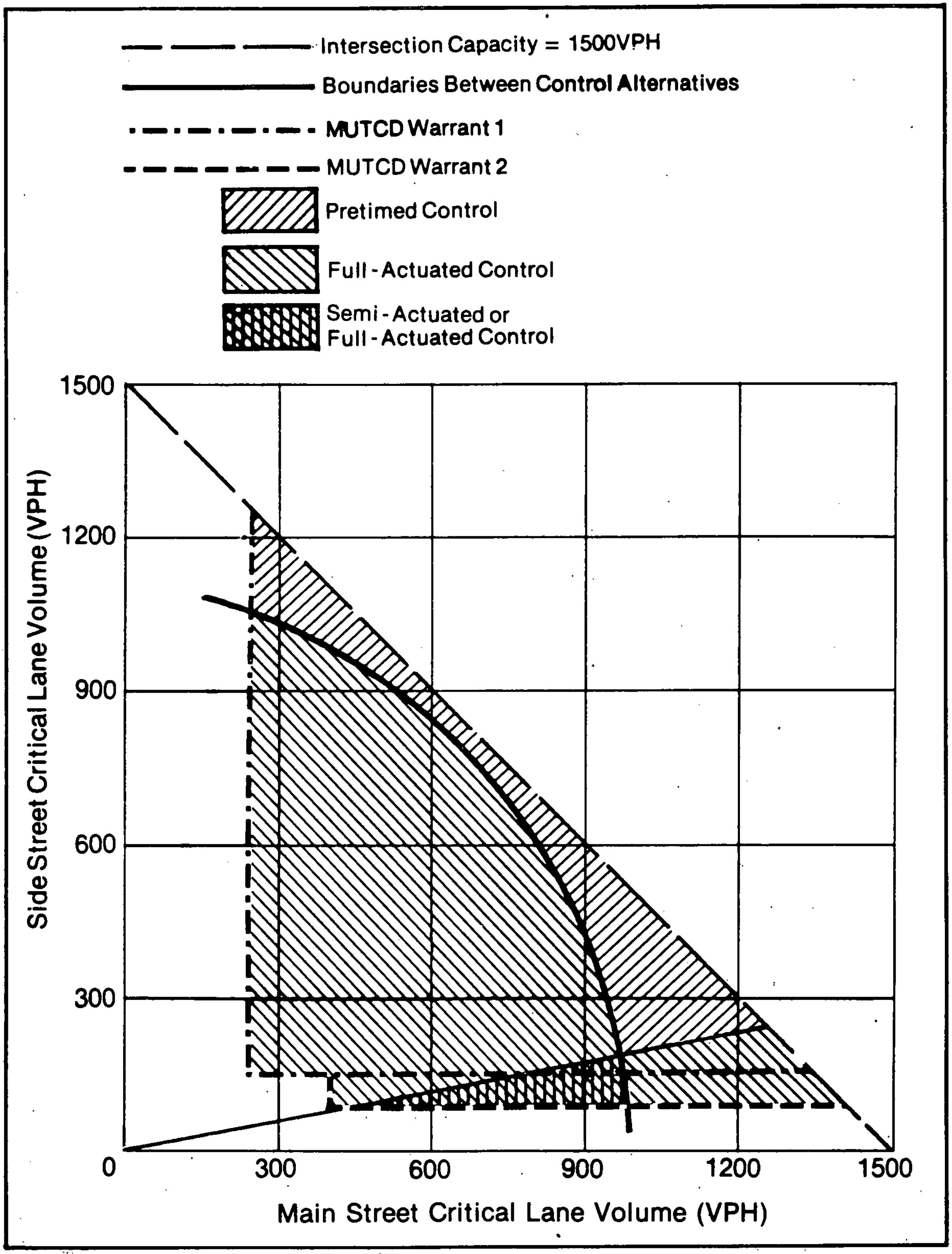

Figure 3. Sample graph of control boundaries.

section in excess of 125 ft require a variable initial green time. The time-waiting extension-reduction option of the volume-density controller did not improve the controller's performance over that of a basic full-actuated controller and, in fact, tended to degrade it.

Evaluation of semi-actuated controller performance at individual intersections demonstrated that these controllers produce a higher level of stops and delays for all traffic conditions than do either the full-actuated or pretimed controllers. However, for side street traffic volumes that are less than 20 percent of main street volumes, there is an insignificant difference between semi-actuated and full-actuated controller effectiveness.

Basic full-actuated controller performance was evaluated for various signal phasing and detectorization schemes. The researchers concluded that full-actuated controllers produce significant benefits when used in an 8-phase, dual-ring configuration. The 8-phase configuration produces significant benefits in terms of both stops and delays, as well as capacity, over that which would be possible with a 4-phase pretimed controller. Further modest gains in performance are possible with the use of long loops and short (or zero) initial and extension settings using the basic full-actuated controller. This application was found to produce a performance similar to a 2-sec extension with a short loop.

Extensive cost data were gathered for each type of control. The cost data indicated that the equivalent annual cost of controller acquisition and installation, spread over the life of the installation, had a limited impact on the benefit-cost comparisons used for the selection of a type of control. Maintenance costs varied significantly with type of control. The variations in these costs were sensitive also to the number of phases, primarily because of the need for increased detectorization with additional phases. The microprocessors used in the new controller design, moreover, tend to reduce annual controller maintenance costs.

The research results demonstrated that the form of control which minimizes the vehicle stops and delays at an intersection also minimizes fuel consumption and emissions. Furthermore, the differences in the annualized costs for equipment acquisition, installation, operation, and maintenance between the control alternatives were significantly less than the differences between the benefits. For this reason, the control alternative that minimized stops and delays also proved to be the most cost-effective installation. Therefore, it is not considered necessary to develop individual estimates for all of the measures of system effectiveness and costs in order to select the best form of control.

APPLICATIONS

Guidelines were prepared in the form of a step-by-step process that enables the traffic engineer to identify the most effective form of control for a given set of roadway, signal timing, and traffic flow conditions. The guidelines identify data collection and data processing procedures that can be used in the comparison of alternatives. Data collection and processing consist of an enumeration of the existing roadway and traffic conditions and a computation of critical signal timing parameters.

Procedures to be followed for the comparison of alternatives are also described. These procedures are based on graphs (similar to Fig. 3) that define regions in which each type of control is most effective. The regions defined are for pretimed, semi-actuated and basic full-actuated control. The applicability of volume-density control is defined in the researchers' recommendations for detectorization. Procedures for estimating the costs of each alternative are outlined, including cost estimates for equipment acquisition, installation, operation, and maintenance. A set of worksheets to help the user make the necessary calculations is also included in the manual.

The final report will not be published in the regular NCHRP series. Persons interested in pursuing the project subject matter in greater depth may obtain, on a loan basis, a draft copy of the agency's report by request to: NCHRP Program Director, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, DC, 20418.

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