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Guidelines for Uniformity in Traffic Control Signal Design Configurations

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 3-23, "Guidelines for Uniformity in Traffic Control Signal Design Configurations," by G. F. King, KLD Associates, Huntington, NY.

THE PROBLEM AND ITS SOLUTION

There are approximately 250,000 signalized intersections in the United States or, roughly, one million signalized approaches. These signal controls exhibit a wide variety in the number, location, mounting details, size, and shielding of signal heads, all of which are factors that define a traffic signal design configuration. Because of this multiplicity in the design elements, scientifically based guidelines for uniform standards are needed to reduce the confusion and hazard to the motorist. These guidelines, although definitive, should also provide the flexibility needed to meet unusual conditions.

The purpose of this study was the preparation of such guidelines for optimum traffic control signal design configurations at intersections and mid-block crossing locations.

Although specific revisions were recommended for various portions of the *Manual on Uniform Traffic Control Devices* and the *Traffic Control Devices Handbook*, the results of the research did fall short of the project objectives in some respects, possibly because the research plan was too ambitious for the funds and staff time available. Nonetheless, usable results were achieved and are reported here to facilitate their application to practice. They should be found attractive to the practitioner because they stand alone and do not have to be combined with results from other research. Furthermore, they are explicit as to their application and are expressed in the language and working tools of the practicing engineer. Copies of the draft final report have been transmitted to the National Advisory Committee on Uniform Traffic Control Devices for consideration of the various contents as replacements for existing sections of the *MUTCD*. The principal drawback to application of the results is that some of the report recommendations for changes in practice have not yet been proved valid by sufficient experimental evaluation in the field.

The project report will not be published in the regular NCHRP series, but loan copies are available. The specific research activities addressed in the report include the following:

1. A bibliography of 250 items, mostly annotated, was prepared and is included in the report as Appendix H.

2. A detailed questionnaire to determine current signal design practices and problems elicited responses from state, municipal, and county traffic engineers. The survey was supplemented by personal interviews and discussions with traffic engineers representing different geographical areas and different sizes and types of jurisdictions.

3. Accident data were collected and analyzed for 668 signalized approaches in eight states.

4. An analytical model of interference with motorist line of sight to the signal head due to trucks in the traffic stream was developed. Truck blockage for various traffic conditions was evaluated through traffic simulation.

5. Speed studies made on the approaches to 38 signalized intersections yielded a description of traffic stream dynamics as a function of both the distance from the stop line and the phase of the signal cycle.

6. A field experiment compared the relative visibility and legibility of circular, arrow, and programmed signal indications.

7. Human factors principles affecting the design of traffic signal configurations were analyzed.

8. An analytical investigation of the optical aspects of traffic control signals was conducted.

FINDINGS

Survey of Current Practice

Analysis of the questionnaires returned by 261 state, county, and municipal traffic engineers revealed a number of implications concerning the future development of standards for traffic signal design configurations, as follows:

- The majority of responding traffic engineers believe that the existing *MUTCD* standards are adequate for most situations; a sizeable minority believe that they have some shortcomings, however, particularly in that the standards are not adequately definitive.

- Although most engineers believe that current standards have achieved uniformity in signal design configurations in their immediate area, only 15 percent believe that nationwide uniformity has been achieved.

- The standard signing in the *MUTCD* to supplement traffic signal indications appears to be inadequate to cover all possible applications.

- Complex phasing is the single most important problem facing traffic engineers in arriving at proper traffic signal design configurations. Also important are problem areas involving approach and intersection geometrics.

Environmental and operational problems generally rank lower. There are no significant differences in rankings between regions and only minor differences between jurisdictional types.

- More than one-half of all respondents indicate a need or desire for changes in current *MUTCD* standards.

- There are no statistically significant differences along geographical or jurisdictional lines in these proportions.

- A major problem area involves the correct signal display for mandatory turns when these turns may conflict with pedestrian traffic or with opposing through traffic.

Accident Studies

The 668 signalized approaches included in this analysis set were controlled by 33 distinct signal design configurations. From analysis of more than 3,400 accidents, it is apparent that the configurations which performed best were characterized by high-mounted signal heads located in the far-right quadrant and at, or beyond, the far curb line of the intersecting street. This good performance was especially pronounced in the case of right-angle accidents--the accident type whose reduction is most desired. Therefore, configuration types that best achieve this reduction should be preferred.

Analysis by aggregation into configuration groups shows that:

- Mixed configurations (combining overhead and post-mounted heads) are generally better than either all-post or multiple overhead configurations, except that the box span performs as well as the mixed configurations.

- The single overhead configuration yields the highest involvement rates for all categories except head-on, left-turn accidents.

- All-post configurations show involvement rates significantly higher than average for all categories except head-on, left-turn accidents.

- The head-on, left-turn accident rate appears to be insensitive to configurations or to configuration elements.

A configuration element affecting involvement rates is the angle between the motorist's line of sight (direction of travel) and the optical axis of the traffic signal indication. Statistically significant lower accident rates are found for approaches where this angle is less than 10 degrees. The findings may explain the relatively good safety record of configurations with over-the-road signal indications in the far-right quadrant; that is, almost directly in line with the driver. This relationship also strongly indicates that the maximum angular displacement requirements now in the *MUTCD* should be reduced.

Insofar as signal head sizes are concerned, locations with all 8-in (200-mm) lenses were significantly worse than average. On the other hand, no safety advantages could be discerned in the use of all 12-in (300-mm) indications. A judicious mix of sizes, with the larger size usually reserved for the red indication, appears best.

Other highlights of the analysis include:

- Signal heads in the far-left quadrant have no significant effect.

- Signal heads in the near-right quadrant have a significant effect in reducing rear-end-violator-type accidents, but not total accidents.

• There is no significant difference between center-of-lane and lane-line positioning for overhead signals.

• Approach speeds have no apparent significant effect on total involvement rate. As far as the individual rates are concerned: (a) the right-angle rate decreases significantly with increased speed; (b) the head-on, left-turn rate increases significantly with increased speed.

Truck Blockage

The line of sight between the signal indication and the point of required visibility may sometimes be blocked by structures, by vegetation, or by large vehicles in the traffic stream.

The extent of this last blockage phenomenon was evaluated by developing an analytical model of the blockage geometry, performing a parametric study with this model, and applying it to a simulated traffic stream. It was found that truck blockage, evaluated over a 10-sec approach period, increases with increasing volume, increasing truck percentage, and increasing speed. The expected amount of truck blockage was quantified over a range of each of these parameters. Raising the height of the signals was found to have a more beneficial effect on expected blockage than changes in signal configuration. A supplementary signal in the far-left position was found to reduce expected truck blockage.

Operational Effects of Traffic Signals

The influence of signal configurations on traffic flow characteristics at approaches to signalized intersections was defined in terms of (a) statistical distributions of spot speed at several locations on the approaches; (b) statistical distribution of brake applications by distance from the stop line during the red indication; (c) queue discharge headways at the beginning of the green phase.

Although the speed data exhibited a considerable amount of scatter, analysis indicated that multiple overhead and mixed signal configurations were most likely to result in desirable values of those measures of effectiveness normally associated with increased safety. Single overhead signal configurations were found to be least effective in this regard.

The study of brake applications showed that configurations with 12-in. red lenses generally induced the type of approaching traffic stream parameters normally associated with a decreased accident potential. This study also showed that a substantial portion of drivers apply their brakes at considerable distance upstream of the minimum visibility distances listed in the *MUTCD*.

A signal configuration's relative efficiency was evaluated by measuring queue discharge headways. Using headways to compute expected delay and capacity showed that multiple overhead configurations were most efficient. Signal configurations equipped with 12-in. green lenses were significantly more efficient than those with 8-in. lenses.

Signal Indications Other Than Circular Lenses

Because arrow and programmed indications are being used increasingly in traffic control, an experiment was carried out to obtain data on their relative visibility and legibility. The results may be summarized as follows:

- Circular indications perform better than arrow indications for all parameters related to reaction time.

- Parameters based on reaction time increase in value with increased offset from the line of sight.

- The circular indications have a higher proportion of correct answers than arrow indications.

An analysis-of-variance series performed on the data showed that indication, distance, and offset may all affect response time and the proportion correct.

Programmed indications were tested only for the zero-offset observer locations. The indications were unmasked and were aimed at a point 500 ft (150-m) away. With this limited test, no significant differences in either response time or accuracy of response were found between standard circular lenses and programmed indications. On the basis of this analysis, standard design considerations apply to the use of programmed signal heads designed to be seen from a head-on position. The criticality of proper alignment must be maintained.

Other Configuration Constraints

An analysis of human factor principles affecting the design of traffic signal configurations revealed that the driver's perception-response tasks depend on his position on the approach. A conceptual model of these tasks was developed that identified and defined three distinct zones on the approach. It was found that important aspects of signal configurations included placing signal indications as close to the line of sight as possible and, also, placing at least one signal head in a consistent location known to and predictable by the driver.

Optical aspects of traffic control signals were also investigated. The major variables affecting signal configuration design were found to be the distance at which the signal first becomes visible and the offset of the signal position from the line of sight. A comparison of required signal illumination at the driver's eye and luminance characteristics of commercially available traffic signals showed that, in most cases, over-the-roadway signals would be required to ensure adequate signal visibility. This comparison also led to development of specific rules for the use of oversize signal indications.

An Interpretation of Findings

Analytical studies--considering both the driver perception-response process and the interaction of the optical aspects of signal head design with the driver's visual attributes--clearly indicate that the major element in traffic signal configuration design is the relationship of the driver's line of sight to the optical axis of the signal indication. Data and formulations developed during previous research efforts were used to quantify this relationship. The importance of this angular relationship was also suggested by operational field studies and confirmed by the accident studies.

Thus, the combination of signal luminance and angular offset determines how well the signal indication will be perceived and responded to. Another important consideration is the location on the approach at which the signal should first become detectable. Analytical considerations of the driving task clearly indicate that a point of first visibility should exceed the distance required for safe stopping. Field observation of actual driver behavior confirmed the conclusion.

The considerations underlying the effect of, and optimum design of, signal configurations are based on the premise that the full light output of the signal is available. Empirical studies have shown a need for adjustments for arrow lenses, where the light output is reduced. This design adjustment should be made when the major direction of travel, normally the through movement, is controlled by arrow indications. The required adjustment--providing an increase in available response time--can be translated into increased minimum visibility distances.

APPLICATIONS

The research resulted in a set of recommended changes in the current *MUTCD*, for which suggested textual revisions were prepared. In addition, a new chapter dealing with the location of traffic signal heads was prepared for the *Traffic Control Devices Handbook*. Many of the recommended changes to the *MUTCD* are based on research findings that desirably require validation before they can be acted upon. In any case, the proposed changes to the *MUTCD* should be considered and acted upon by the National Advisory Committee (NAC) on Uniform Traffic Control Devices before being widely published. Thus, the recommended changes to the *MUTCD* have been transmitted to NAC; they are not being published at this time.

The text, figure, and table that follow are taken from the recommended additions to the *Traffic Control Devices Handbook*. They summarize the principal essential findings from the research with respect to the number and location of signal indications. It is felt that these results can be applied to practice with a reasonable expectation of beneficial results.

Recommended Addition To *Traffic Control Devices Handbook*

Number and Location of Signal Indications

A minimum of two signal indications is required for each approach. A single indication can be used for a single, exclusive turn lane unless the movement accommodated in that lane represents the majority movement from the approach. The two required signal indications should be located on the far side of the intersection. Recommended typical layouts and their applicability are shown in Figure 1.

Supplementary signal indications should be used if they will materially improve the visibility or detectability of the signal indications or enable criteria of minimum visibility, given in the following, to be met. Examples of conditions for which additional signal indications should be used include:

1. Approach widths in excess of three full lanes.

2. Intersecting street width in excess of 80 ft.

3. Driver uncertainty concerning the proper location at which to stop.

4. High percentages of large trucks in the traffic stream that tend to block the view of signal indications in their normal location.

5. Severe approach alignment that makes continuous visibility of signal indications in their normal position impossible.

The additional signal head should be located within the intersection so as to maximize its effectiveness. Typical locations include:

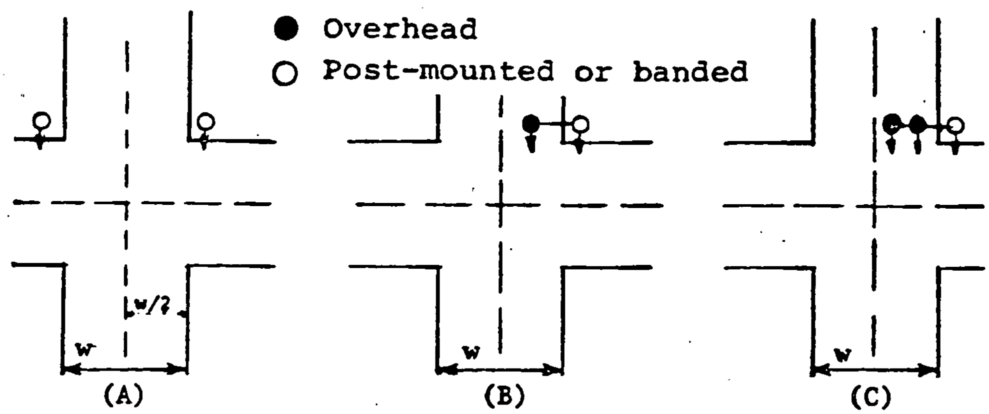
Near right - for conditions 2 and 3.

Far left - for condition 4 unless this location is used for an exclusive left-turn signal.

Far center - for condition 1.

Additional signal heads installed for the purpose of enhancing signal visibility should be located as close as practical to the projection of the driver's line of sight.

Required minimum and desirable viewing distances of traffic signal indications are given in Table 1. These distances should be adjusted, as indicated, for approach grade and should be increased, by the amount indicated, if arrow lenses are used as the principal indication for through traffic.



Note: Configuration (B) should be preferred to Configuration (A) wherever possible.

Configuration	Max. Approach Width, w (ft)	Max. 85 Percentile Speed (mph)	Area Type	Lens Size (in.)
A	24	35	Urban	8
A	24	Any	Urban	12
A	48	30	Urban	12
A	24	Any	Rural	12
A	40	25	Rural	12
B	48	Any	Any	8
B	72	25	Any	8
B	72	Any	Any	12
C	96	35	Any	8
C	96	Any	Any	12

Figure 1. Recommended standard configurations.

TABLE 1

REQUIRED SIGNAL VIEWING DISTANCES

A. MINIMUM AND DESIRABLE VISIBILITY DISTANCES

85 PERCENTILE SPEED		MINIMUM DISTANCE		DESIRABLE DISTANCE	
(MPH)	(KM/H)	(FT)	(M)	(FT)	(M)
20	32	175	53	265	81
25	40	215	66	325	99
30	48	270	82	405	123
35	56	325	99	480	146
40	64	390	119	570	174
45	72	460	140	660	201
50	80	540	165	760	232
55	88	625	191	870	265
60	96	715	218	980	299
65	105			1105	337
70	113			1235	376

B. DISTANCE ADJUSTMENTS FOR APPROACH GRADES AND ARROW INDICATIONS

85 PERCENTILE SPEED		ADJUSTMENT FOR APPROACH GRADE								ARROW ADJUSTMENT: ADD	
		ADD FOR DOWNGRADE				SUBTRACT FOR UPGRADE					
		5%		10%		5%		10%			
(MPH)	(KM/H)	(FT)	(M)	(FT)	(M)	(FT)	(M)	(FT)	(M)	(FT)	(M)
20	32	5	2	15	5	5	2	10	3	60	18
25	40	10	3	20	6	10	3	15	5	75	23
30	48	15	5	30	9	10	3	20	6	90	27
35	56	20	6	45	14	15	5	25	8	105	32
40	64	30	9	65	20	20	6	35	11	120	37
45	72	40	12	90	27	30	9	50	15	135	41
50	80	50	15	120	37	35	11	65	20	150	46
55	88	60	18	150	46	45	14	80	24	165	50
60	96	75	23	190	58	55	17	95	29	180	55
65	105	90	27	220	67	65	20	110	34	190	58
70	113	110	34	280	85	80	24	135	41	205	62

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