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FOREWORD

This RECORD contains papers dealing with traffic control strategies and guidance techniques.

The paper by Messer, Whitson, and Carvell discusses a real-time frontage road progression analysis and control strategy. The discussion addresses the problem of urban freeways that frequently experience congestion due to normal peak-hour demands exceeding capacity. A real-time, traffic-responsive frontage road strategy that could be used in operating frontage roads as a major traffic-carrying facility is presented. This paper is discussed by McDermott, who expands on the concept of using freeway frontage roads as part of urban transportation corridors. Use of a section of the Dan Ryan Expressway in Chicago is discussed to illustrate the concept.

Courage, Wattleworth, and Price present some guides for use in the design of traffic signal installations that require multiphase signalization. Included in the paper is a discussion of some of the possible phasing patterns, and a set of design tables is presented for use at moderately important intersections. Examples of the use of the tables and the computer program are given.

The paper by King and Lunenfeld describes a comprehensive questionnaire dealing with all aspects of urban traffic guidance that was distributed nationwide. Analysis of the returned questionnaires was made in terms of "stranger" and "local stranger" trips. Almost half of all respondents reported feeling lost at some stage of their most recent trip. Analysis showed that those problems ranking highest dealt with difficulties in arterial navigation.

Dewar and Ells describe three experiments conducted for the purpose of comparing three methods of evaluating traffic sign perception. In the first experiment, subjects were required to classify signs according to type and to identify the meaning of the signs while driving toward them under normal highway traffic conditions. The second experiment modified the size of the signs and the approach speed. The third experiment was a laboratory study of verbal reaction times to classify and identify slides of traffic signs. The results showed performance to be similar with all three methods, indicating that laboratory and modified field experiments can yield valid information for evaluating traffic signs.

A REAL-TIME FRONTAGE ROAD PROGRESSION ANALYSIS AND CONTROL STRATEGY

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Urban freeways frequently experience congestion due to normal peak-hour demands exceeding capacity and due to freeway incidents. It is proposed that, at least during these conditions, the adjacent frontage roads should be operated as major arterials to provide additional freeway capacity. A real-time, traffic-responsive frontage road progression analysis and control strategy that could be used in operating the frontage roads as a major traffic-carrying facility is presented. Previous computer control applications and future implementation of the strategy are discussed. The frontage roads are analyzed for progression as if the continuous, one-way frontage roads and diamond interchanges were combined to form a major two-way signalized arterial. To maximize frontage road progression, each interchange is assumed to operate on either a 3-phase or a 4-phase signal sequence. The progression optimization algorithm selects the phase sequence yielding the maximum progression. The traffic-responsive strategy using the 3- and 4-phase signal sequences is also described.

• TRAFFIC control theory and control systems have made significant advances in recent years. This progress is due in part to many research and operating agencies' working toward the common goal of improving the level of service provided the motoring public. As often occurs, progress brings change and, in fact, large changes may be required before any progress can occur.

Noticeable changes have occurred in traffic control concepts as well as in hardware implementation. The implementation of freeway ramp control systems to improve operations had modified, if not changed, the initially accepted view that freeways should be free of traffic signals. The beginning of an apparent widespread application of digital computers in traffic control has been noteworthy. As a result, significant changes have occurred in both method and mode of control.

Even though new traffic control technology and digital computers have been applied to freeways, the generally accepted view has remained that freeways should function as a prime mover of persons and goods. The land access or service function is still to be provided by other facilities, such as by continuous frontage roads when they are available. This is the generally accepted role for frontage roads where the freeway is not operating at or near capacity.

In many urban areas freeways operate during rush hours at or near capacity because of high traffic demands, and as a result traffic congestion frequently exists. The occurrence of an accident or stalled vehicle on the freeway will also cause considerable congestion and delay during many hours of the working day. When these types of freeway congestion occur, more on-freeway or near-freeway capacity would be helpful in reducing congestion and environmental pollution.

Frontage roads appear to offer considerable potential for relieving a significant amount of freeway congestion by increasing the use of the frontage roads by freeway motorists. However, to reach this objective would require that the frontage road operate, at times, like a major arterial and not in its traditional role as an access facil-

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ity. This unique dual role of operation is shown in the traffic movement versus access curve in Figure 1. The plot of the normal frontage road function would fall between the local and collector functions of traffic facilities: i.e., a high level of access in contrast to a low level of desired traffic movement. This high access point would describe the appropriate function for the frontage roads when the freeway is operating at a high level of service. However, when the freeway flow begins to experience congestion due to excessive demand or due to an incident, the frontage road should function as an alternate freeway route. During this time, the function of the frontage road would lie between the freeway and major arterial functions, as shown in Figure 1.

For the frontage road to be able to provide for the high-movement operation, it must be designed and operated to carry satisfactorily large traffic volumes at an acceptable level of service. The design should provide for one-way continuous frontage roads having 3 lanes in each direction of flow. The inside lane should be used for weaving with the freeway and be appropriately marked. The other two lanes should be free to move traffic, and parking should not be permitted during rush hours. Frontage road intersections should be of high-type design and have U-turn bays. From an operational viewpoint, the frontage road intersections (normally diamond interchanges) should be signalized, coordinated to provide progression along the frontage roads, and operated in a traffic-responsive mode to minimize delay and also provide an acceptable operating speed.

SCOPE

To provide the necessary high level of service for the frontage road traffic, a traffic-responsive signal control strategy that provides progression along the frontage roads is needed. This paper describes the theory and application of such a strategy. A one-way pair of frontage roads, as shown in Figure 2, is analyzed to find the best progression along both frontage roads while computing the green splits at each interchange in an effective, traffic-responsive manner considering all traffic using the interchange.

This control strategy has been developed within the Dallas freeway corridor research project conducted by the Texas Transportation Institute for the Federal Highway Administration in cooperation with the Texas Highway Department and the city of Dallas.

INTERCHANGE OPERATIONS

The traffic control strategy requires flexibility in signal operations. The traffic-responsive control strategy, while not actuated, requires that different signal phase sequences be implemented. Computer control at the diamond interchanges would probably be necessary. Two basic diamond interchange signal phasing schemes are considered for possible use at each interchange. These are the 3-phase with variable sequences and the 4-phase with overlaps. Progression analysis, to be described later, will determine which of these two basic phasing schemes should be used at each interchange so that maximum progression is obtained. It is assumed that traffic sensors are located on all approaches to each interchange such that demand volume counts are available for all movements in a real-time environment (e.g., 6-minute volume counts).

The length of green time given to an external approach movement to the interchange is determined, to the extent possible in all phasing schemes, in direct ratio to the movement's demand-to-capacity ratio. That is,

$$g_i \geq \frac{D_i}{S_i} C + L_i; \ g_i \geq M_i \tag{1}$$

where g_i is the green time used for movement i, D_i is the real-time traffic demand on movement i, S_i is the saturation (capacity) flow in vehicles per hour of green, C is the cycle length, and L_i is the total queue and amber lost time. It should be noted that g_i includes the amber time and must equal or exceed predetermined minimum movement times, M_i.

Three-Phase Variable Sequence

The basic 3-phase signal phase sequence is shown in the left section of Figure 3. The sequence begins (from the top) with both frontage roads receiving the green, followed by the two through-movement phases from the interchanging cross street. With this basic 3-phase sequence, the two frontage roads receive the same amount of green time. Therefore, this phasing arrangement is considered satisfactory only when both frontage road volumes are approximately the same. This would usually not be the case for the type of operation envisioned.

The basic 3-phase arrangement can be modified to produce phasing splits that are more responsive to volume variations on the two frontage roads. In order to favor the larger frontage road volume or to provide green times to the frontage roads in proportion to their demand volumes, two additional "3-phase" phasing sequences are used. These sequences are also shown in Figure 3. The phasing sequence that favors the "west-side" frontage road simply inserts an additional west-side frontage road phase into the basic 3-phase sequence.

The phasing arrangement used for favoring the "east-side" frontage road is slightly more complex. As in the previous sequence, an additional phase for providing more green time to the east-side frontage road is added just after the simultaneous frontage roads phase, as shown in the right section of Figure 3. However, the two major cross-street through-movement phases are reversed in this latter phase sequence. Reversing the order of the two through-movement phases provides smoother flow through the interchange and avoids short left-turning movements within the interchange. This variation in phase sequence can be effected with present computer control technology. To summarize the three phasing arrangements previously described, if the basic 3-phase sequence consists of phases A•B•C, then the favor-west-side sequence would be A•A1•B•C and the favor-east-side sequence would be A•A2•C•B. The appropriate sequence is automatically selected based on the level and distribution of frontage road traffic volumes.

Other considerations are necessary in 3-phase operation to promote smooth and orderly flow through the interchange. Traffic blockages of movements following the simultaneous frontage road phase may arise within the interchange area because of the simultaneous movement and storage of the conflicting left-turning movements from the frontage roads. The 3-phase sequence is particularly susceptible to this problem where the internal storage for left-turning vehicles within the interchange is small and left-turning volumes are high.

The following guidelines are offered to minimize the potential for blockages occurring because of simultaneous frontage road movements. No blockage problems are likely to occur until the smaller frontage road left-turning movement volume level reaches

$$q_L = 100 \frac{W}{C} \tag{2}$$

where q_L is the smaller frontage road volume in vehicles per hour, W is the available storage length in feet for vehicles within the interchange, and C is the cycle length in seconds. A 24-ft storage distance per vehicle and a peak flow rate factor of 1.5 were assumed. Thus, if the interchange storage distance were 120 ft and the cycle length 80 seconds, the critical left-turning volume, q_L, would be 150 vehicles per hour. By reducing the cycle length to 60 seconds, the critical volume level could be increased to 200 vehicles per hour. If the left-turning volume exceeds q_L, then 2 lanes for left-turning or a different signal phasing sequence should be considered.

When the critical volume level is reached, the maximum simultaneous frontage road phase, A_{max}, in seconds should not exceed

$$A_{max} = 4.0 + 0.09\ W \div T \tag{3}$$

where W is the interchange storage length and T is the decimal fraction of the inside frontage road lane volume turning left. A 2.1-second average vehicle headway was assumed. Thus, if W were 120 ft and T were 0.9, then A_{max} would be 16.0 seconds.

Four-Phase Overlap

The other basic phasing arrangement considered at each interchange is the 4-phase overlap operation (1, 2). Although this phasing scheme is widely used, few publications are available that describe strategies that could be used for real-time control (3, 4). The basic 4-phase with overlap operation is shown in Figure 4. The lengths of the offsets, or overlaps (ϕ_4 and ϕ_8 in Figure 4), depend primarily on the travel times from one frontage road to the other. Usually, the offsets are the same length but may be different, to reflect grades, locations of stop lines, etc. Phases 2 and 5 are the overlap phases. Movements 1, 4, 5, and 8 are used to compute the phase associated with each movement. Minimum movement times also must be satisfied for each movement.

While operating in a progressive system, the cycle length, C, at each intersection must be the same throughout the system. To generate this cycle at each interchange having overlaps ϕ_4 and ϕ_8, the following green (green plus amber) movement requirements must be satisfied:

$$g_1 + g_3 + g_4 = C \qquad (4)$$

$$g_5 + g_7 + g_8 = C \qquad (5)$$

$$g_3 + g_7 = C - \phi_4 - \phi_8 \qquad (6)$$

where the subscripts of the green movements refer to the movement numbers shown in Figure 4, C is the cycle length, and ϕ_4 and ϕ_8 are the eastbound and westbound offsets respectively. Equations 4 and 5 reflect the requirement that the sum of the conflicting green times at each intersection must add to one cycle. Equation 6 describes the overlap operational requirement and links the two intersections together to operate as an interchange. As indicated, the sum of internal left-turn greens must equal a constant value for a given cycle since the overlaps are fixed.

The green times provided within the interchange cannot be established independently at each intersection because of the requirements placed by Eq. 6 on the two internal left-turn green times. Since the sum of these two green times is predetermined, they must be proportioned so that the time remaining within the cycle at each intersection for moving traffic into the interchange is in proportion to the green time needed at both intersections. This is accomplished by computing the east-side left-turn green, g_7, from

$$g_7 = \frac{P_1 + P_4}{P_1 + P_4 + P_5 + P_8} \cdot [C - \phi_4 - \phi_8] \qquad (7)$$

where P_4 is the demand/capacity ratio of movement 4, etc. This green time is computed before any other time within the interchange. Equation 6 is then solved for the other internal left-turn green, g_3. After the internal left-turn greens are computed, the portion of the cycle remaining at each intersection, as given by Eq. 4 or 5, is allocated to the other two movements in proportion to their respective demand-to-capacity ratios using Eq. 1.

The following example is presented to illustrate the interdependency of the interchange equations and their operational characteristics. Assume that the west-side frontage road demand (movement 1) increases while all others remain the same. The desired increase in the green time of g_1 would be provided in the following manner: Since the demand-to-capacity ratio, P_1, would increase, the east-side internal left-turn green, g_7, as computed from Eq. 7, would be larger. It follows from Eq. 6 that the west-side left-turn green, g_3, would be smaller than before, which provides in itself additional green time for the west-side frontage road (movement 1).

The left-turn green time computed from Eq. 7, g_7, must fall within the bounds

$$M_7 \le g_7 \le C - M_5 - M_8 \qquad (8)$$

Figure 1. General movement and access functional relationships.

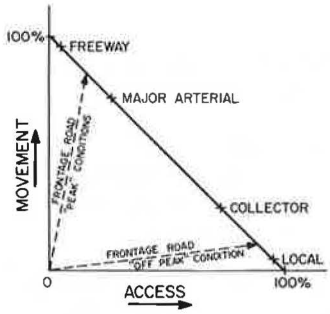


Figure 2. A frontage road progression analysis and control area.

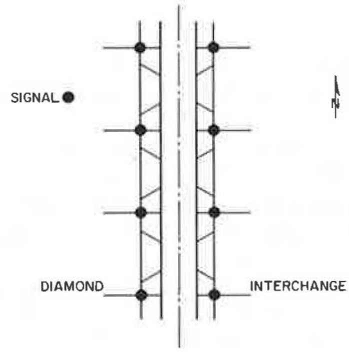


Figure 3. Three types of 3-phase signal sequences.

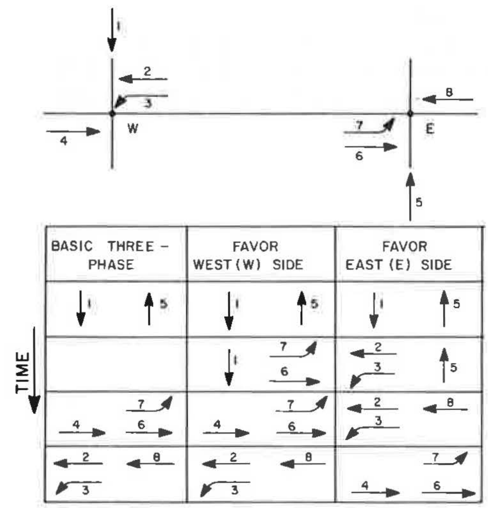


Figure 4. Phasing and interval lengths for 4-phase overlap operation.

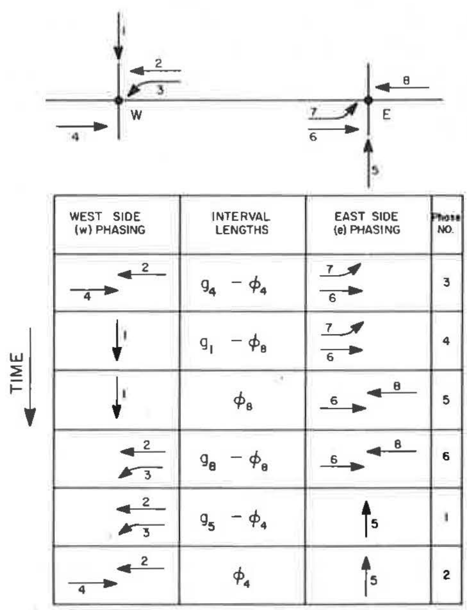
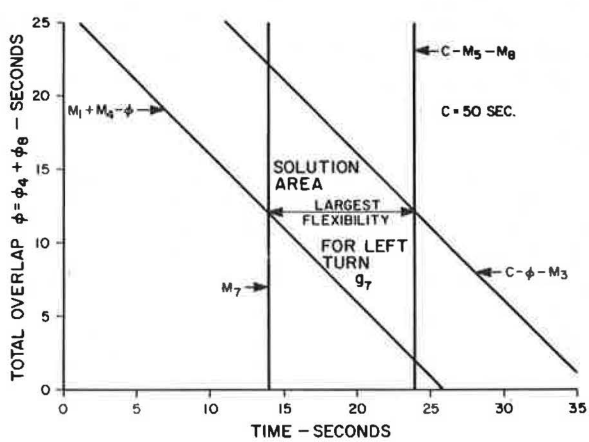


Figure 5. Overlap and minimum green time relationships in 4-phase operations.



and

$$M_1 + M_4 - \phi \leq g_7 \leq C - \phi - M_3 \tag{9}$$

to ensure that adequate time is available for the remaining movements at the two intersections after the left turn at each intersection is computed. Minimum-movement greens are given by M_i and $\phi = \phi_4 + \phi_8$.

Figure 5 shows the allowable range of overlaps for the 4-phase scheme when a relatively short cycle length of 50 seconds is used. The allowable range of overlaps is defined by the upper and lower limits of the solution area for the left-turning movement, g_7. Minimum greens (M_i in Figure 5) of 12 seconds are assumed for the frontage roads and 14 seconds for all other movements. For the minimum values chosen, most normal diamond interchanges can operate at a 50-second cycle since the overlaps will be from 5 to 10 seconds in each direction for a total overlap of 10 to 20 seconds.

Two other important items are evident from Figure 5. First, minimum greens should not be selected without knowing their effects on signal operation. If the minimum greens are large and the cycle length is short, a condition may arise where it is not possible to compute satisfactory movement lengths for the interchange. Second, there exists an optimal overlap that gives the greatest variation or flexibility in signal phase allocation for a given set of minimum greens. In Figure 5, this optimum total overlap is 12 seconds, or an overlap of 6 seconds in each direction.

The converse point of view is also relevant. For a given interchange with a fixed total offset ($\phi = \phi_4 + \phi_8$ in Figure 5) and symmetrical minimum greens, there exists an optimal combination of minimum greens for maximum phase flexibility. That is, from Figure 5,

$$C - M_5 - M_8 = C - \phi - M_3 \tag{10}$$

yields

$$M_5 + M_8 - M_3 = \phi_{opt} \tag{11}$$

and

$$M_1 + M_4 - \phi = M_7 \tag{12}$$

yields

$$M_1 + M_4 - M_7 = \phi_{opt} \tag{13}$$

For the design under consideration, the minimum greens M_1 and M_5 equal 12 seconds, and M_3, M_4, M_7, and M_8 equal 14 seconds. As a consequence, Eqs. 11 and 13 are equivalent. Thus $\phi_{opt} = 12 + 14 - 14 = 12$ seconds. The optimal phase flexibility location is independent of cycle length, although increasing the cycle length increases the allowable solution area and range of feasible overlaps. However, increasing the cycle length increases the sum of the two internal left turns, from Eq. 6, which may cause unsatisfactory operation by reducing external movement capacities.

Progression Optimization

The progression that is maximized is the sum of the progression bands along both frontage roads. The two one-way frontage roads are analyzed as if they were combined to form a single two-way arterial street with the interchange considered to be an intersection having multiphase variable-sequence signal operation. The progression optimization theory used is described in detail in a previous publication (5) on progression optimization for multiphase variable-sequence signals on arterial streets. Only the concepts necessary for converting the arterial progression theory to analyze the frontage road progression analysis problem will be described.

It is assumed that each interchange in a frontage road progressive system can use either the variable 3-phase or the 4-phase overlap signal operation. The progression program will select one of these two types of operation for each interchange such that the total progression along both frontage roads is maximized. Thus, some interchanges may use 3-phase operation whereas others use 4-phase. As traffic conditions change, an interchange may switch from one type of signal phase operation to the other.

The main reason for considering both the 3-phase and 4-phase operation is that usually one or the other will give good frontage road progression. If only one were available, progression might not be possible. This occurs because of the differences in starting times of the green signal for the two frontage road movements. As used in the arterial progression program (5), these differences in starting time of the progressive through movements are called the relative offsets, r_{ij}, of progressive movement j with respect to progressive movement i, with elapsed time being positive.

As shown in Figure 6, the relative offset, r_{15}, for the 3-phase operation is zero. The frontage road green times are shaded to indicate that they are the progressive through movements. From Figure 3 it can be observed that the relative offset of the frontage road greens for 3-phase operation is zero regardless of the phase variation used. That is, both frontage road greens begin at the same time in all three cases.

The relative offset of the frontage road greens for the 4-phase overlap operation is also shown in Figure 6 and is shown to have a value of about one-half cycle, which is in the normal range of values. By referring to Figure 4, it can be shown that the relative offset of movement 5 with respect to movement 1, r_{15}, is given by

$$r_{15} = g_1 + g_8 - \phi_8 \tag{14}$$

Assuming representative values for g_1 of 16 seconds, g_8 of 22 seconds, and ϕ_8 of 8 seconds, then the offset r_{15} would equal 30 seconds, or about one-half of a normal cycle length.

EXAMPLE PROBLEM

An example frontage road progression problem was analyzed to illustrate the operation of the program. Four interchanges were assumed to exist in the frontage road progressive system, and 3-phase or 4-phase overlap operation was assumed possible at each interchange. Traffic and geometric data were assumed. Interchange and progression speed data were as given in Table 1. Cycle lengths from 50 to 70 seconds were evaluated in 1-second increments to find the best possible progression.

The results of the progression analysis revealed that the most efficient (5) progression exists at a 60-second cycle length, as shown in Figure 7. The optimal efficiency was found to be 20 percent; i.e., 20 percent of the cycle is available for progression along the frontage roads. However, as also shown in Figure 7, the attainability (5) of the progression solution is 100 percent; i.e., the progression bands are limited only by the size of the green phases and cannot be improved unless the frontage road green times are enlarged.

Table 1 also shows the optimal signal phase sequence selected for each interchange for the given conditions. Three-phase operation with the east-side frontage road being favored was used at interchange No. 1, 3-phase operation with only simultaneous frontage road greens at interchange No. 2, 4-phase with overlaps at interchange No. 3, and 3-phase with the east-side frontage road favored at interchange No. 4. The optimal progression offsets are also given in Table 1.

The optimal progression time-space diagram is shown in Figure 8. Note in Figure 8 the differences in the location of the frontage road greens. As expected, the three, 3-phase sequences have their greens starting at the same time. The 4-phase overlap operation used at interchange No. 3 has a relative offset of about one-half cycle between the start of the frontage road greens. It can be observed from the time-space diagram that progression would not have been possible if all of the interchanges had been forced to use only 3-phase operation. Further analysis has revealed that the same is true if all interchanges had to use only 4-phase overlap operations. From a

Figure 6. Locations of frontage road progressive movements in 3- and 4-phase sequences.

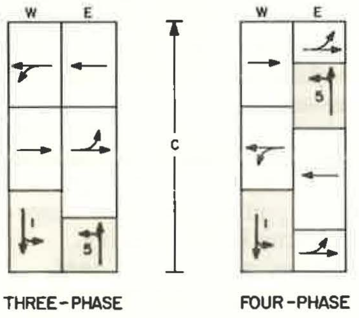


Table 1. Progression results for example problem at optimal cycle length of 60 seconds.

Interchange Number	Spacing	Speed	Optimal Phasing	Optimal Offset (seconds)
1	—	40 fps (12.2 m/s)	3φ - E	0
2	1,200 ft (368 m)	40 fps (12.2 m/s)	3φ - S	30
3	1,800 ft (550 m)	40 fps (12.2 m/s)	4φ	15
4	600 ft (183 m)	40 fps (12.2 m/s)	3φ - E	30

Figure 7. Progression efficiency and attainability variation with cycle length.

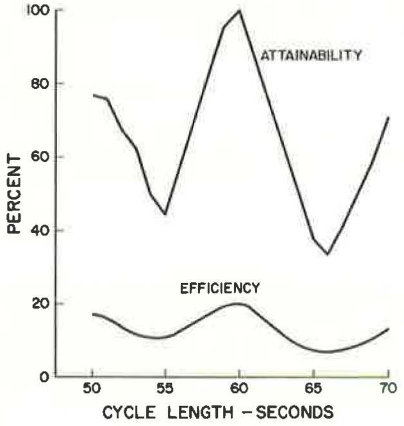
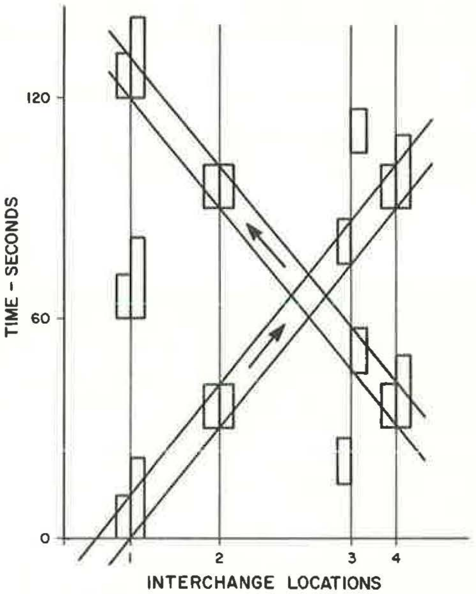


Figure 8. Optimal frontage roads progression solution.



progression point of view, this fact illustrates the need for having more than one type of phasing possible at an interchange.

IMPLEMENTATION

This frontage road progression analysis and control strategy is planned for implementation, testing, and evaluation within the Dallas corridor research project. Computer control will be provided at 15 interchanges in 3 subsystems. All aspects of the control strategy previously described will be used in this computer control system.

Previous real-time computer control using sections of this control strategy indicate that the overall frontage road control strategy presented should be effective. The real-time progression strategy was used on an arterial computer control system in Dallas (5). Real-time diamond-interchange computer control using 4-phase overlap phasing has been operated in both Dallas (5) and Houston (6), with the latter also providing one-way frontage road progression through two diamond interchanges. All of these previous real-time computer control systems have been successful.

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The contents of the paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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DISCUSSION

Joseph M. McDermott, Illinois Department of Transportation

The concept of a traffic-responsive signal control strategy providing progression along freeway frontage roads recognizes the important role of frontage roads as part of urban transportation corridors. Continuous, one-way frontage roads integrated into signalized, coordinated diamond interchanges offer the highest level of efficiency, capacity, and operational flexibility for handling urban freeway overloads and for distributing interchange traffic.

Unfortunately, the implementation of frontage road control strategies will often be limited to subsystems defined by each frontage road discontinuity, since many cities do not enjoy continuous routes. In the Chicago area, for example, over 70 percent of the existing expressway mileage lacks frontage roads. However, one of the Chicago area "subsystems" illustrates the interplay between freeway and frontage road and points out some of the operational variables that should be considered as part of the overall control strategy.

Figure 9 shows a section of the Dan Ryan Expressway. The inbound 4-lane expressway roadway expands to 6 lanes downstream. A 3.5-mile stretch (95th Street to 67th Street) of continuous, one-way frontage road (State Street) has 11 signalized intersections, feeds 6 metered entrance ramps, and empties 5 exit ramps. The city operates the fixed-time frontage road signals to provide progression for the inbound morning rush period. The frontage roads are discontinuous at either end of the subsystem, due to changes in horizontal expressway alignment as well as railroad grade separations and other physical constraints.

In 1966 the Illinois Department of Transportation initiated ramp metering inbound to alleviate freeway congestion caused by overloading near the last inbound entrance merge prior to the frontage road discontinuity (7). Over 1,300 vehicles had been using this one entrance in the morning peak hour. A comparison of travel times on the frontage road and the expressway (Figure 10) showed that the quickest inbound route during normal expressway operations included use of the frontage road followed by expressway entry at the last entrance ramp (71st Street). A study of these ramp users showed that 15 percent had previously been on the freeway and had exited to bypass the congestion. Many other drivers, although not previously on the freeway, bypassed upstream entrance ramps to similarly reduce travel time. The net effect of having too much traffic entering at one ramp was prolongation of the freeway congestion, causing more traffic to use the last ramp, etc., etc.

Ramp metering cut the ramp volume down to about 700 vph, reduced expressway congestion, and improved both freeway and frontage road through-travel times, all by delaying and diverting entrance-ramp users. The experience demonstrates the potential of frontage road progression for handling through bypass traffic as well as the imbalances that can result when the freeway problem is not internal to the frontage road bypass.

The importance of locating freeway incidents as part of the frontage road control strategy should not be overlooked. It may be advantageous to have traffic-responsive control only where needed for incident bypass and not along the whole corridor. It also may be advantageous, under some conditions such as complete freeway blockages, to have capability for extended progression on only one frontage road.

There are other operational variables affecting applications of the control strategy that must be considered. Some of these, such as pedestrian signals, could force longer cycle lengths and reduce progression flexibility. It is common in the Chicago area, for example, to have considerable pedestrian traffic at diamond interchanges, as well as bus stops on internal diamond approaches, to serve rail-transit stations located in freeway median strips. Other important variables include the presence or lack of U-turn bays and left-turn pockets, variable numbers of lanes, ramp metering queues, and parking controls.

The authors are to be complimented for their work thus far. The implementation, testing, and evaluation proposed will determine if the strategies can be tailored to fit day-to-day operational situations. As part of an overall corridor control system, one can envision a freeway surveillance and control system interfaced with traffic-responsive alternate routes and integrated with on-freeway and off-freeway driver information systems.

REFERENCE

7. Fonda, Roy D. An Analysis of Short-Term Implementation of Ramp Control on the Dan Ryan Expressway. Chicago Area Expressway Surveillance Project, Rept. 20, Illinois Department of Transportation, 1968. Abridged in Highway Research Record 279, 1969, p. 157.

Figure 9. Dan Ryan Expressway interchanges, 95th Street to 63rd Street.

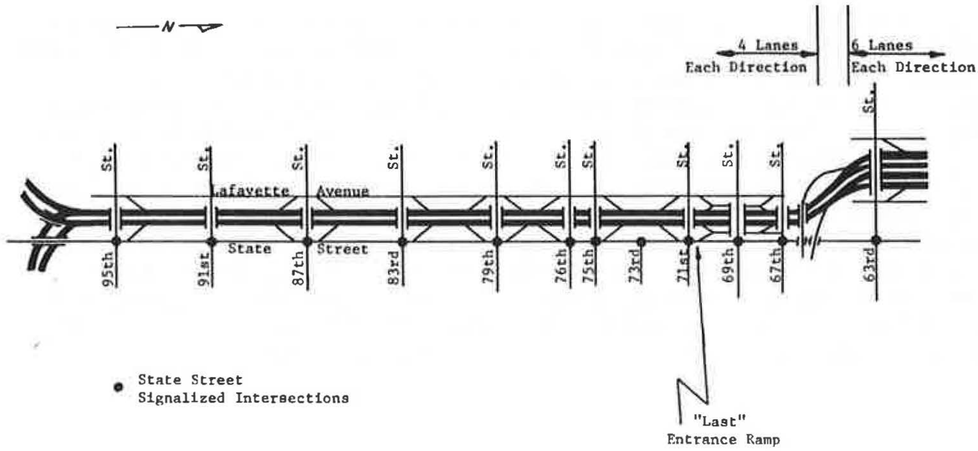
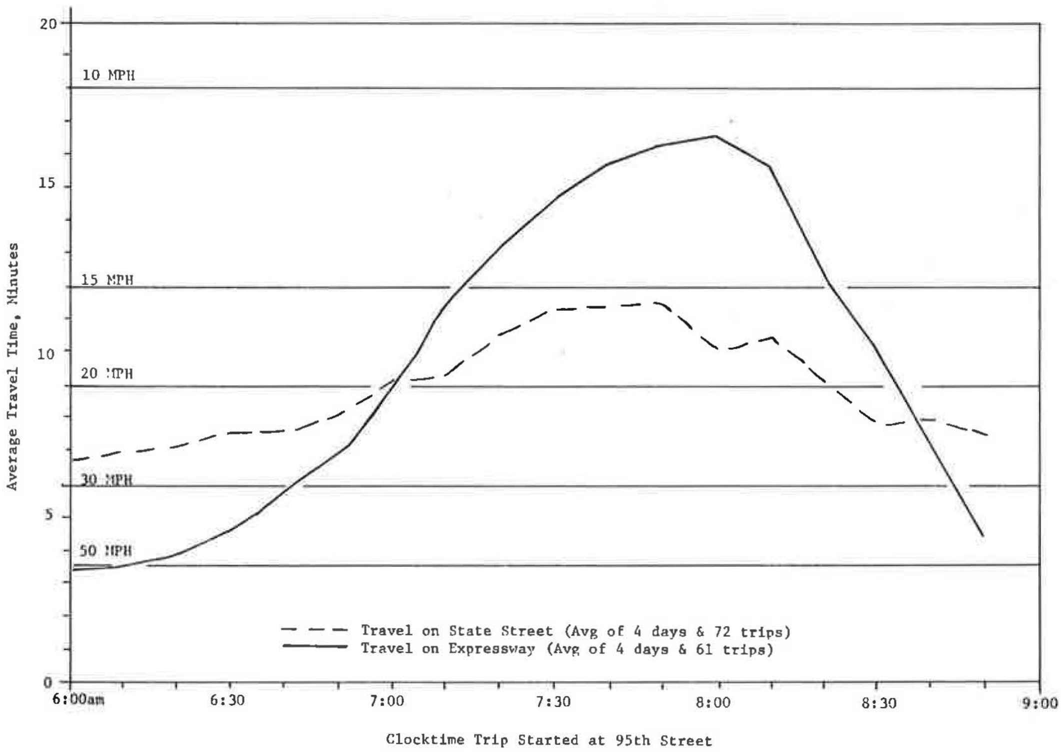


Figure 10. Individual trip travel times (before ramp metering), 95th Street to 71st Street, 3.0 miles.



AUTHORS' CLOSURE

The authors wish to express their appreciation to McDermott. His comments are constructive and informative and provide a meaningful addition to the paper. We would like to take this opportunity to add a few closing remarks to this discussion.

McDermott has presented a freeway-frontage road subsystem in Chicago to which the frontage road control strategy presented in this paper could be applied. Problems of freeway ramp control just upstream of a discontinuous frontage road were noted. Several frontage road discontinuties along the Gulf Freeway in Houston are now being eliminated in recognition of the rising importance of frontage road utilization.

McDermott's summary statement also expresses our position that what is really desired as a future goal is to develop an urban freeway corridor management and control system wherein the freeway, frontage roads, and adjacent arterials are operated as a system to provide the maximum possible utilization of these facilities. We hope that this paper has contributed, in some way, toward meeting this goal.

SOME TRAFFIC SIGNALIZATION DESIGN GUIDES

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Department of Civil and Coastal Engineering, University of Florida; and
Gary C. Price, Florida Department of Transportation

This paper presents some guides for use in the design of traffic signal installations that require multiphase signalization. The procedures permit the signal designer to consider all phasing patterns and to select the optimal pattern. Design tables are presented for use at moderately important intersections. Knowing the critical lane volume for each movement through the intersection permits the designer to select from the tables the required g/c ratio for each phasing pattern. The pattern that requires the smallest g/c ratio is the optimal pattern. For more critical intersections, a more sophisticated design guide is presented. It is a computer program that calculates the required g/c ratio for each signalization pattern. It also computes the vehicular delay that would be obtained under different equipment systems (single-dial pretimed, 3-dial pretimed, and several types of traffic-actuated). It then provides a cost-effectiveness comparison of the alternative equipment configurations. Examples of the use of the tables and the computer program are included.

•AT the present time much importance is attached to getting the greatest efficiency from existing traffic networks. This is due largely to the problems related to construction of new facilities in most urban areas.

The arterial street system continues to be a major carrier of vehicular traffic, and the signalized intersections continue to produce many operational problems. Frequently the efficiency of an entire arterial street is determined by a few critical intersections on it. These critical intersections must be subjected to optimal control if the street is to function most efficiently.

Current traffic signalization design procedures do not permit a truly comprehensive design. It is largely a trial-and-error process in which the experience of the designer is heavily weighted in the ultimate design. Frequently also the phasing pattern that is selected must apply over the entire day, even though the volume patterns may change substantially.

Clearly there is a need for a procedure that will allow the traffic signal designer to consider all phasing possibilities and will allow the varying traffic volumes to be considered. The procedure should also provide data that can be used in a cost-effectiveness evaluation of alternative traffic control equipment.

The purpose of this report is to develop traffic signal design tools that will enable the designer to make a more comprehensive analysis of the signalization at critical intersections with regard to signal phasing sequences, signal control equipment, and intersection volume conditions. For major intersections, the designer has two general types of signal control equipment with which he must concern himself. They are

1. Pretimed control with 1 to 3 dials, which displays a single phasing sequence with 1 to 3 cycle lengths, and
2. Traffic-actuated control, which can accommodate numerous phasing sequences and/or cycle lengths.

The design tool should be able to evaluate and compare these two types of control equipment. In either case, the signal designer should be able to use the design tool to

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1. Evaluate the intersection performance using the optimum phasing pattern with 1-dial pretimed control equipment;
2. Evaluate the intersection performance using the optimum phasing pattern with 3-dial pretimed control equipment;
3. Evaluate the pretimed control equipment performance using given cycle lengths;
4. Evaluate the pretimed control equipment performance using optimum cycle lengths;
5. Evaluate the intersection performance using traffic-actuated control and equipment with 3, 4, 5, and 6 phasing modules for displaying the optimum phasing; and
6. Select the optimal signal control equipment by cost-effectiveness considerations.

OBJECTIVE

The development of a traffic signalization design tool is the objective of this report. The design tool is a computer program, the signal operation analysis program (SOAP).

The program has as its primary application the intersections of major importance to the street system where a complete and thorough analysis is needed for signal pattern optimization, cycle length selection, and the decision to select either a pretimed or an actuated controller. With the many variables and options available for this type of intersection, it was necessary and desirable to develop a computer program.

The signal operation analysis program, although intended primarily for the design of signal control systems at individual intersections, is not limited to this application. The logic involved in the selection of a phasing pattern and cycle length for a single intersection can also be used in making the decisions associated with a computerized traffic signal system or other network control system.

In the development of the signalization design guides, a set of design tables was developed, and these tables can be of great assistance in the design of signals at intersections that are not important enough to warrant use of the program. Space limitations do not permit the inclusion of these tables, however.

DEFINITION OF TERMS

The terminology in this discussion conforms to accepted traffic engineering usage, and therefore a complete glossary of terms is not necessary. However, because of the detailed nature of the developments, it is felt that some clarification is desirable to distinguish between the terms "phase", "pattern", and "sequence".

Figure 1 shows the relationship between these three terms. The detailed definitions are as follows:

1. Phase—A phase is a unique combination of nonconflicting movements given right-of-way simultaneously by the traffic signal. This term, therefore, describes the state of the display at a specific point in time.
2. Sequence—The sequence is composed of a set of phases that, when combined in a specific order, make up the complete signal cycle accommodating all of the movements. A sequence is cyclical, with the first phase following the last phase.
3. Pattern—A pattern is a subsequence that accommodates either the northbound and southbound movements or the eastbound and westbound movements. Since these two sets of movements are independent of each other, the pattern concept simplifies the analysis. Two patterns will constitute a sequence when displayed one after the other. The pattern, unlike the sequence, is not in itself cyclical, but the first phase of a given pattern follows the last phase of its counterpart. The definition of a pattern is especially important here since the tables are designed to analyze alternative pattern movements rather than alternative sequences.

CONCEPT OF OPTIMAL DESIGN OF TRAFFIC SIGNALIZATION

The optimal design of traffic signalization consists of the selection of the phasing pattern that will produce the most efficient traffic operation at an intersection under given volume conditions and the selection of the control equipment that provides the most cost-effective means of accomplishing this operation. In the discussion that follows it is

Figure 1. Typical signal cycle showing phases, patterns, and sequence.

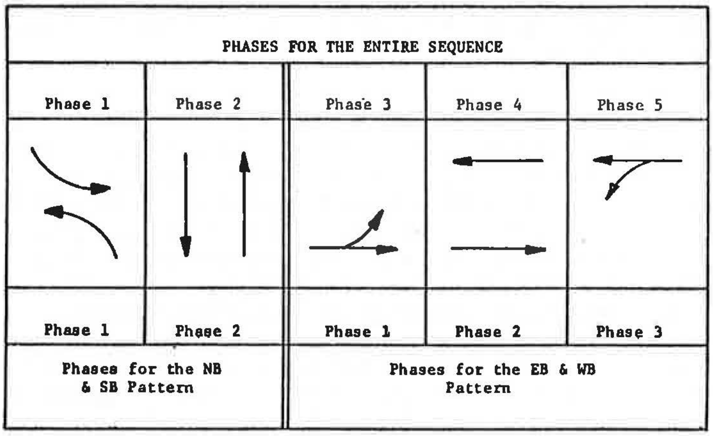


Figure 2. Basic movements and conflicting movements involved in signalization design.

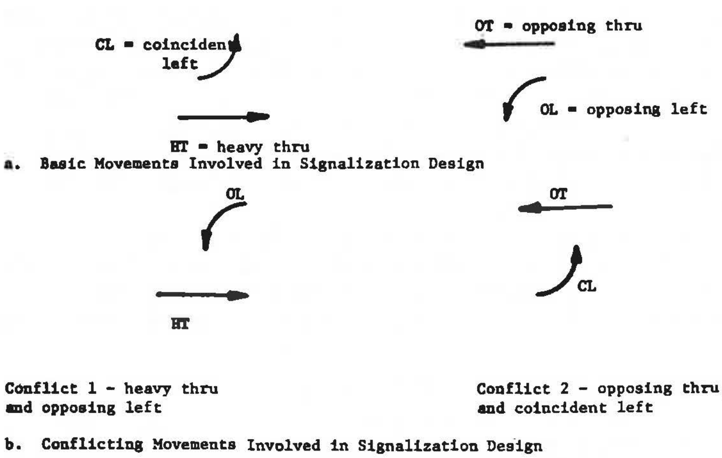


Table 1. Correspondence of movement designations.

Designated Movement			
HT	CL	OT	OL
Eastbound through	Eastbound left	Westbound through	Westbound left
Westbound through	Westbound left	Eastbound through	Eastbound left
Northbound through	Northbound left	Southbound through	Southbound left
Southbound through	Southbound left	Northbound through	Northbound left

assumed that the intersection has four approach legs. It is also assumed that pedestrians do not have a major influence on the automobile flow and that minimum pedestrian intervals can be provided within the optimum sequence design. In other words, pedestrian considerations are not included in the analyses.

Framework of the Analysis

The analyses are intended to provide a means of comparing alternative traffic signal phasing patterns. In doing so, it is convenient to consider at a given time only the two opposing approaches (for example, either the north and south approaches or the east and west approaches). This is because some of the movements on these opposing approaches can move simultaneously, and it is the selection of the simultaneous movements that is the essence of the analysis. The movements from the side approaches cannot move simultaneously with the movements on the approaches under primary consideration.

Basic Movements—Figure 2a shows the basic movements involved in the signalization design for two opposing approaches. The time required for each phase is determined by the requirements for the critical lane volume in each movement. Thus the volumes of the movements shown in Figure 2a represent critical lane volumes. For the purpose of these analyses the right-turn movement is considered with the through movement, since both have the same conflicting movements. This assumption should lead to conservative values of phase lengths and g/c values.

Figure 2a also shows some of the nomenclature used throughout the analyses. The critical lane volume of one of the through movements will be larger than the other, and this movement is designated the "heavy-through" or HT movement. The left-turning movement from the same approach is called the "coincident-left" or CL movement. The movements from the opposite approach are called opposing movements and the through and left movements are respectively "opposing-through", or OT, and "opposing-left", or OL. The designation of the heavy-through movement fixes the designations of all other movements. Table 1 gives for each possible heavy-through movement the corresponding designations for the other movements.

Figure of Merit—The required g/c ratio (the ratio of the required green time to total cycle length) is used as the figure of merit in comparing phasing patterns. The pattern that accommodates all of the critical lane volumes in the shortest time (smallest g/c ratio) is considered to be the optimal pattern. This figure of merit was selected for the following reasons:

1. The g/c ratio is commonly used for signal phasing analysis;
2. It is applicable to oversaturated and undersaturated intersection approaches;
3. For undersaturated approaches it converts easily into a value for delay; and
4. The conclusions of comparisons of phasing patterns are independent of the cycle length.

The comparisons based on g/c ratios are valid only to the extent that the lost times are the same for all phasing patterns. It can be shown that the lost times of all of the phasing patterns are equal if all amber times are equal. Because of overlap considerations the 3-phase patterns lose only the amount of time lost by the 2-phase patterns. Consequently, the g/c comparisons are valid in cases in which all amber times in a pattern are equal, and these comparisons can be considered guides in cases in which the left-turn ambers are slightly different from the through ambers.

Alternative Phasing Patterns and Their Permutations—The alternative patterns that will be considered are those related to opposing approaches of an intersection with four approaches. Each approach is assumed to have a separate left-turn lane. Most critical intersections would be of this general type. Half-cycle patterns will be considered because the two patterns (east-west and north-south) are independent and can be analyzed separately.

In a given pattern there are four possible combinations of two movements, each of which can be made simultaneously without conflict. These are the four nonconflicting phases from which all phasing patterns must be made; they are shown in Figure 3. All five of the basic signal phasing patterns are also shown in Figure 3. It should be recalled that one of the first steps of the analysis is to rank the critical lane volumes of the

Figure 3. Nonconflicting phases and basic phasing patterns.

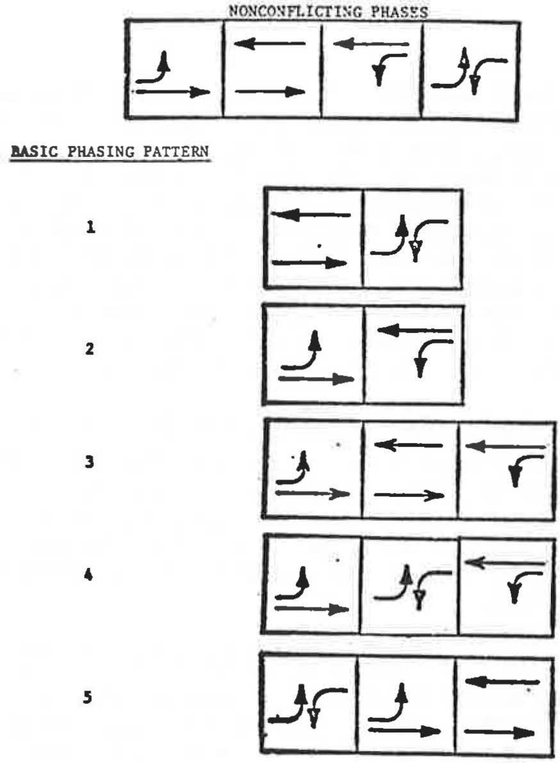
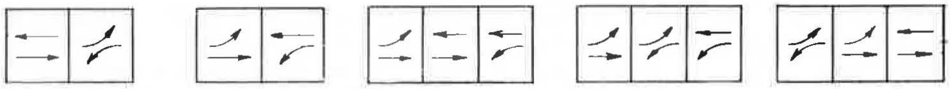


Figure 4. Derivation of g/c requirement for all basic phasing patterns.



Phases	Basic Pattern 1	Basic Pattern 2	Basic Pattern 3	Basic Pattern 4	Basic Pattern 5
1	max (HT,OT)=HT	max (HT,CL)	CL	HT	OL
2	max (CL,OL)	max (OT,OL)	max (HT-CL,OT-OL,0)	max (CL-HT,OL-OT,0)	max (HT-OT,CL-OL,0)
3	-	-	OL	OT	OT
TOTAL	HT+max (CL,OL)	max (HT,CL) + max (OT,OL)	max (HT+OL,OT+CL, CL+OL) Note: if CL+OL is the maximum value, ϕ2=0 and Basic Pattern 2 is preferable to Basic Pattern 3.	max (CL+OT,OL+HT, HT+OT) Note: if HT+OT is the maximum value, ϕ2=0 and Basic Pattern 2 is preferable to Basic Pattern 4.	mas (HT+OL,TL+OT, OL+OT) Note: If OL+OT is the maximum value, ϕ2=0 and Basic Pattern 1 is preferable to Basic Pattern 5.

Definitions: HT = g/c required for heavy through movement
CL = g/c required for coincident left movement
OT = g/c required for opposing through movement
OL = g/c required for opposing left movement

Table 2. Optimal phasing patterns for all volume conditions.

Movement With Highest g/c Requirement	Movement With Second Highest g/c Requirement	Movement With Third Highest g/c Requirement	Movement With Lowest g/c Requirement	Minimum Required g/c	Phasing Patterns With Minimum Required g/c	
					2-Phase	3-Phase
HT	OT	OL	CL	HT + OL	1	3, 5
HT	OT	CL	OL	max (HT + OL, OT + CL)	None	3, 5
HT	OL	OT	CL	HT + OL	1, 2	3, 4, 5
HT	OL	CL	OT	HT + OL	1, 2	3, 4, 5
HT	CL	OT	OL	max (HT + OL, OT + CL)	None	3, 5
HT	CL	OL	OT	HT + OL	2	3, 4, 5
OL	HT	OT	CL	HT + OL	1, 2	3, 4, 5
OL	HT	CL	OT	HT + OL	1, 2	3, 4, 5
OL	CL	HT	OT	HT + OL	1	4, 5
CL	HT	OT	OL	CL + OT	2	3, 4, 5
CL	HT	OL	OT	max (HT + OL, OT + CL)	None	4, 5
CL	OL	HT	OT	max (HT + OL, OT + CL)	None	4, 5

through movements to determine which is the heavy-through movement and which is the opposing-through movement (Figure 2). This allows disregarding a superfluous phasing pattern that would be the same as pattern 5 but with the direction of the second phase reversed. Since the heavy-through is determined, the second phase of basic pattern 5 will always be oriented in the direction of the heavy-through movement.

Examination of all possible permutations of phases in each of the five basic patterns reveals that many of the permutations are not feasible since they would result in the separation of green indications for a movement by a red indication. All of the feasible signal patterns that a designer must consider are those shown in Figure 3 plus the inversion of each (the order reversed). This means that there are exactly 10 phasing patterns that must be considered at each intersection.

Derivation of g/c Requirements for Basic Patterns

This section presents the derivation of the g/c requirements of each of the five basic patterns. The input to the analysis is the g/c required for each of the four movements. The required g/c ratio for a phase must be large enough to satisfy the largest required g/c of either of the two movements of the phase. Figure 4 shows the derivation of the g/c requirements for all five basic phasing patterns and the g/c requirement for each pattern.

Comparison of Patterns for All Volume Combinations

Figure 4 shows the g/c requirement for each basic pattern. The optimal pattern under any given set of volume conditions is the pattern that has the lowest g/c requirement. Thus, a useful tool for the signal designer would be a table that would indicate to him for any volume condition the optimal phasing pattern or patterns to consider.

Table 2 was developed for this purpose. To use this table the designer must rank the critical lane volumes of his four movements. The through movement with the highest g/c requirement is the heavy-through movement, and its designation fixes the designation of the other movements, as summarized in Table 1. With the four movements ranked in order, the designer can look in Table 2 to find the minimum required g/c ratio for his case and can also find the basic phasing patterns that will yield this minimum g/c. He can thus concentrate on these patterns.

Other Considerations of the Basic Patterns

With these values the designer can identify the optimum phasing pattern as the pattern that has the lowest g/c ratio. When more than one pattern gives the minimum g/c value, the choice must be based on other considerations. There are three general rules that may be applied and that will in nearly all cases lead to a unique choice.

Patterns 1 and 2

Because patterns 1 and 2 are simple 2-phase patterns, they are likely to be preferable to the more complicated 3-phase patterns that give the same g/c value. They will probably reduce the safety hazard at a particular intersection, and they will certainly reduce the cost of implementation.

Patterns 3 and 4

If there are no 2-phase patterns with the minimum g/c ratio, the primary basis for choice will be the type of turning interval (restrictive or permissive) that will be used at the intersection. Patterns 3 and 4 are generally preferable under restrictive turning intervals because they do not "split" the red indication as does pattern 5 (for the westbound direction).

The split red can create some confusion for the motorist who expects each movement for the approach (through and left) to be given a continuous green indication.

Pattern 5

Pattern 5 is generally preferable if permissive turns are used since these patterns both end with the phase displaying the two through movements simultaneously, with left turns made on a "yield" basis. Since patterns 3 and 4 both end with a phase displaying the through and left movements in the same direction, the permissive turn from the opposite direction could present some left-turning motorists with unexpected oncoming traffic during this last phase.

Cycle Length Determination

Webster's method (1) is used in the program to calculate the optimal cycle length. As the total traffic volumes approach the capacity of the intersection, an upper limit must be placed on the cycle length to ensure that realistic values are used. The upper limit is set at 120 seconds for pretimed controllers and 150 seconds for actuated controllers to reflect the operation of available equipment.

Comparison of Intersection Control Equipment

The alternative traffic signal control equipment systems are compared in the program through the use of delay. The program calculates the delay each period for each control equipment alternative based on the volumes during the period. Webster's method (1) is used to determine delay for undersaturated conditions. For oversaturated operation, an input-output technique is used to calculate queue lengths on which delay estimates are based.

By comparing the control equipment on a delay basis, an economic analysis can be made that considers the cost and expected advantage (decrease in vehicle hours of delay) incurred with the implementation of one type of control equipment over another. Not only is the operation of the intersection optimized, but a method of justifying the cost for improvements is also provided using the delay comparison.

FUNCTIONAL DESCRIPTION OF THE PROGRAM

The signal operation analysis program performs comparative analyses of various intersection signalization alternatives on a period-by-period basis with 15, 30, or 60 minutes per period. Both the phasing sequence optimization and control equipment selection are considered. The optimum phasing sequence is selected on the basis of g/c ratio. Control equipment is compared on a vehicle-delay basis. This program gives the signalization designer a tool with which to make a complete and comprehensive study of an intersection with a minimum of effort and time.

The program considers the entire portion of the day that is of interest to the signal designer. Many analysis periods during the day are considered, each with its own pattern. Thus the program gives signal design answers that are relevant to the selection of signal control equipment to provide the best operation over an entire day.

Purpose of the Program

The program is structured to answer two major questions:

1. What is the best phasing sequence for an intersection?
2. What is the best way to implement the phasing sequence?

The answer to the first question is determined by summing the g/c requirements (volume-weighted) for each of the five basic patterns for each period of the analysis. The phasing pattern with the lowest average g/c is the optimum pattern. This procedure, except for the volume-weighting, corresponds to applying the phasing pattern tables once for each period of the analysis.

The second question is concerned with different control strategies or equipment, either pretimed or traffic-actuated. The program evaluates the following control equipment:

1. 1-dial, pretimed controller (1 strategy);
2. 3-dial, pretimed controller (1 strategy); and
3. Traffic-actuated controller with 3- to 8-phase capabilities.

Implementation of the phasing sequence necessitates determining certain parameters. Pretimed parameters of cycle length and phase splits are required for all periods (one cycle length and set of splits per dial). Actuated control parameters of cycle length, phase splits, and maximum green time per phase are determined. With actuated control the average cycle length and splits for each period are used. Maximum green times are determined from the total number of analysis periods.

These parameters are used to calculate a value for total vehicle delay for each of the 10 control strategies. The delay value can be used to determine the control equipment to use for optimum efficiency (lowest delay) or to make a cost-effectiveness decision on the control equipment selection. Regardless of the strategy chosen, the parameters of each are available for implementation purposes.

How the Program Works

The program uses the same input data that are collected for use with present design procedures. No special data collection procedures are required. These data include the following:

1. Movement volumes,
2. Effective number of lanes for each movement,
3. Through and turn headways or saturation volumes for each movement, and
4. Lost time per phase.

Additional data for use with the pretimed equipment analysis include

1. Imposed cycle lengths for each dial (for interconnected systems only), and
2. Period to dial associations (required for all systems).

The basic program structure consists of three major analysis routines. The first routine determines the optimum phasing sequence and the best 2-phase and 3-phase patterns for each opposite pair of approaches. Two input variables used in the program are

1. The "more than 1-phase" variable, which allows the insertion of a single phase operation for either pair of opposite approaches (no protected left-turning intervals); and
2. The "2-phase better" variable, which specifies the total g/c percent by which a 3-phase pattern must be less than a 2-phase pattern in order to be chosen as the optimum pattern (default value is 2 percent).

The next routine determines pretimed control parameters and uses them in the delay calculation for both 1-dial and 3-dial equipment. The average optimal cycle length for each pretimed dial is calculated by the program.

The third routine determines average traffic-actuated control parameters such as maximum green time, cycle length, and splits for each period and uses them in the delay calculations for different phasing arrangements used in actuated equipment.

The program uses Webster equations to determine both cycle length and splits for each period of the analysis. The routine for pretimed control uses the period values to establish values for each dial. The routine for actuated control uses the period values directly in the computations. Webster's delay equation is used for undersaturated volume conditions, and an input-output technique determines delay for saturated conditions.

The output of the signal optimization analysis program is of four categories:

1. A visual display of the five basic phasing patterns,
2. A summary of input data,
3. A summary of pretimed control operation, and
4. A summary of actuated control operation.

The visual display is a pictorial representation of the five basic phasing patterns and gives meaning to the pattern numbers printed on the data summary sheet. This is an optional step in the program.

A summary of input data is printed to show the values given to the variables within the program. Its attachment is necessary to clarify the presentation of the results. Also included on the summary sheet is a ranking of the five phasing patterns as to their desirability as the chosen pattern. The volume-weighted g/c for each pattern is the

Figure 5. Signal phasing pattern analysis for sample problem one: input data and value of variables.

HEADWAY THRU (SEC) = 2.20 PED SPEED (FT/SEC) =10 LOST TIME PER PHASE (SEC) = 4
HEADWAY TURN (SEC) = 2.20

	WBT	WBL	EBT	EBL	SBT	SBL	NBT	NBL
	***	***	***	***	***	***	***	***
NUMBER OF LANES	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SATURATION FLOW	1636	1636	1636	1636	1636	1636	1636	1636

APPROACH WIDTHS :
(FEET) NORTH - 50 EAST - 50
SOUTH - 50 WEST - 50

PERIOD	TIME	VOLUME WBT	WBL	EBT	EBL	SBT	SBL	NBT	NBL	GIVEN CYCLE LENGTHS 1 DIAL	3 DIAL
******	************	***	***	***	***	***	***	***	***	**********	**********
1	800 TO 900	100	50	500	150	200	100	500	150	0	0
2	900 TO 1000	100	50	600	150	200	100	600	150	0	0
3	1000 TO 1100	100	50	600	200	200	100	600	200	0	0
4	1100 TO 1200	100	50	400	50	200	100	400	50	0	0
5	1200 TO 1300	400	150	200	100	400	150	200	100	0	0
6	1300 TO 1400	400	150	200	100	400	150	200	100	0	0
7	1400 TO 1500	400	150	200	50	400	150	200	50	0	0
8	1500 TO 1600	400	150	200	50	400	150	200	50	0	0
9	1600 TO 1700	500	50	300	100	500	50	400	50	0	0
10	1700 TO 1800	500	150	300	100	500	150	400	50	0	0
11	1800 TO 1900	500	150	300	100	500	150	400	50	0	0
12	1900 TO 2000	500	50	200	100	400	50	400	50	0	0

VOLUME WEIGHTED PATTERNS FOR ALL PERIODS

	EAST-WEST						NORTH-SOUTH					
PATTERN	3	1	5	6	2	4	3	5	1	6	2	4
AVG G/C	34	38	36	36	41	41	33	34	37	36	45	45

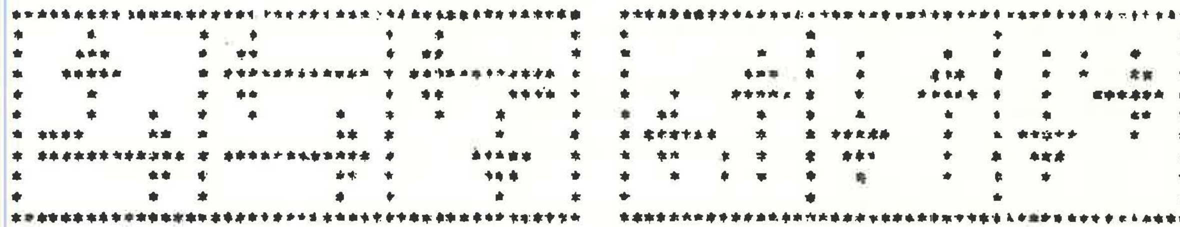
Figure 6. Signal phasing pattern analysis for sample one: pretimed control results.

SINGLE DIAL OPERATION

CYCLE LENGTH USED = 115 OPTIMUM CYCLE LENGTH = 115 AVG VEH DELAY (SEC) = 78.67 TOTAL DELAY (HRS) = 474.21

GREEN TIME PLUS AMBER IN PER CENT OF CYCLE LENGTH

0.13	0.22	0.13	0.11	0.26	0.14

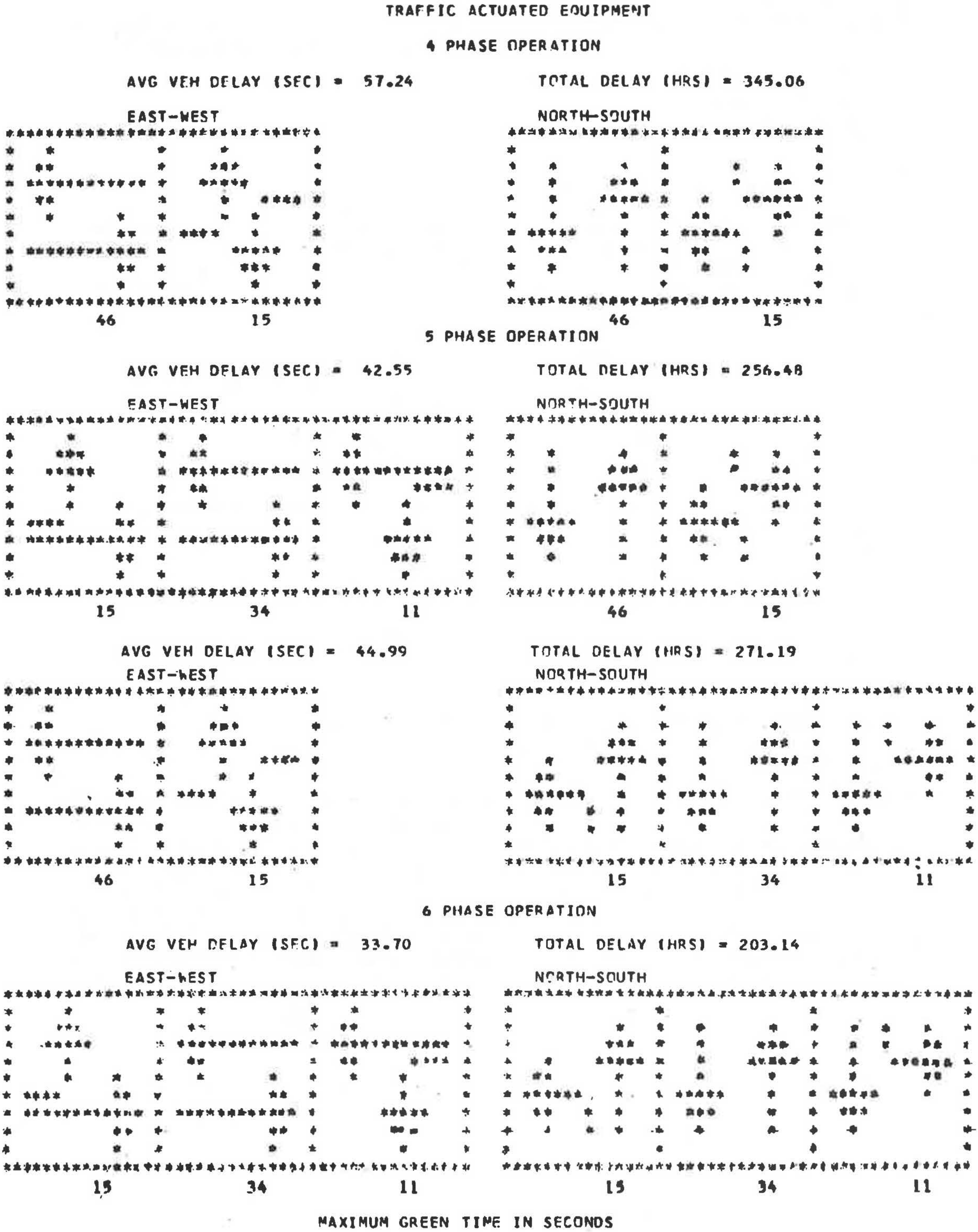


DIAL	USED CYCLE	GREEN TIME PLUS AMBER IN PER CENT OF CYCLE LENGTH						OPT CYCLE
1	120	0.13	0.27	0.07	0.14	0.29	0.11	120
2	75	0.10	0.23	0.17	0.10	0.23	0.17	75
3	100	0.10	0.28	0.10	0.08	0.32	0.12	100

THREE DIAL OPERATION

AVG VEH DELAY (SEC) = 49.74 TOTAL DELAY (HRS) = 299.84

Figure 7. Signal phasing pattern analysis for sample problem one: traffic-actuated results.



average value calculated from all periods. This ranking gives an indication of how much better one pattern is than another.

The pretimed control output is for 1-dial and 3-dial equipment. A visual display of the optimum phasing sequence is given and the following values are printed for each control strategy (1-dial or 3-dial):

1. Cycle lengths used,
2. Optimum cycle lengths,
3. Phase splits,
4. Average vehicle delay, and
5. Total vehicle delay for the analysis.

The actuated control output is for various combinations of 1-, 2-, and 3-phase patterns. If an exclusive left-turn interval is required for each opposite pair of approaches, the program calculates (a) average vehicle delay, (b) total delay for the analysis, and (c) maximum green time for each phase module for the following combination of phasing patterns:

East-West	North-South
2-phase	2-phase
2-phase	3-phase
3-phase	2-phase
3-phase	3-phase

If an exclusive left-turn interval is not required (single-phase pattern), the program also outputs data for

East-West	North-South
1-phase	2-phase
1-phase	3-phase
2-phase	1-phase
3-phase	1-phase

The program output can be seen in the example problem to follow.

Sample Problem

Volume data for 12 consecutive 1-hour periods of a typical 4-legged intersection with left-turn intervals required on each approach were input to the program. The results using nonpermissive phasing patterns are presented as "sample problem one." Output for "sample problem one" is shown in Figures 5, 6, and 7.

With this delay information on hand, a cost-effectiveness analysis can be made to indicate the type of equipment that should be installed. With the equipment chosen the program results would then be used to indicate the phasing sequence and set the timing and splits on pretimed equipment. For actuated equipment the program would be used to indicate the phasing sequence and give an insight into what the "max" setting in the controller should be.

REFERENCE

1. Webster, F.V. Traffic Signal Settings. Road Research Technical Paper No. 39, 1958.

URBAN GUIDANCE: PERCEIVED NEEDS AND PROBLEMS

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A comprehensive questionnaire dealing with all aspects of urban guidance was prepared, field-tested, and distributed nationwide, and 727 usable returns were received. Portions of the questionnaire dealing with trip plan preparation and trip plan execution are analyzed in this paper. Analyses of the returned questionnaire were made separately in terms of "stranger" and "local stranger" trips. Although there was a significant difference in the proportion of each class of respondent insofar as the preparation of a written trip plan is concerned, differences in the relative importance of perceived information needs and problems were less than expected. Almost half of all respondents reported feeling lost at some stage of their most recent trip. Of these, about half were actually lost. Rank ordering of problem types showed that most of those ranking high dealt with difficulties in arterial navigation. Maps were found to be the most important element used in trip plan preparation; map availability and map usability were correspondingly found to rank very high as problem types for stranger trips. Route numbers and street names and numbers were found to rank first or second among needed information types for all classes of respondents.

• THE Urban Area Directional Guidance System is a subsystem of the overall highway information system whose specific purpose is to guide the motorist safely and efficiently to and through urban areas. Any evaluation of this subsystem and improvements to it must be based, to a great extent, on the actual experience of road users. Specifically, data on driver trip-taking behavior, directional information needs, and perceived direction-finding problems must be elicited from real-world drivers so that solutions developed to overcome existing deficiencies in the urban guidance system can be matched to the needs of the ultimate users of the system.

NCHRP Project 3-12(2), "Urban Area Highway Guide Signing" (1), was planned to analyze the existing systems of urban guidance, identify any deficiencies therein, and generate solutions for any shortcomings of the system so identified. Because the research agency was unable to locate a body of data concerning road-user experience with the existing system in either the published literature or in the files of highway departments or interested user groups, a method had to be found to generate this data base.

The method selected as most cost-effective for collecting user urban guidance needs and perceived problems was the implementation of a nationwide self-administered questionnaire.

QUESTIONNAIRE DEVELOPMENT

A previous research effort (2) has postulated that drivers can be placed into one of three broad classes. The first of these, the "stranger", is a driver who is driving the facility for essentially the first time and is unfamiliar with the route and the area. The second class, the "local stranger", is more difficult to define; he may be repeating a trip that he makes only occasionally, or he may be driving the route for the first

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time. In either case, he is assumed to be broadly familiar with the area, but not with the route. The third class, the "local local", is repeating a trip that he regularly makes on a route and in an area that he is familiar with. Of the three classes, the stranger and local stranger categories were of most interest to the research, particularly since technical discussions with signing officials indicated that some of their greatest problems were in providing information for both local residents and visitors to an area.

Two forms of this questionnaire, geared to each of these groups, were prepared, although the differences between them were relatively minor. The definitions used in the questionnaire were as follows:

Stranger: "Where you are unfamiliar with the area and would consider yourself a stranger."

Local stranger: "Where you are familiar with the area but have rarely or never driven to the specific destination."

Questionnaire Items

The final forms of the questionnaire are illustrated elsewhere (1). After categories inappropriate for a self-administered instrument, those of lesser overall importance, and those that were amenable to determination by other means were eliminated, the questionnaire contained seven categories of questions:

1. Urban guidance system problem characteristics—12 questions;
2. Urban guidance system information needs characteristics—7 questions;
3. Respondents' demographic attributes—7 questions;
4. Urban area trip frequency and purpose characteristics—2 questions;
5. Trip planning characteristics—9 questions (an additional item was administered on the local stranger form);
6. Route-following characteristics—4 questions; and
7. Driver comments—2 questions.

Scaling Techniques

The semantic differential scaling technique was the method selected to evaluate driver-perceived problems and information needs. The output of the items derived from this technique provided an estimate of the mean importance rating that drivers placed on common urban area guidance problems and most prevalent information displays. This technique, which is discussed extensively in the literature (3, 4), has been shown to satisfy the criteria of validity, reliability, quantifiability, analysis potential, objectivity, and simplicity of administration required for this phase of the research.

Questionnaire Distribution

A number of persons throughout the country were asked to handle between 50 and 100 questionnaires each, see to their distribution, collect the completed instruments, and return them to the research agency.

No attempt was made to obtain a rigorously stratified sample on the basis of demographic variables. It was felt that such an attempt would place an undue burden on the volunteers assisting in the questionnaire distribution and would result in an insufficient total number of returns. The only requirements placed on the individual distributors were that the two forms of the questionnaire be randomly mixed and that responses not be solicited from persons professionally engaged in traffic engineering, highway signing or routing, and route planning.

Responses were received from 17 different states, of which 10 each represent 3 percent or more of the total sample. Each of the four census regions is represented, with a minimum of 15 and a maximum of 45 percent of the total sample in any one region. The sample includes returns from 7 of the 9 census divisions. The distribution of returns by census regions and divisions is given in Table 1.

Table 1. Distribution of respondents by census regions and divisions.

Region	Division	Number	Percent
Northeast	New England	50	6.9
	Middle Atlantic	107	14.9
	Total	157	21.8
South	South Atlantic	31	4.3
	East South Central	—	—
	West South Central	94	13.1
	Total	125	17.4
North Central	East North Central	273	37.9
	West North Central	56	7.8
	Total	329	45.7
West	Mountain	—	—
	Pacific	109	15.1
	Total	109	15.1
Grand Total		720	100.0

Of the respondents, 69 percent were male and 31 percent female. The percentages of males for the two types of questionnaires were respectively 73 percent for stranger and 65 percent for local stranger. Although this proportion of males is somewhat higher than that of the U.S. population as a whole or of that part of the population licensed to drive, it is felt that it represents a fair approximation of the actual proportion driving on trips into unfamiliar territory.

The distribution of respondents by age when compared with national statistics shows that the older age groups, those in excess of 50 years of age, are somewhat underrepresented. It is not felt, however, that this is critical to the interpretation of the answers.

As can be expected in any questionnaire survey that depends on voluntary cooperation of the respondents, the distribution of respondents by both education and occupation is skewed toward the higher end—that is, the better educated and the white-collar professions. Previous surveys (e.g., 4, 5, 6, 7) have shown that this tail of the distribution contains the segment of the population highest in car ownership and doing the most driving, and therefore, this may not represent a complete drawback. However, the result implies that very few respondents would rank in the lower portion of a distribution of the population by intelligence. Because it has previously been postulated (8) that the low-intelligence driver (IQ below 85) represents a "worst case" insofar as information system design is concerned, the results of the questionnaire survey must be analyzed and applied with this fact in mind.

The other demographic attribute of the respondent population tabulated dealt with type of residence area. As might have been expected from considerations of the distribution mechanism, the rural or farm component of the population is underrepresented in the returns.

In summary, therefore, the respondents to the questionnaire formed a broad sample of the U.S. driving population. While all groups are represented, their representation is not necessarily proportional to their share of the population. Furthermore, no attempt was made to stratify the sample in more than one dimension. The one important sampling control, comparative respondent population to the two questionnaire types, was substantially accomplished.

Results of Questionnaire Survey

The final report on NCHRP Project 3-12(2) contains detailed analyses of the answers to all questions (1). The present paper, however, concentrates on those portions of the study that deal directly with the twin aspects of trip plan preparation and trip plan execution. The responses to the pertinent questions are discussed in the following sections. The final data base consisted of 729 completed questionnaires, of which 365 were strangers and 354 were local strangers.

TRIP PLANNING

A series of questions were posed concerning the type of trip planning done and the informational elements entering into this plan.

Trip Plan Preparation

In the stranger questionnaire, the following was asked:

In planning your trip, did you? ☐ **Plan your own trip from available maps?** ☐ **Use a trip planning service?**

☐ **Get directions from others?** ☐ **Other ________________ (please indicate)**

The local stranger questionnaire asked the following:

Did you make a written trip plan for this drive? ☐ **Yes** ☐ **No**

If yes, did you: ☐ **plan your own trip from maps?** ☐ **get directions from others?**

☐ **plan your trip from memory?** ☐ **Other ________________ (please indicate)**

These questions were designed to elicit information on the type of trip planning done by drivers. In phrasing the questions it was assumed that everybody undertaking a trip of the stranger type would have made some kind of a trip plan. This assumption was borne out by the fact that 98 percent of all respondents to the stranger questionnaire gave positive, specific answers to this question, as shown in Table 2.

On the other hand, the existing state of the art did not permit the making of any a priori assumptions as to whether formal trip plans were made for trips of the local stranger type. For this reason a specific question on this point was included in the local stranger questionnaire. It can be seen that only 28 percent of all respondents did make a written trip plan for local stranger trips.

As expected, self-prepared trip plans, relying mainly on maps as input sources, were the primary mode for trips of the stranger type. Also, for trips of this type, the use of trip-planning services of motor clubs or gasoline companies was considerably less than expected in view of the amount of publicity these types of services have received. For local stranger trips, on the other hand, trip plans based on information obtained from "others" shared equal prominence with self-generated trip plans prepared from maps.

Although the instructions requested information as to type of trip planning only of those respondents who answered that they did make written trip plans, 20 percent of the sample did furnish details concerning their presumably memorized trip plans. The distribution of these corresponded closely with the distribution of written trip plans, splitting almost equally between reliance on maps and reliance on instructions furnished by others. The existence of memorized trip plans can also be inferred from the answer to the next question, where the number of positive responses to six out of eight trip plan elements exceeded the number of trip plans.

Trip Plan Elements

Both the stranger and local stranger questionnaires asked

Did your trip plans to new places near your home include:

	Yes	No
a. Street or road maps.	☐	☐
b. Strip or marked maps.	☐	☐
c. Maps you drew yourself or someone drew for you.	☐	☐
d. Written instructions.	☐	☐
e. Memorized instructions.	☐	☐
f. Mileage or other indications of distance between places or choice points.	☐	☐
g. Driving times between places or choice points.	☐	☐
h. Landmarks along the way that you expect to see, for example, buildings, stores, signs, etc.	☐	☐

This question elicited information on the type of trip plan elements used by respondents. The answers are given in Table 3. It can be seen that only two of the eight elements were used by more than half of all respondents and these—street or road maps and landmarks—were used by more than half in each category. One additional item, memorized instructions, was used by more than half of the respondents making "local stranger" trips; this is consistent with the fact that "get directions from others" was the single most prevalent method of trip planning for this class.

GETTING LOST

To obtain information on the proportion of respondents feeling lost and those actually lost, the following was asked:

On your most recent trip, did you ever feel you were lost or on the wrong road?

☐ **Yes** ☐ **No**

Were you actually lost or on the wrong road?

☐ **Yes** ☐ **No**

Figure 1 contains a set of contingency tables derived from the answers to these questions. The first shows the number and percentages of all respondents who reported feeling lost on their most recent trip. Slightly more than half reported feeling lost; this figure is almost identical for both stranger and local stranger trips.

The remaining contingency tables show, for each class of respondents separately, the relationship between "feeling lost" and "being lost". Again, the results are almost identical for both classes. Approximately half of all motorists who reported feeling lost at some stage of their trip were actually lost. On the other hand, only an insignificant fraction of all respondents reported being lost without previously feeling lost.

The term "lost" is highly subjective and may have been interpreted differently by different respondents. It is almost certain that this tabulation does not include every instance of a wrong directional decision being made and implemented, let alone instances of correct but not optimum decisions. Even with this qualification it can be seen that more than one-quarter of all trips result in the driver being lost, and in another quarter or more of all trips the driver incorrectly felt lost.

Table 2. Types of trip planning.

	Type of Trip		
Type of Planning	Stranger	Local Stranger With Written Plan	Local Stranger With Memorized Plan
Plan own trip from maps	56	37	43
Get directions from others	10	32	40
	19	15	11
Use a trip-planning service	5	7	—
	8	2	—
Plan trip from memory	—	8	14
Other methods	5	—	3
Percentage of sample making plan	98	28	20

Note: All numbers represent percentages. First number denotes exclusive usage; second is combined usage.

Table 3. Trip plan elements.

	Stranger Questionnaires		Local Stranger Questionnaires		All Questionnaires	
Trip Plan Element	No.	Percent	No.	Percent	No.	Percent
Street or road maps	319	85.0	235	66.5	554	76.0
Strip or marked maps	106	28.6	33	9.3	139	19.2
Maps you drew yourself or someone drew for you	106	28.6	147	41.6	253	34.7
Written instructions	144	38.4	152	43.0	296	40.6
Memorized instructions	151	40.3	195	55.1	346	47.5
Mileage or other indications of distance	181	48.2	121	34.2	302	41.4
Driving times	151	40.3	54	15.3	205	28.3
Landmarks	207	55.2	248	70.0	455	62.5
No. of responses	375		354		729	

Figure 1. Respondents' feeling or actually being lost.

NUMBER

Feeling Lost	Stranger	Local Stranger	Total
Yes	201	193	394
No	169	157	326
Total	370	350	720

PERCENT

Feeling Lost	Stranger	Local Stranger
Yes	54.3	55.2
No	45.7	44.8

A. NUMBER AND PERCENTAGE FEELING LOST

Feeling Lost	Actually Lost: Yes	No	Total
Yes	106	95	201
No	4	151	155
Total	110	246	356

Feeling Lost	Actually Lost: Yes	No	Total
Yes	29.8	26.7	56.5
No	1.1	42.4	43.5
Total	30.9	69.1	100

B. STRANGER QUESTIONNAIRES

Feeling Lost	Actually Lost: Yes	No	Total
Yes	90	99	189
No	1	143	144
Total	91	242	333

Feeling Lost	Actually Lost: Yes	No	Total
Yes	27.0	29.7	56.7
No	0.3	43.0	43.3
Total	27.3	72.7	100

C. LOCAL STRANGER QUESTIONNAIRE

GUIDANCE INFORMATION AND PROBLEMS

In view of the main purpose of the research, the identification of problems faced by motorists in the field of urban guidance and the development of feasible solutions to these problems, two of the questions were selected for detailed analyses. These questions, dealing with the relative importance of various types of information and with the relative importance of various types of problems, are shown in Figure 2.

Methods of Analysis

Preliminary analysis consisted of assigning values of from 1 to 5 to the points on the importance scale and computing a mean semantic rank for each item. This mean rank was then used for overall ranking of the 7 information types and the 12 problem types.

The question arises as to whether differences, within an overall ranking, between adjacent ranks are statistically significant. That is, if the answers to item g of the problem types of the stranger questionnaire have a computed mean rank of 3.46 while item h of the same set of answers has a computed mean rank of 3.48, does this represent a significant difference between adjacent ranks or does a de facto tie exist between these two items? A second question that has to be answered in the analysis concerns the significance difference of specific rank orderings between classes of questionnaires and between defined subgroups of respondents.

Although consecutive arithmetic values were assigned to each point for the computation of the mean rank used for the preliminary rank ordering, no evidence exists to show that these 5 semantic descriptors form an even-interval scale. Furthermore, there is no reason to believe that the semantic impact of these 5 descriptors is identical for different individuals or for different demographically defined subgroups. As a matter of fact, internal evidence of the data, such as mean ranks for all answers to all questions for a defined subgroup, although not conclusive, seems to indicate that such differences do in fact exist and that the overall score on a given question, everything else remaining constant, may be significantly higher or lower depending on the age, sex, or education of the respondents.

A test was thus needed that would compare independent samples, each consisting of a 6-point distribution (where "no answer" represented one point on the scale), and determine the level of significance, if any, of a difference between the samples. The basic test selected was the one-tailed version of the Kolmogorov-Smirnov two-sample test (9). The test was applied by constructing, for each specific rank ordering desired, a 2-dimensional significance matrix. These matrices are shown in Figures 3 and 4. The matrix is constructed by applying the Kolmogorov-Smirnov two-sample test to every possible pair of responses and computing the one-tail significance of the answer.

This significance matrix was then used to construct a rank ordering. This was done by determining for each individual item its rank order significance, that is, the difference between the number of answers it was significantly higher than and the number of answers significantly higher than it. In order to display the complete rankings, ties were broken by consideration of such factors as the level of significance of the differences, the numerically computed mean rank, and differences between extremely high and extremely low points in the distribution of answers.

The rank ordering so developed was used to compare the results obtained by different subgroups. Standard nonparametric tests of the significance of differences in ranks, such as the Spearman rank correlation coefficient (9) and Kendall's tau (10), were used.

Overall Analysis

Tables 4 and 5 give the derived comparative rank ordering for information types and problem types. For information types (Table 4), Spearman's rank correlation coefficient is 0.96; for problem types (Table 5), it is 0.64. The hypothesis that there is no significant difference between these rankings can be accepted at the 0.01 level for information types and at the 0.05 level for problem types.

Figure 2. Guidance information and questions on problems.

How important do you feel each of the following types of information are?

	not at all important	of some importance	important	very important	of greatest importance
a. Route numbers	☐	☐	☐	☐	☐
b. Route names	☐	☐	☐	☐	☐
c. Route compass directions	☐	☐	☐	☐	☐
d. Exit numbers	☐	☐	☐	☐	☐
e. City names	☐	☐	☐	☐	☐
f. Street names or numbers	☐	☐	☐	☐	☐
g. Destinations, eg, downtown, airport, etc.	☐	☐	☐	☐	☐

How do you feel about the following types of problems for these new drives in your home area. Please rate these types of problems:

	not at all important	of some importance	important	very important	of greatest importance
a. Road maps were not available.	☐	☐	☐	☐	☐
b. Road maps that did not give enough street details or were hard to read.	☐	☐	☐	☐	☐
c. City directional signs that did not provide the information you expected to see.	☐	☐	☐	☐	☐
d. It was hard to make a decision when signs showed more than one way to get to the same destination.	☐	☐	☐	☐	☐
e. Locally used road and place names were confusing or had no meaning for you.	☐	☐	☐	☐	☐
f. Following a route on a freeway or expressway to a destination in a city was difficult.	☐	☐	☐	☐	☐
g. Finding the best exit off-ramp in a city was hard to do.	☐	☐	☐	☐	☐
h. The entrance ramp to a freeway or expressway was hard to find from city streets.	☐	☐	☐	☐	☐
i. Signs at the end of a city exit ramp did not give enough information to find your way.	☐	☐	☐	☐	☐
j. Following a route on local city streets was difficult.	☐	☐	☐	☐	☐
k. Street addresses were hard to locate.	☐	☐	☐	☐	☐
l. If you made a wrong turn or got lost, it was hard to get back on the right route.	☐	☐	☐	☐	☐

Figure 3. Significance matrices, information types.

	A	F	E	G	D	B	C
A	XXXX	.001	.001	.001	.001	.001	.001
F	XXXX	XXXX	XXXX	.001	.001	.001	.001
E	XXXX	XXXX	XXXX	.05	.001	.001	.001
G	XXXX	XXXX	XXXX	XXXX	XXXX	.001	.001
D	XXXX	XXXX	XXXX	XXXX	XXXX	.001	.001
B	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX

A. "Stranger" Questionnaires

	F	A	E	G	D	B	C
F	XXXX	.005	.001	.001	.001	.001	.001
A	XXXX	XXXX	XXXX	.005	.01	.001	.001
E	XXXX	XXXX	XXXX	XXXX	.001	.001	.001
G	XXXX	XXXX	XXXX	XXXX	XXXX	.001	.001
D	XXXX	XXXX	XXXX	XXXX	XXXX	.001	.001
B	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.001

B. "Local Stranger" Questionnaires

Figure 4. Significance matrices, problem types.

	C	A	B	H	G	L	I	J	F	K	D	E
C	XXXX	XXXX	.005	.05	.05	.01	.05	.001	.001	.001	.001	.001
A	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.005	.01	.001	.001	.001
B	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.005	.01	.001	.001	.001
H	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.01	.005	.001	.001
G	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.01	.05	.001	.001	.001
L	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05	XXXX	.05	.005	.001
I	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.01	.001	.001
J	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05	.001
F	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05
K	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
D	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX

A. "Stranger" Questionnaires

	C	H	K	L	G	I	J	B	A	D	F	E
C	XXXX	XXXX	.05	XXXX	XXXX	.05	.001	.001	.001	.001	.001	.001
H	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05	XXXX	.05	.001	.005	.001
K	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05	.05	.001
L	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05	XXXX	.05	.05	.05	.001
G	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05	XXXX	.05	.05	.05	.001
I	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.01	.05	.001
J	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.001
B	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.001
A	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.01
D	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
F	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	.05

B. "Local Stranger" Questionnaires

Table 4. Ranking of information types.

Information Type (Figure 2)	Stranger Trip	Local Stranger Trip
a	1	2
b	6	6
c	7	7
d	5	5
e	3	3
f	2	1
g	4	4

Table 5. Ranking of problem types.

Problem Type (Figure 2)	Stranger Trip	Local Stranger Trip
a	2	9
b	3	7
c	1	1
d	11	11
e	12	12
f	9	10
g	4	4
h	5	2
i	7	5
j	8	8
k	10	6
l	6	3

Table 6. Subgroup differences: Importance rating of problem types.

Subgroup Criterion	Trip Type	Problem Type	Group Ranking Higher
Age	Stranger	b—Usability of maps	Young (<30)
	Stranger	k—Location of street addresses	Young
	Stranger	i—End of ramp signing	Old
	Local stranger	f—Following a freeway route	Old
	Local stranger	i—End of ramp signing	Old
	Local stranger	l—Recovery from mistakes	Young
Sex	Stranger	a—Map availability	Male
	Stranger	i—End of ramp signing	Female
	Stranger	j—Following route on city street	Male
	Local stranger	j—Following route on city street	Male
	Local stranger	d—Decision between alternate routes	Female
	Local stranger	g—Choice of best exit ramp	Female
Education	Stranger	a—Map availability	College
	Stranger	l—Recovery from mistakes	No college
	Stranger	g—Choice of best exit ramp	No college
	Local stranger	a—Map availability	College
	Local stranger	b—Map usability	College
	Local stranger	i—End of ramp signing	College
	Local stranger	l—Recovery from mistakes	No college
	Local stranger	f—Following a freeway route	No college

The important factors to be abstracted from the ranking of information types is that route numbers and street names or numbers represent the most important single information item. City names and designations of destinations, such as downtown and airports, come next. Exit numbers rank relatively low. However, this result may be misleading because exit numbers are far from a universally installed and known information aid at the present time. Even those jurisdictions that have numbered exits, either with a mileage designation in accordance with the MUTCD or with a sequential designation, have in most cases not done so long enough to establish driving patterns. Route names and compass directions are the information types judged of least importance. As far as route names are concerned, these results support the requirements of the MUTCD that numbers are always to take precedence over names. The low ranking of compass directions was somewhat surprising in view of the fact that the respondent group ranks higher than the population as a whole in educational achievement and socioeconomic status.

In examining the results for problem types it can be shown that, although there is no significant difference between the overall rankings, two of the individual types differ significantly in importance between the two classes of questionnaires. Applying the Kolmogorov-Smirnov test shows that problem type a (Road maps were not available) is more important for stranger trips at the 0.001 level and problem type k (Street addresses were hard to locate) is more important for the local stranger trips at the 0.05 level. These results could have been anticipated. The availability of maps is of concern to the stranger while the local stranger is more concerned with finding local street addresses.

Eliminating these two items, the important problem types in rough order of importance are as follows:

c. City directional signs that did not provide the information you expected to see.
h. The entrance ramp to a freeway or expressway was hard to find from city streets.
g. Finding the best exit off-ramp in a city was hard to do.
l. If you made a wrong turn or got lost, it was hard to get back on the right route.
i. Signs at the end of a city exit ramp did not give enough information to find your way.
b. Road maps that did not give enough city street details or were hard to read.
j. Following a route on local city streets was difficult.

It is interesting to note that 5 of these 7 problem types point to deficiencies in arterial highway signing and only one deals with expressway or freeway signing. One of the items excluded from the classification, as discussed earlier, is also amenable to solution by improving the information system on the conventional road network.

Subgroup Analysis

In addition to this overall comparison, separate comparisons were made on the basis of four demographic variables: age, sex, region, and education. In discussing these results the fact must be kept clearly in mind that, as mentioned earlier, the sample was not stratified. That is, while the overall sample is roughly representative of the U.S. driving population, the same statement cannot be made for individual demographic subgroups. This is especially true of regional differences. For none of the demographic subgroups examined was there any indication of significant differences in information types, so this item will not be discussed further.

Demographic Differences—Apparently significant differences in ranking of problem types are summarized in Table 6.

Because of the great disparity in the demographic makeup of respondents from the four major geographical areas of the country, no statistical inferences can be drawn from the regional analysis. It is, however, instructive to point out certain indicated results. The high importance attached to map availability on the part of respondents from the West may reflect the lower population density of that part of the country and the consequent longer average trip length. The lessened importance of the problem of following a route on city streets as the respondent is located farther away from the East is perhaps due to the more open and more rectilinear street plans of midwestern and western cities.

Differences by Trip Planning Behavior—It has already been mentioned that approximately 28 percent of all respondents to the local stranger questionnaire indicated that they prepared a written trip plan. An analysis of differences between these two groups was made. Surprisingly, there is absolute agreement on the relative rankings of information types. As far as problem types are concerned, the only statistically significant difference was found for problem type 1, dealing with the difficulty of recovering from a wrong movement. This was rated first by the group with a trip plan and is significantly higher, at the 0.05 level, than the relative rank (fifth) given to the same item by the group without a trip plan.

This is probably due to the reliance of one group on their formal trip plan and the difficulties they would expect if they departed from this plan. The other group probably depends more on ad hoc direction-finding and can therefore take getting lost more in their stride.

DISCUSSION AND CONCLUSIONS

Any conclusions to be drawn from the research effort described here must be tempered by the limitations on the sample size and composition. However, with this reservation in mind, the data base appears to be adequate to draw a number of tentative conclusions. [These conclusions are also supported by other aspects of the research program as described elsewhere (1).]

1. The system of urban guidance in its present form is inadequate, as demonstrated by the large number of respondents who either felt lost or were actually lost. Analysis of the individual problem categories shows that these deficiencies make themselves most felt on the conventional portions of the urban highway system and at the interfaces of these portions with urban freeway systems.
2. The most important problem arose from violation of expectancy—city signs that did not provide the expected information. This held for both strangers and local strangers as well as for nearly every demographically determined subgroup examined.
3. Both trip planning and trip plan-following appear to be heavily dependent on the availability and accuracy of highway maps. Maps and signs are both integral elements of the urban guidance system deserving attention from officials charged with the installation, operation, and maintenance of that system. Attention should also be given to improving the ability of the driving public to use the maps in both trip planning and trip plan-following.
4. Insofar as the perceived need for various information types is concerned, the driving public appears to be extremely homogeneous. No significant differences among demographically determined subgroups could be noted. Route numbers and street names are indicated to be the most important single information needs.
5. Insofar as directional information needs are concerned, the differences between the stranger and the local stranger, as these categories had previously been postulated, appear to assume a lessened importance.

The conclusions support, and are supported by, the findings of previous research efforts, although, as far as could be ascertained, none of these were based on a nationwide data base or addressed themselves to all components of the urban street and highway system.

Thus the Automotive Safety Foundation study (2, 11) previously mentioned restricted its data-collection activities to one state, California, and concentrated on the freeway portions of the highway network. That study showed that the freeway signing problem is relatively minor and that the most often identified problem areas dealt with advance notice and with finding freeways. This confirms the findings of the present study that urban direction-finding problems were most prevalent on the arterial system and on its interface with the freeway system. The California study also arrived at comparable results concerning the importance of maps and concerning the proportion of the driving public feeling lost or actually lost.

Another major study of traffic control devices (12) posed some of the questions that the present study has attempted to answer but did not collect any data on. The present conclusions were, however, partly anticipated in the development of proposed solutions. The same holds for a major study of urban information sources in Boston (13).

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COMPARISON OF THREE METHODS FOR EVALUATING TRAFFIC SIGNS

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Three experiments were conducted to compare three methods of evaluating traffic sign perception. In the first experiment, subjects were required to classify signs according to type and to identify the meaning of the signs while driving toward them under normal highway traffic conditions at 30 mph (48 kph) and 50 mph (81 kph). The distances at which subjects were able to classify and to identify each sign were measured. Two classes of sign, regulatory and warning, were used, and half of each class had symbolic messages while the other half had verbal messages. The second experiment was a partial replication of the first, with certain modifications. The signs were one-third normal size and the subject drove the vehicle at 17 mph (27 kph). The third experiment was a laboratory study in which verbal reaction time required to classify and identify slides of traffic signs was measured. Signs used in the first two experiments were used as stimuli in the third experiment. The results indicated that the three measures of performance were closely related. Signs were classified at a greater distance than they were identified. Performance was better on symbolic than on verbal signs (except for the reaction time measure), and it was better on warning than on regulatory signs. In addition, performance on individual sign messages was highly correlated across the different measures.

•A GREAT deal of research employing a variety of methods has been conducted on traffic sign perception. Both laboratory and field techniques have been used, but there has been little attempt to relate these two approaches. Consequently few laboratory techniques have been properly validated against performance in an actual driving situation. Furthermore, both approaches have suffered from such general problems as improper experimental design, inadequate dependent measures, and unrepresentative samples of subjects. A recent review of methodology in traffic sign research (2) points out difficulties specific to each approach.

The most apparent deficiency in many laboratory evaluations of traffic signs is the lack of the normal visual cues and distractions of attention that are part of the driving task. Some driving simulators are an exception to this, but even they do not duplicate the task perfectly. Some researchers have incorporated loading tasks into their sign recognition experiments. This procedure is considered by Forbes (3) to be essential for any laboratory test of signs.

Most experiments examine only one factor in the complex process of detecting, recognizing, and acting on a sign message. For example, an experiment on legibility distance tells little about the attention value of a sign or whether a new symbol will be understood after it has been seen. The problem of whether a new symbol can be easily learned and remembered is almost always overlooked in the evaluation and development of signs.

Investigations carried out on the road (usually observation of driving behavior) have generally been less adequately designed and conducted than have those done in the laboratory. Field studies of any type tend to involve more uncontrollable variables and

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unpredictable events than do laboratory studies. Driving experience and potential lack of familiarity with the signs on the part of the subject are often not taken into account. Some subjects may not know a sign simply because they have never seen it, even though it could be a well-designed sign. Expectation plays an important role here.

Small numbers of observations of a critical event (e.g., entering a restricted area) are a problem in many studies, perhaps because such events are relatively rare. This difficulty can be overcome by observing driver behavior over longer periods of time.

One of the popular methods for evaluating a new sign is the "before-and-after" technique. Driver response to an existing sign (or to a driving situation where there is no sign) is measured for a period of time, after which the new sign is installed (or replaces the old one) and similar measurements are taken again. The major mistakes made by those who use this method involve evaluating the new sign under conditions different from those in the "before" phase (e.g., different time of day, day of the week, month, weather conditions, and drivers). In addition, the novelty effect of any new sign may attract greater attention from the driver, regardless of the adequacy of the sign itself. Therefore, a new sign may have to be in use for many months before an uncontaminated measure can be obtained. A further difficulty with many before-and-after studies is the inadequate base rate (too few observations taken before the new sign is installed).

With several methods available to measure each of a number of variables one might ask, "Which method is best for my particular need?" For example, knowledge of the meaning of signs can be measured by multiple-choice questionnaire, showing photographs or drawings of the signs, measuring reaction time for meaning or action to be taken, and showing a film of the signs on the highway. The signs can be shown alone or in the context in which they will be used; they can be shown for a fraction of a second (as it may be seen while driving) or for an unlimited time. Legibility distance can be determined by showing motion pictures taken from a moving car, showing slides or photographs of the signs at different distances, having subjects walk or drive toward the signs, moving the signs toward the subjects, or by the use of computer simulation techniques. There has been little attempt to evaluate the relative effectiveness of the many techniques that are available. No doubt some are better than others, but there is no information to indicate which methods are best. There is a great need not only to compare methods but also to establish the reliability and validity of many existing techniques. However, it is not clear what the major criteria (in terms of driver performance) should be in evaluating traffic signs. Additional questions that remain unanswered concern the relative importance of such factors as attention value, legibility, and learnability in the development of a new sign.

In summary, the literature on perception of traffic signs shows many methodological problems as well as a tendency for such research to examine only one aspect of the sign recognition process. It appears that a single method will not be adequate but rather that each of the factors involved (e.g., meaning, attention value, legibility, processing time, learnability, influence on driver behavior) requires its own method of evaluation. Some combination of methods may be required to adequately evaluate a sign or signing system.

As mentioned earlier, few comparisons have been made between field tests and laboratory tests. One such experiment is that of Desrosiers (1), who conducted an experiment to validate the substitution of laboratory tests in which motion picture techniques were used for field research methods. Legibility distance was measured in a field test in which the stimuli were guide signs made to one-third the scale of the normal size for a freeway sign. The signs had destination names on them, and the subject was required to indicate when he perceived a specific target word while driving at 20 mph (32 kph)—which would simulate approaching at 60 mph (96 kph) because the signs were one-third normal size—down an unused section of freeway toward the sign. The subject's task was to indicate, by pressing a button, on which line of the sign the target name was located. The laboratory test was similar but involved a film presentation of the same signs at that particular location. Results indicated that the laboratory test and the field measure showed essentially the same trends, but the mean legibility distances were 5 to 6 times as great in the field test.

Markowitz et al. (4) report a laboratory study and a field study using the same 10 signs. The laboratory study involved the method of signal detection (in which stimuli were presented for a fraction of a second), which provides a pure measure of detectability or legibility. The field test was conducted on the road using the Senders' helmet apparatus, which occludes the driver's vision for short periods of time. Subjects were instructed to drive as fast as possible and to make no driving errors while sampling the roadway only when necessary. The signs appeared at irregular intervals along the roadway. The relative recognizability of the individual signs differed between laboratory and field trials. Two of the three most recognizable signs on the road test were among the four least recognizable of the signs in the laboratory test. The reverse holds for two of the three most recognizable signs in the laboratory test as compared with the road measure. The findings showed recognizability to be lower in the road test than in the laboratory test.

It appears, then, that laboratory tests may give somewhat different results from on-the-road measures, depending on the particular techniques used. However, more research needs to be done comparing laboratory and field techniques before a firm statement regarding their relative merits can be made.

Although laboratory methods have a number of limitations and do not represent the actual driving situation, they can be used to advantage if properly validated against adequate on-the-road measures. Laboratory experiments can be more readily controlled and are less expensive and time-consuming (unless they involve sophisticated simulation techniques). Even modified or scaled-down on-the-road measures are somewhat less expensive and time-consuming than on-the-road measures under normal driving conditions.

This paper describes three experimental techniques used in evaluating the same signs. It is part of a larger project intended to develop and compare several techniques for measuring perception of traffic signs. The techniques described involve (a) a controlled experiment conducted on the highway under normal driving conditions, (b) a modified on-the-road measure, and (c) a laboratory reaction time measure. The on-the-road method was considered to be a good technique against which to validate the other methods. The modified on-the-road technique came close to the actual driving situation but under different conditions that are less expensive and time-consuming. The reaction time study, while not intended to simulate a driving situation, was designed so that performance could be meaningfully compared to that of the other two techniques. It involved much less time and expense than the on-the-road methods.

The optimal index of the adequacy of any traffic sign is the degree to which it conveys the intended message to a driver operating a vehicle in an actual driving situation. However, since on-the-road studies are expensive and time-consuming, the development of laboratory measures validated with measures taken in a driving situation would be a major contribution to the study of traffic sign perception.

The signs for all three experiments to be reported were selected on the basis of pilot research that measured the verbal reaction time required to initiate the correct meaning of each sign. Reaction times (time between the onset of the stimulus and the activation of a voice-operated relay by speech production) to 30 sign messages were determined by having subjects verbalize the response as quickly as possible when a signal came on.

The subject was given the correct verbal response (sign meaning) to be made and instructed to produce this response as rapidly as possible whenever a red field was presented (by a slide projector), but to make no response when a green field was presented. Red and green stimulus fields were presented in a random order, with 50 percent of the stimuli being red. Ten reaction time measures were taken to each sign message. The messages were presented in a different random order for each subject, but all measures on one message were taken before the next message was presented. Ten subjects were tested, one at a time. The data were subjected to a series of analyses of variance. Following each analysis the data from the messages that gave the highest and the lowest reaction times were eliminated, and a further analysis of variance was performed on the remaining data. This procedure was followed until the analysis indicated no significant difference in reaction time between the sign messages. In this manner signs were chosen whose verbal reaction times did not differ, thus eliminating the possibility that the data from certain stimuli might be influenced by the time taken to produce the verbal response.

The results of each experiment will be presented individually following its description. However, discussion of the results and comparison of the methods will be delayed until all three experiments have been reported.

EXPERIMENT 1

Purpose

The purpose of the first experiment was to determine the distance at which subjects could classify traffic signs as being one of two types (regulatory or warning) and the distance at which they could identify the meaning of the signs while driving on a highway under normal traffic conditions.

Method

Subjects—The subjects were 16 volunteers (8 males and 8 females) with a minimum of 5 years' driving experience and ranging in age from 20 to 36 years, with a mean of 25.8 years. Each subject was paid $10 for participating in the experiment.

Stimuli—Sixteen regulation-size traffic signs (obtained from the City of Calgary Traffic Engineering Department) were used as stimuli. Their dimensions were 24 by 30 in. (61 by 76 cm) for white, rectangular regulatory signs or 30 by 30 in. (76 by 76 cm) for yellow diamond warning signs. In addition, the messages on half of the signs of each class were symbolic, while the other half were verbal. The specific sign messages are given in Table 1.

Procedure

The experiment was conducted on a flat, straight stretch of 2-lane, paved, undivided highway with a wide shoulder. The signs were placed at either end of a stretch of highway 5,315 ft (1,620 m) in length, each end of which was marked by a ¾-in. (1.9-cm) nylon rope stretched across the pavement. This rope served as a reference point from which to calculate the distances. As the vehicle was driven by the subject over the rope, the sound inside the vehicle was used as a signal for the experimenter to activate a distance-measuring device. At each end of the stretch of highway there was an acceleration-deceleration zone approximately 800 ft (244 m) in length, and at the end of this zone was a roadway where the subject could turn the vehicle around.

The signs were mounted on poles so that the bottom of the sign was 7 ft (2.13 m) above the highway. They were placed 1 ft (0.3 m) from the right edge of the paved shoulder, 10 ft (3 m) from the outside edge of the driving lane. The signs were attached to the poles so that they could be removed and replaced quickly. Stimuli were placed at both ends (north and south) of the stretch of highway so that the subject could be tested while driving in each direction. The stimuli were presented in a predetermined random order in blocks of 16 trials, with half of the signs viewed by the subject while traveling north and the remainder viewed while traveling south (each sign was viewed once during each block of trials). Four blocks of 16 trials were administered, with a 5-minute rest between each block, during which the locations of the signs (north or south end) were changed in accordance with the predetermined random order in preparation for the next block of trials.

Before the experiment began, each subject was given approximately 20 minutes' experience operating the vehicle (a 1970 Kingswood model Chevrolet stationwagon with power steering, power brakes, and automatic shift). In addition, the subject read the instructions that outlined the experimental procedure, was shown all of the signs to be used in the experiment, and was given the correct verbal response to be made in identifying each sign, as well as the correct classification for each sign.

The subject was required to make two verbal responses during each trial as he drove toward the sign, first to classify it as warning or regulatory and second to indicate its meaning as soon as it was legible. Distances were measured to the nearest

Table 1. Mean distances in feet (experiments 1 and 2) and reaction time in milliseconds (experiment 3) for individual signs under each task and speed condition.

Sign and Message Type	Message	Experiment 1 Classification 30 mph	Experiment 1 Classification 50 mph	Experiment 1 Identification 30 mph	Experiment 1 Identification 50 mph	Experiment 2 Classification, 17 mph	Experiment 2 Identification, 17 mph	Experiment 3 Classification 30 mph[a]	Experiment 3 Classification 50 mph	Experiment 3 Identification 30 mph	Experiment 3 Identification 50 mph
Warning, symbolic	Winding Road	3,004.5	2,878.5	1,029.5	1,003.7	831.7	331.2	513.7	521.2	878.1	861.4
	Hill	2,696.8	2,621.3	1,068.2	1,126.1	704.7	284.6	543.3	520.9	876.0	903.3
	Bump	2,899.7	3,080.2	953.0	1,019.2	863.8	286.9	541.6	512.0	787.9	801.3
	Pavement Ends	3,578.0	2,927.2	946.0	864.9	878.7	237.3	551.6	554.2	886.2	958.6
	Men Working							531.7	539.8	772.5	820.7
Warning, verbal	Yield Ahead	3,234.6	3,022.0	596.8	521.3	861.0	140.4	535.8	504.8	657.3	912.8
	Pavement Narrows	2,927.7	3,234.5	410.7	416.2	877.7	98.4	534.0	508.3	773.7	1,030.3
	Soft Shoulder	3,280.8	3,130.6	581.5	555.2	878.6	187.3	546.0	528.9	734.6	979.6
	Fresh Oil	3,210.9	3,075.4	599.3	497.0	934.7	136.1	548.9	526.8	687.3	886.5
	One Lane							542.7	518.3	683.2	873.7
Regulatory, symbolic	No Right Turn	2,540.0	2,781.6	700.4	779.3	694.2	208.7	646.3	596.2	1,036.0	1,048.8
	No U Turn	2,726.3	2,597.5	726.5	764.8	645.1	200.6	568.7	549.4	851.1	876.4
	No Trucks	2,781.9	2,885.7	725.4	675.0	663.3	173.0	541.7	542.4	866.1	905.0
	Turn	2,909.1	2,579.2	721.9	672.7	769.7	196.4	614.6	556.9	1,012.5	1,068.4
	No Stopping							592.8	572.1	926.8	915.1
Regulatory, verbal	No Left Turn	2,638.0	2,868.3	555.3	510.4	610.8	128.5	564.5	575.8	730.0	939.4
	No Parking	3,131.4	3,373.7	486.8	473.9	775.9	106.4	580.6	559.0	763.9	976.1
	Two Way Traffic[b]	3,222.5	3,004.2	443.5	410.4	774.2	121.8	633.1	625.6	781.4	977.2
	Do Not Pass	2,482.3	2,761.3	530.4	521.8	653.1	125.3	579.0	563.2	684.6	888.2
	No Turns							584.1	559.5	652.9	866.9

Note: 1 ft = 0.3048 m.

[a]The speed variable in experiment 3 refers to sign size, 30 mph being the large-sign condition.

[b]The message "Do Not Enter" was used in experiment 3.

Table 2. Partial summary of analyses of variance results for all factors that were statistically significant in any of the three experiments.

Variable	Experiment 1 F	Experiment 1 df	Experiment 1 p	Experiment 2 F	Experiment 2 df	Experiment 2 p	Experiment 3 F	Experiment 3 df	Experiment 3 p
Speed[a] (S)	1.31	1,15	NS	n.a.			4.86	1,28	<0.05
Direction (D)	16.44	1,15	<0.005	2.48	1,15	NS	n.a.		
Sign type (ST)	37.18	1,15	<0.001	96.78	1,15	<0.001	64.15	1,28	<0.001
Message type (MT)	45.07	1,15	<0.001	18.37	1,15	<0.001	22.70	1,28	<0.001
Task (T)	259.18	1,15	<0.001	154.78	1,15	<0.001	410.66	1,28	<0.001
S × D	0.85	1,15	NS	n.a.			n.a.		
S × ST	0.48	1,15	NS	n.a.			0.17	1,28	NS
S × MT	0.21	1,15	NS	n.a.			35.78	1,28	<0.001
S × T	1.32	1,15	NS	n.a.			23.05	1,28	<0.001
D × ST	11.96	1,15	<0.005	8.36	1,15	<0.025	n.a.		
D × MT	0.49	1,15	NS	1.67	1,15	NS	n.a.		
D × T	19.23	1,15	<0.001	2.33	1,15	NS	n.a.		
ST × MT	22.05	1,15	<0.001	29.97	1,15	<0.001	26.86	1,28	<0.001
ST × T	3.34	1,15	NS	33.78	1,15	<0.001	0.03	1,28	NS
MT × T	142.89	1,15	<0.001	61.58	1,15	<0.001	19.94	1,28	<0.001
D × ST × T	13.58	1,15	<0.005	12.36	1,15	<0.005	n.a.		
ST × MT × T	6.95	1,15	<0.025	11.82	1,15	<0.005	47.28	1,28	<0.001
S × MT × T	0.04	1,15	NS	n.a.			27.48	1,28	<0.001
S × ST × MT × T	0.19	1,15	NS	n.a.			6.14	1,28	<0.025

Note: NS = not significant; n.a. = not applicable.

[a]Sign size in experiment 3.

foot by a Numetric Distance Measuring Instrument (DMI) model Number P-140. An experimenter in the vehicle beside the subject recorded the distance from the beginning of the stretch of highway to the point at which the subject classified the sign. This distance was subtracted from the total distance to obtain the distance required to classify the sign. The distance between the sign and the point at which the subject indicated the sign meaning to the experimenter was the identification distance for that sign. A specified speed was maintained over the entire distance during each trial. When the sign was passed the subject slowed the vehicle, turned around at the end of the acceleration-deceleration zone, and started in the opposite direction for the next trial. After the subject had driven past the sign in the other direction an experimenter replaced the sign with a new one for the next trial. Each subject viewed each sign four times, twice while driving at 30 mph (48 kph) and twice at 50 mph (81 kph). Each block of trials was administered at one speed only, the order of the speeds being randomly determined. The total length of time required to complete the experiment was approximately 3 hours.

Results

Table 1 gives the mean classification distance and identification distance for each sign at each speed. The data were subjected to a 5-way analysis of variance (Table 2) involving the following variables: speed (30 mph, 50 mph), direction (north, south), sign type (regulatory, warning), message type (symbolic, verbal), and task (classification, identification).

EXPERIMENT 2

Purpose

This experiment was designed to measure classification and identification distances of "miniature" traffic signs (one-third the size of those used in experiment 1) for subjects driving at one-third of the fast speed used in experiment 1—17 mph (27 kph).

Method

Subjects—The subjects were 16 volunteers (8 males and 8 females) obtained from the same population as those used in experiment 1. Their ages ranged from 19 to 35 years, with a mean of 25.8. Each subject was paid $2 for participating in the experiment.

Stimuli—The same 16 messages used in experiment 1 were used in this experiment; however, the signs were one-third of the size of those used in the preceding experiment—either 8 by 10 in. or 10 by 10 in. (20.3 by 25.4 cm or 25.4 by 25.4 cm). They were made of the same material and in exactly the same manner as the regulation signs (including Scotchlite reflective material).

Procedure

The procedure was essentially a replication of that used in experiment 1 with the following exceptions: The circuit was 1,110 ft (338.4 m) in length and was laid out on an unused roadway, 600 ft (183 m) of which was paved and 510 ft (155 m) of which was oiled gravel. This straight, level roadway ran north and south. Subjects drove the same vehicle as used in experiment 1 at 17 mph (27 kph). The signs were mounted so that the bottom of each was 28 in. (71 cm) from the ground. Subjects viewed each sign twice and were required to indicate the distance at which they could classify the sign and the distance at which they could identify it. The total time taken to conduct this experiment was approximately 50 minutes.

Results

The mean distances at which each sign could be classified and identified are given in Table 1. The data were subjected to a 4-way analysis of variance (direction × sign type × message type × task) as shown in Table 2.

EXPERIMENT 3

Purpose

The purpose of this experiment was to determine the verbal reaction time required to classify and to identify traffic signs of different types (warning and regulatory) and message forms (symbolic and verbal).

Method

Subjects—Fifteen male and 15 female volunteers (with at least 5 years' driving experience) participated in the experiment. Their average age was 26.8 years, with a range from 19 to 62. Each subject was paid $2 for participating.

Stimuli—The stimuli were 26 slides of traffic signs rear-projected onto a screen. Six of the stimuli were information signs (3 symbolic and 3 verbal, green or blue in color) and the remainder were warning or regulatory with either symbolic or verbal messages (5 of each combination). Fifteen of these were the same as those in experiments 1 and 2.

Procedure

The subject was seated in a dark vision tunnel 30 ft (9.2 m) from a rear-projection screen onto which was projected the image of the traffic sign. The subject performed two tasks—classification and identification. Half of the subjects performed the classification task first; half did the identification task first. For the former task, the subject was required to indicate as quickly as possible after the stimulus came on by responding "yes" if it was either a warning or a regulatory sign. No response was to be made if the stimulus was an information sign. The identification task involved the subject's replying with the verbal meaning of the sign as rapidly as possible. Verbal reaction times were measured to the nearest millisecond (by means of a Hunter timer) from the onset of the stimulus to the activation of a voice key. Each stimulus was presented for 2 seconds, followed by a 1.5-second interstimulus interval. Subjects were informed that the click of the projector as the slide changed would occur approximately ½ second before each slide appeared and that this was to serve as a preparatory signal. The stimuli were presented in random order in 5 blocks of 26 trials, with each sign appearing once in each block of trials. Each block of trials was presented in a different random order. Subjects were given a 30-second rest between blocks of trials while the experimenter changed slide trays for the next block. The first block served as practice trials, although subjects were not told this. Before the experiment began the subjects were shown all signs (one at a time) and told their classification and the correct response to make when identifying each.

Subjects were randomly assigned to one of two groups. One group was shown small signs, whose visual image on the retina corresponded to that which would be formed by a regulation traffic sign at a distance of 193 ft (59 m), the approximate stopping distance for a car traveling at 50 mph (81 kph) under optimal conditions. The other group of subjects viewed a larger stimulus, which projected a visual angle on the retina corresponding to that which would be formed by a regulation traffic sign at a distance of 83 ft (25.3 m), the approximate stopping distance for a car at 30 mph (48 kph) under optimal conditions.

Subjects were encouraged to respond as rapidly as possible, yet make as few errors as possible. Data from subjects whose error rate was greater than 5 percent were not used. The experiment took approximately 1 hour.

Results

The mean reaction times for each of the 20 signs of primary interest (warning and regulatory) under each condition are given in Table 1. A 4-way analysis of variance (sign size × sign type × message type × task) was performed on the data (Table 2).

COMPARISON OF RESULTS FROM THE DIFFERENT METHODS

The significant interactions of primary interest are shown in Figures 1, 2, and 3. It can be seen that the trends are similar across the different techniques. The statistical significance levels (as indicated by the analyses of variance) for each of the main effects and the two-way interactions, as well as the other interactions that were significant in any of the three experiments, are given in Table 2.

In summarizing the main findings, the term "better performance" will refer to greater classification distance, greater identification distance, and smaller reaction time. It can be seen that performance was better on the warning signs as compared with regulatory signs in all three experiments. Symbols were identified better than verbal signs in the two roadway experiments, but not in the reaction time study. This discrepancy between the laboratory study and the other two field experiments can best be explained in terms of the type of response. A verbal response to a verbal message would be expected to be faster than a verbal response to a symbolic message, since the latter involves the additional process of translating the stimulus meaning into a verbal form for response. The classification measure was better than the identification measure in all three experiments, as would be expected, since classification requires less information than does identification. The interaction between direction of travel and sign type, which was significant in both field studies, indicated that the regulatory signs were seen relatively better at the north end of the stretch of roadway. This may have been because the signs at the north end were facing the sun, and the white regulatory signs were possibly more dependent on bright illumination for easy detection than were the yellow warning signs. The interaction between sign type and message type was significant ($p < 0.001$) in all three experiments. Performance was relatively better for warning signs when they were symbolic than when they were verbal.

On the basis of the comparison of the data from all three experiments, it can be seen that there is a considerable similarity across the three techniques. In addition to the findings based on the analyses of variance, the rank order correlations of the measures obtained across the different experiments were found to be high (Table 3). The correlations for the classification task indicate a direct relationship between distances in experiments 1 and 2. The negative correlations between the experiment 3 measures and the distance measures indicate that signs classified at greater distances tend to be classified more rapidly. The correlations from the identification task follow a similar pattern except for those involving experiment 3 at 30 mph (48 kph)—the larger slides. When all 16 signs are considered in the calculations the correlations are positive and highly significant ($p < 0.01$). The reason for this appears to be that the verbal signs had lower reaction times and smaller legibility distances than did the symbolic signs, and the symbolic signs had higher reaction times and longer legibility distances than the verbal signs. Hence an overall correlation was positive. However, when the correlations were calculated separately for symbolic and for verbal signs, in all four cases the correlations were negative (but insignificant, primarily because of the small N).

In view of the results obtained from these three methods, it can be tentatively concluded that similar information about the relative adequacy of warning and regulatory traffic signs can be obtained from a reaction time experiment and from a modified field technique as from an on-the-road measure under normal driving conditions.

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Figure 1. Classification distance, identification distance, and verbal reaction time as a function of task and message type.

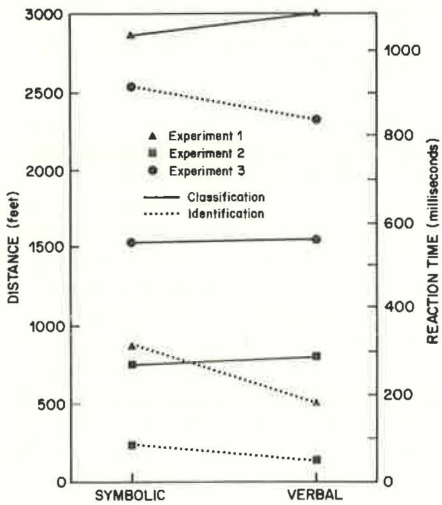

Figure 2. Classification and identification distance (combined) and verbal reaction time as a function of sign type and message type.

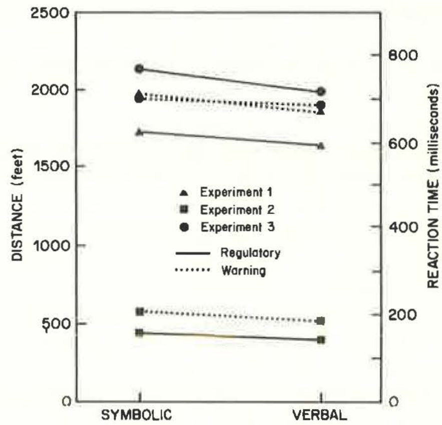

Figure 3. Classification and identification distance (combined) as a function of sign type and direction of travel.

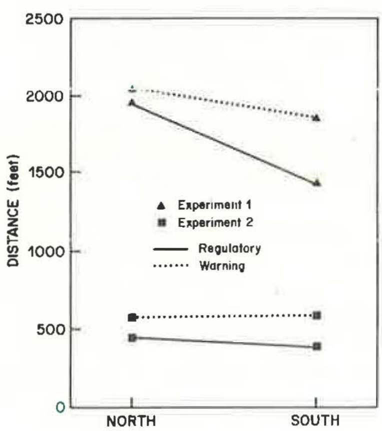

Table 3. Spearman rank correlations between selected measures of sign perception.

Task	Measures Correlated[a]	No. of Signs	r	p
Classification	1 (30)–2	16	0.82	<0.01
	1 (50)–2	16	0.77	<0.01
	1 (30)–3 (30)	15	-0.43	<0.06
	1 (50)–3 (50)	15	-0.58	<0.05
	2–3 (30)	15	-0.50	<0.05
	2–3 (50)	15	-0.49	<0.05
Identification	1 (30)–2	16	0.94	<0.01
	1 (50)–2	16	0.95	<0.01
	1 (30)–3 (30)	15	0.65	<0.01
	1 (50)–3 (50)	15	-0.38	NS
	2–3 (30)	15	0.67	<0.01
	2–3 (50)	15	-0.36	NS

[a]Measures are indicated by experiment number and condition; e.g., 1 (30) means experiment 1, 30-mph condition.

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