Network Representation of Performance Analysis for Intersections

CHRIS HENDRICKSON, CARLOS ZOZAYA-GOROSTIZA, AND SUE MCNEIL

Network representations of performance analysis parameters and relationships are described. In these models, nodes represent variables or other information and links represent relationships. The intersection performance analysis procedures implicit in the *Highway Capacity Manual* are formalized as an example of a network representation. These representations make use of semantic net and frame representations originally developed in the field of artificial intelligence. The purposes of network representations of analysis procedures are (1) to aid flexible, computer-based implementations; (2) to facilitate interpretation of results; and (3) to provide a check on the completeness and uniqueness of particular analysis procedures. For computer-aided analysis and design, these representations provide a means to provide localized or variable specific representation of "intelligent" solution schemes.

Performance analysis for many transportation facilities is complicated by the numerous design characteristics, facility attributes, and measures of effectiveness involved. For example, the evaluation of the performance of an intersection may involve over a hundred separate parameters representing input data, intermediate analysis results, and desired final results. In this paper, we discuss network representations of analytical relationships and procedures. These network representations can provide procedural information for analysis, aid in the interpretation of performance, and serve as a check on analysis aids. They can also serve as representational and analytical building blocks for knowledge-based expert systems. As an example of network representation, we formalize the intersection performance analysis procedures implicit in the *Highway Capacity Manual* (*1*).

We employ two types of network representations of analysis procedures. First, semantic networks or nets represent problem parameters as nodes and relationships as links among these parameters (*2*). In this representation, additional information about link relationships may also be recorded, such as restrictions on the existence of more than one relationship at a time. Second, frame representations provide facilities for storing information about a particular entity as well as links among the different entities (*3*). In our representations, frames can represent particular variables, equations, or higher-level abstractions about the facility performance. The two representations are similar in that frames represent a compact summary of portions of semantic nets. Thus, a frame representation can be generalized into a semantic net if desired. Our frame representation also contains solution information specific to each variable. A third possible representation scheme would be to apply object oriented programming, but this representation is not pursued here (*4*).

Of course, the representation of analysis procedures does not add any new information to the process. However, existing representations typically do not explicitly provide all relevant information. In mathematical or algebraic summaries of relationships, solution procedures are often not formally recorded. Furthermore, constraints to assure meaningful results are often not formally applied; for example, consistency in units of measure can be imposed. Moreover, appropriate analysis procedures may be difficult to represent algebraically. In procedural summaries, such as the tables contained in the *Highway Capacity Manual*, only one set of inputs and outputs is typically described. In many practical analysis cases, a designer may wish to alter the standard analysis procedures to constrain a normal output value or to allow a normal output parameter to be an input. In a network representation, these variations can be accommodated by altering the fashion in which network traversal occurs. As a result, computer aids based on network representations are more flexible in application. Finally, construction of analysis networks serves to insure completeness and uniqueness in the problem and solution description.

Signalized intersections were chosen as an example application because of the complexity of the problem, its considerable practical significance, and the existence of extensive knowledge about intersection analysis. Signalized intersection analysis considers a wide variety of factors, such as geometric characteristics, levels of service, traffic flow volumes and compositions, and signal timing. Analysis procedures typically require a hierarchical application of design decisions and calculations (*5*). Although detailed methodologies for capacity analysis and levels of service determination have been developed (*1*), intersection design is still a complex task because of the many interactions among the design variables.

In the next section, the use of network representations is introduced. Following this, the analysis procedures for signalized intersections contained in Chapter 9 of the *Highway Capacity Manual* are formalized as an example. The following section illustrates the use of the network representation in several example analyses. The final section discusses the merits of alternative procedural representations. The notation used in this paper is listed at its end.

SEMANTIC NETS AND FRAME REPRESENTATIONS

Semantic nets provide a useful model to represent relations among variables of any kind (*6*). In semantic nets, nodes are

C. Hendrickson and C. Zozaya-Gorostiza, Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pa. 15213. S. McNeil, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Mass. 02139.

used to represent variables or values, and links are used to represent relationships. Figure 1 shows some possible node-to-node relations that may occur in the semantic net of an analysis problem. Another type of relation in the semantic net is link-to-link relations. Figure 2 shows some possible link-to-link relations that may occur in a semantic net. Node-to-node and link-to-link relations may vary during the solution process. In particular, the direction of a link in the semantic net depends on the methodology used to solve a specific problem. For example, in certain types of problems V2 has to be determined before V1, and in other problems the order is reversed.

Finally, constraints are relations bound to groups of variables. A constraint might represent a functional relationship among the different variables involved in an equation. Figure 3 shows some alternative semantic net representations for the following simple equation:

$$N * W = TW$$

where

N = number of lanes in an approach,
W = width of each lane in the approach, and
TW = total width of the approach.

Instances 1 and 2 represent the cases where the total width of the approach is a fixed input variable. In this case, design variables W and N are inversely proportional to each other. Instance 3 represents the case where TW is calculated directly from N and W.

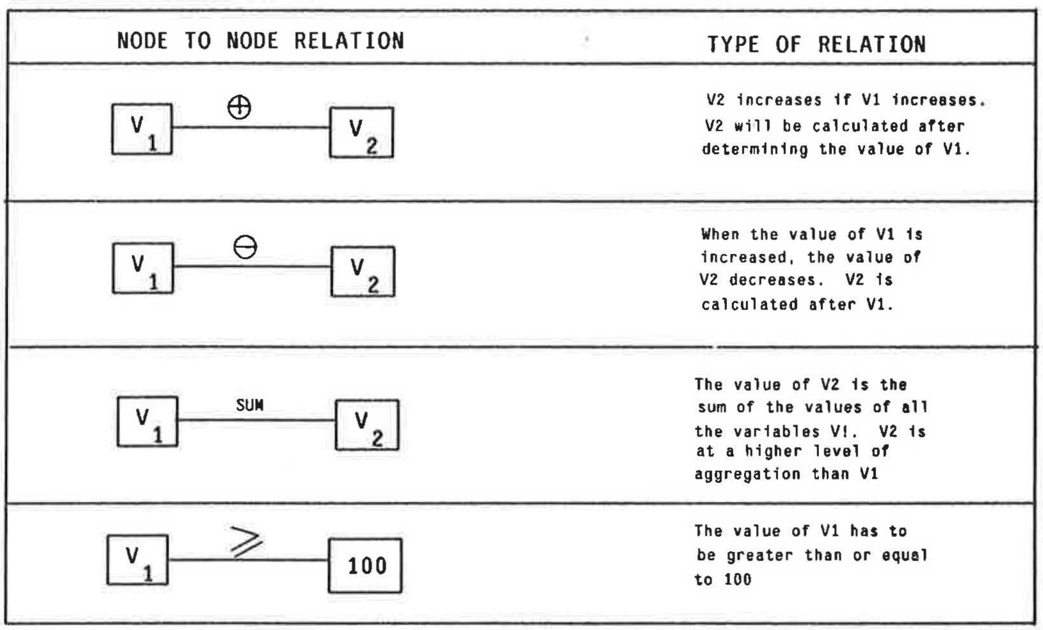


FIGURE 1 Example of node-to-node relations in a semantic net.

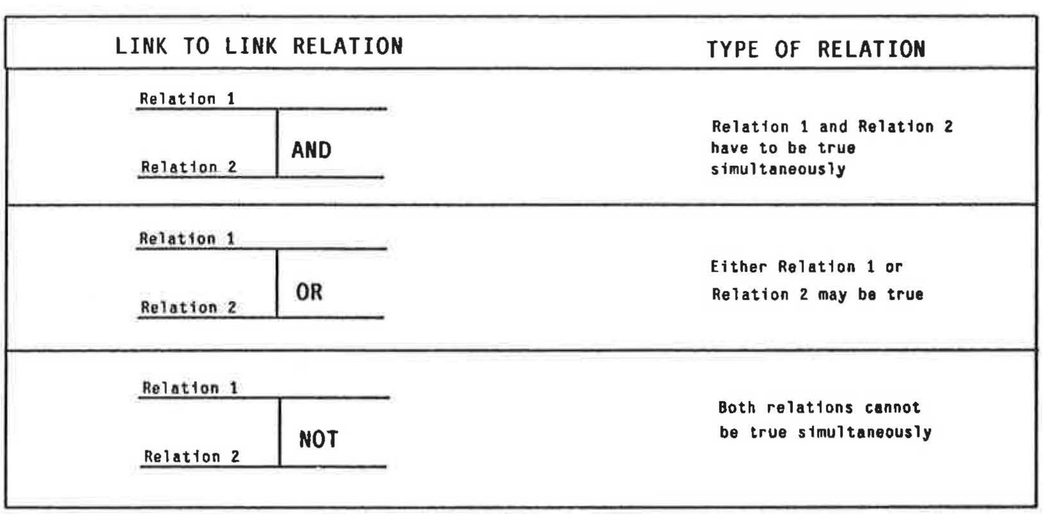


FIGURE 2 Example of link-to-link relations in a semantic net.

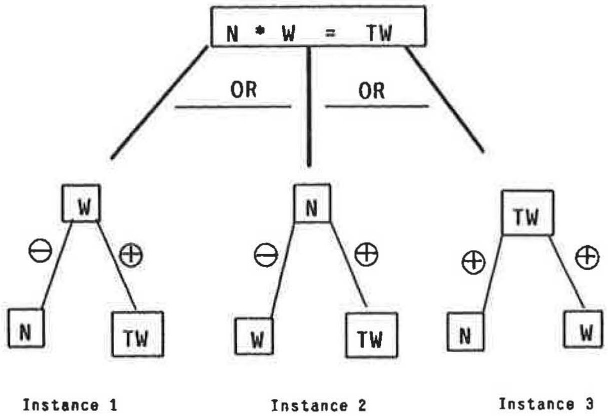


FIGURE 3 Example of a functional relationship involving three variables.

With a semantic network representation scheme, a particular network can represent the general possible relationships or a specific realization, as illustrated in Figure 3. It would be desirable to have a design system capable of generating any of the possible instances of a functional relationship depending on the characteristics of a specific design problem. Figure 4 shows a generic semantic net for the problem in consideration. Instance 1 would be generated as follows. First, the system identifies *W* as a calculated output variable. Then it backtracks to see what variables may be used to obtain *W*. The only possibility is to obtain it using *N* and *TW*. Both of these are input variables, so instance 1 has been fully created.

Constraints may also be used to represent relations among variables at different levels of aggregation. For example, in single-lane approaches the following condition is true: *Flow turns and lane turns must be compatible*. In other words, a flow may only have turn movements that are included in the allowable turn movements for the lane. A left-turn lane cannot have through or right-turn flows. Figure 5 represents the generic semantic net for this constraint. In this example, the object *flow* is more specific than the object *lane*. A lane may have more than one flow, but a flow is in only one lane.

In a complicated analytical problem such as intersection analysis, flexibility in the representation of relationships and equations is very important. As a result, simple types of link relationships such as those shown in Figure 4 will be insufficient. Several alternatives for explicit representation of equations exist. As one possibility, the software package TK!Solver™ uses "R-graph" representations in which the

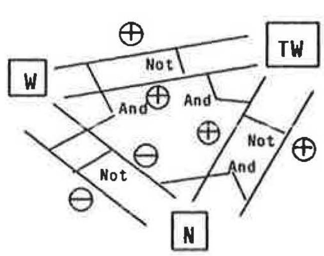


FIGURE 4 Generic semantic net for an equation with three variables.

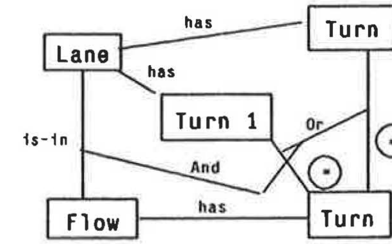


FIGURE 5 Generic semantic net for the constraint relating flow turns and lane turns.

polygonal area of a semantic network surrounding the variables in an equation is associated with additional information (7). With this representation, the program TK!Solver has the capability for automatically generating the solution trees shown in Figure 3. More generally, frames can be used to represent both variables and relationships among variables.

Frames are a general purpose data representation scheme in which information is arranged in "slots" within a named frame. Slots may contain lists, values, text, procedural statements (such as calculation rules), pointers, or other entities. Inheritance and reference to values in other frames is permissible within any slot. Slot functions called "demons" (or daemons) can be used to compute the value of the unknown variables. In addition, full rule sets can be added in slots to provide a local expert system specifically for solution of particular variable values. For example, separate rules could be added in a variable frame slot to indicate when and how the variable could be calculated. Constraints on calculations can also be imposed in these rulesets to insure appropriate ranges of variables, consistent units, etc. Particular calculation rules are only instantiated (or "fired") when the necessary other variable values are available. As a result, intelligent variable frames can be developed that include solution information within the local variable frames. The result would be an extremely flexible analysis system. This representation system should also be amenable to parallel processing on a network of computers.

As a small example of this representation, Figure 6 shows a frame representation of the relationships among the variables *N*, *W*, and *TW* presented earlier. In this representation, each equation's variables is represented as a frame with the following slots:

- (*is-a*) and (*has-children*). These slots are used to specify the other variables that are related with the variable of the frame. Inheritance of values and attributes can be accomplished via such slots, although it is not used here.
- (*current-value*). This slot contains the current value of the variable. The variable may have been calculated or given by the user. This slot also contains the facet (*if-needed*), which has a demon that is fired when a value for the variable is requested. This function calculates the value of each variable if the other defined variables are known.
- (*source-value*). This slot specifies how the value of the variable was obtained. Two values for this slot are possible: input or calculated.

Whenever two variable values are input into this system, the (*if-needed*) demon is invoked to calculate the third. As a

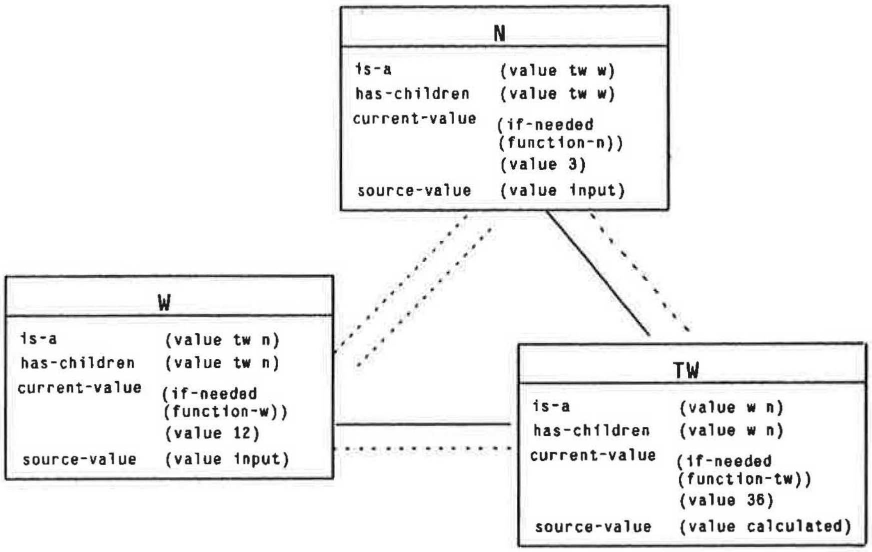


FIGURE 6 Example of a simple frame representation.

result, no control strategy is required to perform analysis in this case since the solution calculation will propagate through the frames automatically.

As noted above, a more general representation would replace the single calculation demon contained in the *(current-value)* slot with a series of calculation or solution rules, with one rule available for each equation in which the variable appears. Rather than simply cycling through all the rulesets to identify available calculation rules, it is also possible to impose a control strategy to search the most likely calculations first. A procedure for guessing at likely values and iteratively solving simultaneous equation sets might also be imposed, as in TK!Solver.

USING SEMANTIC NETS FOR INTERSECTION ANALYSIS

Typical Analysis Problems

The *Highway Capacity Manual* considers four types of components in any design problem of a signalized intersection: service flow rates, geometric design characteristics, signalization conditions, and levels of service. Operational analysis methodologies are used for determining the value of any of these four components when the other three components are known. Figure 7 presents the four typical intersection design problems:

1. Solve for levels of service. Service flow rates, geometric characteristics, and signalization conditions are given to the system. The system directly computes stopped delays for each lane group. Levels of service are obtained using Table 9-1 of the manual, where the level of service criterion is defined as a function of the stopped delay.
2. Solve for allowable service flow rates. Geometric characteristics, signalization conditions, and desired levels of service are given to the system. The system performs an iterative procedure for determining service flow rates that accomplish the desired levels of service. The system may have to try alternative lane group definitions in order to satisfy the design requirements.
3. Solve for signal timing. Geometric characteristics, service flow rates, and desired levels of service are given to the system. Alternative phase distributions and cycle lengths are tested in order to accomplish the desired levels of service.
4. Solve for geometric characteristics. Service flow rates, signal timing, and desired levels of service are given to the system. The system tests alternative geometric characteristics by changing the number or the allocation of lanes in the approaches, in order to satisfy the desired levels of service.

Identifying these four typical intersection design problems is useful to conceptualize mutual relationships among the different design variables. However, implementation of a flexible system capable of applying operational methodologies in any of the four cases is not straightforward. Moreover, a practical intersection design problem may have combinations of the typical design problems described above. For example, a common design problem is to solve for signal timings and geometric characteristics. Alternatively, the user may want to specify a desired level of service for the whole intersection and let the system compute the levels of service of the different approaches. A similar situation would occur when the number and width of the lanes in only one of the approaches may be changed. For both cases, classification of the design variables according to different levels of aggregation is required for solving the problem. In this paper, we shall restrict our attention to the more straightforward analysis problems associated with identifying levels of service.

During the design process, interactions among different subproblems may change dynamically. It is important to identify each subproblem by classifying the design variables related with it. A design variable may be classified with respect to any of these criteria: aggregation level, type of variable, and design condition. The three criteria are required in order to

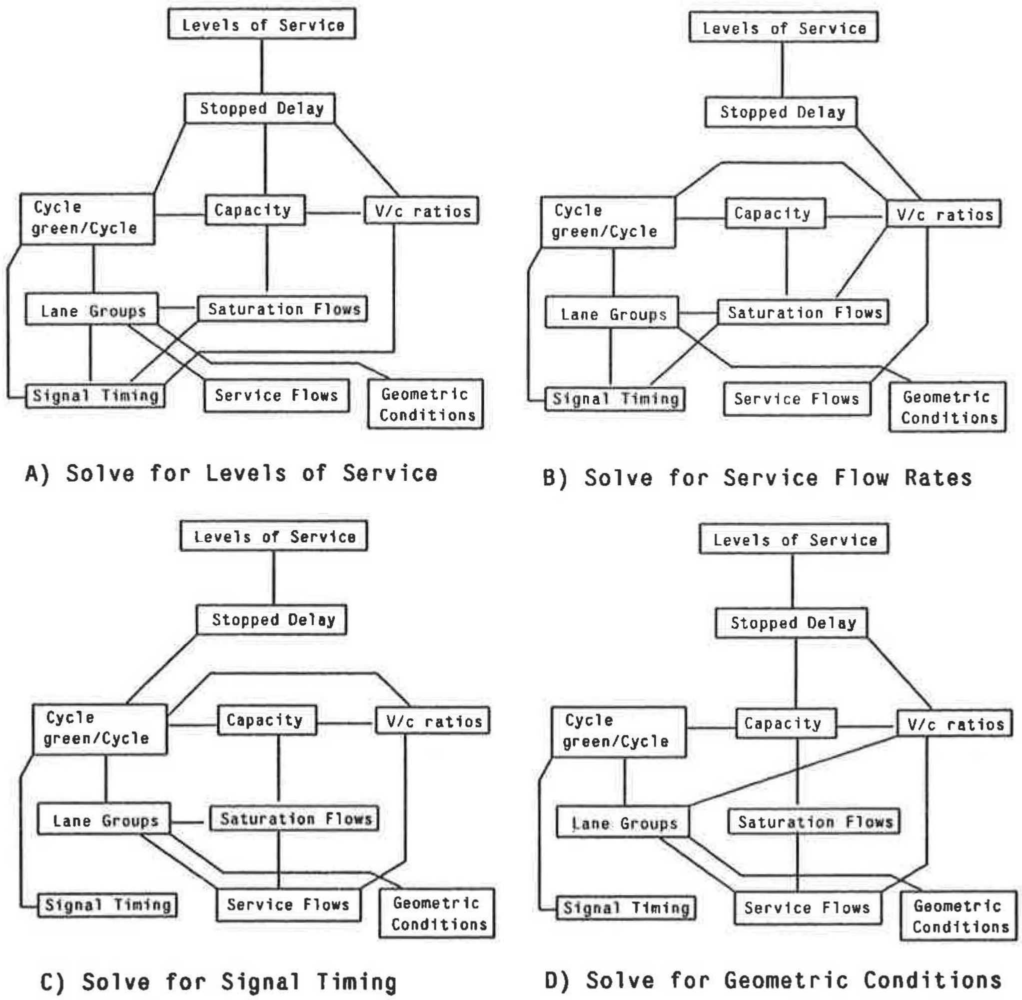


FIGURE 7 Four typical intersection design problems.

have a full classification of a specific design variable. Classification of a design variable may change during the design process.

With regard to aggregation, each design variable may appear at a particular level:

- Intersection.—The design variable has a unique value for the whole intersection. Examples of these variables are the total delay at the intersection, the critical volume/capacity ratio and the type of area (CBD or other) where the intersection is located.
- Approach.—The design variable has a value for each approach of the intersection. Examples of these variables are the number of lanes, the width of these lanes, and the total approach volumes.
- Phase.—The design variable has a value for each phase of the signal cycle. Examples of these variables are the available green time and the red plus yellow time for each phase.
- Lane group.—The design variable has a value for each lane group of the intersection. Examples of these variables are the saturation flow, the average delay, and the opposing volume for each lane group. Lane groups are used to join one or more flow movements of the same approach. A lane group may be in one or more phases. The latter case is called a "phase overlapping" situation.

In addition to the aggregation level, a design variable may be of any of the following types:

- Geometric.—The variable is used to describe a geometric characteristic of the intersection. Examples of these variables are the lane widths, the approach angles and the number of lanes in each approach.
- Signalization.—The variable is used to describe the operation of the traffic light signal. Examples of these variables are the cycle length and the total lost time.
- Traffic condition.—The variable is used to describe a characteristic of a traffic movement. Examples of these variables are the percentage of heavy vehicles and the flow volumes.
- Levels of service.—The variable is used to describe the service that a design alternative provides to a group of flows. Examples of these variables are the average delay for each lane group and the average delay for the intersection.

Finally, design conditions can be used to describe the status of a design variable during the design process. A variable may be any of these design conditions:

- Fixed input.—The value of the variable may not be altered during the design process.
- Design input.—The user has given explicitly a value to the variable.
- Assumed input.—A value has been assumed for the design variable due to lack of additional information.
- Desired output.—The user has expressed explicitly bounds for the value that he or she wants for the design variable.
- Calculated Output.—The value of the variable is calculated using formulas or tables.

Table 1 shows the classification of some design variables for a specific design problem to determine the intersection level of service. Design conditions vary depending on the type of design problem under consideration.

Functional Relationships for Intersection Analysis

A detailed methodology for determining capacities and levels of service in signalized intersections is given in Chapter 9 of the *Highway Capacity Manual*. The methodology corresponds to Case A of Figure 7, in which geometric characteristics, traffic conditions, and signalization timing are known and the goal is to determine levels of service. The portions of the semantic net that will be shown correspond to this particular problem. We shall summarize these relationships with respect to the four levels of aggregation, corresponding to variables and relationships at the lane group level, the approach level, the phase level, and finally at the intersection level. Notation used in the representation is summarized below.

Lane Group Level

Figure 8 presents the functional relationships among different lane group variables and the corresponding semantic nets that may be used to represent them. These semantic nets are particular instances of generic semantic nets, similar to those shown in Figure 3. In the figure, boundaries are used to separate variables at different levels of aggregation. For example, in the first equation, the capacity (C) and the saturation flow (S) are both at the lane group level of aggregation, while the fraction of green time ($g/Cycle$) is at the phase level of aggregation.

Determination of f_{rt} and f_{lt} is done using tables for each of the eight possible types of lane groups: (1) exclusive lane with protected phase, (2) exclusive lane with permitted phase, (3) exclusive lane with protected and permitted phases, (4) shared lane with protected phase, (5) shared lane with permitted phase, (6) shared lane with protected and permitted phases, (7) single lane, and (8) double exclusive lane with protected phase. However, in all tables f_{rt} is inversely proportional to the pedestrian volume ($PEDS$) and to the percentage of right turns (P_{rt}). Similarly, f_{lt} is inversely proportional to the opposing volume (V_o) and to the percentage of left turns (P_{lt}).

Approach Level

Figure 9 shows some functional relationships that occur among design variables at the approach level of aggregation.

Phase Level

Figure 10 shows the functional relationship among the minimum green time in a phase and the green time, walking distance, total red time, and total lost time.

Intersection Level

Figure 11 shows some functional relationships occurring among variables at the intersection level of aggregation.

Example of a Semantic Net

In the previous section we gave representations of some functional relationships among design variables of signalized inter-

TABLE 1 CLASSIFICATION OF SOME DESIGN VARIABLES

Design Variable	Symbol	Aggregation Level	Type	Design Condition
Lane Width	W	Lane Group	Geometric	Design Input
Level of Service	LOS	Intersection	Level of Service	Desired Output
Level of Service	LOS	Lane Group	Level of Service	Calculated Output
% Heavy Vehicles	% HV	Approach	Traffic Condition	State of Nature

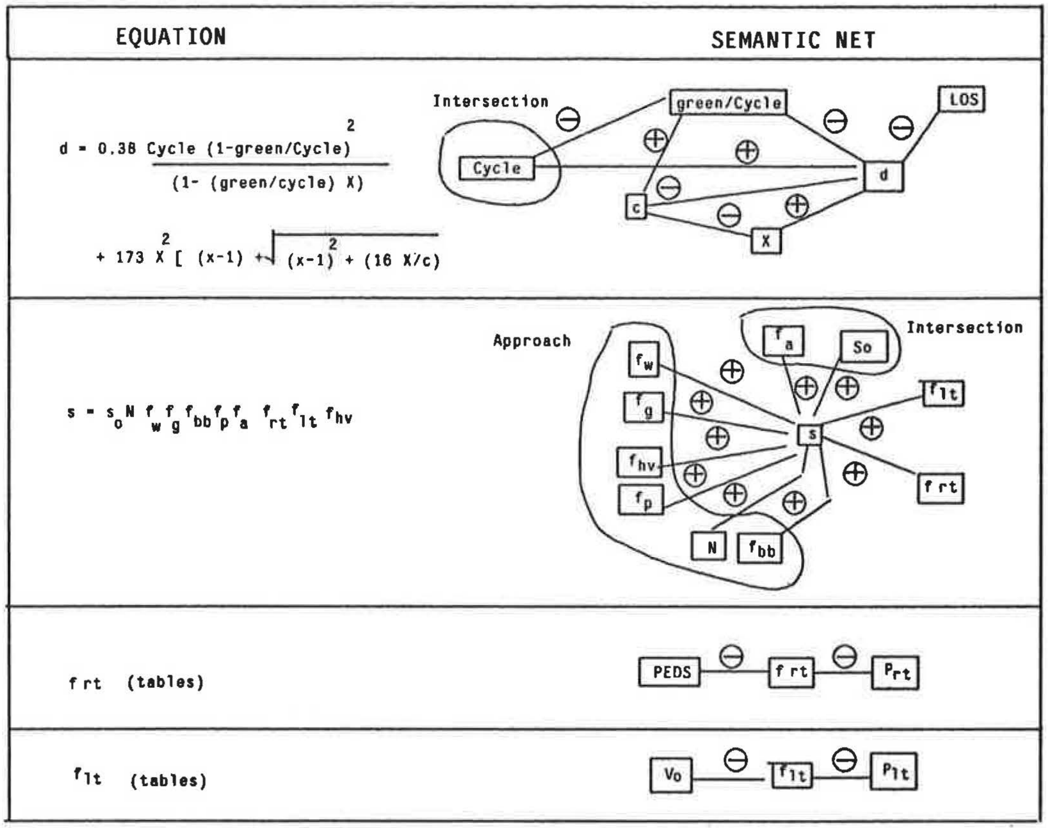


FIGURE 8 Functional relationships at the lane group level.

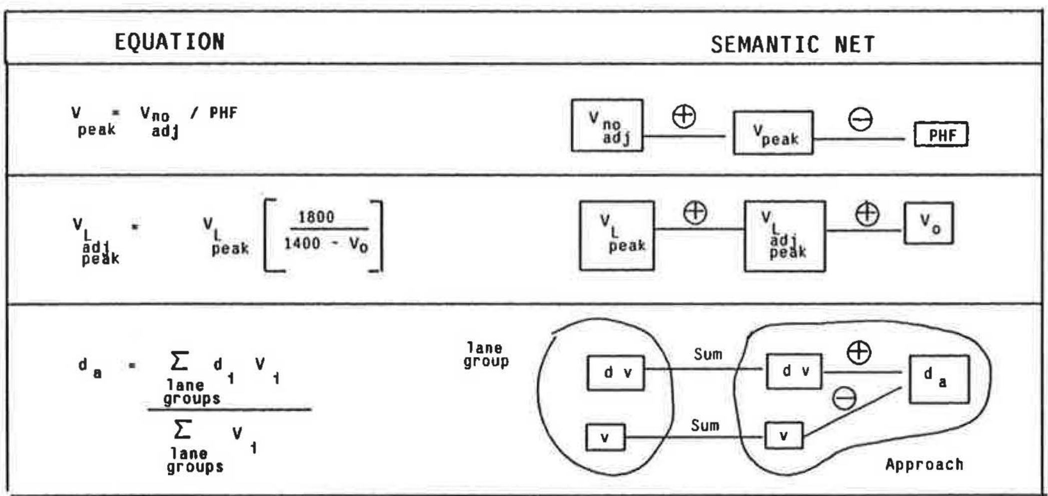


FIGURE 9 Functional relationships at the approach level.

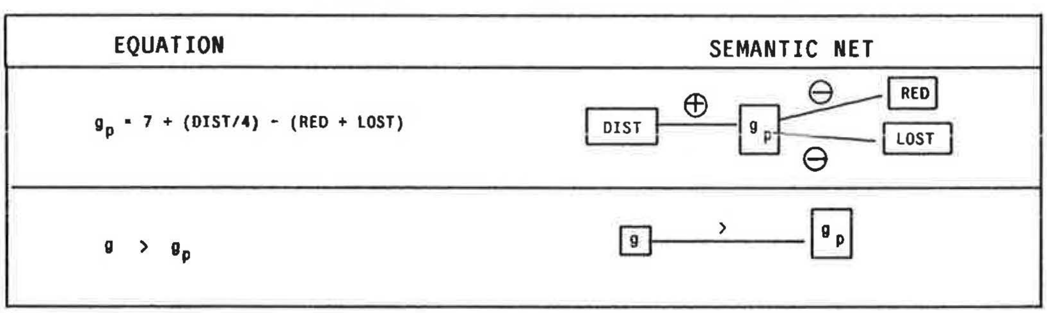


FIGURE 10 Functional relationships at the phase level.

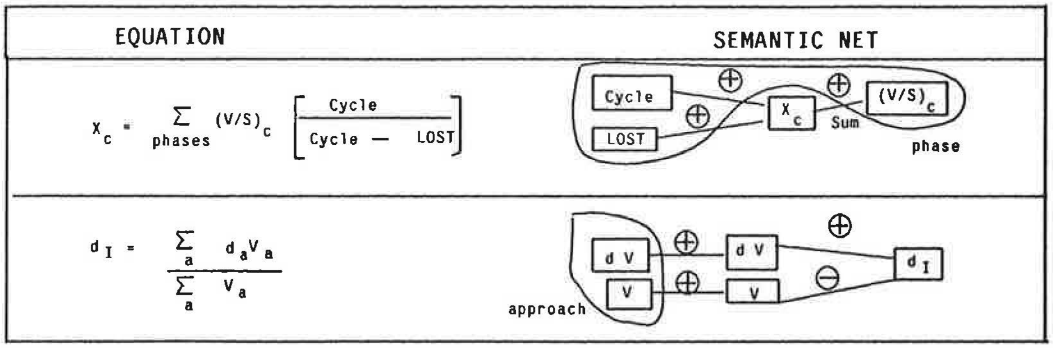


FIGURE 11 Functional relationships at the intersection level.

sections. These representations corresponded to the case where levels of service are unknown. Joining these semantic nets into a common network, we obtain the semantic net shown in Figure 12. Link-to-link relations are not included in the semantic net. However, they were used to create the instances of node-to-node relations shown in the network. The global network is one of the many possible networks that may result when individual instances of functional relationships are changed.

Figure 12 is a simplified version of the complete network. For example, nodes at the approach level of aggregation should be created for each approach of the intersection. Similarly, nodes of the phase level of aggregation should be created for each phase of the signal, and several lane group nodes are

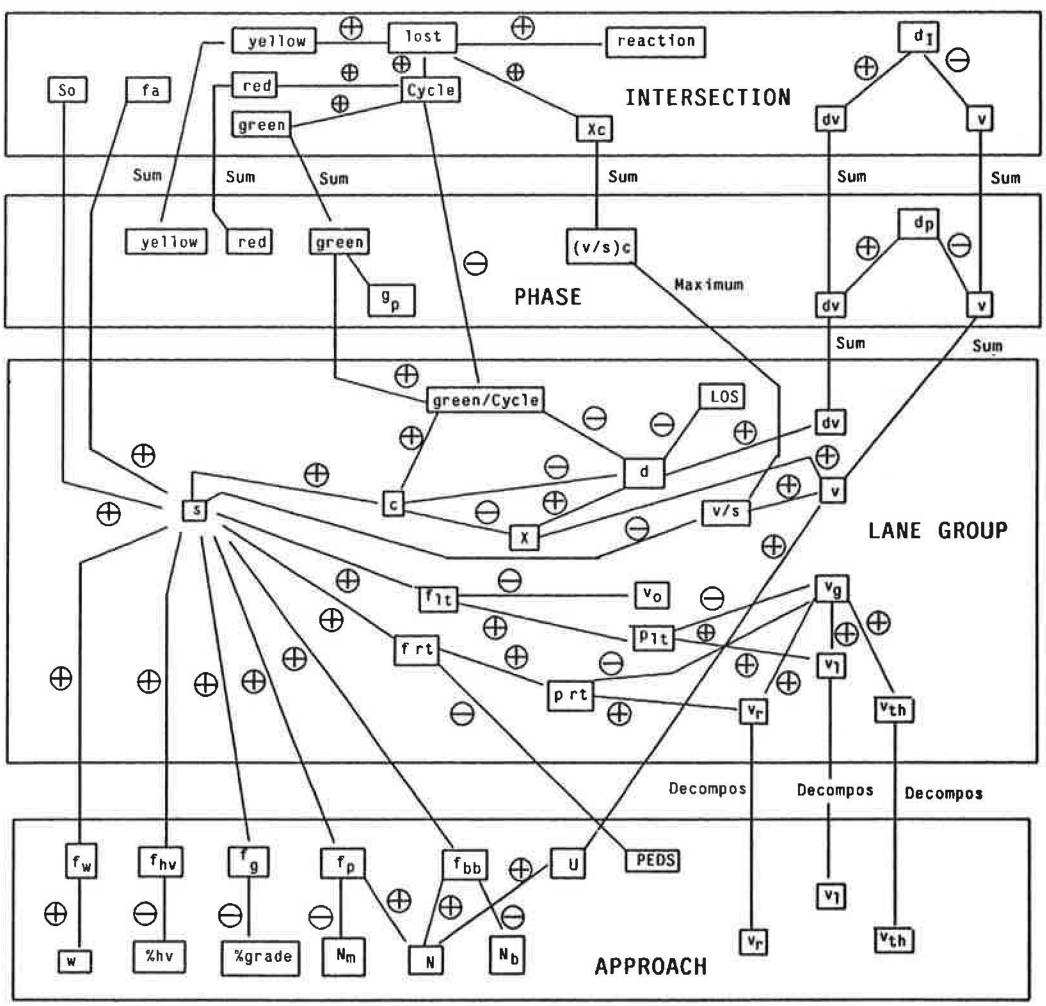


FIGURE 12 Semantic net for the analysis problem.

created for each approach. An expert system example of such groupings appears in the TRALI traffic signal setting system (*5*).

EXAMPLE APPLICATIONS

The following examples illustrate the use of the semantic network shown in Figure 12. The first example is based on a hypothetical intersection and uses the network to aid in assessing the effect of varying an input. The second example is based on volume data from an intersection in Cambridge, Mass., and uses the network to evaluate the impact of changing the phasing.

The input data for the first example are shown in Figure 13, the input worksheets as used in the *Highway Capacity Manual*. The intersection has four lanes on each approach, with large traffic volumes on Main Street and somewhat smaller volumes on First Street. Five phases are used with a total cycle length of 137.7 seconds. The lane group, approach, and intersection level of service are shown in Table 2. Suppose that the local transit authority is considering making a bus stop at the intersection, with a headway of six minutes between buses. The impact of these buses is evaluated with the aid of the network.

With ten buses per hour at the intersection, the input variable N_B at the lane group level of aggregation changes from 0 to 10 for both the eastbound and westbound right turn (EB and WB RT) lanes. Using the semantic net of Figure 12, the impact of the change can be assessed as follows:

- increasing N_B decreases f_{bb}, the factor for buses; and
- decreasing f_{bb} decreases s, the saturated flow for the lane group.

The change in s has two impacts:

- increasing v/s, which affects the critical volume capacity ratio for the intersection if the lane group including the right lane is critical, or becomes critical when the buses are added; and
- decreasing the capacity, which increases the delay for the lane group, approach, and intersection.

After tracing these changes, the level of service associated with the EB approach dropped from category D to E, although the entire intersection remained in level of service category E.

Geometry, volume data, vehicle characteristics, signal phasing, and signal timing for the second example are shown in Figure 14; this intersection can be found in Cambridge, Mass. The existing levels of service are shown in Table 3. As in the previous example, the semantic network can be used to explore the effect of changing inputs. In this case, we wish to assess the impact on the intersection performance of changing the signal phasing. The existing phasing includes an all-red phase for pedestrians, for safety reasons.

Eliminating this pedestrian phase may have two impacts on performance:

- pedestrians may not have sufficient time to cross; and
- the reduced cycle time may affect delay.

Using the semantic network in Figure 12 allows us to trace the impact of these changes. First, with the pedestrian phase present, green time (g) was always greater than the minimum time (g_p) required for pedestrians during that phase to cross the crosswalk that conflicts with right turns. With the pedestrian phase eliminated, g_p is calculated and compared to g. In this example, g is greater than g_p in all cases. Similarly, for the existing phasing the pedestrians do not affect the right turn movements. The presence of pedestrians during the other phases will decrease the factor f_{rt} and decrease the saturation flow. Ultimately, the delay increases for that lane group. This effect is similar to that traced in the first example above. However, in this example, the reduced lost time resulting in a shorter cycle will yield a larger green-to-cycle ratio, thereby decreasing delays. This is demonstrated by tracing the semantic network from the red time input for each phase. Eliminating the red time for one phase has the following effects:

- the total red time for the intersection decreases;
- the cycle length decreases;
- the g/cycle ratio increases for each lane group; and therefore
- the total delay decreases for all lane groups.

This tradeoff between increased delays due to conflicts and decreased delay due to small cycles is not clear in the worksheet analysis of the *Highway Capacity Manual*. When pedestrian volumes are low and the red phase is long, the reduced delay is likely to be greater due to increased g/cycle than increased delay due to the presence of conflicting pedestrians. For this example, the level of service is improved for most lane groups and for the intersection as a whole, as shown in Table 3.

CONCLUSIONS

We have suggested new representations of analysis procedures based on semantic networks and frames. In addition to their usefulness as manual aids to understanding and analysis, these representation schemes could be very useful in the development of computer-aided analysis and design tools. For example, the representation used here could be readily adopted to expert systems for intersection analysis or design (*8*). By localizing analysis knowledge in frames, the network representation used here might also support parallel processing of a network of signals over a geographic area. Further research in this area may be beneficial.

NOTATION

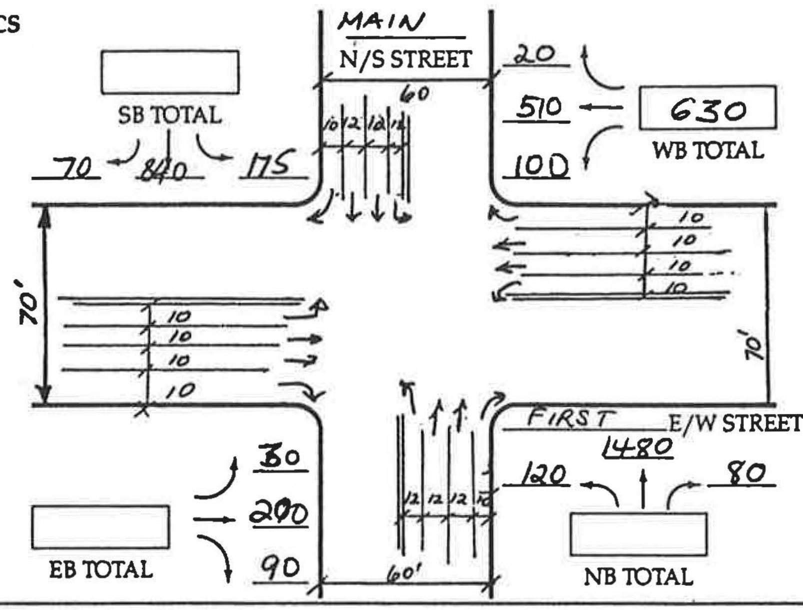
c	capacity (vph)
d	average delay for a lane group (sec)
d_a	average delay for an approach (sec)
d_I	average delay for the intersection (sec)
Cycle	cycle length time (sec)
f_a	adjustment factor for area type

Intersection: MAIN ST & FIRST ST Date: 7/24/86.

Analyst: SM Time Period Analyzed: 8:00–9:00 Area Type: ☒CBD ☐ Other

Project No.: TRB City/State: WASHINGTON D.C.

VOLUME AND GEOMETRICS



IDENTIFY IN DIAGRAM:

1. Volumes
2. Lanes, lane widths
3. Movements by lane
4. Parking (PKG) locations
5. Bay storage lengths
6. Islands (physical or painted)
7. Bus stops

TRAFFIC AND ROADWAY CONDITIONS

Approach	Grade (%)	% HV	Adj. Pkg. Lane		Buses (N_B)	PHF	Conf. Peds. (peds./hr)	Pedestrian Button		Arr. Type
			Y or N	N_m				Y or N	Min. Timing	
EB	0	5	Y	5	0	0.85	200	Y	19.0	3
WB	0	5	Y	5	0	0.85	200	Y	19.0	3
NB	0	2	N	0	0	0.90	50	Y	21.5	3
SB	0	2	N	0	0	0.90	50	Y	21.3	3

Grade: + up, − down
HV: veh. with more than 4 wheels
N_m: pkg. maneuvers/hr

N_B: buses stopping/hr
PHF: peak-hour factor
Conf. Peds: Conflicting peds./hr

Min. Timing: min. green for pedestrian crossing
Arr. Type: Type 1-5

PHASING

DIAGRAM

Timing	G= 6 Y+R=3	G= Y+R=	G=2' Y+R=3	G=71.7 Y+R=3	G= 5 Y+R=3	G=5 Y+R=3	G=20 Y+R=3	G= 10 Y+R=10
Pretimed or Actuated	A							

Protected turns | Permitted turns | ------- Pedestrian | Cycle Length 137.7 Sec

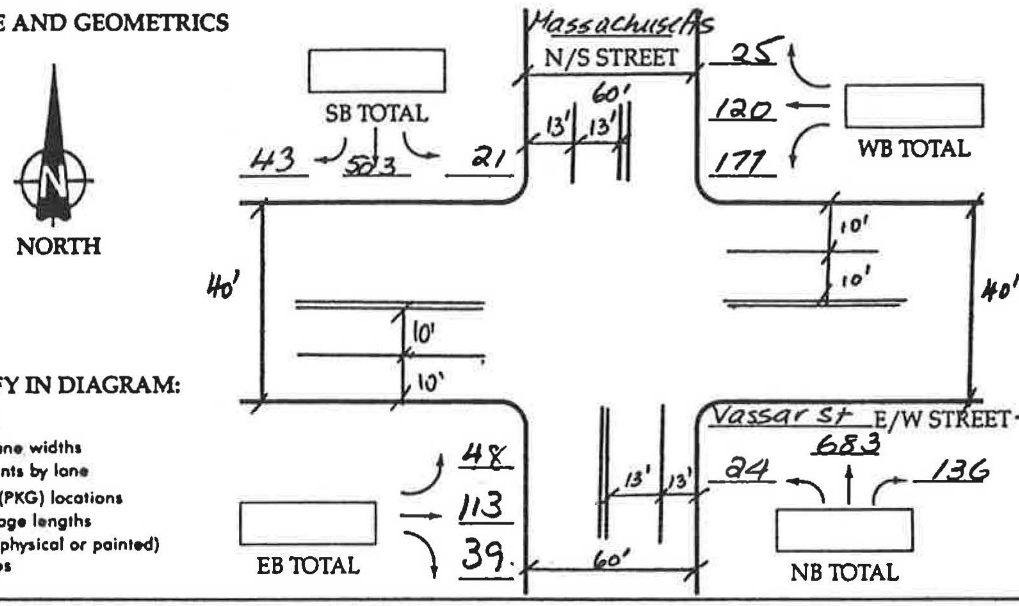
FIGURE 13 ***Highway Capacity Manual*** **input worksheet for Example 1.**

Intersection: Massachusetts Ave and Vassar St Date: Nov '85

Analyst: ______ Time Period Analyzed: 4:30-5:30pm Area Type: ☒ CBD ☐ Other

Project No.: ______ City/State: CAMBRIDGE, MA

VOLUME AND GEOMETRICS



IDENTIFY IN DIAGRAM:

1. Volumes
2. Lanes, lane widths
3. Movements by lane
4. Parking (PKG) locations
5. Bay storage lengths
6. Islands (physical or painted)
7. Bus stops

TRAFFIC AND ROADWAY CONDITIONS

Approach	Grade (%)	% HV	Adj. Pkg. Lane Y or N	Adj. Pkg. Lane N_m	Buses (N_B)	PHF	Conf. Peds. (peds./hr)	Pedestrian Button Y or N	Pedestrian Button Min. Timing	Arr. Type
EB	0	1	Y	11	1	0.75	162	N		4
WB	0	1	Y	3	1	0.89	141	N		4
NB	0	1	Y	14	6	0.83	301	N		1.
SB	0	-	Y	5	14	0.87	157	N		3

Grade: + up, − down
HV: veh. with more than 4 wheels
N_m: pkg. maneuvers/hr
N_B: buses stopping/hr
PHF: peak-hour factor
Conf. Peds: Conflicting peds./hr
Min. Timing: min. green for pedestrian crossing
Arr. Type: Type 1-5

PHASING

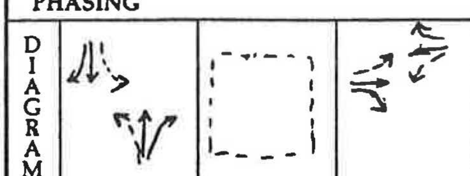


DIAGRAM	1	2	3	4	5	6	7	8
Timing	G = 42 Y+R = 3	G = 0 Y+R = 23	G = 29 Y+R = 3	G = Y+R =	G = Y+R =	G = Y+R =	G = Y+R =	G = Y+R =
Pretimed or Actuated	P	P	P					

Protected turns | Permitted turns | ------- Pedestrian | Cycle Length 100 Sec

FIGURE 14 Input worksheet for Example 2.

TABLE 2 INTERSECTION LEVEL OF SERVICE FOR EXAMPLE 1

Lane Group Level of Service			Approach Level of Service		Intersection Level of Service
EB	LT	D			
EB	TH	D	EB	D	
EB	RT	E			
WB	LT	D			
WB	TH	F	WB	F	
WB	RT	D			E
NB	LT	C	NB	E	
NB	TH	E			
NB	RT	B			
SB	LT	F			
SB	TH	B	SB	D	
SB	RT	B			

TABLE 3 INTERSECTION LEVEL OF SERVICE FOR EXAMPLE 2

Approach and Lane Group	Existing Level of Service	Level of Service Without Red Phase
EB LT-TH-RT	B	B
WB LT-TH-RT	C	B
NB LT-TH-RT	E	C
SB LT-TH-RT	B	B
INTERSECTION	D	B

f_{bb}	adjustment factor for blocking effect of local buses
f_g	adjustment factor for approach grade
f_{hv}	adjustment factor for heavy vehicles
f_{lt}	adjustment factor for left turn
f_p	adjustment factor for the existence of a parking lane
f_{rt}	adjustment factor for right turn
green	green time (sec)
g_p	minimum green time (sec)
LOS	level of service
N	number of lanes
N_b	number of buses (buses/hr)
N_m	number of parking maneuvers (maneuvers/hr)
PEDS	pedestrian volume (peds/hr)
PHF	peak-hour factor
P_{lt}	percent of left turns
P_{rt}	percent of right turns
reaction	average reaction time for a driver (sec)
red	red time (sec)
s	saturation flow rate for lane group (pcphg)
s_0	ideal saturation flow rate per lane (usually 1,800 pcphgpl)
U	lane utilization factor
V	flow rate (vph)
V_{adj}	adjusted flow rate (vph)
$V_{adj,peak}$	adjusted peak flow rate (vph)
$V_{no\ adj}$	unadjusted flow rate (vph)
V_o	opposing volume (vph)
V_{peak}	unadjusted peak flow rate (vph)
X	V/C ratio for a lane group
X_c	critical V/C ratio for the intersection
W	lane width
yellow	yellow time (sec)
% grade	percent of grade
% HV	percent heavy vehicles

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