Procedure for Analysis and Design of Weaving Sections,

A User's Guide

NOTE: The guide in this appendix is provided in its original form, which means that it will not contain the Analysis Procedures Manual footer.

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PROCEDURE FOR ANALYSIS AND DESIGN OF WEAVING SECTIONS

A USERS GUIDE

by Jack E. Leisch
JACK E. LEISCH & ASSOCIATES

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PROCEDURE FOR ANALYSIS AND DESIGN OF WEAVING SECTIONS

A USERS GUIDE

P r e f a c e

The material as finally presented in this Guide has evolved through a series of research efforts and iterations to include most recent data. The technique developed for analysis and design of weaving sections is directed largely toward improving efficiency and safety in the rehabilitation and redesign of congested and outmoded freeways. Thus, its application is important.

The initial procedure was developed by Jack E. Leisch utilizing the BPR 1963 data base; the results, including two nomographs, were published in the March 1979 issue of ITE Journal. In January 1980 this procedure was presented in the TRB Circular No. 212 for review and consideration as one of two possible methods for inclusion in the new Highway Capacity Manual (HCM). The other method was that developed by Polytechnic Institute of New York (PINY) in 1973 as part of an NCHRP research project.

In 1983 Jack E. Leisch & Associates (JEL) was contracted to enlarge upon and complete the work previously published in ITE Journal, by utilizing a larger data base with greater degree of statistical analysis and documentation. This work was completed under FHWA Project DTFH61-82-C-00050 and published in two volumes, (1) Research Findings and Development, and (2) Users Guide, dated December 1983 and February 1984, respectively.

Subsequent to the JEL research, JHK & Associates under FHWA contract evaluated both the PINY and the JEL procedures and, in the process, developed a third method utilizing a set of equations. This procedure was further modified as a fourth variation, under NCHRP contract for preparation of the HCM; and, in January 1985 the TRB Committee on Highway Capacity and Quality of Traffic Flow found it expedient to include the procedure in the Manual.

Although the Committee followed this course in preparation of the weaving chapter for the first loose-leaf version of the Highway Capacity Manual (published in 1985 as TRB Special Report 209), a problem still remains in that the equation method of analyzing and solving weaving sections does not lend itself readily to design-type applications.

As a result, the JEL procedure utilizing nomographs (which in its current form has been updated, reflecting all the data bases--BPR 1963, PINY 1973, JEL 1983 and JHK 1984) is presented herewith as a supplementary or an alternative means of analyzing and designing weaving sections on freeway facilities. This procedure in its original form, and more recently with its successive refinements, has been well received throughout the profession for its relatively simple and direct approach to solution of a variety of operational and design problems on weaving sections. The procedure generally would tend to be favored because of its ability to produce consistent results and a factor of safety in design.

The Guide is structured, together with a series of example problems, to provide a quick means of understanding the procedure. The 20 problems included with solutions represent "real" cases taken from numerous rehabilitation/reconstruction freeway projects over a period of time. The selection of examples presented, for the most part, covers a full range of possible situations, thus providing a complete guide for analysis and design of weaving sections.

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Procedure for Analysis and Design of Weaving Sections

A USERS GUIDE

Introduction

On freeways weaving sections are frequently formed by closely spaced interchanges or ramps which can adversely affect traffic operation and be a source of facility breakdowns. Weaving is the crossing of traffic streams moving in the same general direction, accomplished by successive merging and diverging. Weaving maneuvers are especially prevalent on urban freeways and must be carefully examined to ensure a reasonably balanced design and a uniform level of service over the length of the freeway.

The process to measure and achieve this is accomplished by harmonizing the performance of: (1) the freeway proper characterized by uninterrupted flow, removed from influence of interchanges; (2) the sections of freeway associated with interchanges involving merging and diverging facilities and their sequence and arrangement; and (3) the weaving sections formed along the freeway. The weaving section configuration, although a form of ramp sequential arrangement, is sufficiently distinct to require an independent analysis to bring it into level of service balance with the freeway as a whole.

Following the research performed, and further updated with new data, the procedure has been expanded and formulated to assist the user in applying the techniques for solution of a great variety of problems representative of actual conditions. It is intended that the practitioner, by referring to the set of example problems provided in this volume, will be able to solve any form of weaving problem which may present itself within a freeway corridor. The procedure developed provides practical and uniform results, which are considered to be in consonance with analysis results on other elements of the freeway.

Characteristics and Forms of Weaving Sections

Weaving sections which constitute a particular arrangement or sequence of ramps--an entrance ramp followed relatively close by an exit ramp along a highway--require a special procedure in determining quality of operation or level of service. There are several variations of weaving sections which, although somewhat different in form, perform with a degree of similarity. Because of this, it has been possible to devise analysis procedures to solve problems associated with all forms of weaving sections using minor variations in the basic process.

There are four principal means of classifying weaving sections--simple or multiple, and one-sided or two-sided--as shown in Figure 1:

A. Simple weaving section is a general term for a single weaving segment consisting of two joining roadways followed by two separating roadways.

B. Multiple weaving section is formed by several ramp junctions in sequence; for example, an entrance ramp followed by two exit ramps, or two entrance ramps followed by a single exit ramp. A multiple weaving section may also be of a mixed variety, such as a right-hand ramp followed successively by a left- and a right-hand ramp.

C. One-sided weaving section is formed by one right-hand entry followed by a right-hand exit, sometimes referred to as a ramp weave; it is also a form of simple weaving section. In special cases (as along a continuous C-D road) a one-sided weaving section could involve a left-hand entry followed by a left-hand exit.

D. Two-sided weaving section is formed by a right-hand entry followed by a left-hand exit, or a left-hand entry followed by a right-hand exit.

The major difference between a simple weave and multiple weave is that the first represents a single weaving action, whereas the second produces two overlapping weaving sections, resulting in a much more complex operation. The difference between a one-sided and a two-sided weave is that the first is simpler, with weaving taking place along one side, while through traffic proceeds along the

other side of the section. The second, two-sided section, is much more complex on which weaving traffic completely crosses the path of freeway traffic.

The more detailed arrangement depicting the comparison between a one-sided and two-sided weaving section is illustrated in Figure 2. An important feature noted is the method of measuring the length of weaving section, which is accomplished from a merging tip of 2 feet (between normal edges of traveled way of freeway and entering ramp) to a dimension in vicinity of the diverging point where the dimension between the normal edges of traveled way is equivalent to a lane width, or 12 feet.

Basic forms of one-sided weaving sections are noted in Figure 3, demonstrating three different arrangements applicable to the analysis procedure developed herein. Section A is a case of simple merge (accelerating facility) followed by a normal diverge (decelerating facility), without the use of an auxiliary lane. Section B is a more expansive form of simple weave in which the entrance and the exit are connected by an auxiliary lane, providing continuous lane between the two. The third variation of one-sided weave shown in Section C, entails a C-D (collector-distributor) road which separates all weaving from through traffic.

Further configurations of weaving sections have to do with internal lane arrangement and lane balance. Examples of a variety of patterns which provide different degrees of operational flexibility and extent of lane changing are shown in Figure 4. Lane continuity and lane balance play a primary role in the efficiency and quality of operation. The arrangements shown demonstrate considerable variations in lane configurations and different lane changing maneuvers within the weaving sections. Designs which do not fully provide lane balance (where lane balance has the feature of "one more lane going away"), tend to produce two and possibly three times the number of lane shifts (L.S.) than on fully lane-balanced weaving sections. Those sections with the greater number of lane changes, even if the total number of lanes and weaving volume are the same, would be expected to operate at a lower level of service. The more complex weaving sections should receive individual attention and special analysis to achieve as high an operational quality as feasible, even though much of it would be accomplished by rational deduction.

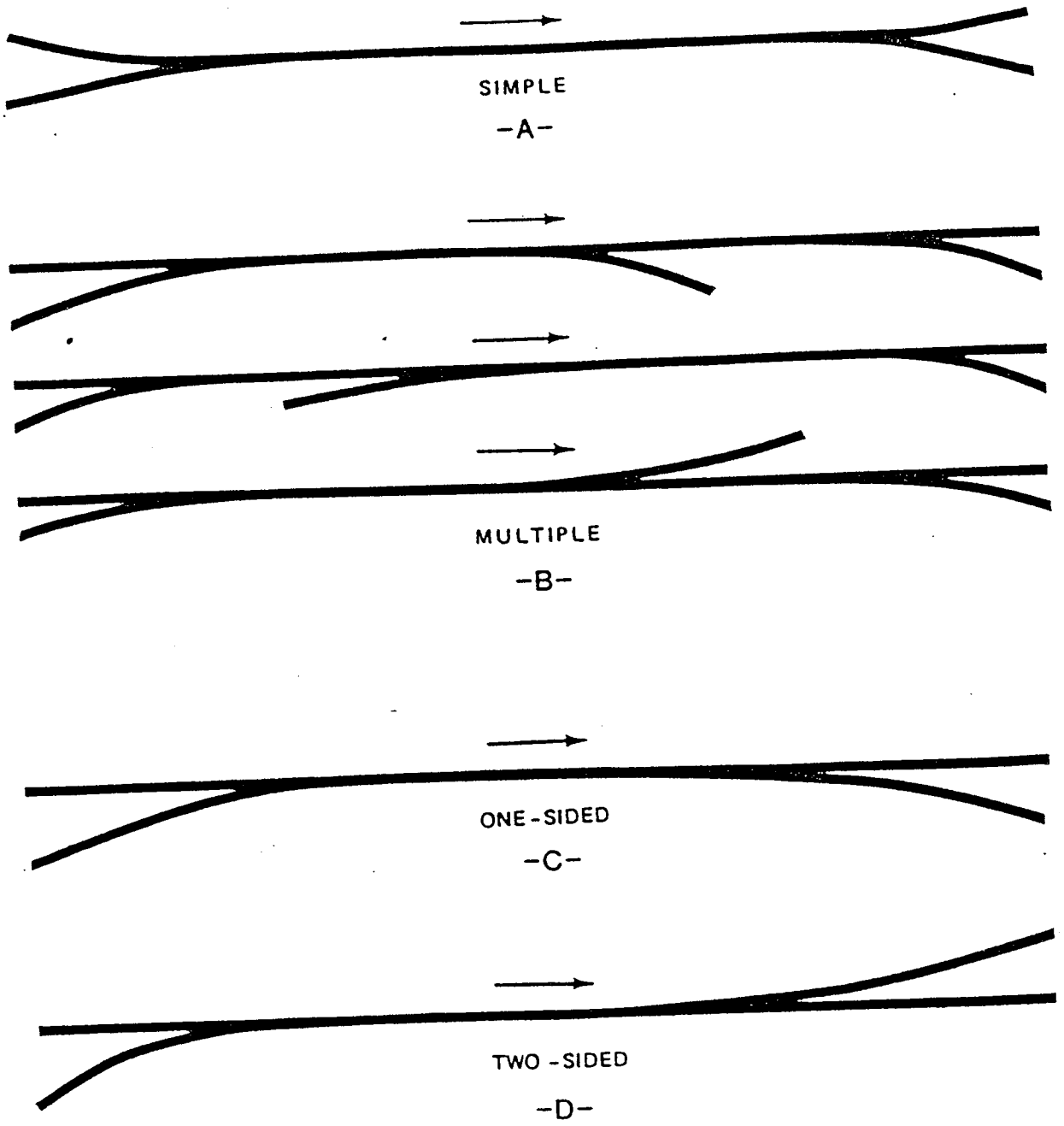
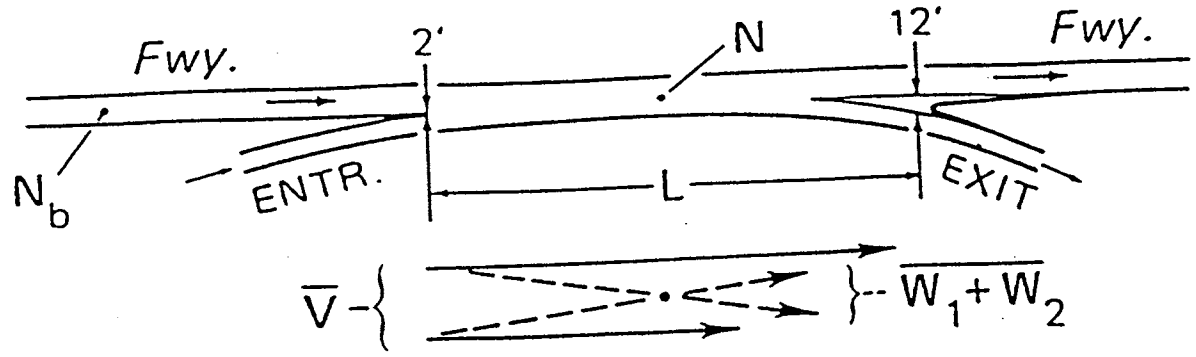
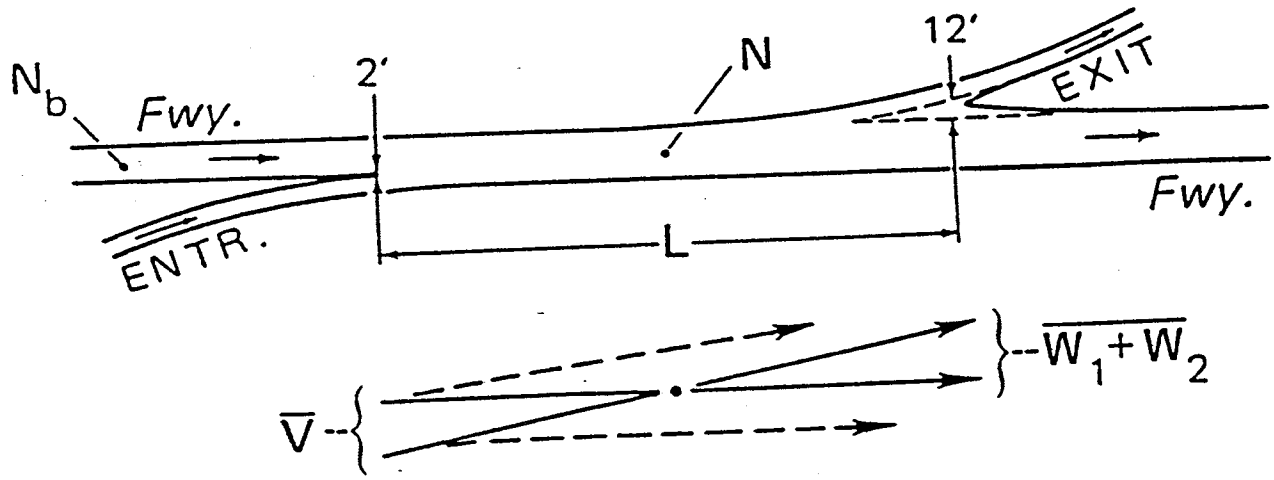


Figure 1. FORMS OF WEAVING SECTIONS



ONE-SIDED SECTION

-A-



TWO-SIDED SECTION

-B-

Figure 2. NOMENCLATURE OF ONE-SIDED AND TWO-SIDED WEAVING SECTIONS

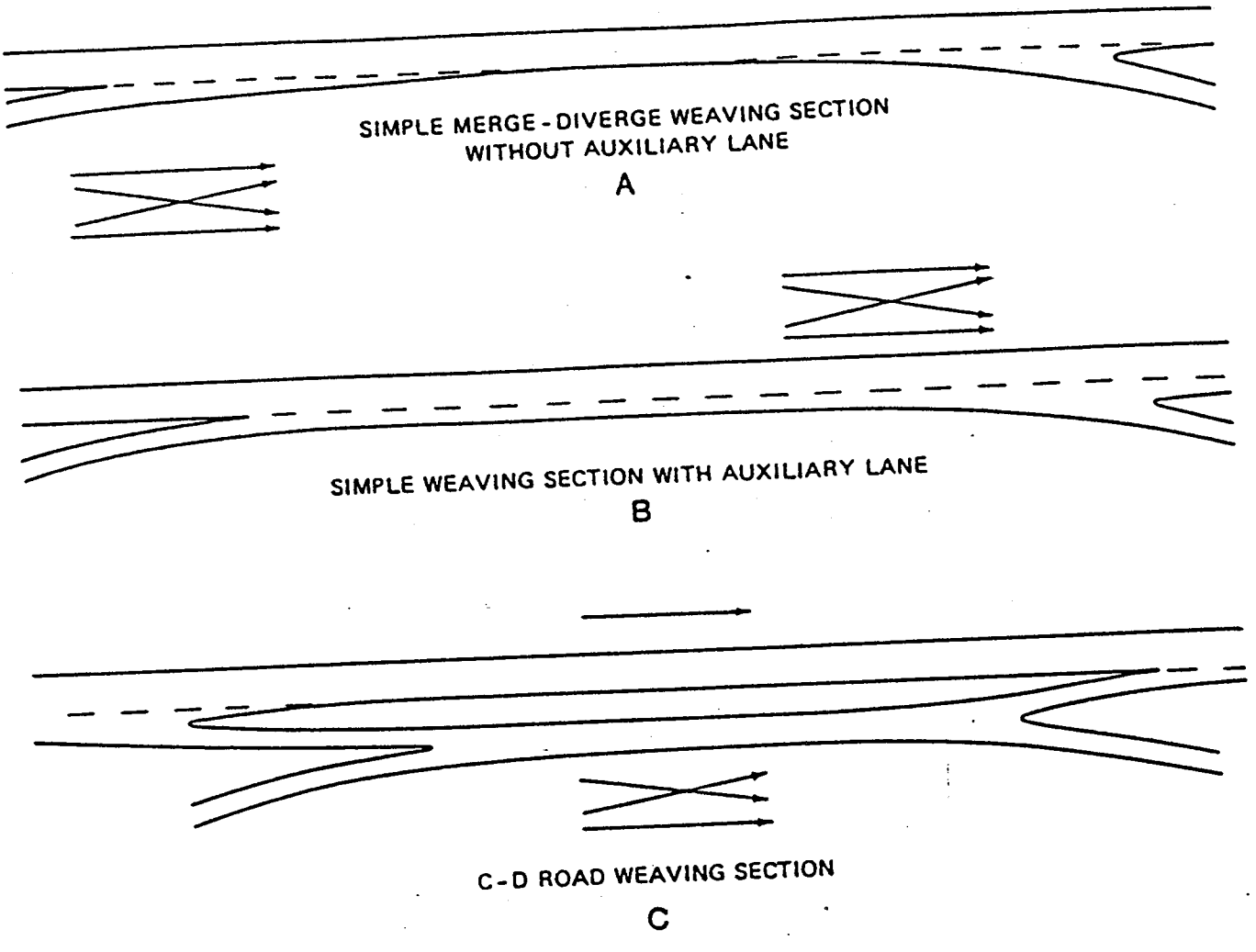
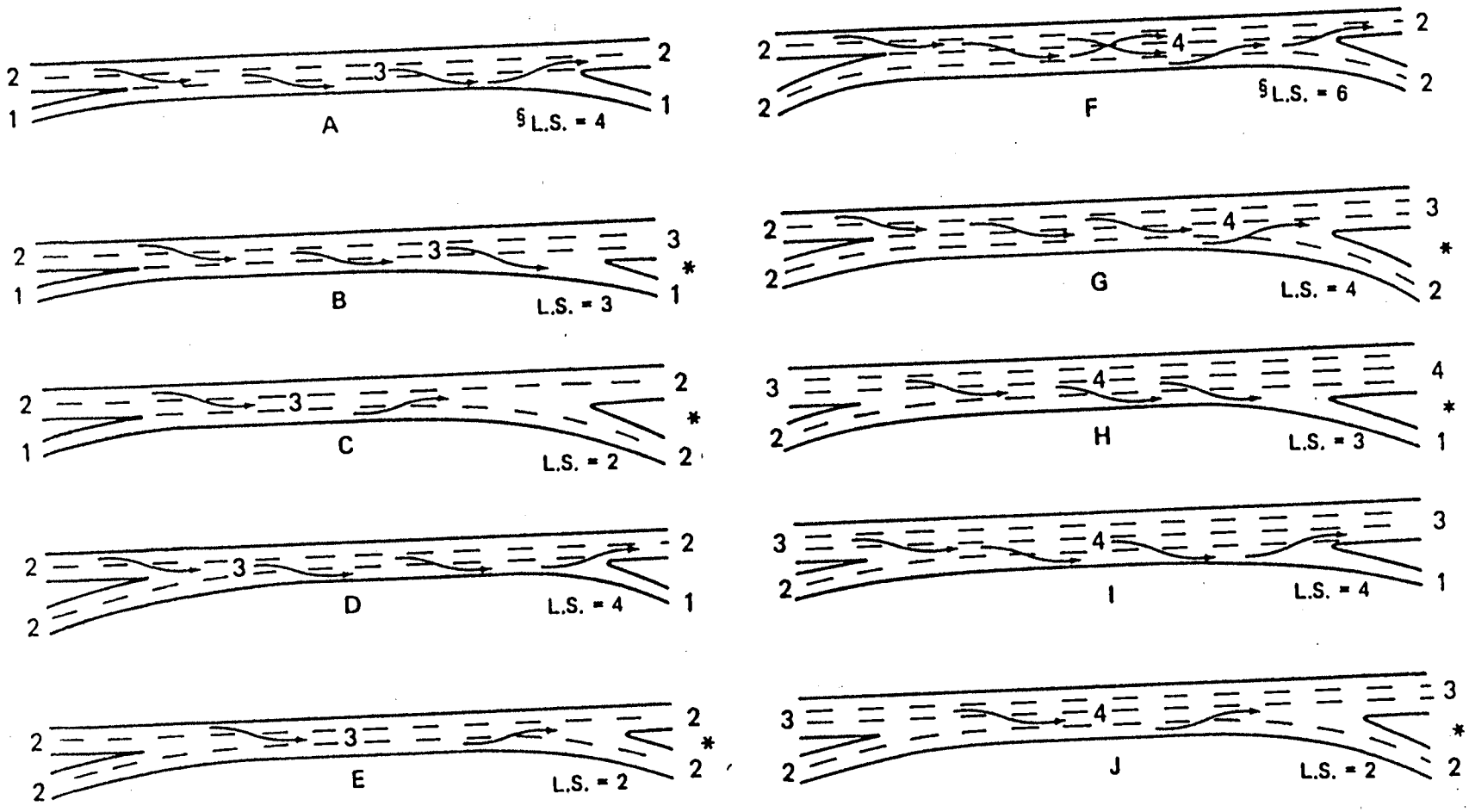


Figure 3. VARIATIONS OF ONE - SIDED WEAVING SECTIONS



* DENOTES LANE BALANCE – OPTIONAL LANE AT EXIT, i.e., ONE MORE LANE GOING AWAY

§L.S. – POTENTIAL LANE SHIFTS, CONSIDERING MAX. OF 2 LANES INVOLVED ON ANY ONE APPROACH

Figure 4. CONFIGURATION OF WEAVING SECTIONS – LANE ARRANGEMENT AND LANE BALANCE

Definition of Terms

In presentation of the following material, particularly as it relates to general application and specifically to solution of example problems, the nomenclature and principal definition of terms follow:

V_w or W_1+W_2	Total weaving volume	pcph
V_{nw}	Total nonweaving volume	pcph
V	Total volume	pcph
W_2	Smaller weaving volume	pcph
k	Weaving intensity factor	--
SF	Service flow	pcph or pcphpl
S_w	Speed of weaving traffic	mph
S_{nw}	Speed of nonweaving traffic	mph
S	Speed of all traffic (composite)	mph
N_w	Width of traveled way occupied or required for weaving	Number of lanes
N_{nw}	Width of traveled way occupied or required for nonweaving	Number of lanes
N	Width of traveled way of weaving section, total	Number of lanes
N_b	Number of basic lanes on major approach to weaving section	Number of lanes
R	Ratio of smaller weaving to total weaving volume	$W_2 \div (W_1+W_2)$
VR	Ratio of weaving volume to total volume	V_w/V
LOS	Level of Service, designated as A, B, C, D, E and F.	
PHF	Peak-hour factor: Hourly volume divided by 4 times the 15-min. peak flow within the hour.	

Operationally Balanced Section: Section with weaving traffic operating at or near LOS of nonweaving traffic.

Constrained Section: Section with weaving intermixing with nonweaving traffic, and each tending to operate at different LOS.

Operational Features and Levels of Service

Weaving sections are formed along a highway by merging followed by diverging traffic, with the separation between the points of entering and exiting traffic being sufficiently close to cause a degree of turbulence and intensity of lane changing beyond that experienced with other arrangements or sequences of ramp junctions. The complexity of operation within a weaving section becomes evident, where one element of traffic is destined to pass through the section (nonweaving traffic), while another element of traffic is required at the same time to cross the paths of other vehicles within the section (weaving traffic). Due to stream friction, introduced by weaving traffic and often by intermixing of weaving and nonweaving traffic elements, an impact or adverse effect on the overall operation of such sections occurs along the freeway. To account for or compensate for the possible degeneration in the quality of operation, the weaving section as a distinct component of the freeway should be separately analyzed and adjusted as required with respect to geometrics and traffic pattern.

Weaving performance is fundamentally dependent upon the length and width of the weaving section, as well as on the amount and makeup of weaving and nonweaving traffic. Other geometric and operational features--such as, design speed, lane widths, gradients, proportion of trucks, and potential speeds of entering or exiting traffic as affected by ramp geometry and nearby traffic control devices--all have an effect on weaving section performance. Conversion of traffic volumes to equivalent passenger cars (pcph) is accomplished prior to analysis of the weaving section. The method for doing so is covered in the Highway Capacity Manual. The model and procedures developed, as well as the demonstration of example problems presented, are thus simplified by a common pcph base.

In design or in improvement of operations of weaving sections, an attempt is made to provide the required number of lanes for each traffic component--weaving traffic and nonweaving traffic. Meeting the separate lane requirements works toward providing unconstrained weaving sections or operationally balanced sections, wherein both the weaving and the nonweaving traffic tend to operate at the same level of service. Even so, there is an impact of exiting and entering traffic upon the flow of traffic on the freeway. Some slow-down in the freeway

movement or degradation of quality of operation under such circumstances is evident and is expected; however, such effect for proper design should be minimal and of short duration, allowing the overall freeway flow to recoup and reestablish its quality of operation otherwise experienced prior to the merging-diverging section. This approach is the basis for design and operation of weaving sections, and is reflected in the level of service criteria utilized.

Level of service measures (A through E) relating to freeway proper or basic freeway sections, are quantified primarily on the basis of speeds of operation and service flows (per lane) generated. These provide a general basis for establishing levels of service for weaving sections. Consideration of level of service values utilized for ramp merging and diverging traffic are further taken into account. Also of importance is the peak-hour factor (PHF) which accounts for fluctuations within the hourly volume and permits the higher rates of flow generated during the shorter periods within the hour (normally taken for 15 minutes) to be established and incorporated into the level of service measurement process. The basic service flows per lane per full hour of operation derived through research for this procedure are multiplied by a "representative" PHF for each applicable level of service (C through E). This produces numerically lower service flows (SF) as part of the level of service criteria which, when applied to design-hour or demand volumes (DHV), account for higher rates of flow in evaluation of operation or design.

The performance criteria for weaving sections, defining levels of service in terms of speed and volume measures are shown in Table 1. The weaving traffic element is predicated directly on the average speed of weaving traffic, with the corresponding SF serving as a dependent variable; for the overall weaving section, involving both weaving and nonweaving traffic, SF first serves as the independent variable but then the speed is calibrated to adjust for the final level of service measure, as later explained in the use of nomographs.

For level of service determination on one-sided weaving sections the speed of weaving traffic is taken to be 5 mph less than the speed on the overall section. On two-sided sections, since the freeway through flow is part of the weaving movement, the weaving and the overall speeds tend to be nearly equal; hence the level of service is predicated on the same speed for both. With respect to maximum service flows (SF) in pcph per lane, the values reflect built-in peak-hour factors as expressed in the third note of Table 1.

TABLE 1

PERFORMANCE CRITERIA FOR WEAVING SECTIONS ON FREEWAYS

A. SPEED MEASURES FOR LEVELS OF SERVICE

LEVEL OF SERVICE	AVERAGE RUNNING SPEED – MPH*		
	ONE-SIDED WEAVING SECTION		TWO-SIDED WEAVING SECTION
	WEAVING TRAFFIC S_w	COMPOSITE SECTION S	WEAVING AND COMPOSITE S_w & S
A	50	55	55
B	45	50	50
C	40	45	45
D	35	40	40
E	30-25**	30	30†

B. VOLUME MEASURES FOR LEVELS OF SERVICE

APPLICABLE TO ALL TRAFFIC – WEAVING AND NON-WEAVING

LEVEL OF SERVICE	SF – MAXIMUM SERVICE FLOW – PCPH PER LANE§ FOR NUMBER OF BASIC LANES (N_b) ON MAJOR APPROACH ROADWAY		
	$N_b = 2$	$N_b = 3$	$N_b = 4$
A	750	800	850
B	1000	1100	1200
C	1250	1350	1450
D	1550	1600	1650
E	1900	1900	1900

* Either measured or indicative of Space Mean Speed (SMS).

** LOS F operation when average speed < 25 mph

† LOS F operation when average speed ≯ 25 mph.

§ Predicated on uniform periods (15-minutes) indicating hourly flow rates based on representative PHF of 0.85, 0.90 and 0.95 for LOS of C, D and E, respectively.

Analysis Techniques

The procedure for analysis and design of weaving sections is based largely on the results of a FHWA research project,* and further updated with recent operational data. As presented, the solution of problems is accomplished by the use of two composite graphs, Nomograph 1 shown in Figure 5 and Nomograph 2 in Figure 6; these are supplemented by Nomographs 3 and 4 in Figures 7 and 8 for calibration of speeds, as required, in operational analyses. Nomographs 1 and 3 pertain to one-sided and Nomographs 2 and 4 to two-sided weaving sections.

The use of nomographs is fully discussed and demonstrated in conjunction with the solution of problem examples. As an introduction, however, the basic procedure in the use of the major nomographs, Figures 5 and 6, is indicated by dotted projection lines with arrows. Referring to Figure 5, the use for a typical design example of a one-sided weaving section is shown, for which the necessary traffic information is provided, and the solution for length, L, and width, N, as required to accommodate operation at level of service C.

The nomograph is entered on the left with the weaving volume, W_1+W_2 (or V_w) followed by projection to the right, intersecting the desired weaving LOS or speed curve; a vertical drop from this point provides distance L = 1300 feet. Returning to first intersection point of V_w with LOS line, an upward projection along the LOS or speed curve is intersected with the horizontal, heavy dashed, "turning line for k;" from here the solution line is extended vertically to intersect the k values curve, from which a horizontal extension meets the desired W_2 volume. Then a downward turn to total volume, V, from which the line is horizontally projected to the right, intersecting (in this case) the desired LOS = C curve having an SF of 1450 (representing the overall or composite operation of the weaving section), from which a downward extension yields an N of 5.2; this would be rounded to N = 5 lanes.

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* Leisch, Jack E. and Leisch, Joel P., "Procedure for Analysis and Design of Weaving Sections," Vol. 1 and 2, Federal Highway Administration, DTFH61-82-C-00050, December 1983 and February 1984.

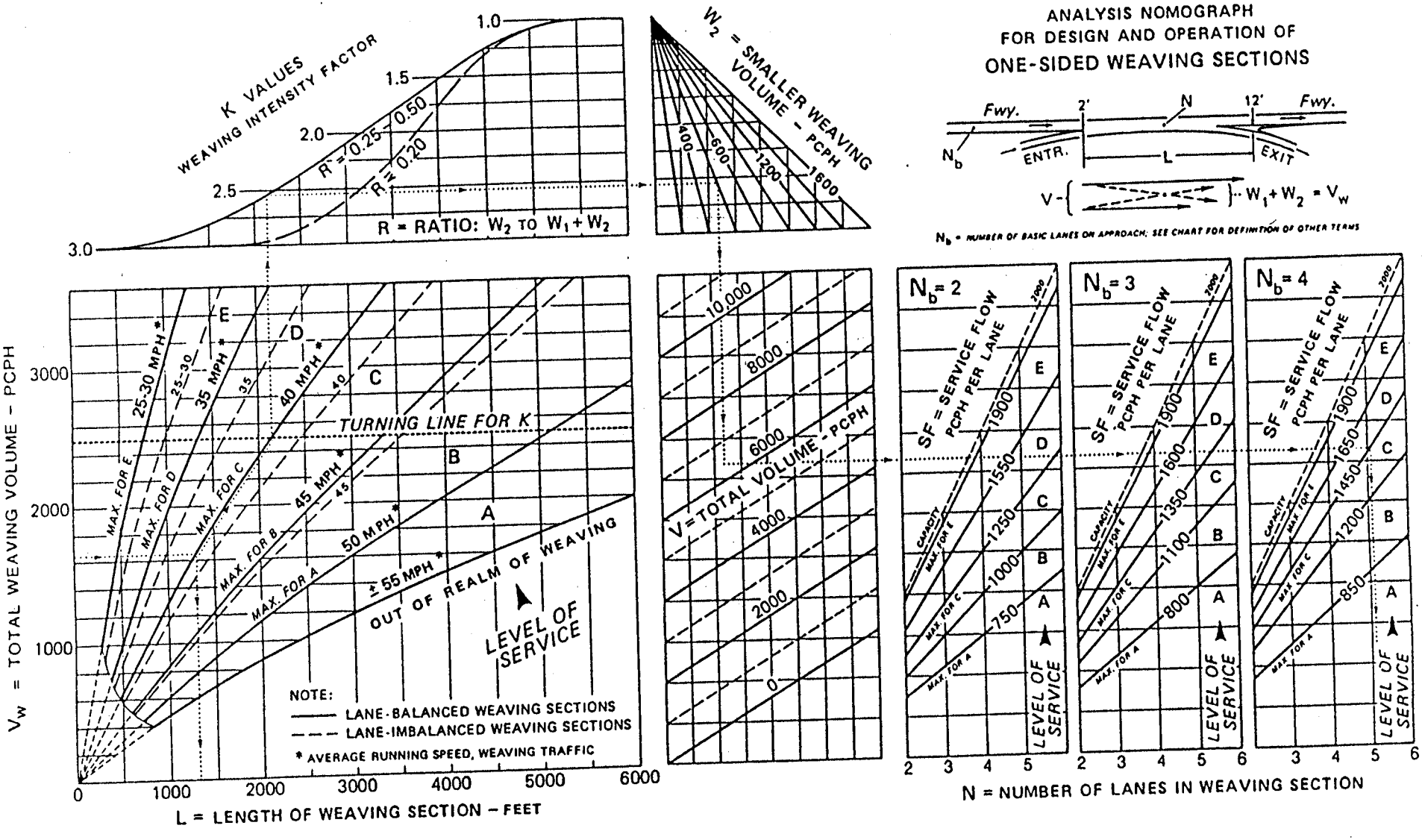


Figure 5. NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS—ONE-SIDED CONFIGURATIONS

NOMOGRAPH 1

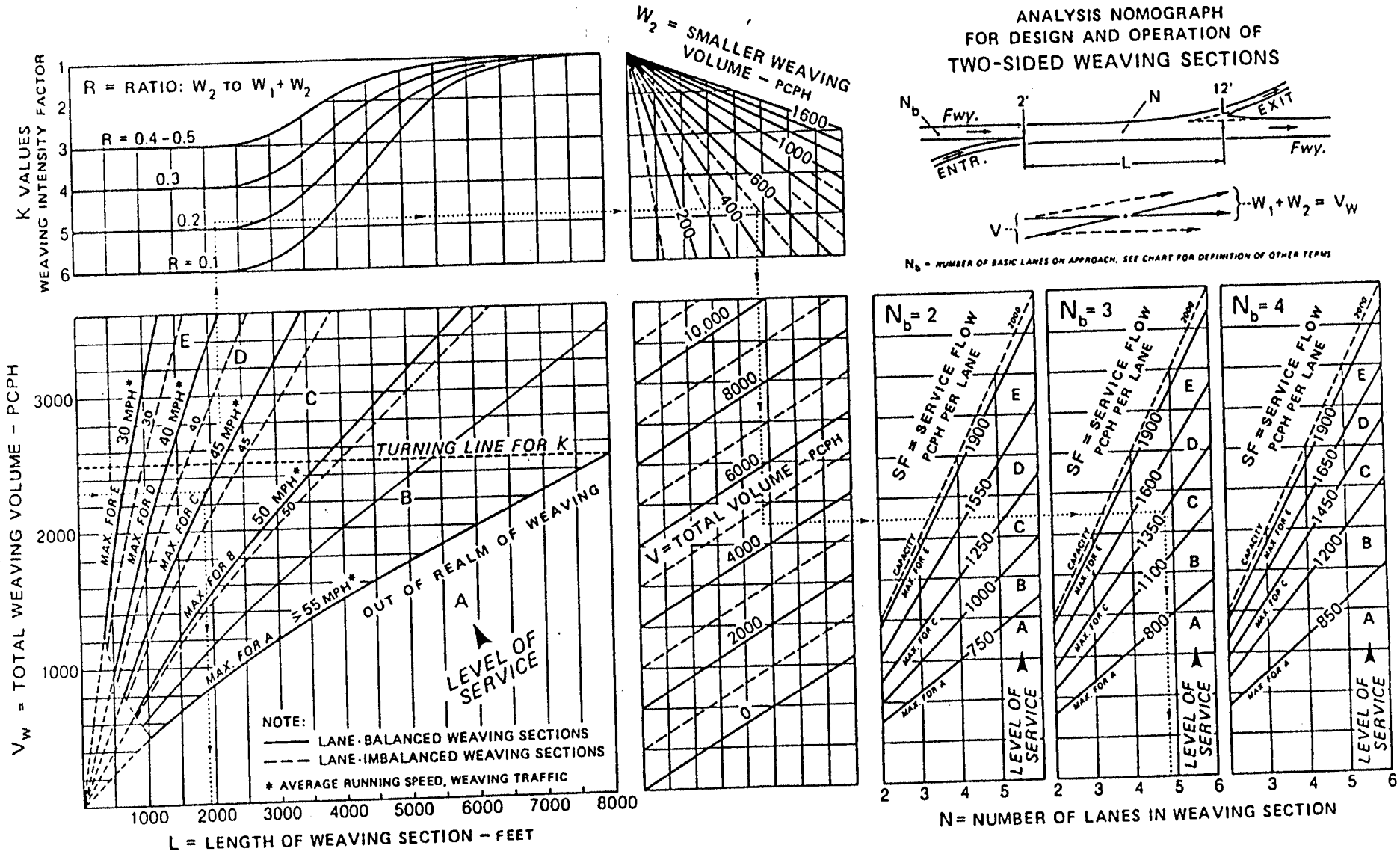
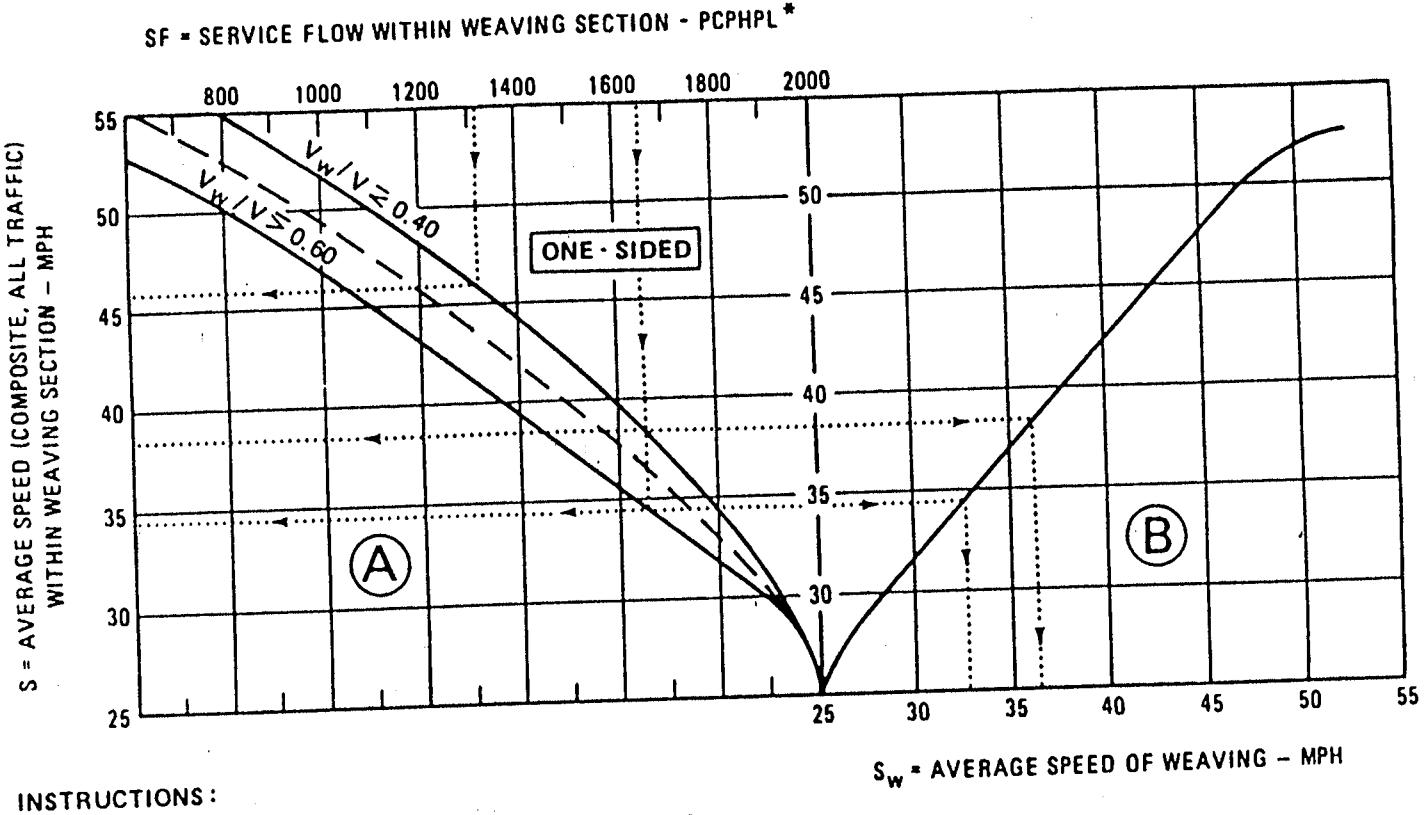


Figure 6. NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS—TWO-SIDED CONFIGURATIONS

NOMOGRAPH 2



INSTRUCTIONS:

1. WHEN V IS WITHIN ONE LOS (±) OF V_w, S_w REMAINS THE SAME AND S IS READ FROM GRAPH (A) ABOVE.
2. WHEN V IS ONE OR MORE LOS BETTER THAN THAT OF V_w, S_w REMAINS THE SAME AND S IS READ FROM GRAPH (A).
3. WHEN V IS ONE OR MORE LOS WORSE THAN THAT OF V_w, S_w IS REDUCED AND BOTH S & S_w ARE READ FROM GRAPHS (A) & (B).

NOTE:

LOS OF V IS THE OVERALL LEVEL OF SERVICE AS A COMPOSITE WITHIN THE WEAVING SECTION, DETERMINED IN THE RIGHT PORTION OF NOMOGRAPH 1.

LOS OF V_w REFERS TO THE LEVEL OF SERVICE OF WEAVING TRAFFIC ELEMENT, DETERMINED IN LEFT PORTION OF NOMOGRAPH 1.

* SF READ FROM INITIAL SOLUTION OF NOMOGRAPH 1.

TABLE 1a

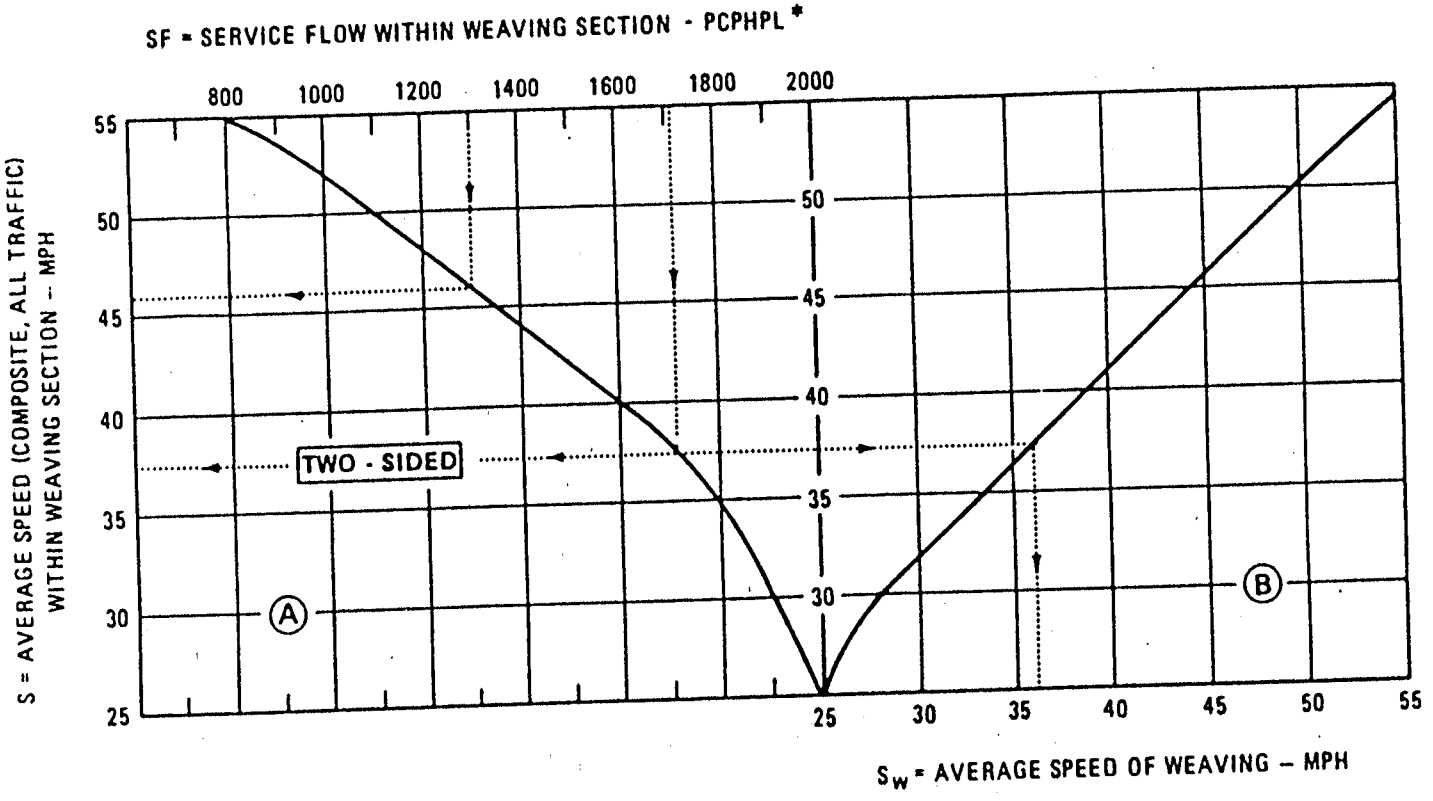
LEVEL OF SERVICE RELATED TO SPEED NOMOGRAPH ABOVE - MPH

LOS	WEAVING S_w	COMPOSITE S
A	50	55
B	45	50
C	40	45
D	35	40
E	30 - 25	30

F < 25 MPH

Figure 7. SUPPLEMENTARY NOMOGRAPH FOR SPEED CALIBRATION – ONE-SIDED WEAVE

NOMOGRAPH 3



INSTRUCTIONS:

1. WHEN LOS OF V IS SAME AS LOS OF V_w, S_w REMAINS THE SAME AND S EQUALS S_w.
2. WHEN V IS AT A BETTER LOS THAN THAT OF V_w, S_w (AND THE SPEED OF FREEWAY THROUGH TRAFFIC) REMAINS THE SAME, AND OVERALL SPEED S IS READ FROM CHART Ⓐ.
3. WHEN V IS AT A WORSE LOS THAN THAT OF V_w, S_w (AND THE SPEED OF FREEWAY THROUGH TRAFFIC) IS REDUCED AND BOTH S AND S_w ARE READ FROM CHARTS Ⓐ AND Ⓑ.

NOTE:

LOS OF V IS THE OVERALL LEVEL OF SERVICE AS A COMPOSITE WITHIN THE WEAVING SECTION, DETERMINED IN THE RIGHT PORTION OF NOMOGRAPH 2.

LOS OF V_w REFERS TO THE LEVEL OF SERVICE OF WEAVING TRAFFIC ELEMENT, DETERMINED IN LEFT PORTION OF NOMOGRAPH 2.

* SF READ FROM INITIAL SOLUTION OF NOMOGRAPH 2.

LOS RELATED TO SPEED - MPH

LOS	S & S_w
A	55
B	50
C	45
D	40
E	30
F	≅25

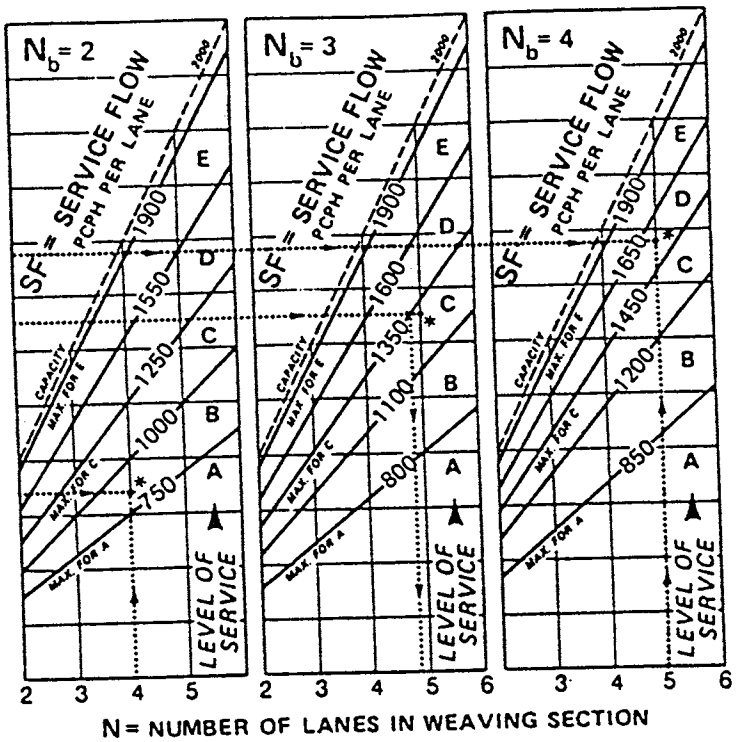
Figure 8. SUPPLEMENTARY NOMOGRAPH FOR SPEED CALIBRATION – TWO-SIDED WEAVE

NOMOGRAPH 4

Using the nomograph for analysis of operation rather than design, the procedure is similar except that some of the projections, with respect to L and N are made in reverse order, or in the upward direction. The use of Nomograph 2, Figure 6, for solution of two-sided weaving sections follows basically the same procedure. The dotted projection lines indicate a design procedure in which a solution with L = 1800 feet and N of 4.8, or rounded to N = 5 lanes was determined for LOS C.

Nomographs 3 and 4, Figures 7 and 8, are supplementary to Nomographs 1 and 2, respectively. The additional nomographs allow for speed calibration where the weaving section is not operationally balanced; i.e., where LOS of weaving movement is different from LOS of the overall weaving section. A specific group of notes and an organized set of instructions on Nomographs 3 and 4 provide the necessary information for their use. The calibration for certain conditions adjusts S_W for a final reading, and provides associated values of overall or composite speed of weaving section, S. Thus, the combination of Nomographs 1 and 3, and combination of Nomographs 2 and 4, provide a full solution.

In order to comply with instructions for application in conjunction with Nomographs 3 and 4, levels of service relating to V_W and V have to be derived to reflect sublevels within a level of service. To establish whether there is one or more levels of service difference between V_W and V, it becomes necessary for analysis purposes (only) to determine what may be termed as fractional levels of service. Such sublevels may be expressed, for example, as $B_{.4}$, $C_{.8}$, $D_{.6}$ which mean the first is 0.4 into the B band of LOS, the second 0.8 into the C band of LOS, and the third 0.6 into the D band of LOS. These readings, interpolated visually, are demonstrated by intersection points marked by an asterisk on the right-hand portion taken from Nomograph 1 (or 2) shown below; represented by these points are the composite levels of service for V on the overall weaving section.



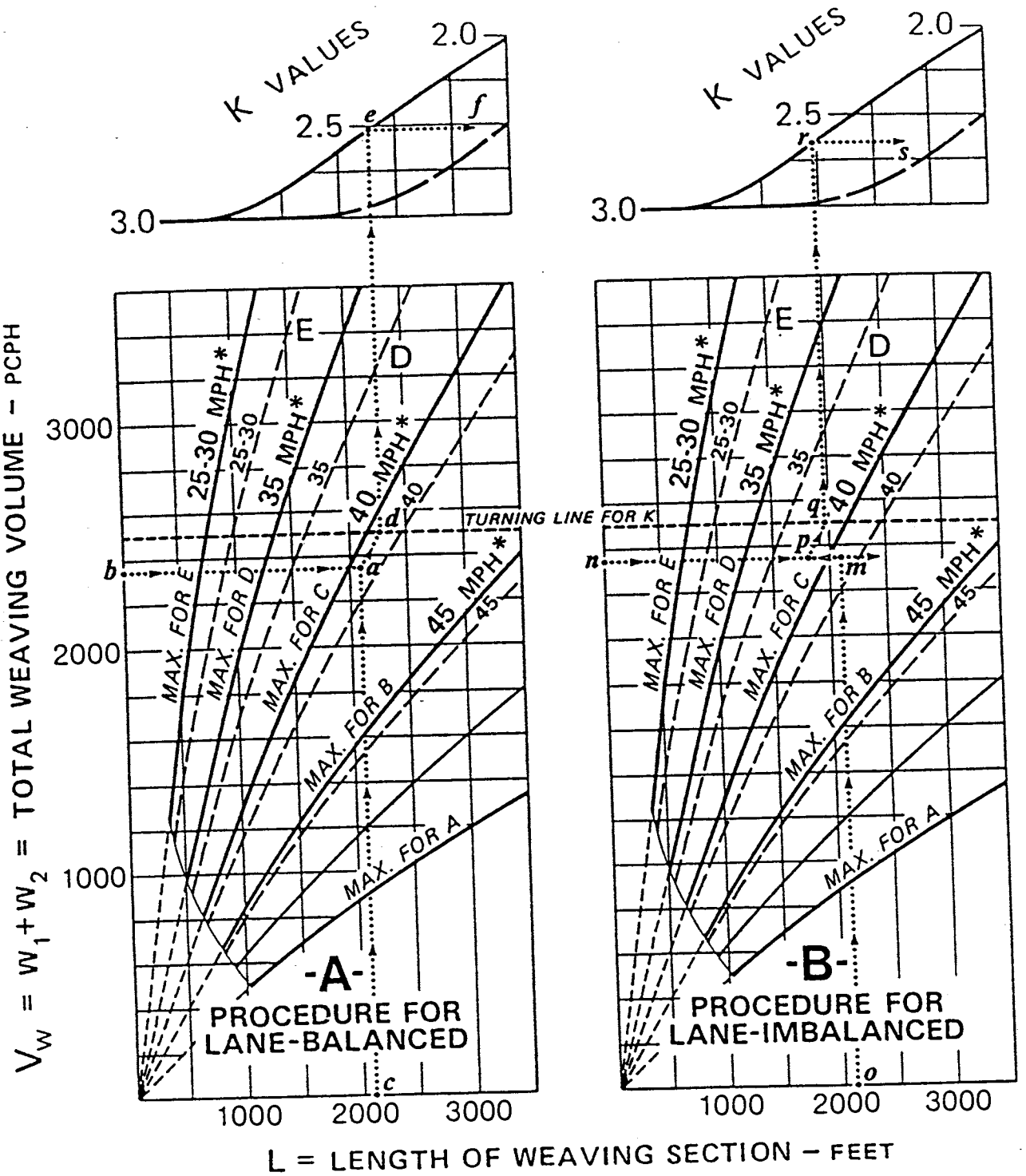
The corresponding service volumes can then be calculated as may be required for further use in conjunction with Nomographs 3 and 4. This would be accomplished by interpolating between the upper and lower SF within which the point of intersection is formed. For example: for $B_{.4}$ the corresponding SF (referring to portion of nomograph above) is 750 + 0.4 (1000-750) = 850 pcph per lane; for $C_{.8}$ the corresponding SF = 1100 + 0.8 (1350-1100) = 1300 pcph per lane; and for $D_{.6}$ the corresponding SF = 1450 + 0.6 (1650-1450) = 1570 pcph per lane.

Fractional levels of service can similarly be found for V_w in the lower left portion of Nomographs 1 and 2. Referring to Nomograph 1, Figure 5, an entry of W_1+W_2 (or V_w) of 1600 and L of 1500 would form an intersection point (visually interpolated at 42 mph, or 3 mph within LOS band of C. This would represent a fractional LOS of 3/5 or 0.6 within LOS C, or LOS $C_{.6}$. Other fractional values would be similarly established as required.

Another feature in the use of Nomographs 1 and 2 is the special projection movement required in the lower left portion of the nomograph for solution of lane-imbalanced weaving sections. The nomographs have two sets of LOS curves (associated with average speeds)--solid curves for lane-balanced weaving sections and dashed curves for lane-imbalanced weaving sections. Figure 9 shows an enlargement of Nomograph 1 which demonstrates the difference in procedures for lane-balanced and lane-imbalanced sections. The two portions within Figure 9 show the identical portion of the nomograph--on the left to demonstrate the procedure for lane-balanced, and on the right for lane-imbalanced sections.

The lane-balanced procedure has already been described in conjunction with use of Nomographs 1 and 2; however, the initial entries are repeated here in the left diagram for comparative purposes with the lane-imbalanced condition. For the case when V_w and L are given along with traffic information, the procedure in the left diagram shows an entry at point *b* with V_w = 2350 and at point *c* with L = 2100, producing an intersection at *a* within LOS C and interpolated speed of 40.5 mph; then proceeding along the trend of the series of solid curves upward to "turning line for k" to point *d* ; from this point the solution line is extended vertically to point *e* on " k factor" curve, and hence to the right to *f* and the remainder of the nomograph. This demonstrates a standard procedure for lane-balanced sections.

The solution procedure for the same conditions with V_w = 2350 and L = 2100 but for a lane-imbalanced situation is shown, by contrast, in the right diagram of Figure 9. Here, entries at *n* and *o* are intersected at *m* (corresponding locationally to point *a* in previous example). Point *m*, however, with respect to the dashed set of LOS or speed curves (which represent lane-imbalanced conditions) falls within LOS D band with an interpolated speed of 39 mph. In order to utilize the remaining movements through the nomograph, it is necessary to shift point *m* to the left to a comparable position with respect to the solid speed curves. Thus, the lateral shift is made from *m* to *p* , which places point *p* at 39 mph with respect to solid speed curves. The process continues, along the trend of the speed curves to point *q* and hence to *r* and *s* , and through the remainder of the nomograph. The procedure with the lateral shift allows the same overall nomograph to be used properly for both lane-balanced and lane-imbalanced sections.



NOTE:

——— LANE-BALANCED WEAVING SECTIONS

— — — LANE-IMBALANCED WEAVING SECTIONS

* AVERAGE RUNNING SPEED, WEAVING TRAFFIC

Figure 9. NOMOGRAPH PROCEDURE FOR LANE-IMBALANCED SECTIONS
ONE-SIDED WEAVING SECTIONS

Multiple weaving sections (see Figure 1) embody the overlapping of two or more simple weaving sections and hence produce more complex operations. It follows that analyses of multiple weaving sections involve more difficult procedures. The basic principles for simple weaving apply to multiple weaving sections. Before the nomographs can be used, however, it is necessary to determine how to handle any of the overlapping weaving maneuvers which may take place between the two segments (possibly three segments in special cases) of the overall multiple weaving section.

Variation occurs in the manner in which weaves are distributed between segments, depending upon geometrics, including lane arrangements and spacing of multiple entrances and exits, relative traffic volumes comprising indivudual weaving maneuvers, truck traffic, signing, and other factors. Several procedures have been considered and utilized. A method has been deduced from limited observations and is presented here for application.

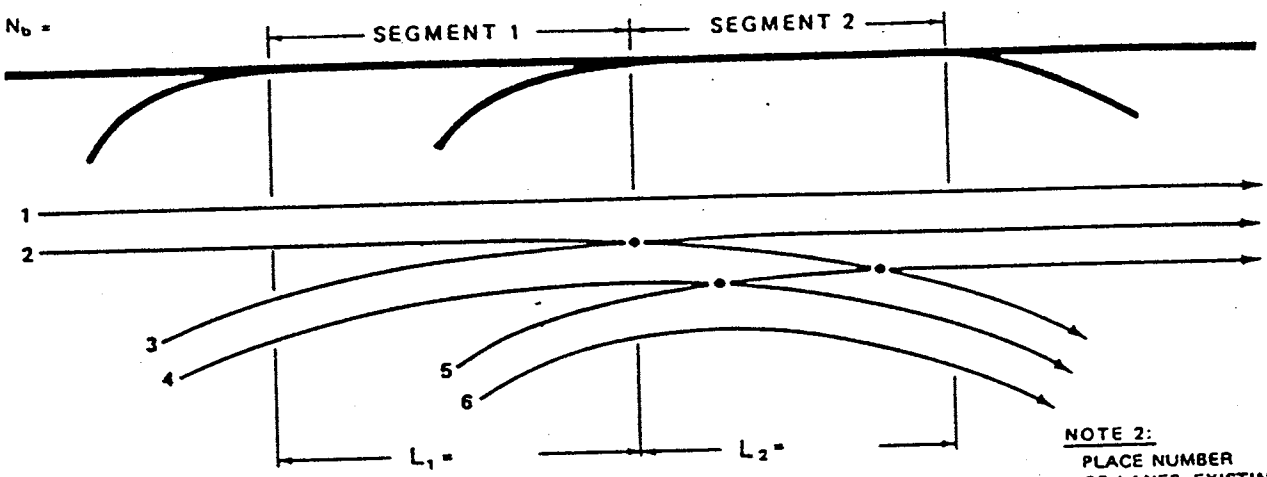
For clarity of discussion reference is made initially to the upper diagrams of Figures 10 and 11, showing two most common configurations of multiple weaving sections and the pattern of traffic movements therewith. The primary consideration relates to the distribution of weaving volumes between segments 1 and 2, which involve movements 2 and 3 for the 2EN-EX case and movements 2 and 4 for the EN-2EX type of multiple weaving section. Once this is established and the traffic diagram (with its individual movements) for each segment determined, the process involves a separate analaysis of each segment by the standard nomograph procedure.

The method in the 1965 HCM utilized a division in the long weave volume in proportion to the length of segments 1 and 2. In a more recent procedure*

* "Weaving Area Operations Study," Polytechnic Institute of New York, NCHRP Project 3-15, Final Report, 1973; and Transportation Research Circular 212, January 1980.

ANALYSIS WORKSHEET
MULTIPLE WEAVING 2 EN - EX

PROJECT _____



NOTE 2:
PLACE NUMBER OF LANES, EXISTING OR SOLVED, ALONG UPPER DIAGRAM.

LONG WEAVE — VOL 2. VS. VOL. 3 (SEE NOTE 1)*

SEGMENT 1

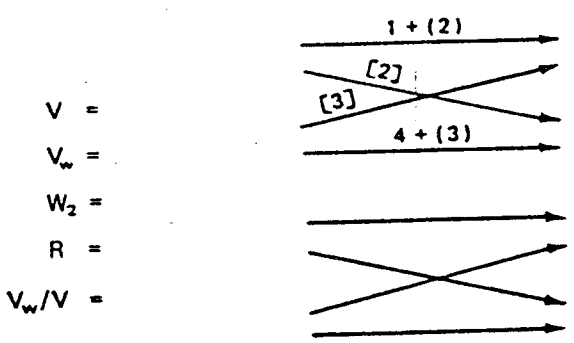
[2] = P x VOL. 2
= X = _____

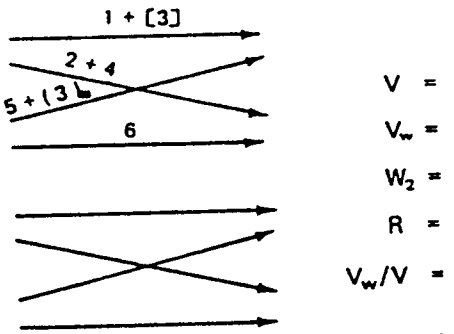
[3] = P x VOL. 3
= X = _____

SEGMENT 2

(2) = (1 - P)(VOL. 2)
= X = _____

(3) = (1 - P)(VOL. 3)
= X = _____





NOTE 3:
ALL VOLUMES IN PCPH. RECORD ON DIAGRAM.

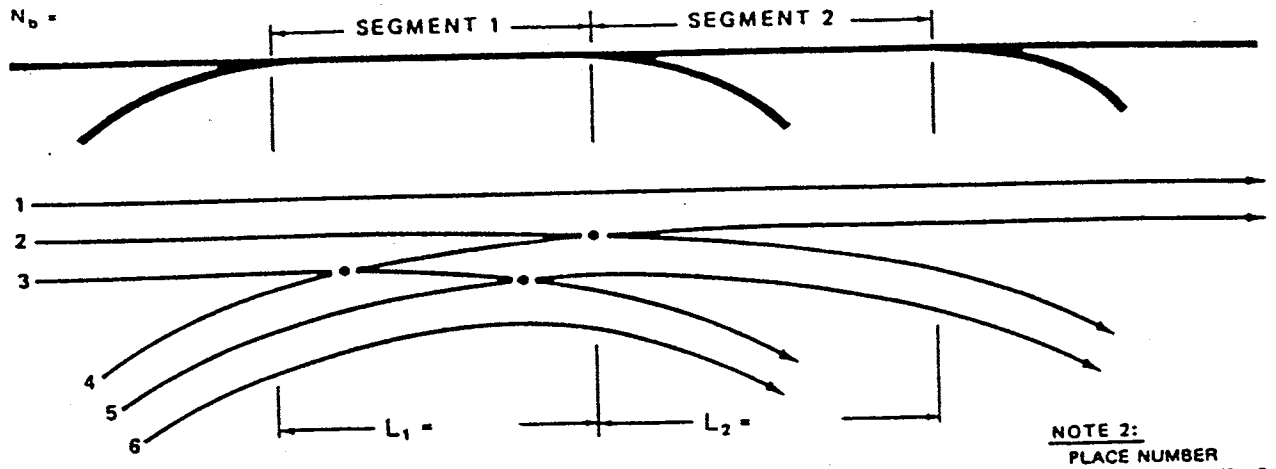
COMPUTATIONS

NOTE 1. ALL OF LONG WEAVE TENDS TO TAKE PLACE IN SEGMENT 1, WITH PROPORTION P INCLINED TO APPROACH 1.0: P, HOWEVER, MAY VARY IN INDIVIDUAL CASES. IN DESIGN AND IN GENERAL OPERATIONAL ANALYSIS, NORMALLY USE P = 0.75 IN SEGMENT 1. OTHERWISE, IN MORE DETAILED OPERATIONAL ANALYSIS, FIELD SAMPLING OF TRAFFIC MAY GIVE INDICATION OF P.

Figure 10. ANALYSIS WORKSHEET FORM FOR 2 EN - EX MULTIPLE WEAVING SECTIONS

ANALYSIS WORKSHEET
MULTIPLE WEAVING EN-2EX

PROJECT _____



NOTE 2:
PLACE NUMBER OF LANES, EXISTING OR SOLVED, ALONG UPPER DIAGRAM.

LONG WEAVE – VOL. 2 vs. VOL. 4 (SEE NOTE 1)*

SEGMENT 1:

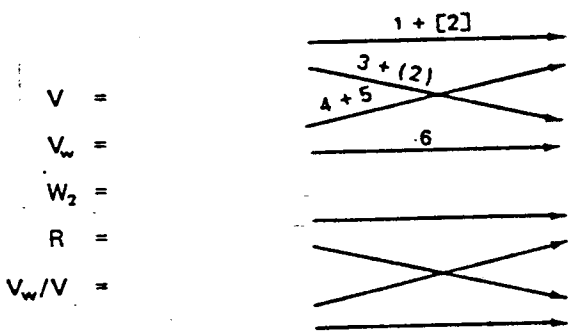
(2) = (1 - P)(VOL. 2)
= X = _____

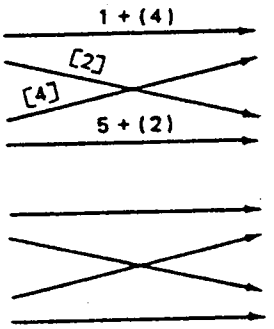
(4) = (1 - P)(VOL. 4)
= X = _____

SEGMENT 2:

[2] = P x VOL. 2
= X = _____

[4] = P x VOL. 4
= X = _____





V =
V_w =
W_2 =
R =
V_w/V =

V =
V_w =
W_2 =
R =
V_w/V =

NOTE 3:
ALL VOLUMES IN PCPH, RECORD ON DIAGRAM.

COMPUTATIONS:

NOTE 1 ALL OF LONG WEAVE TENDS TO TAKE PLACE IN SEGMENT 2, WITH PROPORTION P INCLINED TO APPROACH 1.0; P, HOWEVER, MAY VARY IN INDIVIDUAL CASES. IN DESIGN AND IN GENERAL OPERATIONAL ANALYSIS, NORMALLY USE P = 0.75 IN SEGMENT 2. OTHERWISE, IN MORE DETAILED OPERATIONAL ANALYSIS, FIELD SAMPLING OF TRAFFIC MAY GIVE INDICATION OF P.

Figure 11. ANALYSIS WORKSHEET FORM FOR EN-2EX MULTIPLE WEAVING SECTIONS

(taken from limited observations) it is indicated that the long potential weave such as between movements 2 and 3 for the 2EN-EX case (Figure 10) would tend to take place completely in segment 1; and, for the EN-2EX case (Figure 11) the long potential weave between movements 2 and 4 would tend to take place completely in segment 2. This was generally supported by observation of drivers with respect to: "necessity to weave," where most drivers will not weave until they have to; and "presegregation," where drivers enter a weaving section already in lanes appropriate to their desired travel path. This procedure was generally considered to be applicable, except in cases where the two segments are extremely disproportionate and particularly short.

The basic principles thus expressed are generally adopted in this report; however, due to a multitude of variables affecting operations, as innumerated above, it was rationalized that a small part of the long weave would take place in the other segment. Thus, as an overall analysis procedure, some amount less than all weaving traffic between the first ramp and last ramp would occur in segment 1 of the 2EN-EX type of section, and in segment 2 of the EN-2EX type of section.

The portion (p) of the long weave, in these segments, was considered to be generally representative at 75 percent, expressed as p of 0.75. This value evolved from a series of test calculations for various combinations of weaving volumes and length of segments for multiple weaving sections, in which several methods were used. Most logical and more-nearly balanced results were found for the method presented here.

The analysis worksheets of Figures 10 and 11 provide a convenient way of organizing multiple weaving problems. The form allows for a complete record to be made of input data, calculations as required, nomograph readings, and solution results. The form also has the flexibility of varying the proportion p of the long weave, should it be judged appropriate to do so to more closely fit a given set of conditions. A p of 0.75, however, is recommended generally as noted at the bottom of the form.

The above discussion deals with multiple weaving configurations which operate as multiple weaving sections. However, there are instances when such configurations have widely spaced ramps, or sufficiently light traffic, or both, so that a portion within the overall section may be out-of-realm of weaving. In such a case the configuration may be reduced to a simple weaving section. It would be prudent, therefore, to make an initial test to determine whether the overall configuration is indeed a multiple weaving section. The procedure for the test is outlined in Table 2.

To summarize the application of nomographs and analysis procedures for different types of weaving sections and variety of conditions therewith, Table 2 has been prepared to serve as a guide. It provides concise information as an adjunct to the use of nomographs and a reference for solution of problems.

TABLE 2

USE OF NOMOGRAPHS INCLUDING ADJUNCT PROCEDURES FOR WEAVING SECTIONS

A. FREEWAY SECTIONS

(1) One-Sided Weaving Sections--General:

- Use Nomograph 1, for which general application is demonstrated thereon by dotted solution lines with arrows; followed by Nomograph 3, for which application is indicated thereon by "Instructions," 1 through 4.

(2) Two-Sided Weaving Sections--General:

- Use Nomograph 2, for which application is demonstrated thereon by dotted solution lines with arrows; followed by Nomograph 4, for which application is indicated thereon by "Instructions," 1 through 3.

B. C-D ROADS

(1) Local Sections provided for individual interchanges, arranged for simple weaving between two ramps; generally use Nomograph 1 only for the C-D road (freeway proper analyzed separately). S_w with corresponding LOS is determined from the lower-left portion of Nomograph 1, provided that sufficient number of lanes is available. Overall speed of weaving section, S, equals S_w. Nomograph 3 should be referred to, however, when the outer flow from one ramp to the other exceeds about 15 percent of V.

(2) Sections on Continuous or Extended C-D Roads along the freeway serving several interchanges are analyzed in the same manner as freeway weaving sections, utilizing Nomographs 1 and 3, and Nomographs 2 and 4, as noted under A(1) and A(2) above.

C. LANE-BALANCED AND LANE-IMBALANCED WEAVING SECTIONS

(1) Lane-Balanced Sections as previously defined, refer primarily to exits with provision of "one more lane going away" (i.e., combined number of lanes on freeway and ramp after exit being one more than on freeway preceding the ramp). This case is directly accounted for by the solid curves in the lower-left portion of Nomographs 1 and 2. Direct use of these curves and continuation through the nomographs are demonstrated by dotted solution lines.

(2) Lane-Imbalanced Sections which normally refer to bifurcations without change in total number of lanes (i.e., the number of lanes on freeway and ramp after exit is the same as on freeway preceding the ramp). This case is accounted for by the dotted speed curves in the lower-left portion of Nomographs 1 and 2--indicating that for the same weaving volume, more length of weaving section is required to maintain level of service; or, for the same length, less weaving traffic can be handled than for the lane-balanced section. In using the lower-left portion of the nomograph and then proceeding upward toward the k curve requires, for the lane-imbalanced section, a jog or lateral shift to the left, from the dotted set of speed curves to the solid set of speed curves. This is necessary to permit the remaining elements of the nomograph to serve equally the lane-balanced and lane-imbalanced sections. The method for handling this situation, in solution of problems, is demonstrated in Figure 9; note that the procedure as shown by the sample solution lines in part A of the figure is direct for lane-balanced sections, and for lane-imbalanced sections it requires an equivalent speed jog to the left (from dotted to solid speed curve set), as shown in part B of the figure.

TABLE 2 (continued)

D. WEAVING SECTIONS AS RELATED TO LANE ARRANGEMENTS

(1) Configurations with Normal Lane Shifts. Weaving sections with various lane arrangements have an effect on operational quality and speed, a feature closely allied to lane balance. The combination with different configurations produces different amount of lane shifting in the process of weaving. The concept of potential lane shifts is demonstrated in Figure 4. As shown, most of the well designed sections produce 2 to 3 potential lane shifts. Weaving sections with 4 potential lane shifts also may be considered within acceptable limits, in which solutions achieved by the procedures of Nomographs 1 - 4 apply.

(2) Configurations with Excessive Lane Shifts. Weaving sections requiring 5 and 6 potential lane changes, indicate from examination of limited data, that levels of service and associated speeds, S and S_w, would be lowered 3- to 5-mph below those normally produced by Nomograpahs 3 and 4. For such conditions as a rational deduction, 3- to 5-mph speed increments should be deducted from the nomograph readings to estimate the final result.

E. MULTIPLE WEAVING SECTIONS

(1) Test for Multiple Weaving. Ramp junctions in sequence involving two or more overlapping simple weaving configurations should be tested prior to analysis if, in fact, multiple weaving is present (see Figures 10 and 11). The check is made with respect to the portion of the long weave (between first and last ramps) which occurs in segment 1 for 2EN-EX form and in segment 2 for EN-2EX form; if this portion in either case is within realm of weaving, the configuration is analyzed as a multiple weaving section and, if not, as a simple weaving section.

(2) Distribution of Long Weave:

- Type 2EN-EX--Portion of weave occurring in segment 1 is normally taken to be three-quarters of movements 2 plus 3, and remainder in segment 2, as shown in Figure 10.

- Type EN-2EX--Portion of weave occurring in segment 2 is normally taken to be three-quarters of movements 2 plus 4, and remainder in segment 1, as shown in Figure 11.

(3) Use of Nomographs and Analysis Worksheets. Nomographs 1 - 4 are applied in normal manner to each segment separately in accordance with weaving diagrams formulated per above explanation. Analysis Worksheets, Figures 10 and 11 provide an organized means of evaluating multiple weaving problems.

Example Problems

The following set of problem examples is included to serve as a guide in the application of procedures developed and presented herein. The problems and accompanying solutions have been carefully selected to cover a broad spectrum of weaving situations which may occur in the planning, design and operation of freeway facilities.

The problems are structured so as to provide the user with a sufficiently detailed explanation of the procedure employed. Also, the selected problems are representative of a variety of actual conditions.

The solution of problems normally has been considered in terms of two aspects--design problems and operational analaysis problems. Although the situations seem different, in essence the overall solution or end result, by the technique presented here, is much the same or similar.

For design problems, usually the solution involves finding L and N, with an attempt at an operationally balanced section for a given or desired LOS, using Nomographs 1 or 2; should a balanced section not be feasible, a supplementary Nomograph 3 or 4 would be used to calibrate speeds of operation, S_W and S, and thus levels of service. For operational analysis problems, the solution also involves Nomograph 1 or 2, but since the values of L and N are given, entries for them are made in reverse order, while procedures in Nomograph 3 or 4 are accomplished as before. The final results in this case involve the determination of LOS and speeds for the weaving movement and for the overall weaving section.

Accordingly, the example problems presented are not separated and are handled in the same manner for either condition. A set of 20 problems with solutions follow.

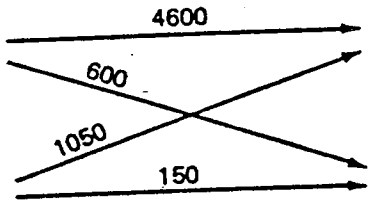
Special Note for Use of Guide

In order to allow for expedient review of these problems and to facilitate the use of this Guide by the user in solving other problems, a complete set of the four nomographs with Table 2, and multiple weaving Forms 1.01 and 1.02, are repeated at the very end of the report, following the example problems.

Planning/Design Problems:

Problem 1. The problem to be investigated is a one-sided lane-balanced weaving section formed along the freeway between two interchanges. The design calls for level of service C. The volumes noted have all been converted to equivalent passenger cars per hour (pcph). Referring to the weaving configuration at the upper-right portion of Nomograph 1 in describing the example, the approach free-way volume is 5200 pcph on 4 lanes with 4600 pcph proceeding through and 600 pcph departing at the next exit. At the entrance ramp 1200 pcph are merging, of which 1050 pcph are proceeding on the freeway, and 150 pcph are destined to the next exit. The total volume through the weaving section amounts to 6400 pcph. The problem is to determine the minimum spacing (for weaving) between ramps and the number of lanes required through the weaving section to maintain level of service C operation.

TRAFFIC VOLUMES IN PCPH

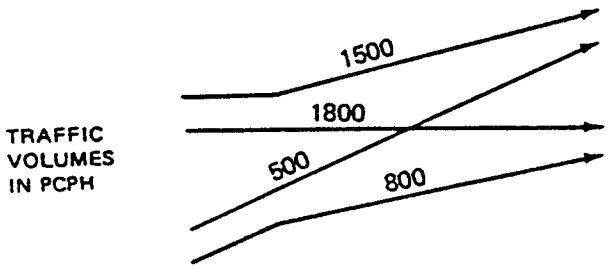


$V = 6400$
$V_w = 1650$
$W_2 = 600$
$R = 0.36$

Solution:

Enter Nomograph 1 with a weaving volume of $V_w = W_1 + W_2 = 1050 + 600 = 1650$, proceed right to the 40-mph curve (maximum for C) and turn downward to read a minimum required weaving length of L = 1300 feet. (The fine dotted lines with arrows projected through the nomograph show the process in solution.) Then, from the original intersection point proceed along the 40-mph curve to the "turning line for k" and continue upward to intersect the upper k values curve (for R = 600/1650 = 0.36); at this point turn right and advance to the smaller weaving volume, W_2 of 600, followed by a downward turn to V = 6400; then a horizontal projection to level of service C line (1450 pcph) for $N_b = 4$ yields a total number of lanes N of 5.2. A rounding to N = 5 is close enough to maintain a balanced section. The weaving movement would operate at $S_w = 40$ mph and the overall section (see Table 1a) at approximately 45 mph.

Problem 2. In this case a two-sided weaving section is formed by an entering ramp on the right and an exiting ramp on the left as diagrammed in the upper part of Nomograph 2. It is desired to produce an operationally balanced facility at level of service C. The freeway is planned for 6 basic lanes, 3 lanes in each direction. The total projected volume in one direction of V = 4600 pcph within the weaving section includes 1800 pcph (W_1) proceeding through on the freeway, and 500 pcph (W_2) crossing the freeway from entrance to a lane-balanced exit ramp. Determine minimum length and the width of weaving section required.

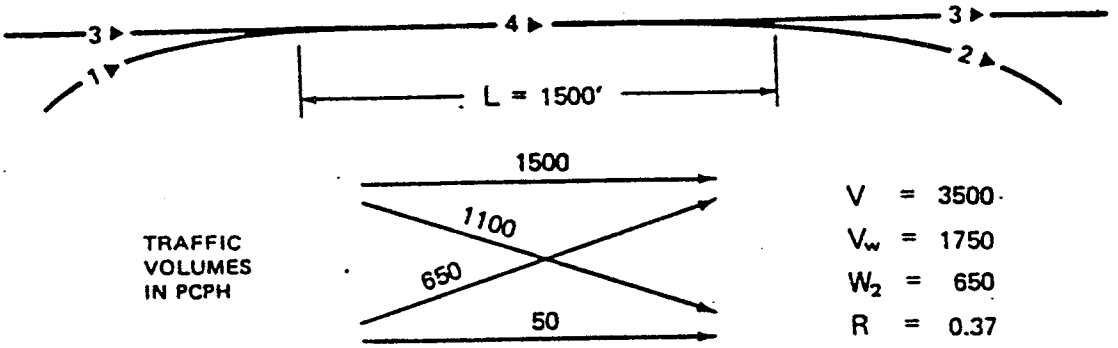


$V = 4600$
$V_w = 2300$
$W_2 = 500$
$R = 0.22$

Solution:

Following the solution arrows in Nomograph 2, it is noted that with $V_w = 2300$ and level of service C, the spacing between ramps has to be so that L = 1900 feet. Proceeding further through the graph with R = 0.22, $W_2 = 500$, and a proposed N_b of 3 lanes, the required number of lanes in the weaving section is indicated to be 4.8. A rounding to N = 5 lanes would be appropriate, maintaining reasonable balance with possibly a very slight improvement in operation. The resulting SF for 5 lanes approximates 1300 pcphpl and, according to Table 1, the overall section (as well as the weaving movement) would operate at LOS C.

Problem 3. Determine level of service and approximate average speeds for the design of a one-sided, lane-balanced weaving section with the length and width shown in the following sketch.



TRAFFIC VOLUMES IN PCPH

$V = 3500$

$V_w = 1750$

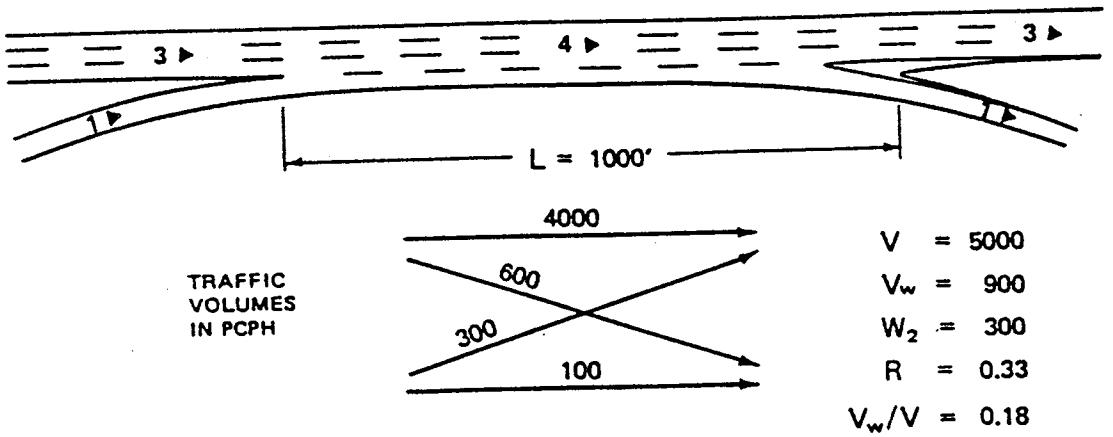
$W_2 = 650$

$R = 0.37$

Solution:

Enter Nomograph 1 at bottom left with $V_w = 1750$ and $L = 1500$; read $S_w = 41$ mph using solid curves for lane-balanced condition. Continue upward from turning line to $R = 0.37$, then to $W_2 = 650$, $V = 3500$, and $N = 4$ within $N_b = 3$ graph; read overall SF = 1150 and equivalent level of service of high C. Thus, both the overall weaving section and the weaving movement would operate within a service level range of C, with a speed of 41 mph, (as shown above) for weaving and 45 to 50 mph (Table 1) for the composite movement.

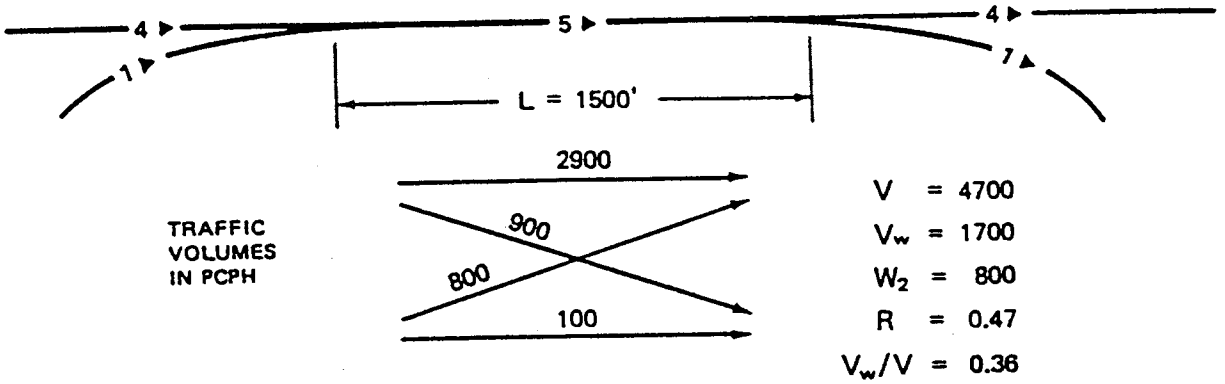
Problem 4. Determine level of service and associated average speeds for the existing one-sided weaving section, with lane balance, shown in the following sketch.



Solution:

Enter Nomograph 1 with V_w = 900 and L = 1000. Using solid curves, read initial S_w = 44 mph and LOS of slightly over B, or C.2 (about 20% into level C). Continue through nomograph using R = 0.33, W_2 = 300, V = 5000 and N = 4 preceded by N_b of 3; read LOS of nearly D, or C.9, and corresponding SF = 1325. Refer to Nomograph 3, Instruction 1, since C.2 VS 6.9 is less than one LOS; using SF = 1325 and V_w/V = 0.18 find S = 46 mph while weaving speed remains as initially read, or S_w = 44 mph. According to Table 1a in Nomograph 3, both elements of the weaving section, weaving and overall, operate at LOS C. To complete the analysis, a check of ramp entrance and exit levels of service shows favorable operation.

Problem 5. An operational analysis is required to determine the level of service and associated speeds on the existing one-sided weaving section, without lane balance shown in the accompanying sketch.



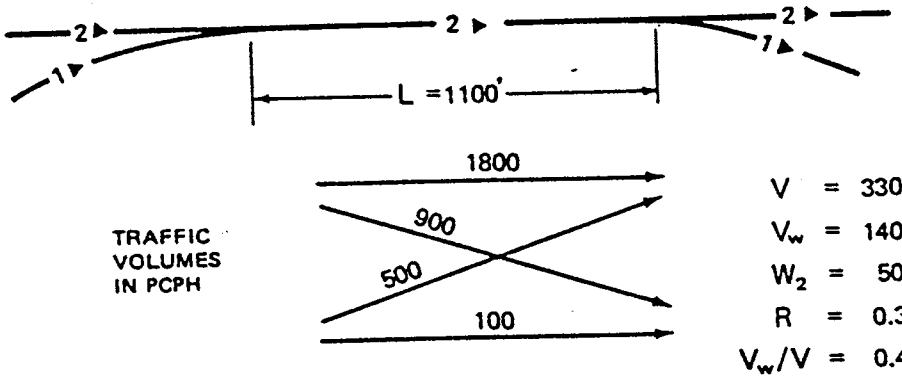
Solution:

Enter Nomograph 1 with V_w = 1700 and L = 1500; using the dotted speed curves representing lane-imbalanced condition, find initial S_w = 40 mph with associated LOS of C_{max}. In order to continue through the nomograph, it is necessary (according to nomograph structure) to transfer this intersection point laterally to the left to a comparable position with respect to the basic solid speed curves, as per demonstration in Figure 9. Proceed from this point along the trend of the curve to "turning line for k," and then vertically up to the upper k curve (since R = 0.47). From this position of k = 2.6 proceed in the usual manner using W_2 = 800, V = 4700, and N = 5 within N_b = 4 graph; read overall (composite) LOS B_{max} with corresponding SF = 1200. Refer to Nomograph 3, Instruction 2, since LOS for overall (V) is B_{max} and one LOS better than C_{max} for weaving; find S = 48 mph for SF = 1200 in graph A, while S_w = 40 mph reading remains the same a per initial determination in Nomograph 1. Check of ramp entrance and exit operations (not shown) indicates compatible levels of service with the weaving section. In summary, the overall (composite) weaving section and the weaving movement would both operate (see Table 1a) generally at LOS C with S = 48 mph and S_w = 40 mph, respectively.

General statement for Problems 6, 7 and 8.--An existing freeway within the outskirts of an urban area is to be improved to accommodate increased traffic due to system reorientation and concentrated development projected along the corridor. Design studies produced several alternatives for consideration. As part of performing "capacity" analysis using projected future traffic, the existing configuration (Problem 6) has been included for comparison in the evaluation; it consists of a simple merge-diverge section formed by a standard entrance ramp followed by a normal exit ramp, with tapered speed-change lanes and no auxiliary lane within the weaving section as depicted in Figure 3-A. The second alternative (Problem 7) utilizes an auxiliary lane between the entering and exiting ramps as shown in Figure 3-B. The third alternative (Problem 8) incorporates a section of C-D road as in Figure 3-C. The projected traffic in conjunction with weaving is to be accommodated at LOS D and preferably LOS C. For convenience of demonstrating the problem solutions, all traffic volumes have been adjusted for the effect of trucks and grades to pcph preparatory to using the nomographs. The presentation of this three-part overall problem emphasizes the sensitivity of geometric changes and indicates the visual aspects of the use of nomographs in quickly analyzing alternative plans.

(Individual Problem Examples Follow on Succeeding Pages.)

Problem 6. The skeletonized plan, including the number of lanes, length of weaving and projected traffic for the various movements, is shown in the accompanying sketch. The problem is to determine if the projected traffic can be accommodated. If so, at what level of service and associated speeds of weaving and overall traffic within the weaving section?

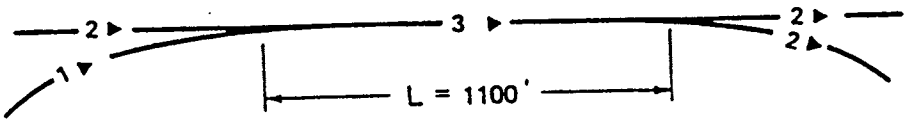


PROJECTED FUTURE TRAFFIC

Solution:

Enter Nomograph 1 at the lower left and bottom with V_w = 1400 and L = 1100, and locate intersection at approximately 40 mph (initial reading of S_w). Project along the 40-mph line to k turning line and then upward to the k value curve (considering R = 0.36); from there continue right to W_2 = 500, down to V = 3300, right to N_b = 2 portion of graph and intersect N = 2 at SF = 2000 (representing V). The latter value indicates a highly constrained section with overall operation of weaving section at or beyond capacity. In Nomograph 3, Instruction 3, enter with SF = 2000 and find both overall (composite) speed and weaving speed to be 25 mph, indicating operation at LOS F. Extremely poor conditions would prevail if this configuration were to be maintained in the future.

Problem 7. A minimum improvement is represented in this case by merely adding an auxiliary lane within the weaving section between the ramp terminals and reconstructing the facility to a modern standard, including a 2-lane exit. The weaving section assumes the following configuration.

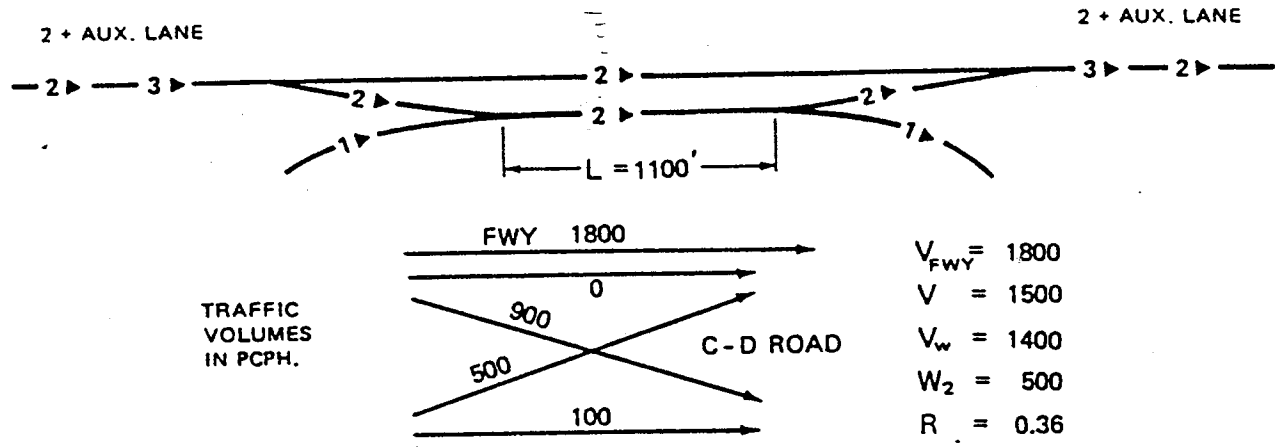


TRAFFIC DIAGRAM
SAME AS IN PROBLEM 6

Solution:

Proceed through Nomograph 1 in the same manner as in Problem 6, except that the horizontal projection from V = 3300 to N_b = 2 zone is intersected with N = 3. This yields for the overall section an SF of about 1350, just within LOS C. Thus, both the overall and weaving movements operate at LOS C. Proceeding further with Instruction 1 in Nomograph 3, the initial reading of S_W = 40 mph remains the same and the overall speed is found to be S = 45 mph. Levels of Service C are further verified in Table 1a, indicating a fully balanced section.

Problem 8. A more elaborate improvement, emphasizing greater freedom of operation on the freeway is presented in this case by separating the weaving movement from the freeway. The accompanying sketch demonstrates the plan.

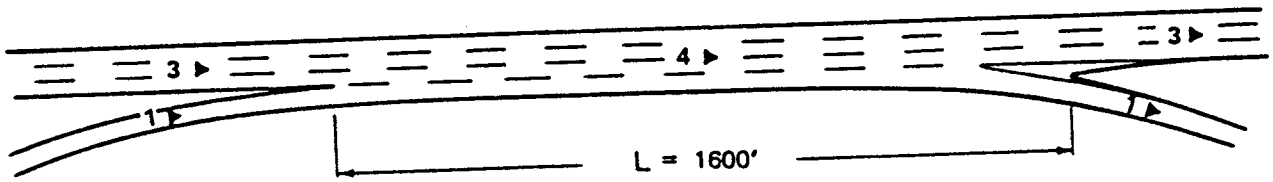


Solution:

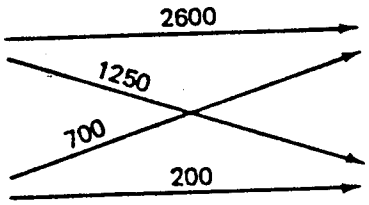
Proceed through Nomograph 1 in the same manner as before, except that the downward projection of W_2 = 500 is intersected with V = 1500 (C-D road traffic only); then, project to the right (within N_b = 2 zone) to intersect with N = 2, which yields an SF of about 1250. In the case of a local C-D road weaving section, Nomograph 3 normally is not used as indicated previously (Table 2, instruction B(1); thus, S_w with corresponding LOS is determined by the lower-left portion of Nomograph 1, which yields on the C-D road an S_w of 40 mph and corresponding LOS C. The through movement on the main line, 1800/2 = 900 pcph per lane, is indicative of operation on the freeway proper at LOS B at an average speed upward of about 55 mph.

Problem 9. An existing 6-lane urban freeway with a 50-foot median, in need of considerable maintenance and safety improvements, along with anticipated traffic growth, is slated for reconstruction. Preliminary design studies indicate utilizing for the most part the existing location in plan and profile, providing a continuous additional lane for each direction in the median, pavement strengthening, and modernizing exits and entrances. Of particular concern is a weaving section along the freeway shown in the accompanying sketch prior to construction. As a first step in the analysis and design process determine the operational condition of the existing facility--Case A, considering the indicated current traffic.

CASE A — INITIAL (EXISTING) CONDITION



TRAFFIC VOLUMES IN PCPH



$V = 4750$

$V_w = 1950$

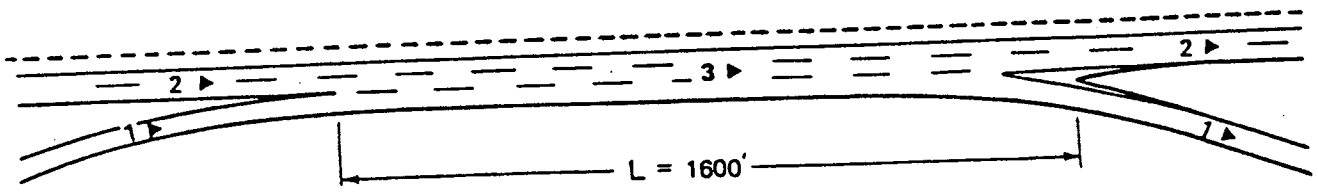
$W_2 = 700$

$R = 0.36$

$V_w/V = 0.41$

During construction one lane is to be closed on the median side, providing 3 lanes within the weaving section and 2 lanes approaching and leaving the section--Case B. Determine whether it is feasible to handle the indicated traffic during construction and, if so, at what level of service and associated speeds. The condition is depicted in the following sketch.

CASE B — CONSTRUCTION STAGE, ONE LANE CLOSED

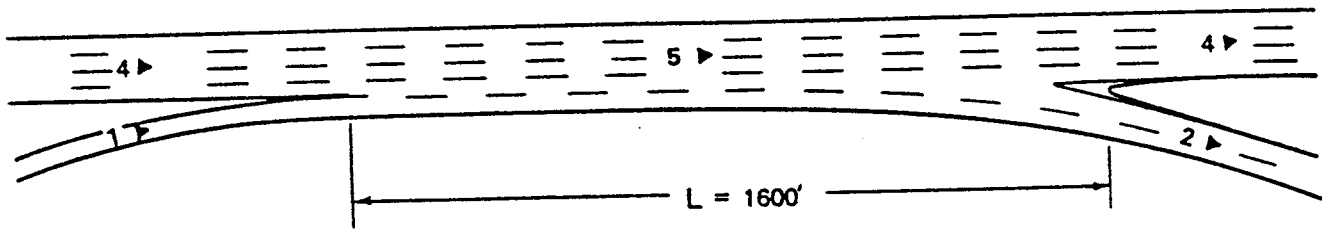


TRAFFIC AS SHOWN FOR CASE A

Problem 9. (continued)

Upon completion of construction, the freeway will consist of 4 basic lanes with a 5-lane weaving section and a 2-lane exit at the far ramp--Case C. Determine the level of service and associated speeds of the reconstructed section upon opening the freeway to full operation. The reconstructed facility is shown in the following sketch. Also check future operation for the assumptiuon that traffic will increase uniformly within the pattern by 50 percent.

CASE C — RECONSTRUCTED FACILITY



TRAFFIC AS SHOWN FOR CASE A

Solution:

Case A (Existing condition). Enter Nomograph 1 with V_w = 1950 and L = 1600. At intersection relative to dotted speed curves (lane-imbalanced condition) find initial S_w = 39 mph with corresponding level of service of 20 percent into D zone, or LOS D.2. Shift horizontally a comparable increment to left (as described in Figure 9-B) and proceed in conventional manner through nomograph using R = 0.36, W_2 = 700, V = 4750, and N = 4 within N_b = 3 zone; read LOS D.4 with corresponding SF = 1450. Referring to Nomograph 3, Instruction 1 (since LOS of V LOS V_w) S_w = 39 mph, and S = 43 mph using V_w/V = 0.41 in Graph A; according to Table 1a both the weaving movement and overall section operates at LOS D. Check of ramp entrance and exit indicates operation of each within LOS D.

Case B (Reduced cross section). Proceed through Nomograph 1 in identical manner as for Case A except that the terminal reading is made for N_b = 2 and N = 3; read LOS E_{max} and SF = 1900. Using Nomograph 3, Instruction 3, with SF = 1900, find S = 30 mph and S_w = 28 mph, corresponding to LOS E_{max}. Check of ramp entrance and exit indicates operation in the range of LOS D to E.

Problem 9. (Solution continued)

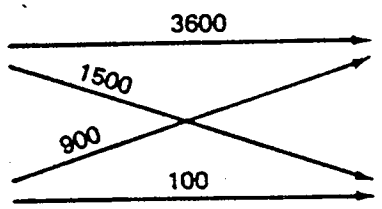
Case C (Widened cross section). Enter Nomograph 1 with V_w = 1950 and L = 1600; use solid speed curves directly (lane-balanced condition) and read initial S_w = 40 mph and corresponding LOS C_{max}. Continue through nomograph with R = 0.36, W_2 = 700, V = 4750, and N = 5 within N_b = 4 zone, locate SF = 1150 with corresponding LOS of B.9. Using Nomograph 3, Instruction 2, with SF = 1150, find S = 49 mph and weaving speed as initially read of S_w = 40 mph. Thus, the overall (composite) weaving section will operate at LOS C (near B) and weaving movement at LOS C (see Table 1a). Check of ramp entrance and exit indicates operation in the range of LOS B to C.

In checking the design for a uniform increase of traffic movements by 50 percent in the future (V = 7125, V_w = 2950, W_2 = 1050), Nomograph 1 indicates LOS D_{max} for weaving at 35 mph and an SF of 1775 equivalent to LOS E.5. Using Nomograph 3, Instruction 1, with SF = 1175 and V_w/V of 0.41, find S = 35 mph and weaving speed as initially read of S_w = 35 mph. Thus, the overall weaving section is expected to operate at LOS E, and the weaving movement just within LOS D.

Problem 10. An existing 3-lane freeway in one direction having a 1500-foot long one-sided weaving section is to be upgraded to 4-basic lanes. Projected one-directional traffic volumes in pcph are: through on freeway, 3600; exiting at second ramp, 1500; entering at first ramp, 900 (producing a weaving volume of 2400); and an outer flow between the ramps of 100. An alternative solution to be considered is to remove the existing ramp and provide via a new interchange an exit ramp about 1/2 mile farther downstream, producing an improved weaving section of 4000 feet.

TRAFFIC DIAGRAM

TRAFFIC VOLUMES IN PCPH



$V = 6100$
$V_w = 2400$
$W_2 = 900$
$R = 0.38$
$V_w/V = 0.39$

ALTERNATIVE 1: L = 1500'
ALTERNATIVE 2: L = 4000'

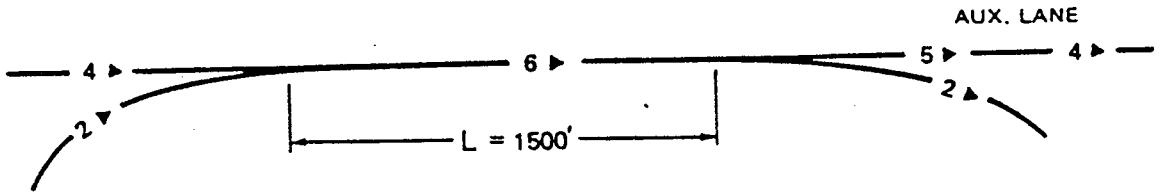
Determine the number of lanes required in each case, considering lane balance, to satisfy a design of the overall freeway weaving section at not less than level of service C operation; include level of service and average speed of weaving traffic, and the resulting average speed of traffic on the overall weaving section.

(Solution Follows on Next Page)

Problem 10. . (continued)

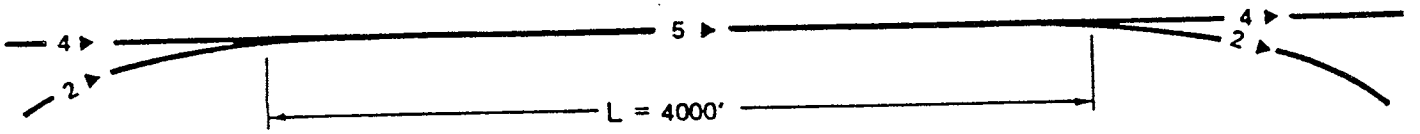
Solution:

Alternative 1. Enter Nomograph 1 with V_w = 2400 and L = 1500; read initial S_w = 37 mph and corresponding LOS D.7. Continue through nomograph using upper k curve (R = 0.38), W_2 = 900, V = 6100 and LOS C (SF = 1450) for N_b = 4. Find N = 5.4; round to N = 6 lanes with corresponding LOS C.4, and SF of 1300. For further calibration, using Nomograph 3, Instruction 2, determine S = 46 mph in Chart A, and S_w = 37 mph as initially established in Nomograph 1. Thus, for Alternative 1, LOS C at S = 46 mph is satisfied, while the weaving movement operates at S_w = 37 mph corresponding to LOS D. The number of lanes required for this solution is shown as follows:



ALTERNATIVE 1

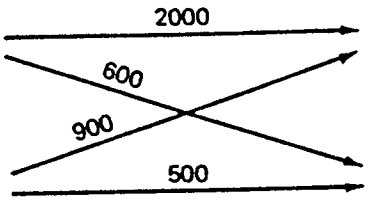
Alternative 2. Enter Nomograph 1 with V_w = 2400 and L = 4000; read initial S_w = 47 mph and corresponding LOS B.5. Continue through remaining nomograph as before and find N = 4.5 for LOS C and N_b = 4; round to N = 5 with corresponding LOS C. 5 and SF of 1325. For further calibration, using Nomograph 3, Instruction 3 S = 46 mph and S_w = 43 mph. Thus, the solution of the alternative design provides improved operation, although with one lane less. The overall (composite) speed of 46 mph and weaving speed of 43 mph, each indicates LOS C operation. The number of lanes required for Alternative 2 is shown below.



ALTERNATIVE 2

Problem 11. Alternative designs are being considered for a 6-lane high-type freeway in a rural area on which it is intended to maintain a level of service B. For one design it would result in a one-sided weaving section while the other would create two-sided weaving. The alternative arrangements under study, including the volume and pattern of traffic, are shown below. The analysis requires the determination of respective lengths of weaving sections, lane arrangements, and resulting speeds of operation.

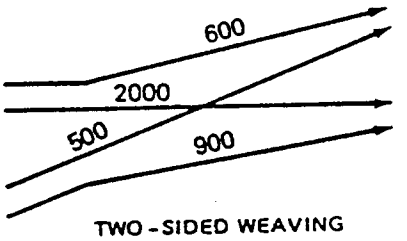
ALTERNATIVE A



ONE-SIDED WEAVING

$N_b = 3$

ALTERNATIVE B



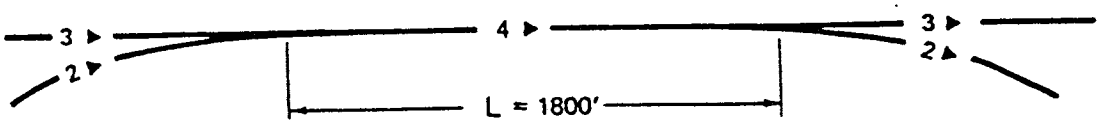
TWO-SIDED WEAVING

$V = 4000$	$W_2 = 600$	$V = 4000$	$W_2 = 500$
$V_w = 1500$	$R = 0.40$	$V_w = 2500$	$R = 0.20$
$V_w/V = 0.38$			

TRAFFIC VOLUMES IN PCPH

Solution:

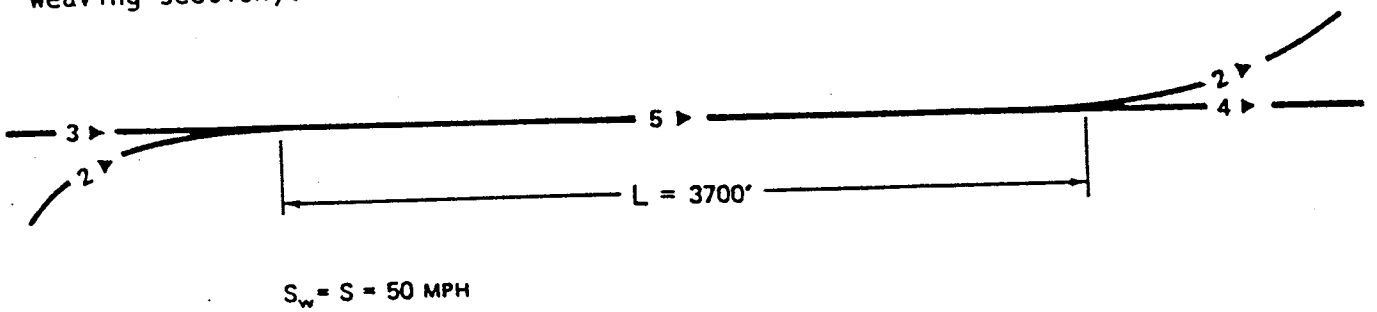
Alternative A. Using Nomograph 1 find L = 1800 feet for V_w of 1500 pcph and LOS B curve (45 mph). Proceed through nomograph to R = 0.38, W_2 = 600, V = 4000 and LOS B line for N_b = 3; read N = 4.1 lanes. Round back to a whole number of N = 4 lanes and a corresponding SF of 1100. Referring to Nomograph 3, Instruction 1, the resulting average speeds are S_w = 45 mph (as previously read at lower left of Nomograph 1) and S = 50 mph, satisfying LOS B operation. Pertinent dimensions are shown as follows (note lane balance has been provided).



S_w = 45 MPH S = 50 MPH

Problem 11. (Solution continued)

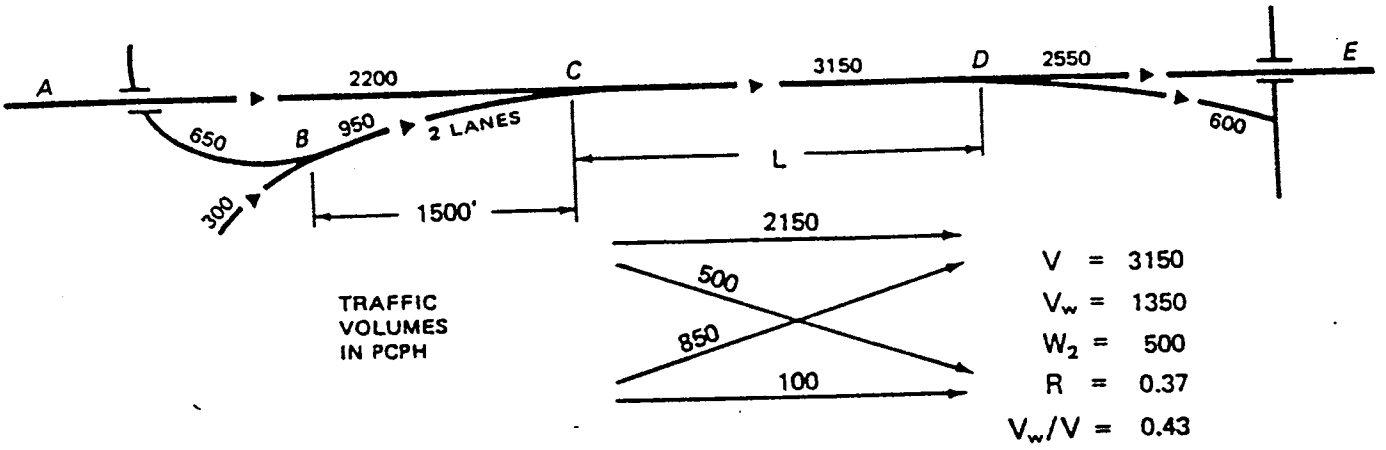
Alternative B. Using Nomograph 2 find L = 3700 feet for V_w of 2500 pcph and LOS B curve (50 mph). Proceed through nomograph to R = 0.20, W_2 = 500, V = 4000 and LOS B line for N_b = 3; read N = 4.9 or 5.0. Using 5 lanes, the section is fully balanced at LOS B, which obviates the use of Nomograph 4. Overall and weaving speeds are 50 mph. The following dimensions are produced (note provision of lane balance and need to continue auxiliary lane on freeway forward beyond the weaving section).



S_w = S = 50 MPH

Summary Although the basic volume and pattern of traffic entering and leaving the weaving section is the same in each alternative, the dimensional features differ materially. The two-sided section in this case, due to the makeup of a larger weaving volume, in conjunction with inherently more stringent requirements of two-sided weaving, requires greater length and width of section, with an extra auxiliary lane carried forward which would be terminated appropriately on the right as a lane drop on the freeway or a lane drop via the next ramp exit. The comparative dimensions for a two-sided weaving section as a general case are not necessarily more critical. There are situations for certain combinations of volumes and patterns of traffic where the reverse may be true. The problem example does demonstrate the difference which frequently exists.

Problem 12. A diamond-type interchange is to be located on a modern freeway downstream from a fully directional, freeway-to-freeway interchange as shown in the accompanying diagram. For the traffic movements indicated, what distance is required between the merging end and the exit nose (C to D) to take the intervening freeway section out-of-realm of weaving? Assuming this can be accomplished, a level of service B is to be maintained on the freeway; in which case the number of lanes required and the approximate average speed for this section are to be determined.

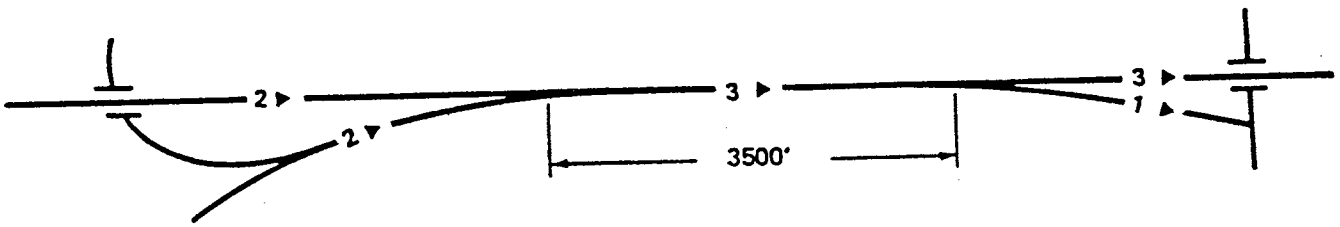


Solution:

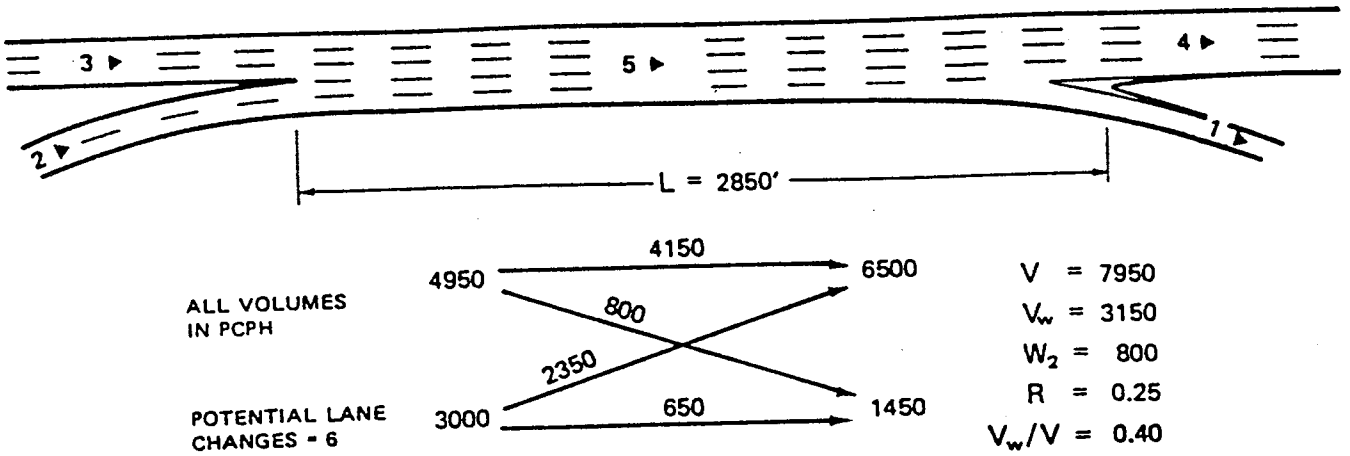
As a prelude to the problem solution, it is of interest to note that upon examination of the two-interchange complex and its configuration that a variety of possible weaving situations could arise. Depending on the following conditions--volume and pattern of traffic, distances between merging and diverging points, B, C and D, and number and arrangement of lanes--the configuration may function as a multiple weaving section, a simple weaving section, or as a freeway uninterrupted-flow condition with spaced out entrances and exits. A preliminary analysis (not shown) of the double 2-lane ramp entry from the major interchange (section B-C) indicates that it is out-of-realm of weaving. Further, an appropriate elongation between interchanges, of what otherwise could constitute a major weave along the freeway (C to D), can provide a no-weaving situation for the overall plan.

Problem 12. (Solution continued)

Proceeding with the solution, Nomograph 1 is used to determine the required distance along the freeway (section C-D), where V_w of 1350 pcph shows operation to be out-of-realm of weaving at 3500 feet. At this or greater distance between the ramps the intervening section is analyzed as a free-flow highway section, for which the number of lanes required is calculated by the uninterrupted-flow relationship of V/SF. A maximum SF of 1100 pcphpl for LOS B is designated at approximately 57 mph for freeway operation in the HCM. Accordingly, the number of lanes on the section is calculated to be, N = 3150/1100 = 2.9 or, rounded, N = 3. Further analysis indicates the following lane arrangement for the overall facility.



Problem 13. Determine the level of service and speeds of operation on the following weaving section formed by right-hand ramps between two interchanges.

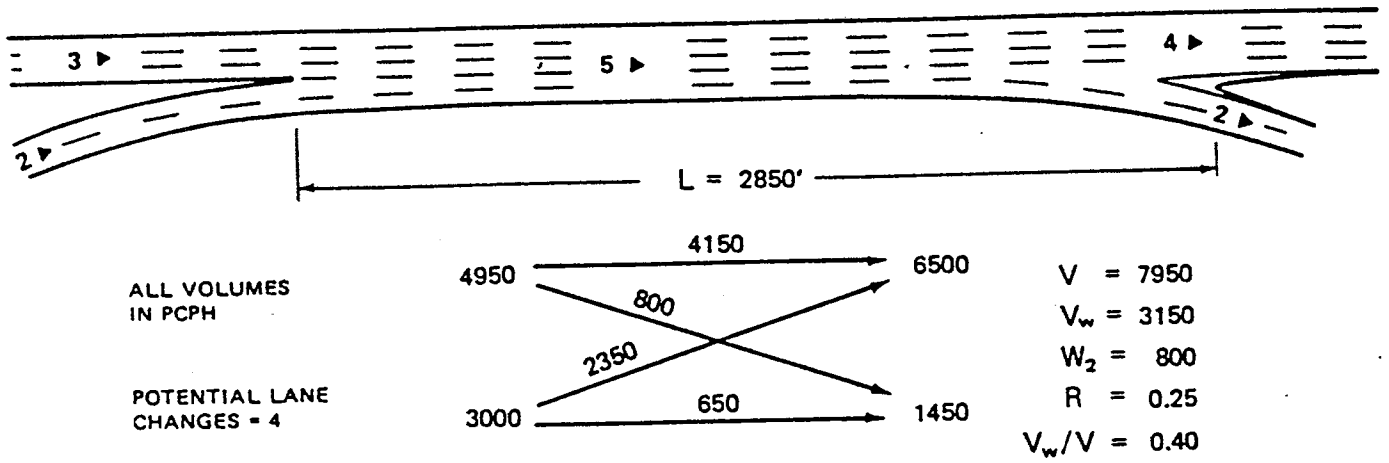


Solution:

Enter Nomograph 1 with V_w = 3150 and L = 2850, and locate an initial S_w of 38 mph at LOS D.4 with respect to dotted curves for lane-imbalanced condition. Transfer S_w = 38 to left then downward along "turning line for k" to a position between solid curves comparable to 38 mph before proceeding upward to k (see special application in Figure 9-B). Continue through nomograph with R = 0.25, W_2 = 800 and V = 7950; then, project horizontally to N = 5 within N_b = 3 zone, and read LOS = E.8 and corresponding SF = 1840. Using Nomograph 3, Instruction 3, with SF = 1840, find S = 33 mph and S_w = 31 mph, indicating operation at this point of analysis to be at LOS E. Ramp entrance and exit levels of service were evaluated (analysis not shown) to check for possible constraints. The single-lane exit at the far end of the weaving section would operate at or slightly beyond ramp exit capacity, which is apt to impact on the speeds derived above. Also, since the weaving section generates a potential number of 6-lane shifts (see Figure 4 and related discussion), average speeds of operation are considered to be lowered by 5 mph (according to special condition D(2) in Table 2); thus, with final adjustment, overall speed S = 33 - 5 = 28 mph, and weaving speed S_w = 31 - 5 = 26 mph, producing generally LOS F operation.

This problem demonstrates that under some circumstances a variety of constraints and impacts such as those brought about by the level of service of the ramp merge and diverge, the level of service of freeway downstream, and the lane configuration in the overall makeup of the weaving section as reflected in potential lane shifts, may cause operational conditions difficult to predict.

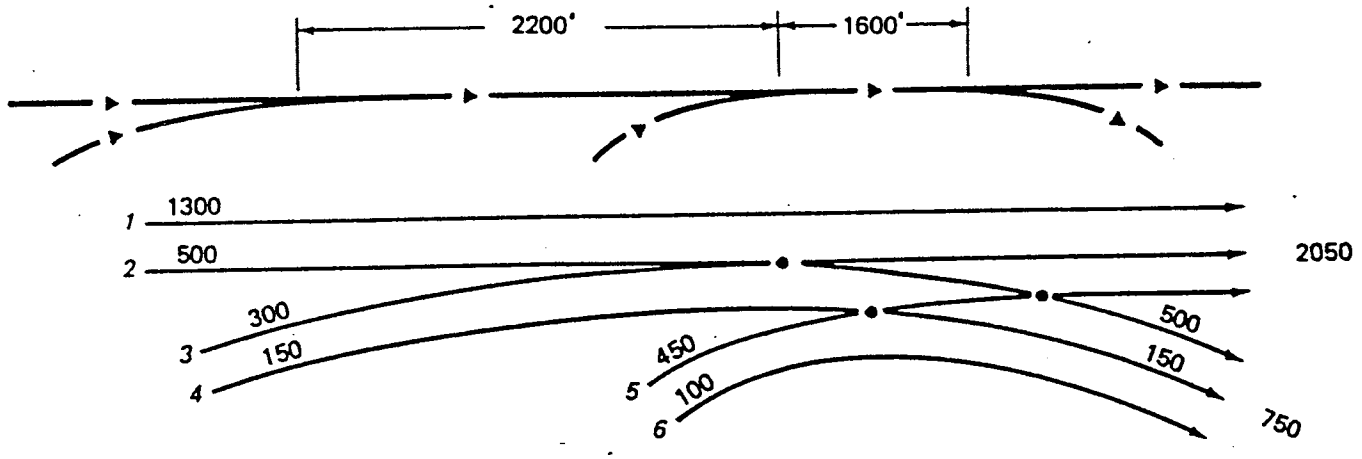
Problem 14. What improvement in operation could be expected on the weaving section in Problem 13 if the design is altered to provide lane balance, accomplished by adding an extra (second) lane to the ramp exit; number of lanes on all other elements would be retained. The adjusted arrangement is shown below.



Solution:

Since this configuration reduces the number of potential lane shifts to 4 and mitigates the constraint at the exit, the solution is accomplished by the direct use of Nomographs 1 and 3. As before, enter Nomograph 1 with V_w = 3150 and L = 2850, except that in this case the intersection point is made with respect to solid curves for the lane-balanced condition; locate an initial S_w of 40 mph at equivalent LOS C_{max}. Continue through the nomograph with R = 0.25, W_2 = 800, V = 7950, and N = 5 within N_b = 3 graph; read LOS E.7 and corresponding SF = 1800. Using Nomograph 3, Instruction 3, with an entry of SF = 1800, find S = 34 mph and S_w = 32 mph, indicating overall operation at LOS E. The predicted operational improvement in this example can be significant when compared with the arrangement of the previous problem in which low, critical speeds subject to intermittent time intervals of stop-and-go traffic would be evident.

Problem 15. A section of modern freeway including two successive entrances followed by an exit, with indicated ramp spacing and traffic volumes (pcph), is under design as illustrated below. Although the overall configuration has a general form of a multiple weaving section, it is to be established first whether it is a simple or a multiple section; then, for level of service B operation, determine the number of lanes required and if the length or lengths of weaving section are adequate.

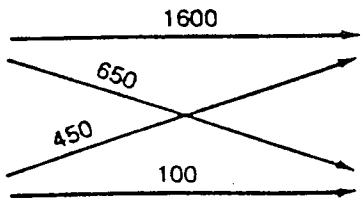


TRAFFIC VOLUMES IN PCPH.

Solution:

A standard check for a multiple weaving section of the 2EN-EX form is made by determining the amount of weaving that would take place in the first segment with relation to the out-of-realm of weaving limit (see Section E(1), Table 2). Weaving in the first segment, as described in Section E(2), Table 2, would normally be 0.75 of (Vol. 2 + Vol. 3), or 0.75 (800) = 600 pcph. For a length of 2200 feet, the movement is out-of-realm of weaving, according to Nomograph 1, which places the solution into a simple weaving section involving the primary weave only of the second segment. The weaving diagram for the second segment then resolves to be as follows.

TRAFFIC VOLUMES IN PCPH



$V = 2800$

$V_w = 1100$

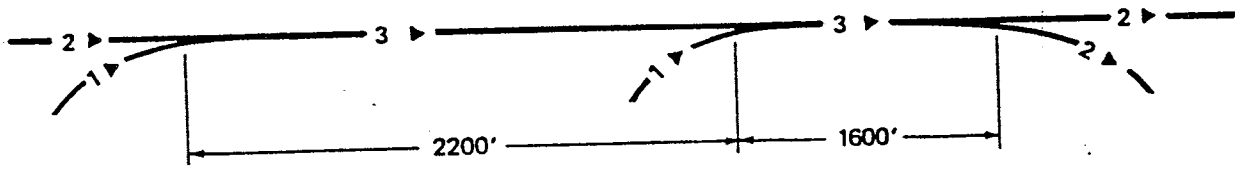
$W_2 = 450$

$R = 0.41$

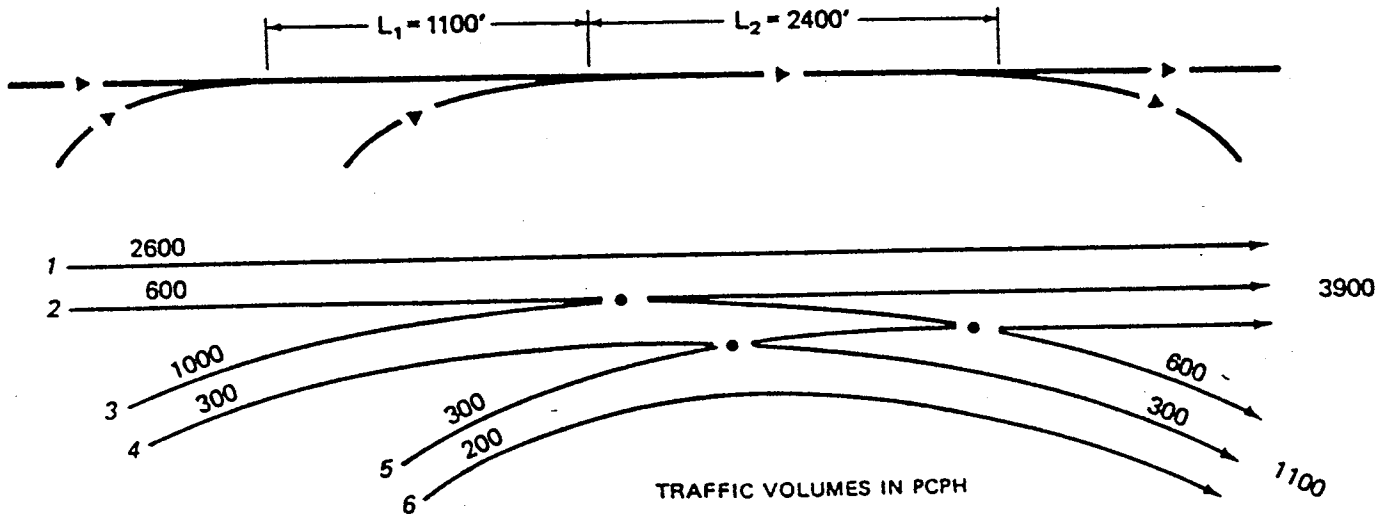
$V_w/V = 0.39$

Problem 15. (Solution continued)

Using Nomograph 1 for a simple weaving section with V_w = 1100 and L = 1600 feet, read LOS $B_{.6}$ (47 mph); follow trend of speed curves to turning line k, then continue to R = 0.41, W_2 = 450, V = 2800, and LOS B line for N_b = 2, read N = 3.1; round to N = 3, corresponding to LOS $C_{.1}$ and SF of 1025. Refer to Nomograph 3, Instruction 1, which verifies S_w = 47 mph and also indicates that S = 52 mph. The remaining elements of the highway within the range diagrammed would operate as uninterrupted flow at LOS B and SF of under 1125 pcph, producing average overall speeds upward of 55 mph. At the extreme right of the configuration the higher speed would be achieved, at some distance beyond the ramp exit, after the through flow has recovered from the influence of the weaving section. The number of lanes, utilizing a lane-balanced condition would be as shown below. Although not included herein, in all cases LOS of ramp merges and diverges would be checked in completing the solution.



Problem 16. A section of modern freeway including two successive entrances followed by an exit (2EN-EX configuration) is under design as indicated in the accompanying figure. The design-hourly volumes shown have been converted to equivalent passenger vehicles (pcph) accounting for the effect of trucks and grades. The traffic diagram is arranged to demonstrate the pattern of weaving. A preliminary level of service analysis along the facility has been accomplished and a basic number of lanes determined to be $N_b = 3$. Operation at level of service C is to be provided.



Determine the following features: whether simple or multiple weaving is present; whether the length or lengths of weaving section are adequate; and, the number of lanes required on the various elements, incorporating the feature of lane balance.

Solution:

The problem constitutes a potential multiple weaving section of the type 2EN-EX. The first step in the analysis is a check to determine whether the configuration is indeed a multiple weaving section. If so, the analysis proceeds on the basis of a multiple section; if not, it is analyzed as a simple weaving section. The procedure for the test is provided in Section E(1) Table 2, and as demonstrated in the previous problem.

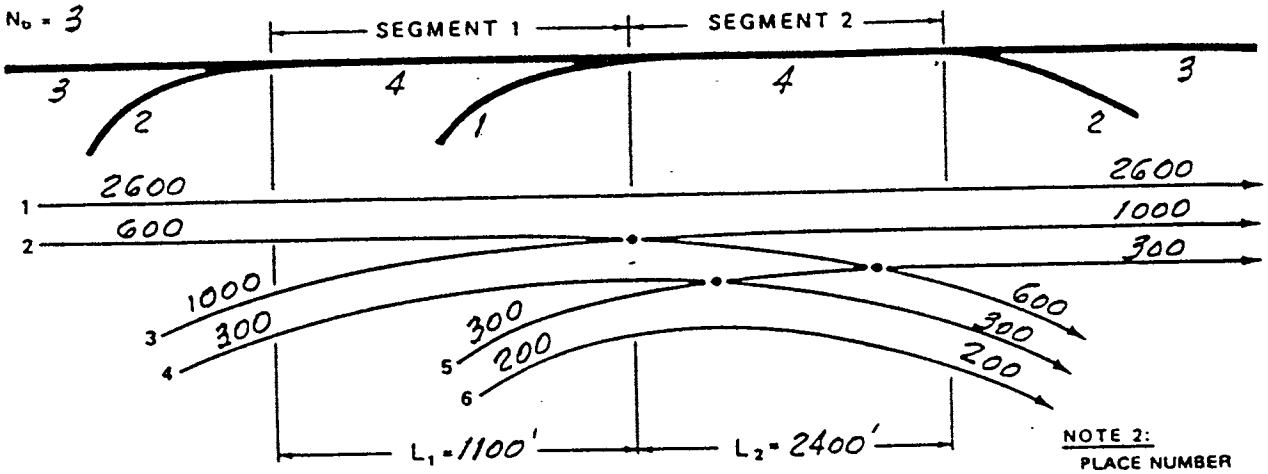
Problem 16. (Solution continued)

In segment 1, using a length of 1100 feet and a weaving volume of 0.75 times the sum of movements 2 and 3, or 1200 pcph, indicates operation to be to the left of the limiting curve in the lower part of Nomograph 1, or within the realm of weaving. The configuration, therefore, represents a multiple weaving section, and is thus analyzed in accordance with the analaysis worksheet of Figure 10 for a multiple weaving section of the form 2EN-EX. The computations in the lower part of the form utilize Nomograph 1 for the initial weaving volume-length effects and width requirements for both segments, while Nomograph 3 is used to calibrate and finalize average overall and weaving speeds, along with levels of service of each. The level of service C is satisfied as a composite throughout the facility, and generally for weaving traffic (S = 47 mph for both segments, and S_W = 42 and 44 mph for segments 1 and 2 respectively). In both segments, N = 4 conforms to required operation. As a whole, the number of lanes fit into proper sequence and provide lane balance. The details of the analysis and results are shown on the following worksheet.

ANALYSIS WORKSHEET
MULTIPLE WEAVING 2EN - EX

PROJECT PROBLEM 16

12-8-85



NOTE 2:
PLACE NUMBER OF LANES, EXISTING OR SOLVED, ALONG UPPER DIAGRAM.

LONG WEAVE — VOL 2. vs. VOL. 3 (SEE NOTE 1)*

SEGMENT 1

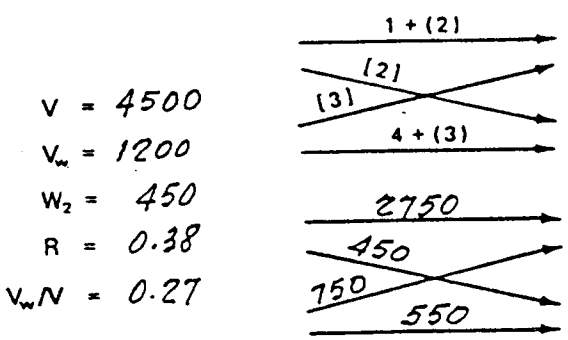
[2] = P x VOL. 2
= 0.75 x 600 = 450

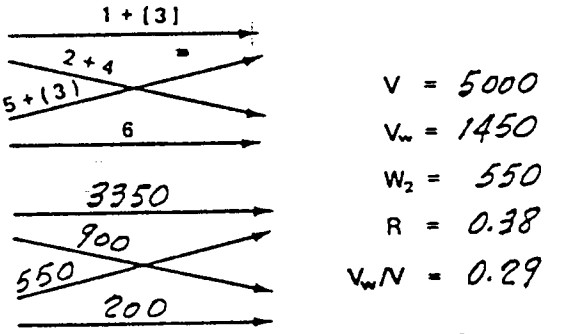
[3] = P x VOL. 3
= 0.75 x 1000 = 750

SEGMENT 2

(2) = (1 - P)(VOL. 2)
= 0.25 x 600 = 150

(3) = (1 - P)(VOL. 3)
= 0.25 x 1000 = 250





NOTE 3:
ALL VOLUMES IN PCPH. RECORD ON DIAGRAM.

COMPUTATIONS

NOMOGRAPH 1:
V_W initial LOS C.6 (S_W = 42)
N = 3.7, LOS C_{max}, Round to
N = 4, LOS C.7, SF = 1275

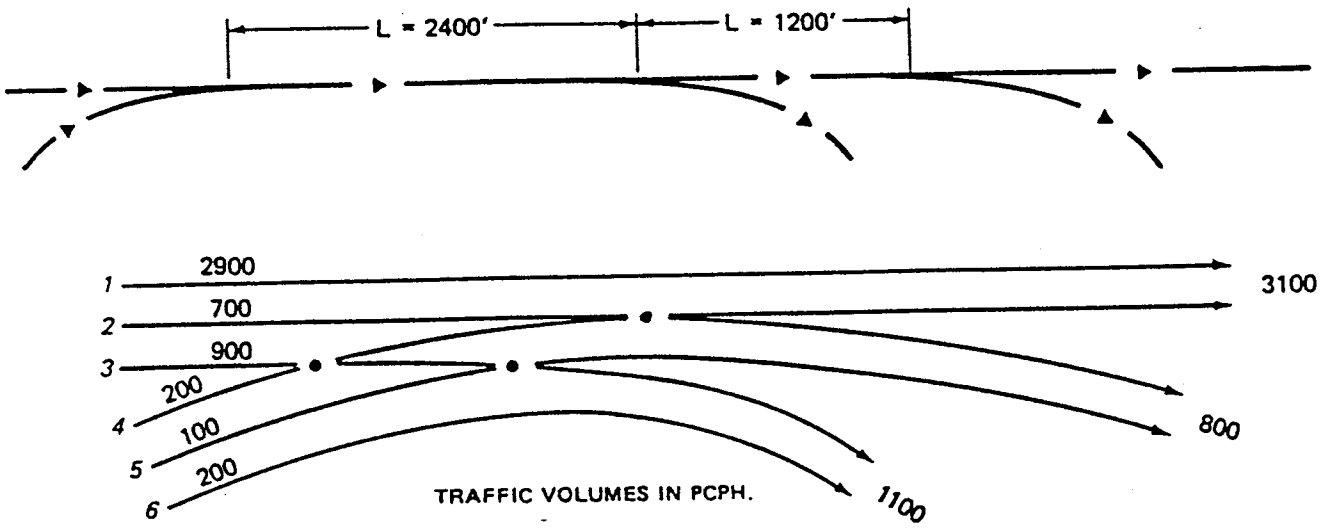
NOMOGRAPH 3, Instr. 1:
S = 47 mph, LOS C
S_W = 42 mph, LOS C
N = 4
} RESULT

NOMOGRAPH 1:
V_W initial LOS B.2 (S_W = 49)
N = 3.7, LOS C, (Round to
N = 4, LOS C.7, SF 1275

NOMOGRAPH 3, Instr. 3:
S = 47 mph, LOS C
S_W = 44 mph, LOS C
N = 4
} RESULT

* NOTE 1: ALL OF LONG WEAVE TENOS TO TAKE PLACE IN SEGMENT 1, WITH PROPORTION P INCLINED TO APPROACH 1.0; P, HOWEVER, MAY VARY IN INDIVIDUAL CASES. IN DESIGN AND IN GENERAL OPERATIONAL ANALYSIS, NORMALLY USE P = 0.75 IN SEGMENT 1. OTHERWISE, IN MORE DETAILED OPERATIONAL ANALYSIS, FIELD SAMPLING OF TRAFFIC MOVEMENTS MAY GIVE INDICATION OF P.

Problem 17. A multiple weaving configuration of the EN-2EX variety, along the same freeway as in the previous problem with segments of 2400 feet and 1200 feet, respectively, is to be tested for level of service C operation, including the determination of the numbers of lanes required. Design-hourly volumes, expressed in pcph, and the pattern of movements are shown in the accompanying figure.



Preliminary analysis indicated the one-directional basic lanes of $N_b = 3$, and verified that the configuration constitutes multiple weaving, according to the standard test. The analysis and design, therefore, is to be predicated on a multiple weaving section of the EN-2EX form, providing the necessary details for the overall solution including a lane-balanced design.

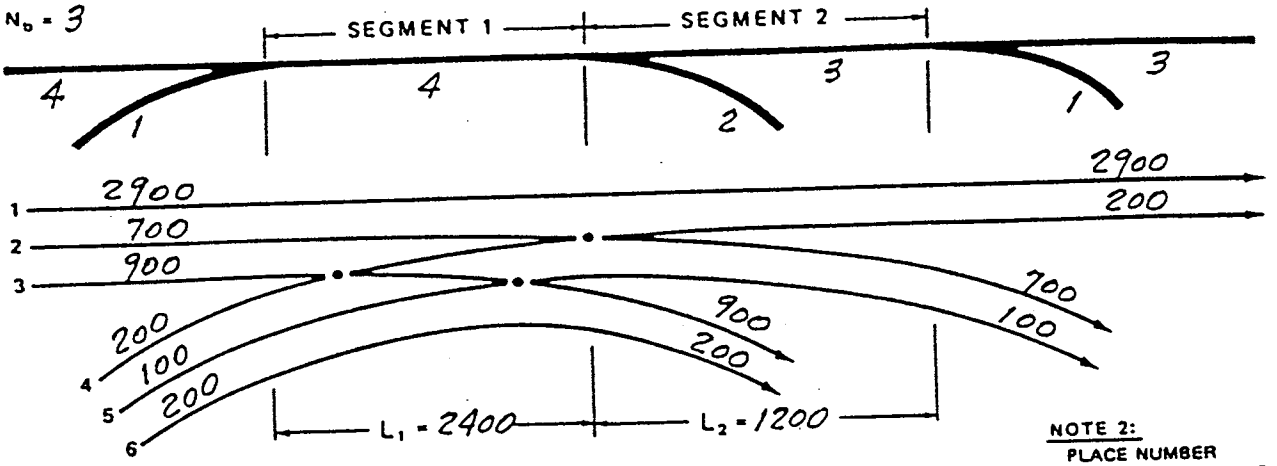
Solution:

The solution is advanced in accordance with the analysis worksheet of Figure 11. The computations in the lower part of the form which follow utilize Nomograph 1 for initial weaving volume-length effects and width requirements, while Nomograph 3 is used to calibrate and finalize average overall and weaving speeds, along with levels of service of each segment. The solution indicates that the level of service C is satisfied as a composite throughout the facility multiple weaving section. The details and results of the analysis are shown on the following worksheet.

ANALYSIS WORKSHEET
MULTIPLE WEAVING EN-2EX

PROJECT PROBLEM 17

12-8-85



NOTE 2: PLACE NUMBER OF LANES, EXISTING OR SOLVED, ALONG UPPER DIAGRAM.

LONG WEAVE — VOL. 2 vs. VOL. 4 (SEE NOTE 1)*

SEGMENT 1:

(2) = (1 - P)(VOL. 2)
= 0.25 x 700 = 175

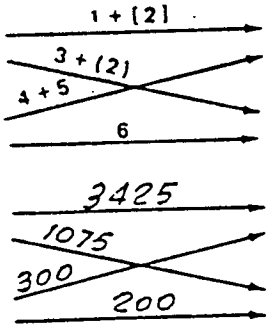
(4) = (1 - P)(VOL. 4)
= 0.25 x 200 = 50

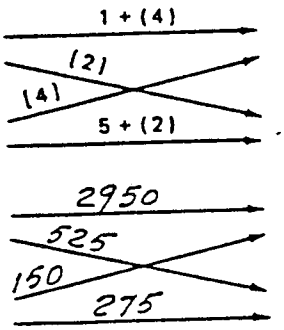
SEGMENT 2:

[2] = P x VOL. 2
= 0.75 x 700 = 525

[4] = P x VOL. 4
= 0.75 x 200 = 150

V = 5000
V_w = 1375
W_2 = 300
R = 0.22
V_w/V = 0.28





V = 3900
V_w = 675
W_2 = 150
R = 0.22
V_w/V = 0.17

NOTE 3: ALL VOLUMES IN PCPH. RECORD ON DIAGRAM.

COMPUTATIONS:

NOMOGRAPH 1:
V_w initial LOS B.1 (S_W = 49.5)
N = 3.7, LOS Cmax, Round to
N = 4, LOS C.7, SF = 1275

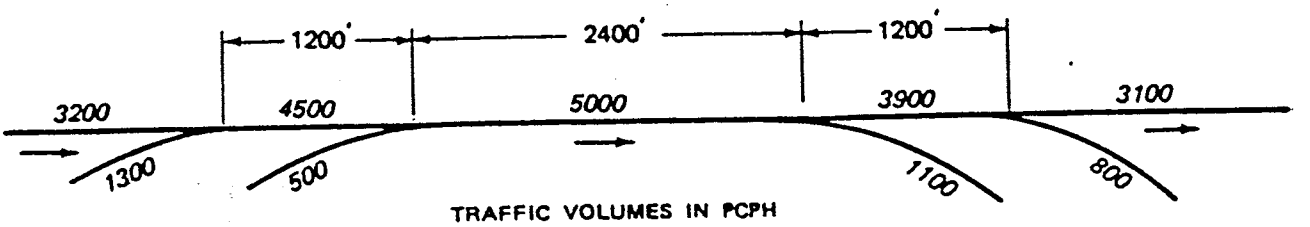
NOMOGRAPH 3, Instr. 3:
S = 47 mph, LOS C
S_W = 44 mph, LOS C
N = 4
} RESULT

NOMOGRAPH 1:
V_w initial LOS A.8 (S_W = 51)
N = 2.9, LOS Cmax, Round to
N = 3, LOS C.9, SF = 1325

NOMOGRAPH 3, Instr. 3:
S = 46 mph, LOS C
S_W = 43 mph, LOS C
N = 3
} RESULT

*NOTE 1: ALL OF LONG WEAVE TENDS TO TAKE PLACE IN SEGMENT 2, WITH PROPORTION P INCLINED TO APPROACH 1.0: P, HOWEVER, MAY VARY IN INDIVIDUAL CASES. IN DESIGN AND IN GENERAL OPERATIONAL ANALYSIS, NORMALLY USE P = 0.75 IN SEGMENT 2. OTHERWISE, IN MORE DETAILED OPERATIONAL ANALYSIS, FIELD SAMPLING OF TRAFFIC MOVEMENTS MAY GIVE INDICATION OF P.

Problem 18. A section of modern freeway including two successive entrances followed by two successive exits (2EN-2EX), comprising a 3-segment multiple weaving configuration, is under design as indicated in the accompanying figure. Length of segments provided are 1200, 2400 and 1200 feet, respectively. The design-hourly volumes (in pcph) are shown for the various elements of the facility. Individual movements comprising the pattern from which weaving movements can be determined are discussed in conjunction with the solution of the problem. A preliminary analysis of the facility indicates a basic number of lanes to be N_b = 3 in each direction. Operation at level of service C is to be provided.



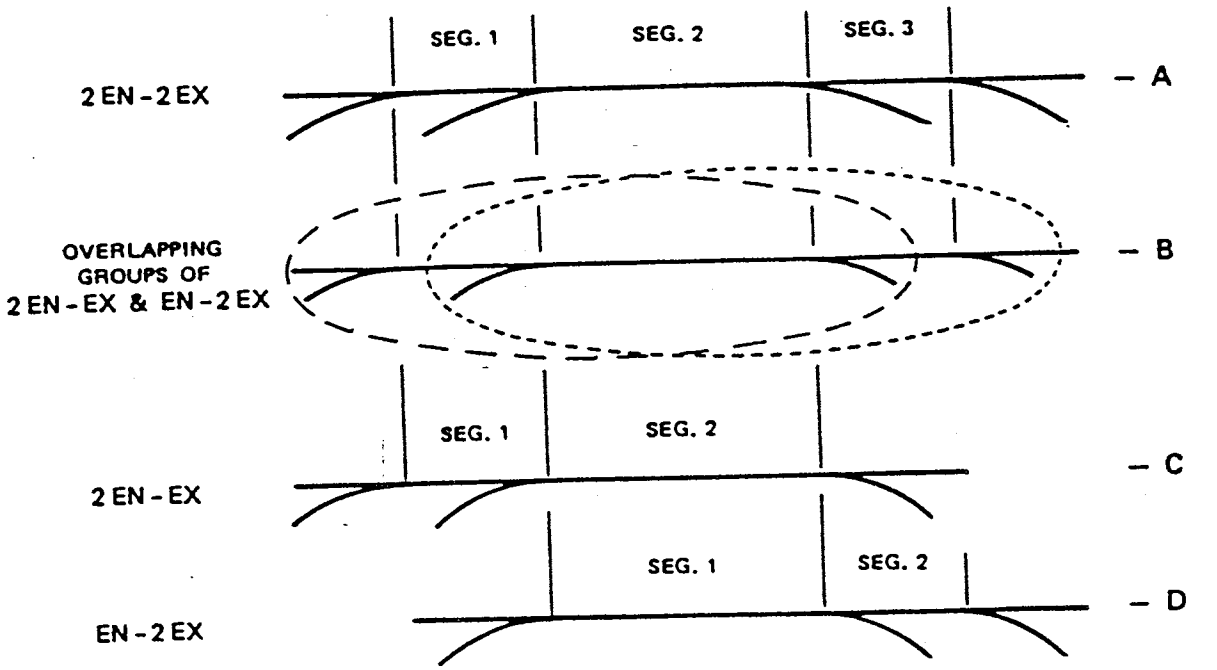
TRAFFIC VOLUMES IN PCPH

SEE PROBLEM SOLUTION REFERENCE TO DETAILED TRAFFIC MOVEMENTS

Determine: whether 3-segment multiple, 2-segment multiple, or simple weaving is present; whether the length or lengths of weaving sections are adequate; and the number of lanes required on the various elements, incorporating the features of lane balance.

Solution:

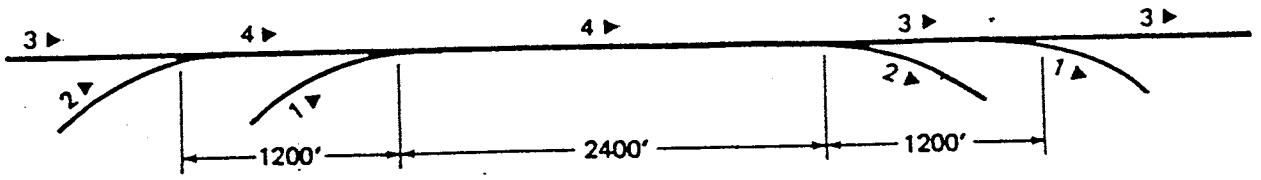
Multiple weaving section configurations of more than two segments are analyzed by a rational technique of breaking down the overall section into overlapping 2-segment sections. For a potential 3-segment section, the separation process involves two overlapping 2-segment weaves as shown below.



After the indicated separation each 2-segment section, C and D above, is analyzed independently--in this case, as 2EN-EX and EN-2EX sections, following the standard procedure previously described and utilized in problems 16 and 17. The test for each (for C and for D) is first applied to determine if it constitutes a multiple or simple weaving. If both involve multiple weaving, standard analysis worksheets (Figures 10 and 11) are utilized to solve Section C and Section D. The two sections are then rejoined and the results of the overlappling portion are harmonized, as required, to produce an overall continuous solution.

Problem 18. (Continued)

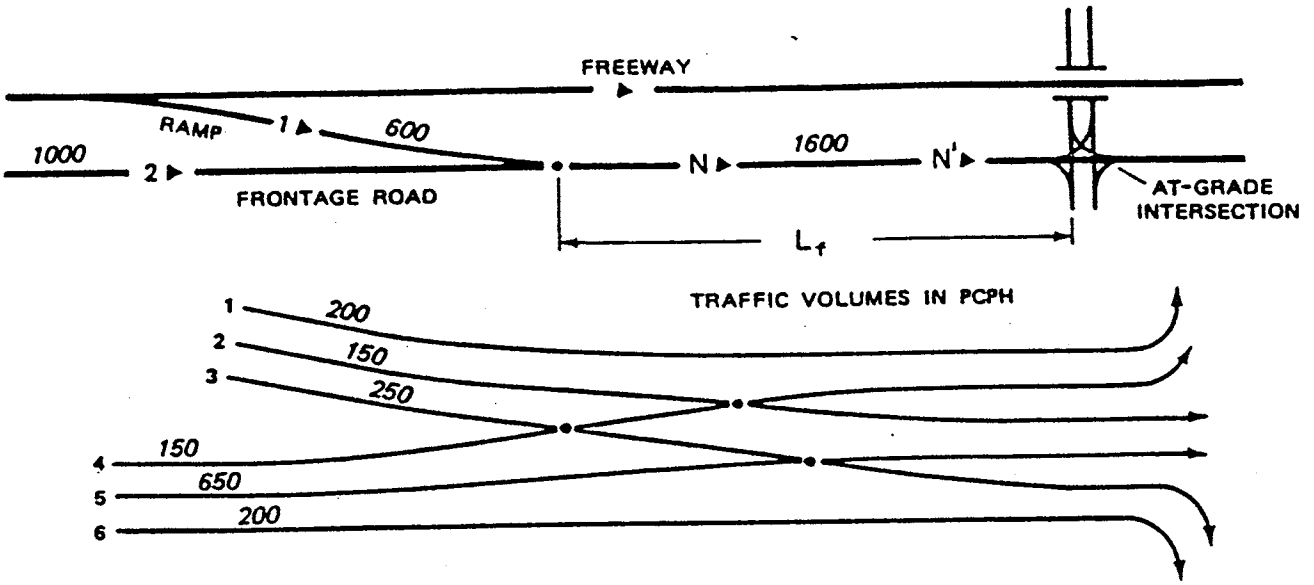
The facility presented in the problem statement for this example is actually a combination of Problems 16 and 17 and their solutions, each representing and being identical, respectively, to the separated Sections C and D noted above. Thus, the final solution involves merely the rejoining of the sections of Problems 16 and 17 results as follows:



In this case the two rejoined sections required no adjustments in solution results, producing an overall harmonuous geometry. (This may not always be so, in which case the overall section would be adjusted through the overlap to provide an appropriate balance in number of lanes or segment widths.)

Although a specific problem is not presented for a multiple weaving section of 2 or 3 segments involving left-hand ramps intermixed with right-hand ramps (as may be the case along a continuous C-D road), the procedure is the same as for Problems 16, 17 and 18, except that both Nomographs 1 and 2 would be utilized.

Problem 19. An urban freeway with continuous one-way frontage roads is being designed with diamond interchanges utilizing slip ramps between freeway and frontage road, for the condition shown in the accompanying figure. Determine the length L_f and width N (and N' if wider than N) required to accommodate the indicated traffic.



WEAVING MOVEMENT: RAMP + FRONTAGE ROAD

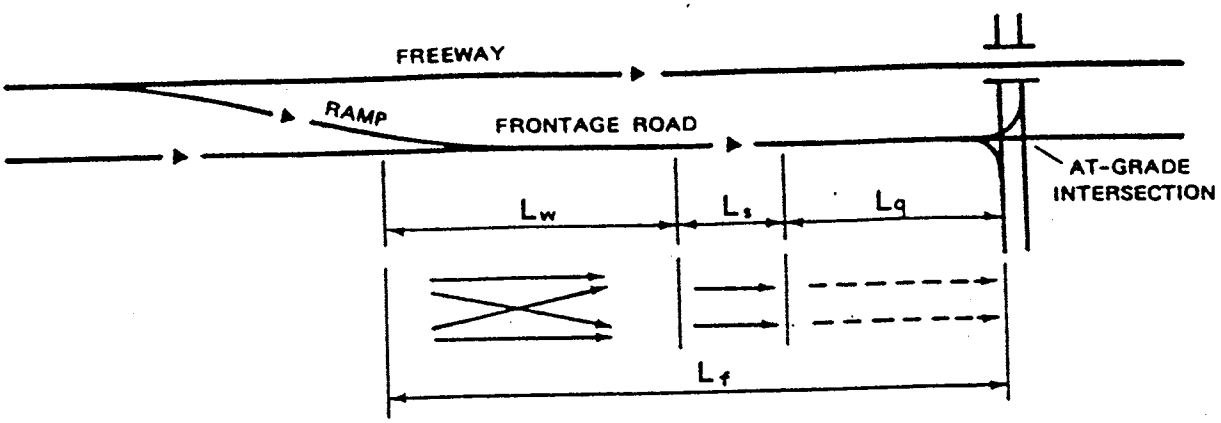
$V_w = (2+3)+(4+5)$

$= 400 + 800 = 1200$ pcph

Solution:

Since no specific research or data are available for this prevalent condition associated with freeways, a rational method to solve the problem is utilized, deduced from general observation and operational experience. The technique employs the sum of three dimensions during a representative peak hour, where $L_f = L_W + L_S + L_q$ as structured in the following diagram. The first element, L_W, involves the distance required for the traffic weaving between the ramp and frontage road (in this problem, as shown above, V_W = 1200 pcph from which--according to appropriate weaving speed and SF--both L_W and N can be determined. The second length, L_S, is that required for the complete weave to come to a stop, considering its speed, before reaching the end of the queue of stopped vehicles in advance of the intersection. The third length, L_q, is the average distance per signal cycle occupied by queued vehicles produced by operation of the intersection.

Problem 19: (Continued)



The weaving maneuver, unlike that along a freeway or C-D road, takes place on the frontage road at a variable speed, after which the traffic alternately must come to a stop at the end of an appropriate queue of the intersection. The three-length element is logically quantified in the following manner, considering that the configuration for the condition described does not lend itself to a specific level of service but to an acceptable and appropriate operational situation.

The speeds of ramp and frontage road upon merging and beginning of weaving are considered well represented by 40 mph in urban areas. Since the weaving maneuver is faced by a queue of standing vehicles, the variable speed of weaving is assumed to be accomplished by the time the speed is reduced to about 15 mph followed by a deceleration to a stop at the queue end. Accordingly, the average speed of weaving over distance L_w may be approximated at about 25 mph, which is used in Nomograph 1 to determine distance L_w. In this case for V_w of 1200 pcph it is found to be 300 feet.

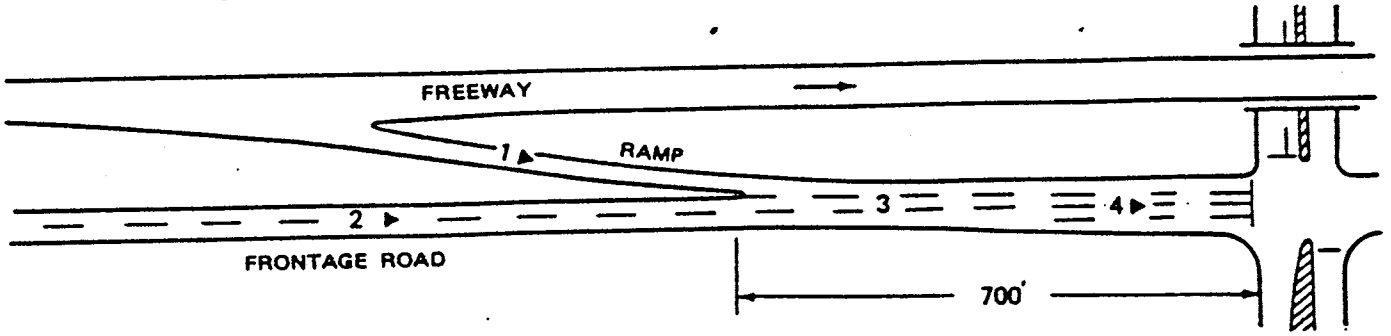
Length L_s, according to AASHTO design policy, is equivalent to a stopping distance of 80 feet from a speed of 15 mph. The average length of queue is dependent upon the design and operation of the at-grade intersection. Although the analaysis of the intersection is not shown here, for the resulting N' of 4 lanes on the approach, an L_q of 320 feet was determined. Thus, the distance between ramp junction and intersection is L_f = 300 + 80 + 320 = 700 feet.*

* Generally, dimension L_f as a minimum is smaller than demonstrated, since traffic requirements are likely to be less stringent than presented here.

Problem 19: (Continued)

Using Nomograph 1 with values of V_w = 1200, S_w = 25 mph, resulting k = 3, W_2 = 400, V = 1600, and an assumed value of SF = 800, N closely approximates 3 lanes. (An SF of 800 pcph per lane is taken to be representative of uninterrupted flow operation on portions of non-access controlled facilities.)

The following plan is the result of this analysis.



Problem 20. For the same basic configuration of freeway, ramp and frontage road for the urban condition in Problem 19 (in which L_f of 700 feet was established), determine the length, L_f, required between ramp junction and intersection if the facility is located in a rural area. Assume identical traffic pattern and the need for 320 feet at the intersection for queuing.

Solution:

The method is the same as for Problem 19, except that higher speeds on ramp and frontage road, and thus of weaving traffic, must be accounted for in the solution. In rural areas the speed at the beginning of the weave is taken to be representative at 50 mph and at the completion of the weave at 20 mph, for which an approximate average weaving speed is equivalent to 35 mph. For V_w = 1200 pcph and a weaving speed of 35 mph, Nomograph 1 indicates L_w = 660 feet. Stopping distance from 20 mph is equal to L_s = 120 feet. Thus, L_f = 660 + 120 + 320 = 1100 feet.*

* Generally, dimension L_f as a minimum is smaller than demonstrated, since traffic requirements are likely to be less stringent than presented here.

BIBLIOGRAPHY

Evaluation of Freeway Traffic Flow at Ramps, Collector Roads and Lane Drops (The Collector Road Study), State of California, Division of Highways, April 1972.

Gafarian, A.V., Ward-Fairmont Weaving Study, Technical Memorandum, System Development Corp., California May 1, 1968.

Hess, J.W., Ramp-Freeway Terminal Operation as Related to Freeway Lane Volume Distribution and Adjacent Ramp Influence, Highway Research Record No. 99, 1965.

Hess, J.W., Traffic Operation in Urban Weaving Areas, unpublished, 1963 Bureau of Public Roads Study (1963 BPR Weaving Area Study Data Base).

Highway Capacity Manual, U.S. Government Printing Office 1950.

Highway Capacity Manual, Special Report 87, Highway Research Board, 1965.

Highway Capacity Manual, Special Report 209, Transportation Research Board, 1985.

Leisch, Jack E. and Leisch, Joel P. "Procedure for Analysis and Design of Weaving Sections," Final Report, Vol. 1 and 2, FHWA Research Project DTFH61-832-C-00050, December 1983 and February 1984.

Leisch, Jack E., A New Technique for Design and Analysis of Weaving Sections on Freeways, ITE Journal, March 1979.

Leisch, Jack E., Capacity Analysis Techniques for Design and Operation of Freeway Facilities, FHWA-RD-74-24, Department of Transportation, Feb. 1974 (Publication issued Sept. 1975)

Leisch, Jack E., Procedural Framework for Analysis of Freeway Sections, Australian Road Research Board, September 1972.

Leisch, Jack E., Lane Determination Techniques for Freeway Facilities, CGRA Proceedings, 1965.

McNess, Roger, "An 'In-Situ' Study Determining Lane Maneuvering Distance for Three- and Four-Lane Freeways for Various Traffic Volume Conditions," submitted for presentation at 61st Annual Meeting of TRB, Washington, January 1982.

New Highway Capacity Manual, The (Draft) Chapter 3, Basic Freeway Sections, NCHRP 3-28(B), Polytechnic Institute of New York, Texas A&M Research Foundation, University System., March 1983.

Norman, O.K., Operation of Weaving Areas, HRB Bulletin 167, pp 38-41, 1957.

Pignataro, et al., "Weaving Areas: Design and Evaluation," National Cooperative Highway Research Program Report 159, Transportation Research Board, 1975.

Reilly, W.R., Kell, J.H., and Johnson, P.J., Weaving Analysis Procedures For TheHighway Capacity Manual, FHWA, Technical Report, Contract No. DTFH61-83-C-00029, July 1983 - August 1984.

Roess, Roger P. McShane, William R., and Pignataro, Louis J., Freeway Level of Service: A Revised Approach, Transportation Research Record 699, 1979.

Sequin, E.L., Data Base Documentation, FHWA Interim Report, September 1982 (Editorial Note: Portion Used on Weaving Area Operational Studies--all vehicles).

Transportation Research Circular 212, January 1980.

Weaving Area Operations Study, Polytechnic Institute of New York, NCHRP, Project 3-15 Final Report, Phase 1, November 1973.

GUIDELINES AND NOMOGRAPHS

TABLE 2

USE OF NOMOGRAPHS INCLUDING ADJUNCT PROCEDURES FOR WEAVING SECTIONS

A. FREEWAY SECTIONS

(1) One-Sided Weaving Sections--General:

- Use Nomograph 1, for which general application is demonstrated thereon by dotted solution lines with arrows; followed by Nomograph 3, for which application is indicated thereon by "Instructions," 1 through 4.

(2) Two-Sided Weaving Sections--General:

- Use Nomograph 2, for which application is demonstrated thereon by dotted solution lines with arrows; followed by Nomograph 4, for which application is indicated thereon by "Instructions," 1 through 3.

B. C-D ROADS

(1) Local Sections provided for individual interchanges, arranged for simple weaving between two ramps; generally use Nomograph 1 only for the C-D road (freeway proper analyzed separately). S_w with corresponding LOS is determined from the lower-left portion of Nomograph 1, provided that sufficient number of lanes is available. Overall speed of weaving section, S, equals S_w. Nomograph 3 should be referred to, however, when the outer flow from one ramp to the other exceeds about 15 percent of V.

(2) Sections on Continuous or Extended C-D Roads along the freeway serving several interchanges are analyzed in the same manner as freeway weaving sections, utilizing Nomographs 1 and 3, and Nomographs 2 and 4, as noted under A(1) and A(2) above.

C. LANE-BALANCED AND LANE-IMBALANCED WEAVING SECTIONS

(1) Lane-Balanced Sections as previously defined, refer primarily to exits with provision of "one more lane going away" (i.e., combined number of lanes on freeway and ramp after exit being one more than on freeway preceding the ramp). This case is directly accounted for by the solid curves in the lower-left portion of Nomographs 1 and 2. Direct use of these curves and continuation through the nomographs are demonstrated by dotted solution lines.

(2) Lane-Imbalanced Sections which normally refer to bifurcations without change in total number of lanes (i.e., the number of lanes on freeway and ramp after exit is the same as on freeway preceding the ramp). This case is accounted for by the dotted speed curves in the lower-left portion of Nomographs 1 and 2--indicating that for the same weaving volume, more length of weaving section is required to maintain level of service; or, for the same length, less weaving traffic can be handled than for the lane-balanced section. In using the lower-left portion of the nomograph and then proceeding upward toward the k curve requires, for the lane-imbalanced section, a jog or lateral shift to the left, from the dotted set of speed curves to the solid set of speed curves. This is necessary to permit the remaining elements of the nomograph to serve equally the lane-balanced and lane-imbalanced sections. The method for handling this situation, in solution of problems, is demonstrated in Figure 9; note that the procedure as shown by the sample solution lines in part A of the figure is direct for lane-balanced sections, and for lane-imbalanced sections it requires an equivalent speed jog to the left (from dotted to solid speed curve set), as shown in part B of the figure.

TABLE 2 (continued)

D. WEAVING SECTIONS AS RELATED TO LANE ARRANGEMENTS

(1) Configurations with Normal Lane Shifts. Weaving sections with various lane arrangements have an effect on operational quality and speed, a feature closely allied to lane balance. The combination with different configurations produces different amount of lane shifting in the process of weaving. The concept of potential lane shifts is demonstrated in Figure 4. As shown, most of the well designed sections produce 2 to 3 potential lane shifts. Weaving sections with 4 potential lane shifts also may be considered within acceptable limits, in which solutions achieved by the procedures of Nomographs 1 - 4 apply.

(2) Configurations with Excessive Lane Shifts. Weaving sections requiring 5 and 6 potential lane changes, indicate from examination of limited data, that levels of service and associated speeds, S and S_w, would be lowered 3- to 5-mph below those normally produced by Nomograpahs 3 and 4. For such conditions as a rational deduction, 3- to 5-mph speed increments should be deducted from the nomograph readings to estimate the final result.

E. MULTIPLE WEAVING SECTIONS

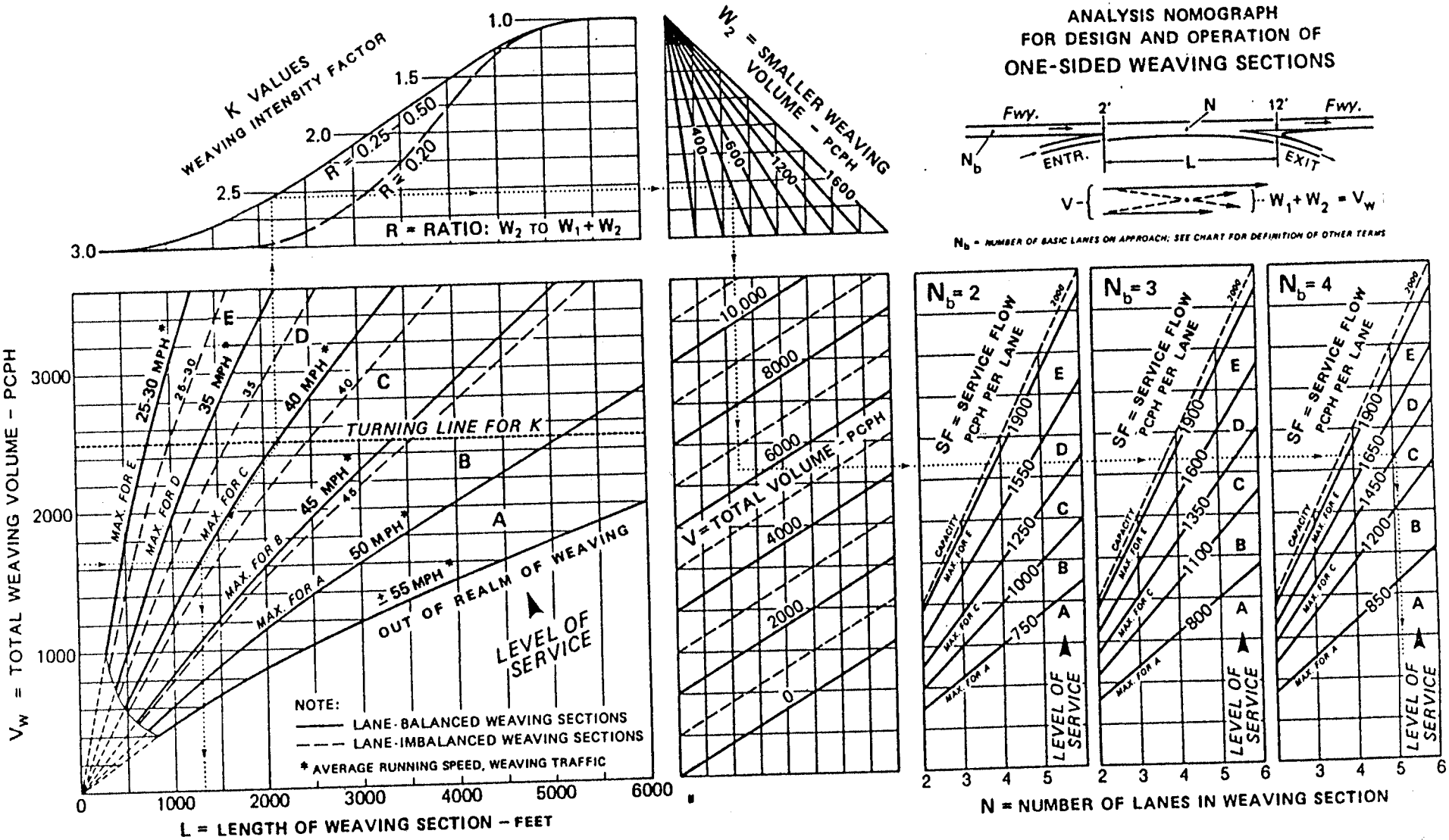
(1) Test for Multiple Weaving. Ramp junctions in sequence involving two or more overlapping simple weaving configurations should be tested prior to analysis if, in fact, multiple weaving is present (see Figures 10 and 11). The check is made with respect to the portion of the long weave (between first and last ramps) which occurs in segment 1 for 2EN-EX form and in segment 2 for EN-2EX form; if this portion in either case is within realm of weaving, the configuration is analyzed as a multiple weaving section and, if not, as a simple weaving section.

(2) Distribution of Long Weave:

- Type 2EN-EX--Portion of weave occurring in segment 1 is normally taken to be three-quarters of movements 2 plus 3, and remainder in segment 2, as shown in Figure 10.

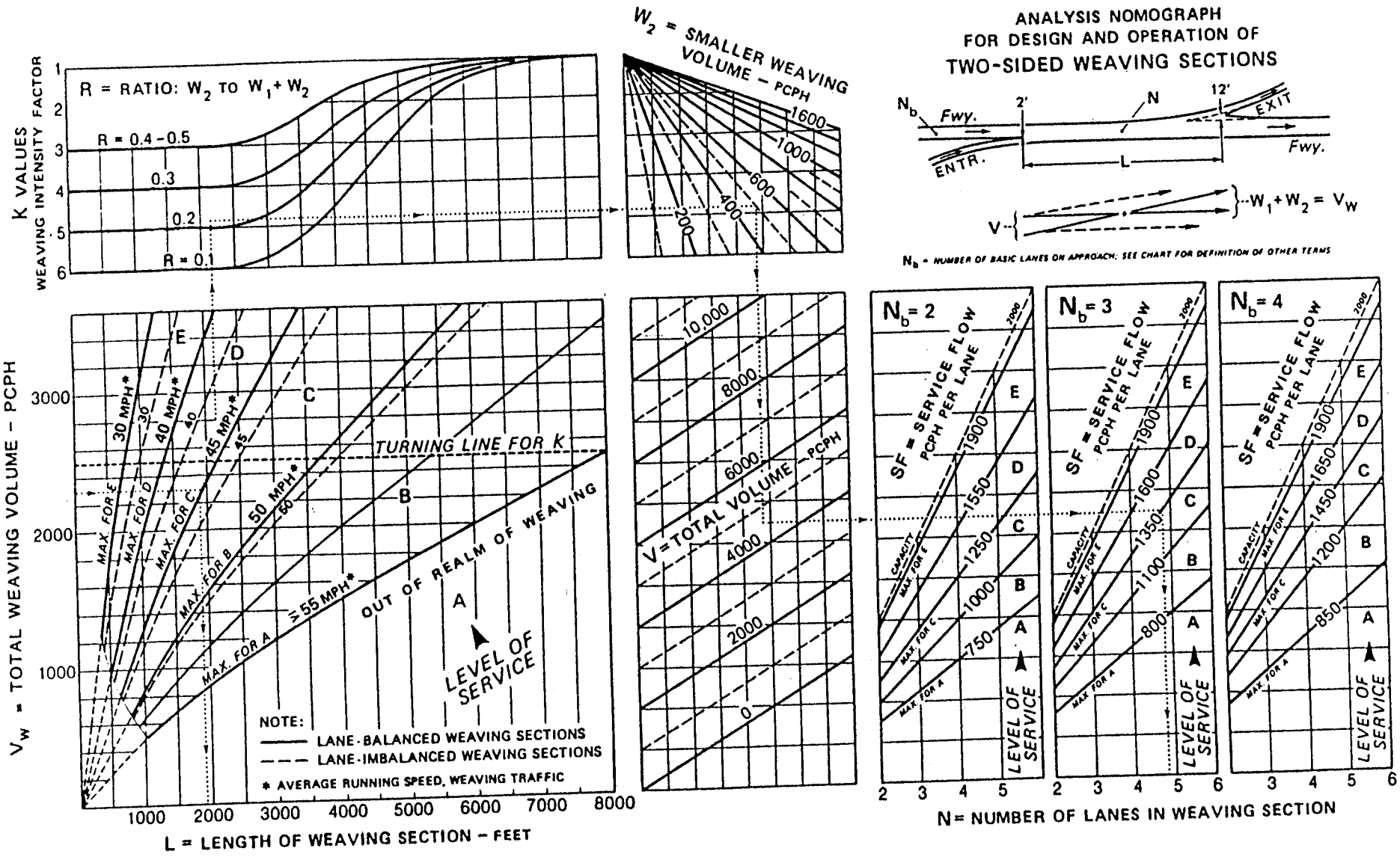
- Type EN-2EX--Portion of weave occurring in segment 2 is normally taken to be three-quarters of movements 2 plus 4, and remainder in segment 1, as shown in Figure 11.

(3) Use of Nomographs and Analysis Worksheets. Nomographs 1 - 4 are applied in normal manner to each segment separately in accordance with weaving diagrams formulated per above explanation. Analysis Worksheets, Figures 10 and 11 provide an organized means of evaluating multiple weaving problems.



NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS—ONE-SIDED CONFIGURATIONS

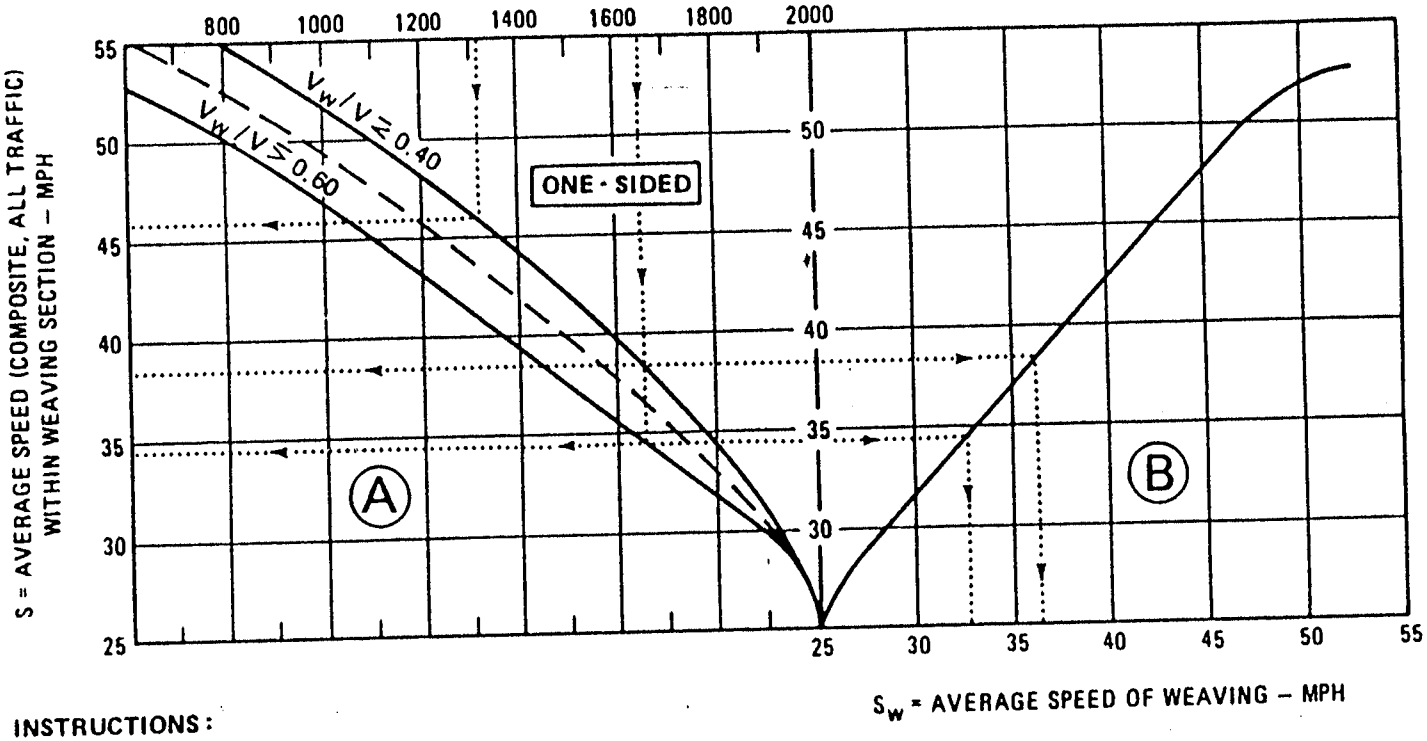
NOMOGRAPH 1



NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS – TWO-SIDED CONFIGURATIONS

NOMOGRAPH 2

SF = SERVICE FLOW WITHIN WEAVING SECTION - PCPHPL *



INSTRUCTIONS:

1. WHEN V IS WITHIN ONE LOS (±) OF V_w, S_w REMAINS THE SAME AND S IS READ FROM GRAPH (A) ABOVE.
2. WHEN V IS ONE OR MORE LOS BETTER THAN THAT OF V_w, S_w REMAINS THE SAME AND S IS READ FROM GRAPH (A).
3. WHEN V IS ONE OR MORE LOS WORSE THAN THAT OF V_w, S_w IS REDUCED AND BOTH S & S_w ARE READ FROM GRAPHS (A) & (B).

NOTE:

LOS OF V IS THE OVERALL LEVEL OF SERVICE AS A COMPOSITE WITHIN THE WEAVING SECTION, DETERMINED IN THE RIGHT PORTION OF NOMOGRAPH 1.

LOS OF V_w REFERS TO THE LEVEL OF SERVICE OF WEAVING TRAFFIC ELEMENT, DETERMINED IN LEFT PORTION OF NOMOGRAPH 1.

* SF READ FROM INITIAL SOLUTION OF NOMOGRAPH 1.

TABLE 1a

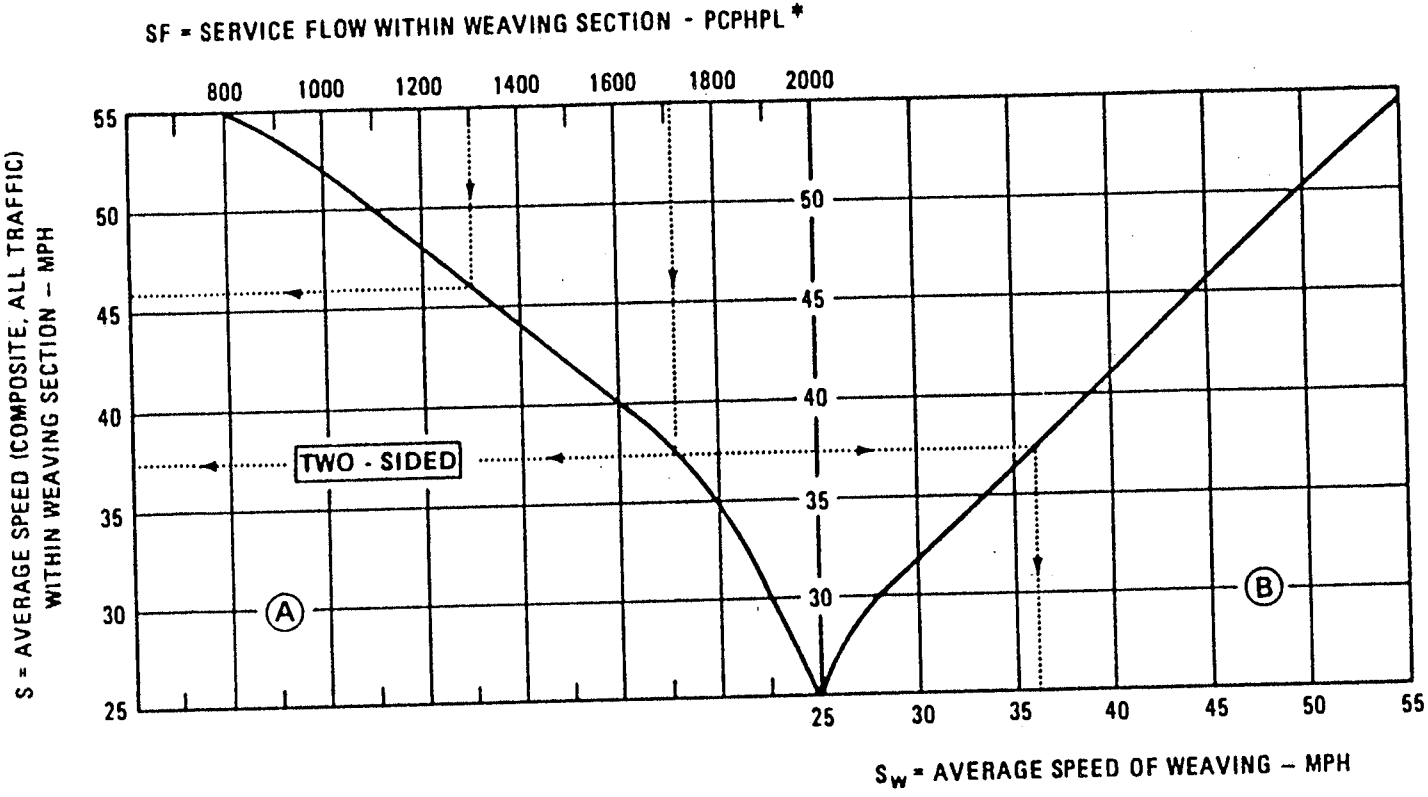
LEVEL OF SERVICE RELATED TO SPEED NOMOGRAPH ABOVE - MPH

LOS	WEAVING S_w	COMPOSITE S
A	50	55
B	45	50
C	40	45
D	35	40
E	30 - 25	30

F < 25 MPH

SUPPLEMENTARY NOMOGRAPH FOR SPEED CALIBRATION – ONE - SIDED WEAVE

NOMOGRAPH 3



INSTRUCTIONS:

1. WHEN LOS OF V IS SAME AS LOS OF V_w, S_w REMAINS THE SAME AND S EQUALS S_w.
2. WHEN V IS AT A <u>BETTER</u> LOS THAN THAT OF V_w, S_w (AND THE SPEED OF FREEWAY THROUGH TRAFFIC) REMAINS THE SAME, AND OVERALL SPEED S IS READ FROM CHART Ⓐ.
3. WHEN V IS AT A <u>WORSE</u> LOS THAN THAT OF V_w, S_w (AND THE SPEED OF FREEWAY THROUGH TRAFFIC) IS REDUCED AND BOTH S AND S_w ARE READ FROM CHARTS Ⓐ AND Ⓑ.

NOTE:

LOS OF V IS THE OVERALL LEVEL OF SERVICE AS A COMPOSITE WITHIN THE WEAVING SECTION, DETERMINED IN THE RIGHT PORTION OF NOMOGRAPH 2.

LOS OF V_w REFERS TO THE LEVEL OF SERVICE OF WEAVING TRAFFIC ELEMENT, DETERMINED IN LEFT PORTION OF NOMOGRAPH 2.

* SF READ FROM INITIAL SOLUTION OF NOMOGRAPH 2.

LOS RELATED TO SPEED - MPH

LOS	S & S_w
A	55
B	50
C	45
D	40
E	30
F	≷25

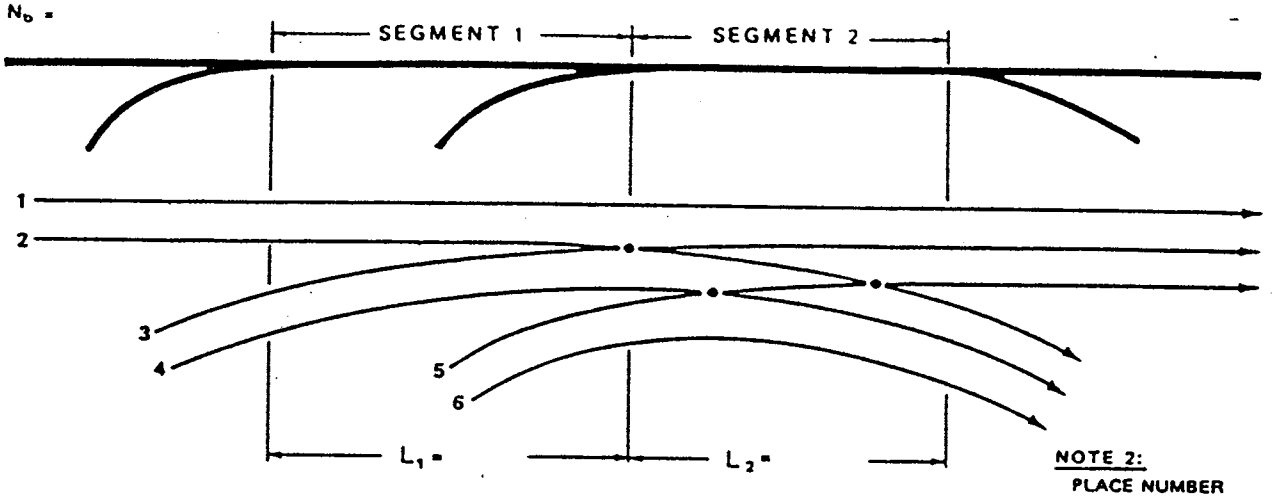
SUPPLEMENTARY NOMOGRAPH FOR SPEED CALIBRATION – TWO-SIDED WEAVE

NOMOGRAPH 4

ANALYSIS WORKSHEET
MULTIPLE WEAVING 2 EN - EX

PROJECT _____

N_o =



NOTE 2:
PLACE NUMBER OF LANES, EXISTING OR SOLVED, ALONG UPPER DIAGRAM.

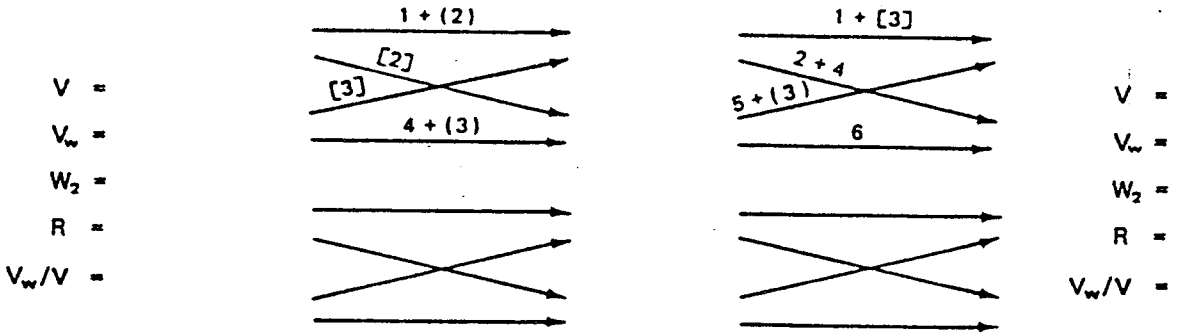
LONG WEAVE -- VOL 2. vs. VOL. 3 (SEE NOTE 1)*

SEGMENT 1

[2] = P x VOL. 2
= X = _____
[3] = P x VOL. 3
= X = _____

SEGMENT 2

(2) = (1 - P)(VOL. 2)
= X = _____
(3) = (1 - P)(VOL. 3)
= X = _____



V =
V_w =
W_2 =
R =
V_w/V =

V =
V_w =
W_2 =
R =
V_w/V =

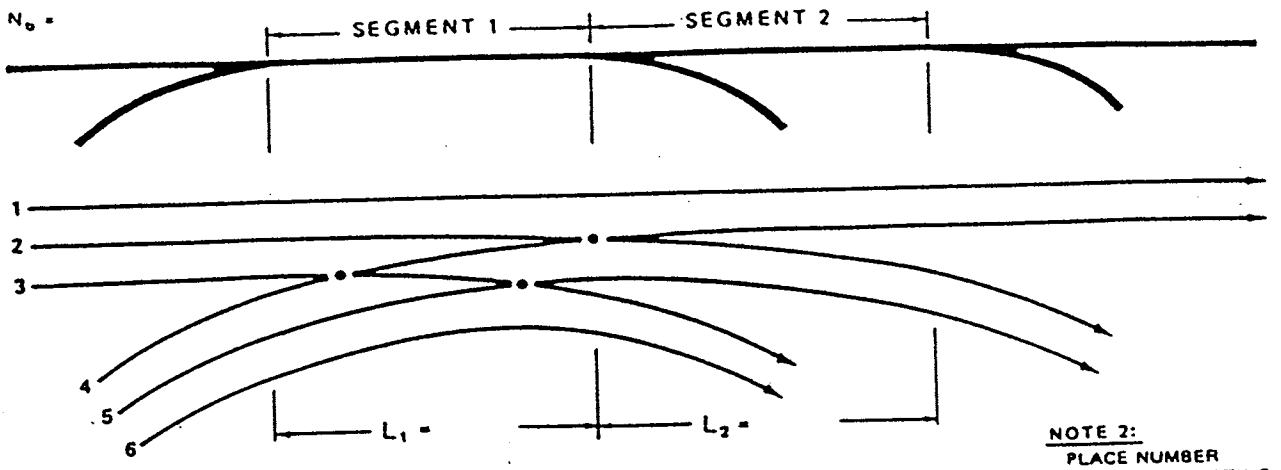
NOTE 3:
ALL VOLUMES IN PCPH. RECORD ON DIAGRAM.

COMPUTATIONS

NOTE 1: ALL OF LONG WEAVE TENDS TO TAKE PLACE IN SEGMENT 1, WITH PROPORTION P INCLINED TO APPROACH 1.0: P, HOWEVER, MAY VARY IN INDIVIDUAL CASES. IN DESIGN AND IN GENERAL OPERATIONAL ANALYSIS, NORMALLY USE P = 0.75 IN SEGMENT 1. OTHERWISE, IN MORE DETAILED OPERATIONAL ANALYSIS, FIELD SAMPLING OF TRAFFIC MAY GIVE INDICATION OF P.

ANALYSIS WORKSHEET
MULTIPLE WEAVING EN-2EX

PROJECT _____



NOTE 2:
PLACE NUMBER OF LANES, EXISTING OR SOLVED, ALONG UPPER DIAGRAM.

LONG WEAVE – VOL. 2 vs. VOL. 4 (SEE NOTE 1)*

SEGMENT 1:

(2) = (1 - P)(VOL. 2)
= X = _____

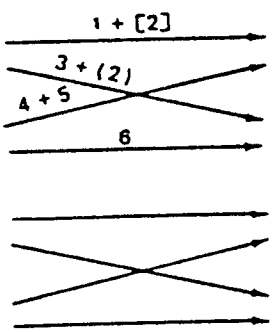
(4) = (1 - P)(VOL. 4)
= X = _____

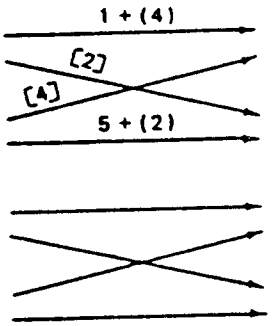
SEGMENT 2:

[2] = P x VOL. 2
= X = _____

[4] = P x VOL. 4
= X = _____

V =
V_w =
W_2 =
R =
V_w/V =





V =
V_w =
W_2 =
R =
V_w/V =

NOTE 3:
ALL VOLUMES IN PCPH. RECORD ON DIAGRAM.

COMPUTATIONS:

NOTE 1. ALL OF LONG WEAVE TENDS TO TAKE PLACE IN SEGMENT 2, WITH PROPORTION P INCLINED TO APPROACH 1.0; P, HOWEVER, MAY VARY IN INDIVIDUAL CASES. IN DESIGN AND IN GENERAL OPERATIONAL ANALYSIS, NORMALLY USE P = 0.75 IN SEGMENT 2. OTHERWISE, IN MORE DETAILED OPERATIONAL ANALYSIS, FIELD SAMPLING OF TRAFFIC MAY GIVE INDICATION OF P.