PROCEDURE FOR ANALYSIS AND DESIGN OF WEAVING SECTIONS

VOLUME 1. Research Findings and Development of Techniques for Application

FINAL REPORT

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16. Abstract

This research was performed to complete and advance the status of recently developed procedures for analysis and design of weaving sections (known as the Leisch method and initially published in the 1979 issue of ITE Journal). The objective was to enlarge upon and complete the earlier work through calibration of the method by using data from the BPR Weaving Area Study, NCHRP Project 3-15, and studies of Institute for Research of Pennsylvania State College; also to expand and refine the initial statistical analysis to provide full documentation; as well as to update the nomographs previously developed, including a demonstration of problem solutions for application.

The research and development conducted closely verified the previous work, and largely expanded on documentation and application of the procedure.

The general framework of the procedure is patterned to some degree upon the 1965 Highway Capacity Manual in order to maintain familiarity and ease of application. This was verified in using the technique, allowing for relatively simple and rapid solutions. The method is applicable to both design and operational analysis situations, and oriented to be in consonance with AASHTO Design Policies.

The report is presented in two parts: Volume 1--covering the development and verification of the procedure; and Volume 2--providing a users guide to demonstrate the solution of a variety of weaving problems.

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FOREWORD

This report summarizes the results of a research effort in the development of a procedure for design and analysis of weaving sections on freeways. The technique developed was directed toward improving efficiency and safety in rehabilitation and redesign of congested and outmoded freeways. The technique, utilizing new data, was structured to some extent upon the 1965 HCM procedure, with the objective of presenting a direct, easy-to-use method facilitated by the application of several nomographs. The method is quite different, although utilizing much of the same data, from that developed by the Polytechnic Institute of New York and reported under NCHRP Project 3-15, Weaving Area Operations Study, 1973. The results of the two projects are being analyzed under an independent FHWA research effort for comparison and evaluation, to serve as input in this area, toward development of the New Highway Capacity Manual.

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Chapter 1

INTRODUCTION

The design and operation of freeways and analyses related thereto are concerned primarily with three elements--(1) the freeway proper, (2) the merging and diverging facilities and their sequence on the freeway associated with interchanges, and (3) the weaving sections along the freeway. The latter is related to element (2)--a special configuration of ramp terminals, produced by a merge followed by a diverge, such that the auxiliary traffic imposes upon the freeway difficult operational conditions. Because of contingency-like operation which frequently is created by a weaving section, it has been recognized as a special feature of the freeway requiring individual attention in design and operation.

The concern for and the need to investigate weaving sections, since the very early approach to capacity analysis, was made evident with the 1950 Highway Capacity Manual (HCM), was expanded upon in the 1965 HCM, and pursued further with extensive research under the NCHRP Project 3-15 carried out by the Polytechnic Institute of New York (PINY) during the early 1970's. The attention and concern for dealing with weaving sections on freeways continues to carry high priority, with its planned inclusion in the new Highway Capacity Manual currently under preparation.

The NCHRP 3-15 weaving procedure, documented in NCHRP Report 159, was found to be difficult to apply, so much so that a special effort was made to simplify the structure to make it more easily applied and understood, while still retaining its major, well-developed concepts and strived-for accuracy.

Despite the updating of the procedure by PINY, the revised effort and its application, although much improved, did not produce results that were significantly more usable and understandable. Because this continued to pose a problem in design and analysis of weaving sections, a different technique was tentatively devised by J. E. Leisch, essentially an in-house development of Jack E. Leisch & Associates (JEL). (As such it was internally funded and not subject to outside monitoring.) It was primarily oriented toward the designer user, although it had some application to operations analysis but not to the detail of the PINY procedure.

Because of the urgent need for an updated and readily usable technique in the improvement of operational efficiency and safety in the rehabilitation of congested and outmoded freeways--particularly with the need for continual upgrading and reconstruction of the Interstate Systems under the 4R program--the Leisch procedure was published in the ITE Journal, March 1979. The article was presented as an abbreviated account of the development of the method, utilizing much of the same data base and associated information employed by PINY. Essentially, the article introduced the procedure in conjunction with two nomographs, with explanation of application including several problems. A statistical approach coupled with rational formulations, and analytical modeling, was utilized in the research effort. The details of development, some of it accomplished in abbreviated form, were not put together in a fully documented manner because of immediate lack of time and resources. However, the procedure and nomographs, although tentative, were presented with full confidence of a sufficiently sound and accurate method for application. There was extensive evidence that the method was favorably received by numerous users.

Following the publication of the Leisch method and updating of the PINY procedure, the TRB Committee on Highway Capacity and Quality of Service recognized a significant difference in the two approaches and at the same time the merit of each. As a result, when it was expedient to publish the preliminary work developed by the Committee on the various chapters of the forthcoming HCM for general review in the Transportation Research Circular 212, January 1980, the two methods were presented therein with a request for the profession to apply and evaluate both procedures, and to respond with any comments as appropriate.

The request by the Committee to review and transmit comments on the Interim materials on capacity in Circular 212, using an evaluation form, produced a small return with limited useful information. Comments relating specifically to the two procedures on weaving sections likewise produced minimal results, with about one-half favoring PINY procedure and one-half favoring the Leisch procedure. Responses preferring the PINY procedure gave general reasons of "apparent greater accuracy," and those preferring the Leisch procedure gave overall reasons of "much simpler to use with more direct results achieved."

The mixed responses, and the need to resolve the problem of dealing with two procedures, have made it evident that a most desirable goal for the final Manual would be an agreement on a single procedure. To accomplish this, it was decided that additional work would be required on the Leisch method by generating a fully documented research report which would permit the Capacity Committee to make the decision on how to proceed--whether one or the other method should be adopted, or possibly both methods utilized with one for planning/design purposes and the other for more detailed operational analyses.

The report presented here is the result of such an effort, carried out as a special research project by Jack E. Leisch & Associates for the Federal Highway Administration (FHWA), entitled "Completion of Procedures for Analysis and Design of Traffic Weaving Sections," with the following general tasks to be accomplished.

1. Expand upon and detail previously accomplished statistical analyses, and execute additional analyses as required.
2. Update technique previously formulated and readjust nomographs.
3. Test and validate procedure.
4. Prepare research report and documentation.
5. Prepare a users' guide with appropriate problem examples.

The research presented and the technique developed for design and analysis of weaving sections was approached on the basis of the following premises:

a. The procedure was to be simple and easy to use.
b. The format, to all feasible extent, was to follow the makeup and terminology applied in the 1965 HCM.
c. The revised procedure was to make appropriate and extensive use of both the 1963 BPR data base, and the supplementary data and development of the NCHRP Project 3-15 on "Weaving Area Operations Study."
d. Statistical analyses, independently performed, to reflect the data of both projects, were to play a major role in establishing the needed relationships.
e. Elements of analytical modeling and rational formulations were to be utilized to supplement and expand upon portions of findings determined statistically to provide a sufficiently broad spectrum for application.

The adherence to these objectives, and the confidence that at least the general framework of an already long-standing procedure in Chapter 7 of the 1965 HCM (despite some of its shortcomings) could provide a definitive avenue of investigation, gave impetus to the study. The 1963 BPR data base furnished the major basis of investigation, coupled with numerous elements of research derived in the NCHRP 3-15 Project. The latter provided valuable information and insights previously unavailable; this further aided the development of the revised or updated methodology reported herein. Direct experience of the authors in design, construction, and operation of innumerable weaving sections throughout the process of the Interstate System development has provided an additional dimension to the practical considerations of real conditions to be reflected in the results.

Chapter 2

CHARACTERISTICS OF WEAVING SECTIONS

Weaving simply defined is the crossing of traffic streams moving in the same general direction accomplished by successive merging and diverging. There are several variations of weaving sections which, although somewhat different in form, perform with a degree of similarity. Each can be broken down to a set of operational components which are much the same although interrelated a bit differently. Because of the similarity in the basic operational elements, it has been possible to devise analysis procedures to solve problems associated with all forms of weaving sections using minor variations in the 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-segment of weaving element 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; such facility, in essence, constitutes two or more overlapping weaving sections. 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 a 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. As a special case, a one-sided weaving section technically could involve a left-hand entry followed by a left-hand exit.

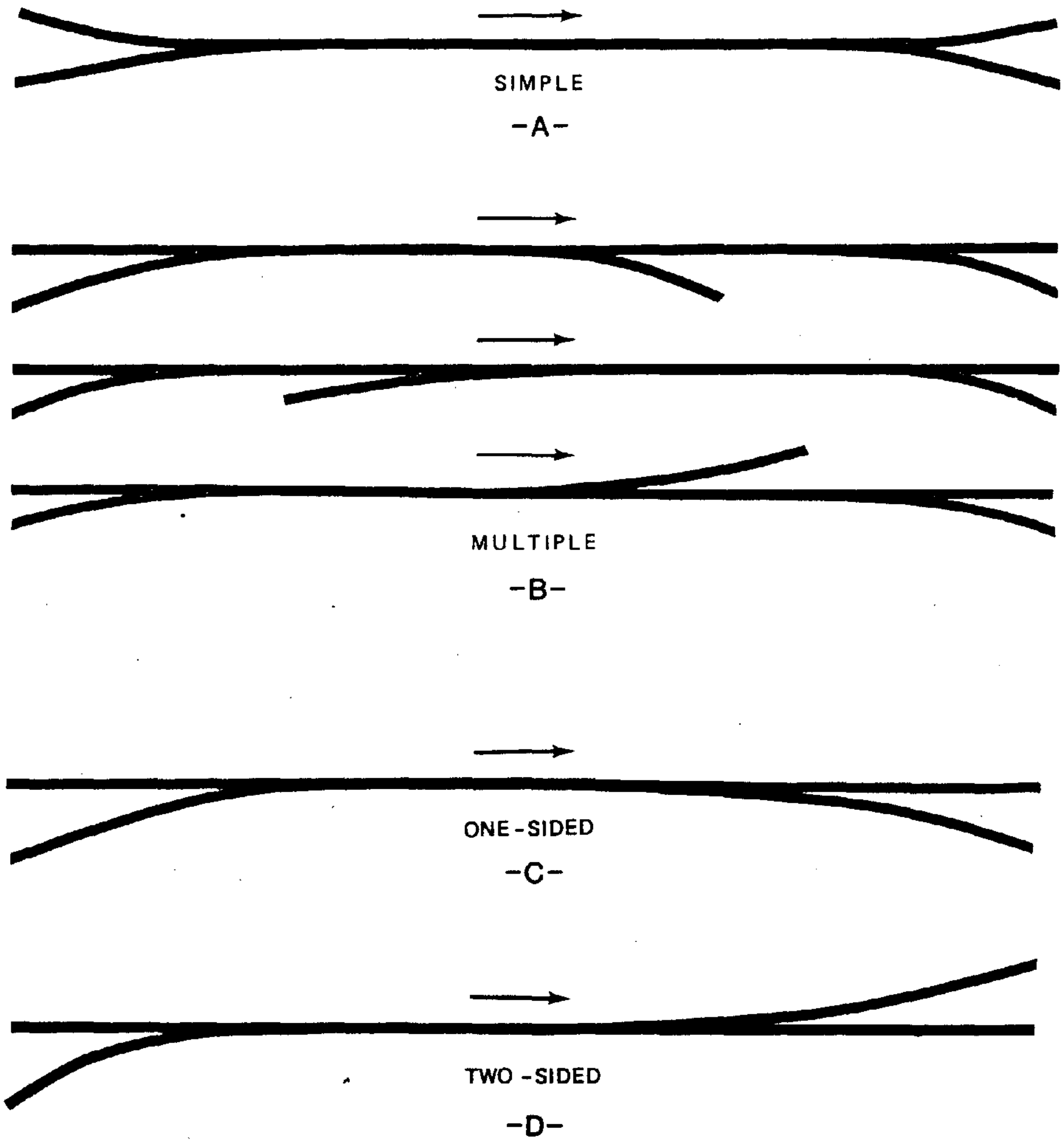


Figure 1. FORMS OF WEAVING SECTIONS

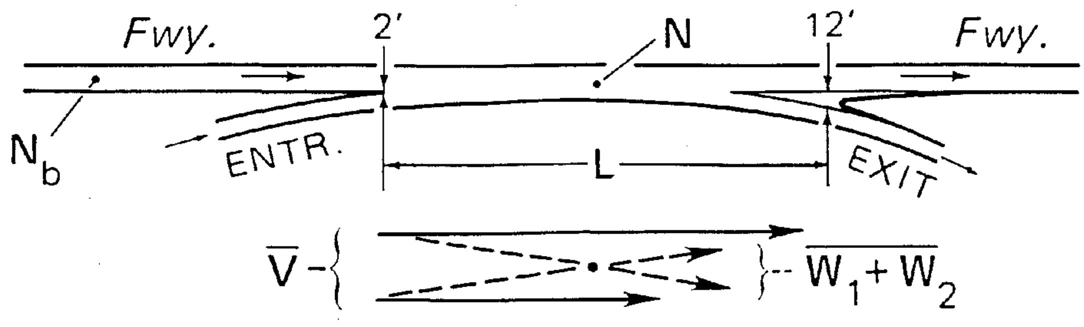
D. Two-sided weaving section is formed by a right-hand entry followed by a left-hand exit, or a left-hand entry followed by a right-hand exit.

The major difference between a simple weave and multiple weaves 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 traffic 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.

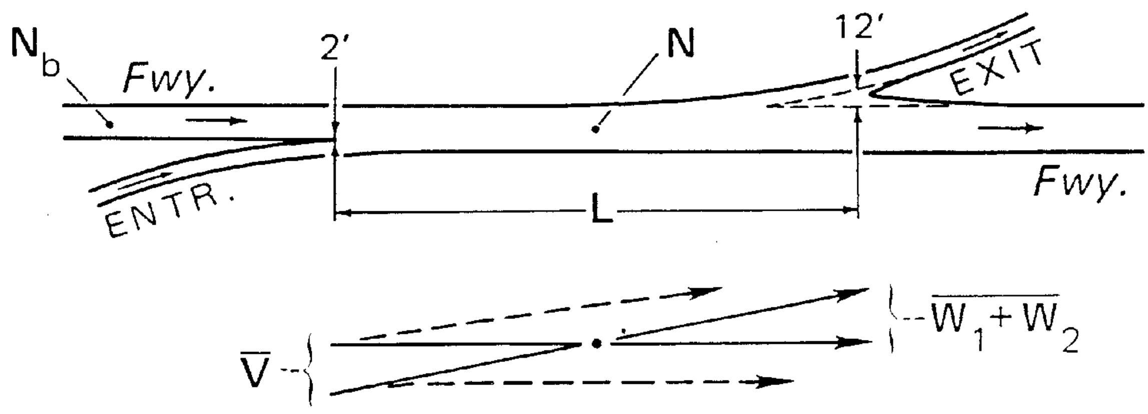
The more detailed arrangement depicting the comparison between a one-sided and two-sided weaving section is illustrated in Figure 2. The nomenclature referring to the various geometric and traffic elements are also identified and explained further on in the text. An important feature noted is the method 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.



ONE - SIDED SECTION

–A–



TWO - SIDED SECTION

–B–

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

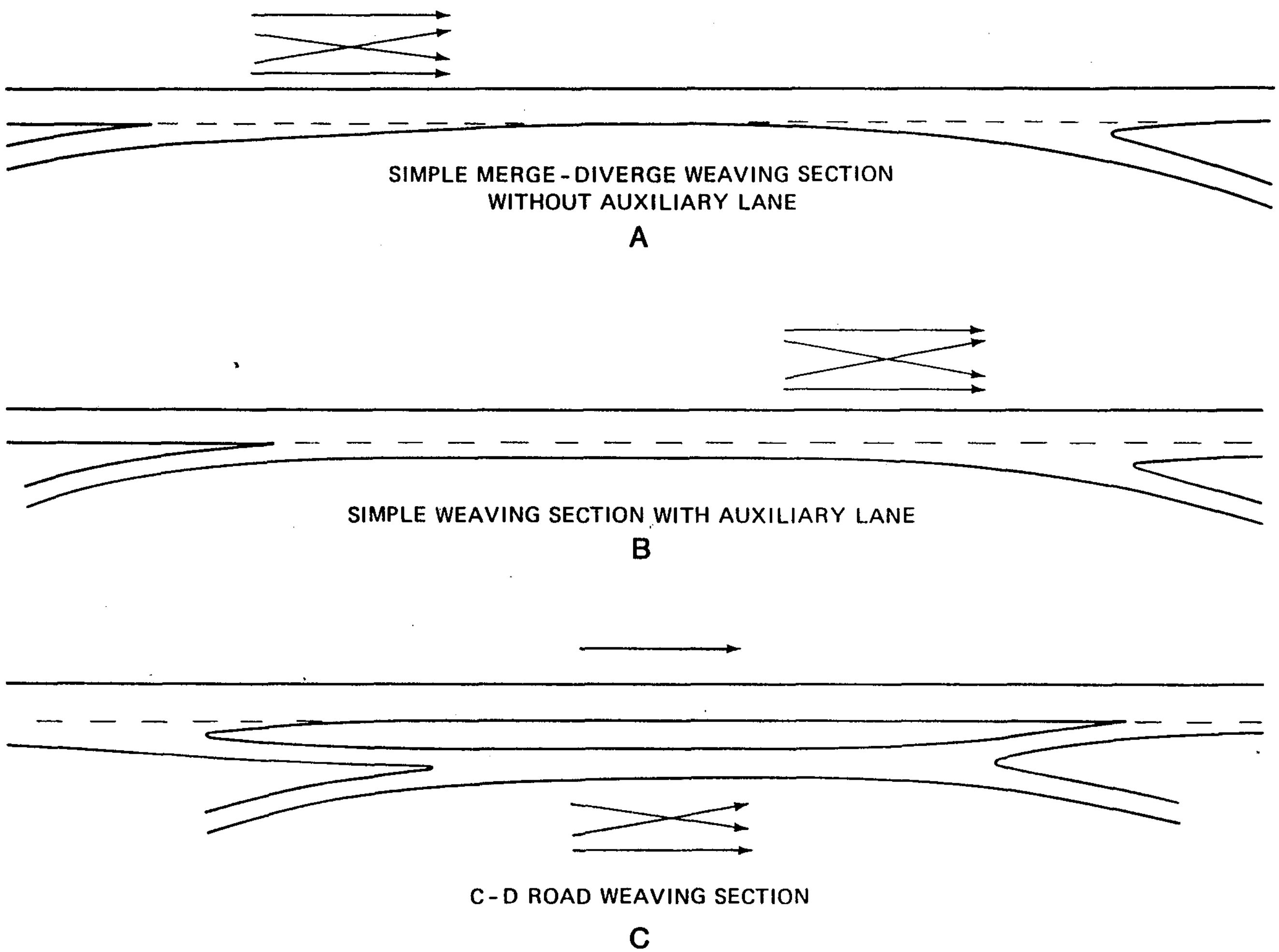
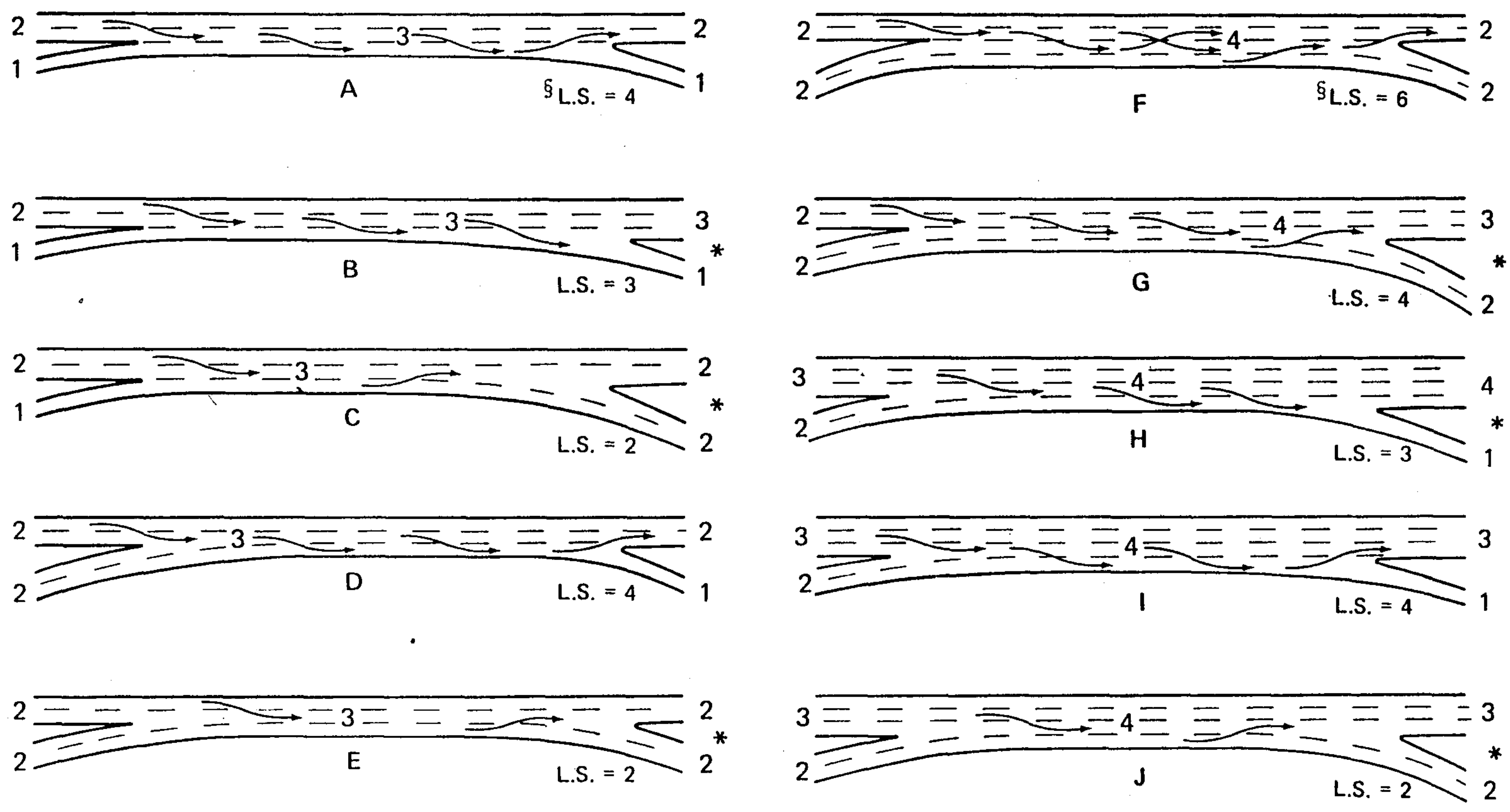


Figure 3. VARIATIONS OF ONE - SIDED WEAVING SECTIONS

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, and an extra lane throughout the weaving section. 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. The C-D weaving section is intended to handle only the crossing (weaving) of entering and exiting traffic, simplifying operations on the freeway.

Further configurations of weaving sections have to do with internal lane arrangement and lane balance. Lane balance refers to the arrangement of lanes at ramp entrtances and exits which provides a degree of efficiency and flexibility in operation of merging and diverging traffic. With respect to exits, lane balance simply means the provision of "one more lane going away" (the combined number of lanes on the freeway and ramp after the exit should be one more than on the freeway preceding the exit); also, not more than one preceding lane should be dropped at a time. At entrances, the requirement is that the number of lanes must "add up," with the merged or combined number on the freeway equal to, or one less, after the merge.

Examples of a variety of patterns involving single- and double-lane entrances and exits which may be required to accommodate the traffic, and 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



* 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

balance, particularly where the feature of "one more lane going away" is not present, 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.

Accordingly, the number and arrangement of lanes through the weaving section must be carefully selected to satisfy a series of requirements including volumes and patterns of traffic entering and leaving the weaving section. 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. The basic relations and principal design elements are determined by the procedure developed herein, which serves as the major tool in design and analysis of weaving sections; however, the features and insights described above must be used as an adjunct to optimize results. An attempt to account for some of this as part of the model, is covered further in Chapter 6 under the heading of "Configuration of Weaving Sections and Lane Balance."

An important observation with respect to characteristics of weaving sections is the significant difference between the overall makeup of weaving sections in the PINY report, and the form, variations and characteristics of weaving sections dealt with in this report. The approach by PINY is rather fundamental and much more on the theoretical side than treated here. PINY's definition and treatment of weaving sections pertains primarily to what is referred to as "ramp weaves" and "major weaves." In the 1973 PINY Report (page 10 and Figure 2.6) a ramp weave is defined as "a weaving section which is a highway mainline with an on-ramp, off-ramp sequence (both single lanes) connected by an auxiliary lane"; a major weave is defined as "a weaving section in which three or more legs each having two or more lanes." Illustrations of these definitions are shown in Figure 5 (reprinted directly from Figure 2.6 of the 1973 PINY Report) for clarity of discussion.

The definition of a "ramp weave" is quite clear and represents one of actual and representative forms of weaving sections in practice. As a ramp weave, however, it is limited to only one specific variation according to the PINY definition; i.e., with single-lane entrance and single-lane exit, connected by an auxiliary lane. In real practice a "ramp weave" may have several additional variations, as for example Section A, Figure 3, and Sections A, B, C and D in Figure 4.

Referring to "major weave" sections as shown in Figure 5 (Figure 2.6, PINY report) the arrangements are nondescript with respect to actual facilities and to design-operations modes. Because the "major weave" (PINY definition) is so variable and not really definitive with respect to actual and particularly modern freeways, a question may be raised as to what is a "major weave" and how does it apply in a real planning-design-operations situation.

Another difference between the two research projects being discussed, is that the PINY report does not deal with nor recognizes a two-sided weaving section, as shown in Section D of Figure 1 and Section B of Figure 2. It does, however, address the multiple weave problem--an important feature in freeway design.

SOURCE: ILLUSTRATION REPRODUCED
DIRECTLY FROM NCHRP 3-15 REPORT, 1973
ON " WEAVING AREA ANALYSIS "

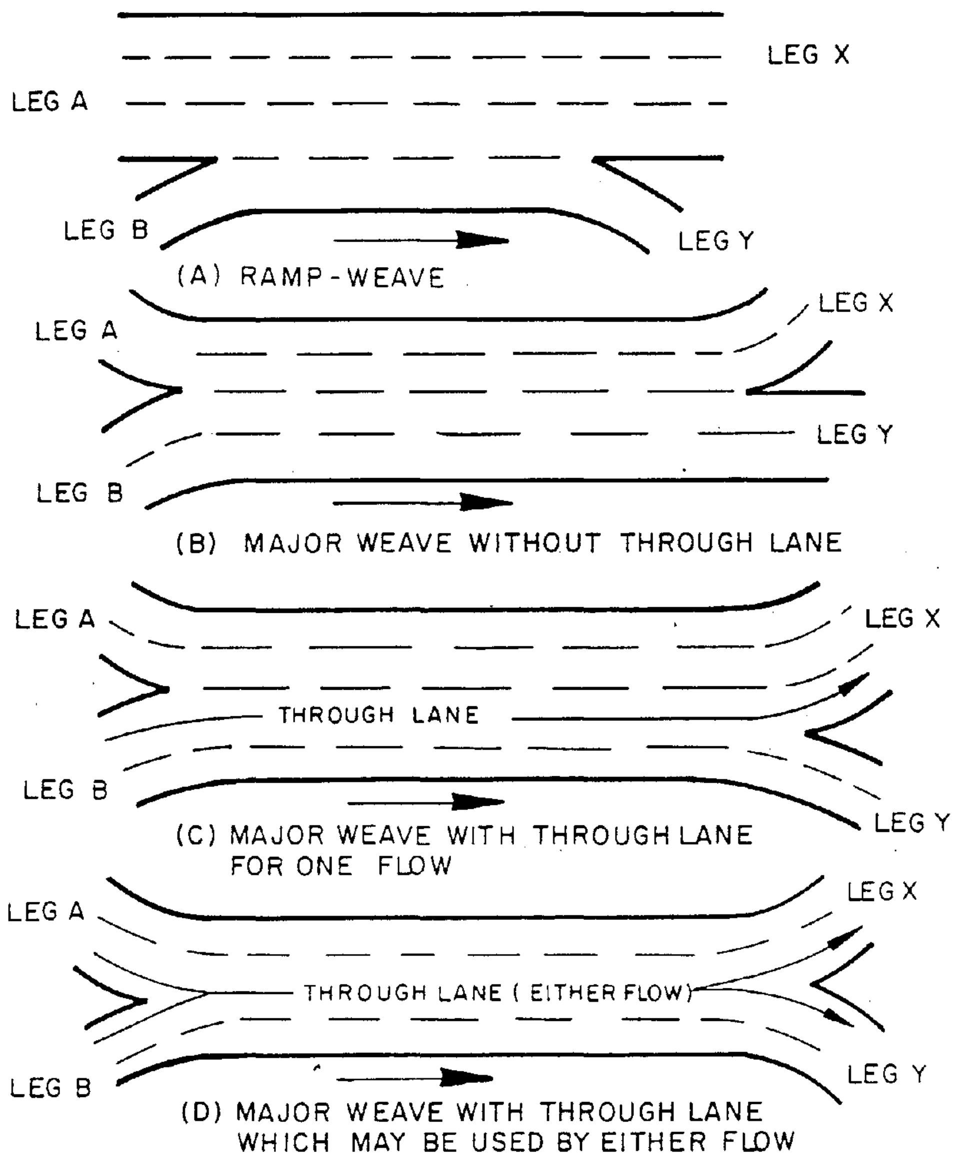


FIGURE 2.6 RAMP-WEAVE AND MAJOR-WEAVE ILLUSTRATIONS (FROM NCHRP 3-15)

Figure 5. WEAVING SECTION FORMS USED TO DEVELOP " PINY " PROCEDURE FOR ANALYSIS IN NCHRP 3-15 REPORT, 1973.

Furthermore, the PINY report has not utilized any of the C-D weaving data from the BPR data base, nor identified the C-D form of weaving section, shown in Section C of Figure 3. Actually both the two-sided weave and the C-D weave are significant forms of weaving sections in the modern aspects of rehabilitation and reconstruction of the Interstate System. The first pertains to sections of continuous C-D roads involving upgrading of several interchanges in series, and the second pertains to short sections of C-D roads introduced to remove or mitigate weaving on the freeway proper.

All of the forms described in this Chapter, as part of the project, are set up for analysis and solutions by the procedures developed herein.

In presentation of the following material some of the nomenclature and definitions are noted. It is intended that these match as closely as feasible the terms utilized in the PINY report. Otherwise some of the terminology already used in the current HCM and in AASHTO publications is included for purposes of this report.

The following terms are defined and used throughout the text:

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	--
SV	Service volume	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
R	Ratio of smaller weaving to total weaving volume	-
V	Ratio of weaving volume to total volume	-
LOS	Level of Service, designated as A, B, C, D and E; V_w measured by S_w directly with SV as dependent variable; V_{nw} and V are measured directly by SV.	

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

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

Additional terms are defined as introduced in the text.

Chapter 3

DATA BASE

The 1963 Bureau of Public Roads (BPR) data base formed the nucleus of information for this project. The form in which it was finally compiled and made available to PINY for study consisted of 45 experiments at 34 different locations. The BPR project known as the Urban Weaving Area Capacity Study involved collection of weaving movements by type for one- to two-hour periods in 6-minute intervals at a number of locations throughout the United States. The sites studied represented a variety of conditions--simple, multiple, one-sided, two-sided and C-D (collector-distributor) road weaving situations. The data points (coded "B") representative of full hourly (peak) periods, compiled directly from PINY's report Tables 1.4, 1.5, and 1.6 therein, are shown in Table 1. This tabulation provided the major input for analysis on the project.

Another important source of data was supplied from additional field studies carried out by PINY at 17 sites, from which 8 locations were chosen by PINY for analysis. Data points (coded "P") from these selected locations were made available to the project by PINY as shown in Table 2.

Further data from four weaving locations in different cities carried out by the Institute for Research, Pennsylvania State College, were furnished by FHWA. Listed in terms of full hourly measurements, the data points (coded "I") are shown in Table 3. As an addendum to this tabulation, two additional studies (coded "M") available from JEL files are included.

Although the information in Tables 1, 2 and 3 is on the basis of full hourly measurements, or equivalent, summaries of data tabulated on one-hour rates of flow expanded from 18-minute counts, were also made available. Table A-1 in the Appendix includes such information for coded points "B" and "P," compiled from tabulations furnished by PINY. Similar data points expressed as hourly rates are also included in Table A-2 for coded points "I" and "M." The tabulations in Table A-1 were compiled by PINY primarily to expand the "B" and "P" data base to formulate situations with a greater variation of speeds, primarily higher speeds, of which there was only slight incidence in the full hourly base. A number of relatively high full hourly speeds, however, were produced by "I" coded points, which helped to broaden the overall data base.

Table A-1, which was specifically devised for the form of analysis carried out in the PINY study, did not lend itself directly to the model utilized in this study. Although it provided a more expansive set of data points, the additional hourly rates with certain variations in speed generally did not enhance the statistical analysis. Some selected points, however, which, further in the research effort, were found to be compatible with the full hourly base and used as supplementary data to good advantage.

The full hourly data base played a primary role in establishing the relationships of this study. The 31 study sites utilized by JEL from the BPR data base, was the same number as used by PINY, although all the sites were not identical. These were supplemented by eight sites from PINY's field studies, four sites from the

Institute for Research, Pennsylvania State College, and two miscellaneous sites from JEL data file--a total of 45 sites. With the use of additional experiments at some sites, a total of 58 data points were utilized in the regression analysis for the volume/speed/length relationships. Of these, 40 points were used in the derivation of k values, augmented by additional experiments for a total of 52. An index of data points and how these were used in the various analyses are tabulated for ready reference in Tables 13 and 14.

Other characteristics and means of developing the data base, are thoroughly covered in the 1973 PINY Report.

TABLE 1

BPR DATA BASE FOR WEAVING AREA OPERATIONS STUDY

Full Hour Data, Collected 1963——As Presented in PINY NCHRP Report 3-15, 1973

SITE NO.	LOCATION	LANE ARRANGEMENT	WEAVE LENGTH Feet	WEAVE WIDTH Feet	AVERAGE SPEED -Space Mean- mph WEAV'G.	NON-WEAV'G.	ALL	TRAFFIC VOLUMES--FULL HOUR COUNTS vph **MOVEMENT 1	2	3	4	WEAV'G. VOL.	SMALLER WEAV'G.	TOTAL VOL.	PEAK HOUR FACTOR PHF	TRUCKS %	EQUIV. WEAV'G. VOL. pcph
B- 3	Eastshore Fwy. N. B. San Pablo to Soland Ave., San Francisco, Cal.	3 4 3 1 1	917	48	34.6	34.7	34.7	3893	385	713	93	1098	385	5084	0.91	3	1130
B- 4	Bayshore Fwy. S. B. Army St. to Alemany St., San Francisco, Cal.	3 4 3 1 2	3760	48	33.4	34.2	33.9	3902	1445	1041	747	2486	1041	7135	0.98	3	2560
B- 5	Eastshore Fwy. N.B. University Ave. (C-D Loops) San Francisco, Cal.	1 2 1 1 1	425	24	33.5	--	33.5	4	537	734	1	1271	537	1276	0.87	2	1295
B- 6	Eastshore Fwy. N.B. University Ave. (Collector Loops) San Francisco, Cal.	1 2 1 1 1	425	24	32.2	32.2	32.2	5	928	622	6	1550	622	1561	0.83	2	1581
B- 7	Bayshore Fwy. N.B. Whipple Ave. (Inner Loops) San Francisco, Cal.	3 4 3 1 1	445	48	26.6	42.1	35.3	3374	773	883	0	1660	778	5040	0.91	7	1785
B- 8	Bayshore Fwy. N.B. Whipple Ave. (Inner Loops) San Francisco, Cal.	3 4 3 1 1	445	48	29.8	50.1	40.4	3157	772	1003	0	1775	772	4932	0.83	6	1890
B- 9	Bayshore Fwy. N.B. at San Bruno Ave., San Francisco, Cal.	4 5 4 1 1	449	62	28.4	31.9	30.9	4572	716	810	0	1526	716	6090	0.93	6	1625
B-10	Bayshore Fwy. N.B. 19th Ave. (Inner Loops) San Francisco, Cal.	1 2 1 1 1	503	24	34.4	--	34.4	7	586	462	2	1048	462	1057	0.74	11	1165
B-11	Hollywood Fwy. Vermont to Melrose, Los Angeles, Cal.	4 5 4 1 1	1054	62	33.0	49.7	44.4	4973	865	489	35	1354	489	6362	0.90	1	1370
B-12	Harbor Fwy. Vernon to 51st, Los Angeles, Cal.	4 5 4 1 1	910	62	26.1	26.6	26.5	5885	268	370	33	638	268	6556	0.90	1	645
B-13	Golden State Fwy. Ventura Fwy. to Colorado Fwy., Los Angeles, Cal.	3 5 4 2 1	2875	64	22.2	22.2	22.3	3825	723	2251	730	2974	723	7529	0.96	6	3165
B-14	Harbor Fwy. N.B. 51st to Vernon, Los Angeles, Cal.	4 5 4 1 1	963	62	34.8	28.9	29.3	6172	319	303	50	627	308	6849	0.92	3	645
B-15	Harbor Fwy. S.B. (Coll-Dist.) Exposition to Santa Barbara, Los Angeles, Cal.	1 2 1 1 1	900	24	39.9	--	39.9	0	525	1036	0	1561	525	1561	0.83	2	1595
B-16	Harbor Fwy. N.B. Vernon to Santa Barbara, Los Angeles, Cal.	4 5 4 1 1	935	62	17.0	17.0	17.0	5602	370	572	117	942	370	6661	0.94	3	970
B-17	Edens Expy. S.B. Dempster Road, (Inner Loops) Chicago, IL.	3 4 3 1 1	710	52	36.7	50.4	46.3	3897	493	619	0	1112	493	5009	0.88	5	1070
B-18	Edens Expy. S.B. Touhy St. Ramps Chicago, IL.	3 4 3 1 1	725	52	36.3	55.0	48.3	2482	309	642	5	951	309	3438	0.76	7	1020

** See page 3 of Table

TABLE 1 (cont'd)

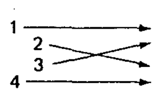
SITE NO.	LOCATION	LANE ARRANGEMENT	WEAVE LENGTH Feet	WEAVE WIDTH Feet	AVERAGE SPEED -Space Mean- mph WEAV'G.	NON-WEAV'G.	ALL	TRAFFIC VOLUMES--FULL HOUR COUNTS vph **MOVEMENT 1	2	3	4	WEAV'G. VOL.	SMALLER WEAV'G.	TOTAL VOL.	PEAK HOUR FACTOR PHF	TRUCKS %	EQUIV. WEAV'G. VOL. pcph
B-20	Congress Expy. E.B. California Ave. to Western Ave., (Coll-Dist.) Chicago, IL.	1 2 1 / 1 1	868	27	36.5	32.9	36.4	0	736	415	40	1151	415	1191	0.78	10	1265
B-21	Edens Expy. S.B. Peterson Ave. (Inner Loops) Chicago, IL.	3 4 3 / 1 1	625	52	33.0	37.2	36.8	4220	272	317	0	589	272	4809	0.90	5	620
B-23	Dan Ryan Expy. S.B. Congress St. to Taylor St., Chicago, IL.	4 5 4 / 2 1	659	64	26.3	34.0	30.7	3401	326	2176	77	2502	326	5980	0.86	11	2780
B-24	Dan Ryan Expy. S.B. Congress St. to Taylor St., Chicago, IL.	4 5 4 / 2 1	659	64	29.9	43.5	36.2	2912	503	1890	107	2392	503	5412	0.93	13	2750
B-27	Congress Expy. W.B. Western Ave. to California Ave. (Coll-Dist.) Chicago, IL.	1 2 1 / 1 1	844	27	39.3	--	39.3	2	375	861	4	1236	375	1242	0.87	10	1360
B-28	Congress Expy. W.B. Racine to Ashland, Chicago, IL.	4 5 4 / 1 1	1032	72	43.9	46.9	46.4	5068	396	970	24	1366	396	6458	0.90	5	1440
B-29	Dan Ryan Expy. S.B. 51st St. to 55th St. Chicago, IL.	2 3 2 / 1 1	894	33	19.1	22.9	19.2	1803	814	620	3	1434	620	3240	0.93	13	1610
B-30	Dan Ryan Expy. N.B. 55th St. to 51st St. Chicago, IL.	2 3 2 / 1 1	890	38	26.9	28.3	28.1	2013	517	591	17	1108	517	3138	0.92	37	1515
B-32	Dan Ryan Expy. S.B. Pershing to 43rd St. (Local Lanes) Chicago, IL.	3 4 3 / 1 1	822	50	36.1	38.9	38.0	3885	477	823	17	1300	477	5202	0.84	8	1400
B-33	Dan Ryan Expy. S.B. 71st. St. to 75th St. Chicago, IL.	4 5 4 / 1 1	521	62	29.6	32.9	31.4	6128	846	406	5	1252	406	7385	0.94	5	1315
B-34	Dan Ryan Expy. N.B. 63rd St. to 59th St. (Local Lanes) Chicago, IL.	3 4 3 / 1 1	621	50	34.4	41.5	39.2	2702	274	857	4	1131	274	3837	0.87	5	1190
B-39	South Conduit Ave. E.B. at Van Wyck Expy. (Inner Loops) New York, N.Y.	3 4 4 / 2 1	556	42	19.1	22.9	19.2	2024	1054	1826	4	2880	1054	4908	0.91	4	2995
B-40	South Conduit Ave. E.B. at Van Wyck Expy. (Inner Loops) New York, N.Y.	3 4 4 / 2 1	556	42	23.6	29.2	25.6	2017	865	1986	1	2851	865	4869	0.91	4	2970
B-41	South Conduit Ave. E.B. at Van Wyck Expy. (Inner Loops) New York, N.Y.	3 4 4 / 2 1	556	42	26.9	32.2	28.3	1067	1116	1253	4	2369	1116	3440	0.89	3	2440
B-42	North Conduit Ave. W.B. Van Wyck Expy. to Southern State Pkwy., New York	3 4 1 / 1 3	625	40	31.6	21.4	31.5	264	923	888	290	1811	888	2365	0.81	7	1945
B-43	North Conduit Ave. W.B. Van Wyck Expy. to Southern State Pkwy., New York	3 4 1 / 2 3	625	40	29.6	26.1	29.4	98	2042	613	369	2655	613	3122	0.87	15	3050

** See page 3 of Table

TABLE 1 (cont'd)

SITE NO.	LOCATION	LANE ARRANGEMENT	WEAVE LENGTH Feet	WEAVE WIDTH Feet	AVERAGE SPEED -Space Mean- mph WEAV'G.	NON-WEAV'G.	ALL	TRAFFIC VOLUMES--FULL HOUR COUNTS vph **MOVEMENT 1	2	3	4	WEAV'G. VOL.	SMALLER WEAV'G.	TOTAL VOL.	PEAK HOUR FACTOR PHF	TRUCKS %	EQUIV. WEAV'G. VOL. pcph
B-47	So. Conduit Ave. E.B. Idlewild Airport to Southern State Pkwy., New York	4 2 4 2 3	980	40	24.3	22.0	23.3	628	2957	461	418	3418	461	4464	0.87	7	3675
B-48	So. Conduit Ave. E.B. Idlewild Airport to Southern State Pkwy. New York	4 2 4 2 3	980	40	27.1	27.5	27.2	633	3019	422	463	3441	422	4567	0.83	1	3475
B-49	Northern State Pkwy. Guinea Woods Rd. to Meadow Brook Pkwy., Long Island, N.Y.	4 2 4 1 2	564	50	26.3	19.9	22.2	2568	1698	417	365	2115	417	5048	0.92	0	2115
B-50	Northern State Pkwy. Guinea Woods Rd. to Meadow Brook Pkwy., Long Island, N.Y.	4 2 4 1 2	564	50	19.3	13.6	15.7	3430	1865	375	385	2240	375	5054	0.92	0	2240
B-51	Northern State Pkwy. Guinea Woods Rd. to Meadow Brook Pkwy., Long Island, N.Y.	4 2 4 1 2	564	50	38.3	42.7	37.2	1498	1350	330	415	1680	330	3593	0.85	0	1680
B-52	Van Wyck Expy. S.B. Main St. to Hillside Ave., New York, N.Y.	2 3 4 3 1	497	54	29.7	35.3	32.1	2155	272	2181	27	2453	272	4635	0.86	4	2550
B-53	Southern State Pkwy. E.B. Bayshore Rd. to Heckscher Pkwy., Long Island, N.Y.	3 2 4 1 3	1583	50	47.8	46.1	47.3	586	1643	182	206	1825	182	2617	0.84	0	1825
B-54	Sunken Meadow Pkwy. N.B. to Northern State Pkwy. (Inner Loops), Long Island, N.Y.	2 2 3 2 1	738	38	37.6	45.8	39.3	609	296	1469	22	1765	296	2396	0.89	0	1765
B-60	Baltimore-Washington Pkwy. S.B. Rt. 50 to South Dakota Ave., Washington, D.C.	2 2 3 2 1	4665	*	33.8	31.7	32.7	1822	932	1927	562	2859	932	5243	0.83	4	2980
B-61	Geo. Washington Pkwy. W.B. Key Bridge to Spout Run Pkwy., Arlington, Va.	2 2 2 2 2	1900	*	26.5	27.7	27.1	958	465	1407	1212	1869	462	4039	0.95	1	1890
B-63	Baltimore-Washington Pkwy. S.B. Rt. 50 to South Dakota Ave., Washington, D.C.	2 2 3 2 1	4650	*	34.5	32.0	33.7	1153	1059	1507	445	2564	1059	4162	0.90	9	2785
B-64	Geo. Washington Pkwy. W.B. Key Bridge to Spout Run Pkwy., Arlington, Va.	2 2 2 2 2	1900	*	23.1	24.5	24.0	1240	798	2217	1860	3015	798	6115	0.95	0	3015
B-65	Baltimore-Washington Pkwy. South Dakota to Rt. 50, Washington, D.C.	2 2 3 1 2	4700	*	45.1	45.1	45.1	1375	1274	387	1090	1661	387	4126	0.92	4	1730

** Movement Identification



* Approximate width of 36' for 3 lanes, and 24' for 2 lanes.

TABLE 2

SUPPLEMENTARY DATA BASE FOR WEAVING AREA OPERATIONS STUDY

Hourly Rates (Based on 18-min. Periods from Peak Hour) for PINY Experiments of Selected Sites
Conducted and Furnished by PINY, NCHRP Report 3-15, 1973

SITE NO.	LOCATION	LANE ARRANGEMENT	WEAVE LENGTH Feet	WEAVE WIDTH Feet	AVERAGE SPEED -Space Mean- mph			TRAFFIC VOLUMES--HOURLY RATES Converted from 18-min. Counts of Peak Periods pcph					TRUCKS	EQUIV. WEAV'G. VOL.
					WEAV'G.	NON-WEAV'G.	ALL	MOVEMENT** 1 and 4	MOVEMENT** 3 and 4	WEAV'G. VOL.	SMALLER WEAV'G.	TOTAL VOL.	%	pcph
P- 2	Southern State Pkwy., W.B. at Meadowbrook Pkwy. (L.I., N.Y.)	3 4 3 / 1 1	968	48	42.7	46.6	45.8	3660	900	900	100	4560	DATA NOT FURNISHED All Volumes Precalculated in pcph	900
P- 5	Cross Bronx Expy. E.B. over Alexander Hamilton Bridge (N.Y.,N.Y.)	2 4 3 / 2 2	950	48	44.1	45.6	44.9	1390	1090	1090	261	2480		1090
P- 7	Kensington Expy. N.B. at Fillmore Ave. (Buffalo, N.Y.)	2 3 2 / 1 1	750	43	44.7	55.3	50.0	1190	1200	1200	260	2390		1200
P- 8	I-84 E.B. at Capital Ave. (Hartford, Conn.)	4 5 3 / 1 2	1355	60	44.1	46.2	45.5	2610	1190	1190	420	3800		1190
P-10	Cross Westchester Expy. E.B. at New York State Thruway (Elmsford, N.Y.)	2 3 3 / 2 1	527	48	41.5	43.9	43.2	1700	730	730	234	2430		730
P-11	Rte. 202 S.B. at Valley Forge, (King of Prussia, PA.)	2 3 2 / 1 1	1200	36	49.3	52.9	51.6	1380	820	820	300	2200		820
P-14	I-80 E.B. at Garden State Pkwy. (Saddle Brook, N.J.)	2 3 2 / 1 1	1467	36	50.2	55.1	53.1	1960	1370	1370	80	3330		1370
P-15	I-95 N.B. at Route 7, (Alexandria, VA.)	3 4 3 / 2 1	2000	48	42.6	45.4	44.8	2280	680	680	200	2960		680

** Movement Identification

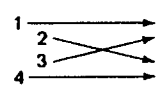


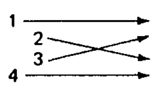
TABLE 3

SUPPLEMENTARY DATA BASE FOR WEAVING AREA OPERATIONS STUDY

Full Hourly Data of Selected Sites Furnished by Institute for Research, Pennsylvania State College, 1983
Includes Separate Addendum of Miscellaneous Experiments——Pre 1960

SITE NO.	LOCATION	LANE ARRANGEMENT	WEAVE LENGTH Feet	WEAVE WIDTH Feet	AVERAGE SPEED -Space Mean- mph			TRAFFIC VOLUMES--FULL HOUR COUNTS vph							PEAK HOUR FACTOR PHF	TRUCKS %	EQUIV. WEAV'G. VOL pcph
					WEAV'G.	NON-WEAV'G.	ALL	**MOVEMENT 1	2	3	4	WEAV'G. VOL.	SMALLER WEAV'G.	TOTAL VOL.			
I- 2	Katy Fwy., I-10 E.B., Entr. Frontage Rd. to Exit (753B) Dairy Ashford Rd., Houston, TX.	3 3 3 1 1	1100	36	52.6	59.5	58.8	3335	26	376	2	402	26	3739	0.99	13	455
I- 6	No. Central Expy., US 75 N.B. No. Perimeter of Dallas to Exit 25, Arapaho Rd. Dallas, TX.	2 2 2 1 1	1950	24	48.1	54.4	52.3	1515	658	124	11	782	124	2308	0.97	10	860
I- 8	I-285 E.B., Entrance Clark Howell Hwy. to Exit (42B) I-75 South, Atlanta, GA.	2 3 2 1 1	1450	36	52.0	60.1	57.2	1469	733	92	13	825	92	2307	0.87	18	970
I-11	Calumet Expy., I-94 East, S.B. Entr. 11th St. to Exit (66B) 115th St., Chicago, IL.	3 4 3 1 1	1150	48	50.5	57.2	56.1	1959	228	160	6	388	160	2353	0.93	35	525
M-1	Eisenhower Expy., I-290 E.B., Entr. Damen Ave. to Exit Paulina St., Chicago, IL.	4 6 4 2 2	650	72	28.6	40.0	36.9	4950	1200	500	0	1700	500	6650	0.78	3.5	1755
M-2	Shirley Hwy., I-95 S.B. Entr. Va. Rte. 27 to Exit Washington Blvd., Arlington, VA.	3 4 3 3 2	921	48	40.0	-	-	915	1000	310	790	1310	310	3015	-	4.0 G=+3.	1450

** Movement Identification



Chapter 4

MODEL FORMULATION

The decision to formulate a weaving analysis model that would be relatively simple and easy to use and, if feasible, would closely follow the already familiar procedure established in Chapter 7 of the 1965 HCM, was made and the model preliminarily tested as reported by J. E. Leisch in the March 1979 issue of the ITE Journal. As noted in the introduction, the same objective was to be pursued in this study to extend and complete the earlier work. The major elements of the basic framework which constituted the 1965 HCM procedure, although presented in two separate parts--the weaving element and the width element--still provided the structure upon which to build a more refined model.

In accepting the rationale used in the procedure for analyzing weaving area operations first introduced in the 1950 HCM, it was necessary to examine and test the various elements of the procedure to determine if the general formulation was sufficiently sound and could be refined to produce a model that would closely predict actual operations and serve as a basis for design and improvement of freeway facilities. In a critical analysis of the 1965 HCM procedure, the various shortcomings, problems, and certain inaccuracies became evident. Identifying these along with examination of new data and recent research, revealed that the basic framework could be utilized and adjusted to a more refined and explicit model.

The major shortcomings and requirements revealed that: weaving volume/speed/length relationships needed adjustment (the BPR data base was already oriented toward this process; some confidence in the position of the out-of-realm of weaving curve had to be demonstrated; weaving intensity factor (k) as a key element of the process necessitated a positive means of determination and correction of values; the separate parts in the 1965 HCM process for determining weaving requirements and width requirements indicated the need for a continuum which could be accomplished through the process of k factor determination; the level of service measures had to be set out in a direct and simple manner to be related to but not necessarily identical to uninterrupted flow conditions on the freeway; the basic model could be made fully workable through a mechanism by which the data were reduced to simulate operationally balanced sections, where the weaving element and nonweaving element of traffic operated at the same level of service; the model could then be augmented to handle operationally imbalanced conditions to broaden its application by utilizing a composite service volume (SV) which enabled the use of derived k values and determination of N for the overall weaving section; the composite speed of the weaving section (S) and its relationship to the speed of weaving (S_w) would finally provide an important adjunct in the overall process.

This analysis and preliminary testing of the various steps described permitted the formulation of the basic structure for the weaving model as shown in Figure 6. Only the major elements are shown which provide a continuum in the process. The model is not expressed as an equation or a series of equations, but as steps which are individually developed and tied together into one continuous process. The sections of the report which follow develop each component of the model for which individual statistical analyses are carried out and equations, as appropriate, are developed. Because of limited data and the need to segment some of the data in the process of development, it was recognized at the outset that a statistical approach, coupled with rational formulations and analytical modeling, was essential to achieve the results of the process presented, and to broaden the scope of its application.

The developmental aspects are fully covered in the report, utilizing simplified procedures and limiting the number of variables where feasible. Greater sophistication in the analysis and development of material could have been attempted but with considerable complication and questionable practicality.

LEVEL OF SERVICE DETERMINATION FOR WEAVING SECTION ELEMENTS

→

WEAVING TRAFFIC

$S_w \propto (V_w \text{ vs. } L)$

OR WEAVE $LOS = f(V_w \,\&\, L)$

↓

WEAVING INTENSITY FACTOR

K

1 — 3 ONE-SIDED

1 — 6 TWO-SIDED

↓

COMPOSITE WEAVING SECTION

$LOS = f(SV)$ AND

$N = [V + (k-1) W_2] \div SV$

↓

BASIC MODEL

SPEED RELATION

$S_w \approx S$

OPERATIONALLY BALANCED WEAVING SECTION

↓

MODIFIED MODEL

SPEED RELATION

$S_w \lesssim S$

OPERATIONALLY IMBALANCED WEAVING SECTION

DEFINITION OF TERMS:

S_w	=	AVERAGE RUNNING SPEED OF WEAVING TRAFFIC	mph
V_w	=	WEAVING VOLUME	pcph
L	=	LENGTH OF WEAVING SECTION	feet
K	=	WEAVING INTENSITY FACTOR	
LOS	=	LEVEL OF SERVICE (VARIES A THROUGH E)	
SV	=	SERVICE VOLUME	pcphpl
N	=	NUMBER OF TOTAL LANES IN WEAVING SECTION	lanes
V	=	VOLUME OF TRAFFIC IN WEAVING SECTION, TOTAL	pcph
W_2	=	VOLUME OF SMALLER WEAVING MOVEMENT	pcph
S	=	AVERAGE RUNNING SPEED, COMPOSITE OF ALL TRAFFIC WITHIN WEAVING SECTION	mph

Figure 6. WEAVING MODEL FORMULATION

Chapter 5

LEVEL OF SERVICE MEASURES

The analysis in the planning, design and operation of weaving sections, as for other elements of the highway, is dependent upon and must be correlated with the level of service measures. The definition of levels of service for weaving sections, with its application, is a key element of measurement process and part of the basis in establishing a workable procedure.

Levels of service of weaving sections embody the freeway and the connecting ramps which jointly make up the weaving section. The consideration of levels of service and resulting operations on weaving sections, in a broad sense, are similar to situations of ramp junctions--entrances and exits--either as isolated cases or in combinations along the freeway. Both, for weaving (a special configuration of ramps sequence) and for other, less operationally stringent ramp configurations, the levels of service are considered separately for the freeway and for the ramp associated movements.

An attempt is made to maintain, to extent feasible, a constant level of service on the freeway, with ramps operating at their own level of service, preferably equal to or at a level higher than specified for the freeway. 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 experienced prior to the diverging or merging junction. This approach is the basis for design and operation of weaving sections.

Since the beginning of formalized method of evaluating operational quality of weaving sections, which first appeared in the 1950 HCM, the speed of traffic and the service volume (average traffic accommodated per lane within the section, referred to as "design" capacity per lane at that time) were used in combination as the method of measurement. Speed and service volume also were utilized in the 1965 HCM, as well as in later studies, PINY (1973) and Leisch (1979).

The levels of service for weaving sections, including an indication of speeds involved (which are deduced and selected further on) are expressed first in general terms; these are believed to be representative of current applications, and relevant to this project. The following definitions pertain to one-sided sections, relating to the weaving element of the section, as well as to the overall, composite operation of all traffic on the section, for the condition assuming operationally balanced sections. (The descriptions are slightly modified for operationally imbalanced sections where weaving and nonweaving traffic are intermixed; definitions are also slightly altered for two-sided weaving sections. These are clarified later on.)

Level A. Operations are indicative of open highway conditions, with weaving having little, if any, effect on stream flow. Average weaving speeds of 50 mph can be readily maintained, with freeway or nonweaving flows operating upward of 50-55 mph.

Level B. The effect of weaving on freeway flow is relatively minor. Weaving movements are accomplished at average running speeds of about 45 mph. Some speed variations may occur, but average speeds of freeway traffic of 45-50 mph would be expected to prevail for the most part.

Level C. Although overall operations are still within a stable mode of flow, the speeds and maneuverability of weaving movements are characterized by some restrictions in maintaining uniform flow. Weaving vehicles would maintain average running speeds of about 40 mph, although speeds may vary between individual vehicles and short periods within the hour. Through movements of freeway traffic are apt to be more sensitive to possible influence from weaving traffic than at higher levels of service; maintenance of average speeds of 40-45 mph of the major flow, however, generally would be expected.

Level D. With stable flow surpassed and tendency of speeds between individual vehicles to vary, weaving vehicles are expected to be limited to an average speed of 35 mph. Operation would be subject to restrictions in maneuverability and noticeable slowdowns in both weaving and nonweaving traffic, with the overall section operating at about the same or slightly higher average speed as weaving traffic.

Level E. This level of operation is indicative of the condition approaching or reaching maximum weaving volume that can be accommodated. Variation in speeds with periods of slow operation, including momentary stopping of weaving vehicles may be anticipated. Average speeds of weaving traffic of 25 to 30 mph would be representative along with overall speeds of similar magnitude of around 30 mph.

The definitions are presented for the purpose of providing a qualitative measure of levels of service of operationally balanced sections of the more common one-sided variety. (Elaboration with regard to two-sided sections is covered later on.) Since both speeds and service volumes are utilized to measure levels of service on weaving sections, specific values for each must be established in order to provide a uniform and appropriate means of measurement. Due to the nature and detail in which weaving area studies had been made, a set of average running speeds as a primary indicator for evaluating levels of service of weaving movements was to be appropriately established. Also to be in consonance with the manner in which operations on other elements of the freeway are measured, a set of lane service volumes for each level of service in evaluating the freeway traffic as well as the overall composite weaving section operations had to be specified.

Precedents have been established (some recently and in process) of logical speeds on weaving sections for both the weaving element and associated freeway traffic. In setting the criteria for service level values, these are reviewed and serve as a basis for appropriate selection of individual values.

Speed Element

Previous studies and evaluations of quality of operation have been related to speed. The 1965 HCM and research efforts since early 1970's provide the necessary insights. The following is a summary of values to be examined.

Consideration of speeds in Tables 4 and 5, some of which are under development, coupled with intensive study and reevaluation of the BPR weaving area studies and some of the more recent investigations, provided insights to levels of service. Also the author's personal evaluations, since the inception of the Interstate System and its recent operational (uncontrolled) studies, have shown a definitive direction toward establishment of performance criteria for weaving sections summarized in this research effort.

To be in concert with the many speed values presented in Tables 4 and 5--the proposed levels of service measures on this project, which in essence demonstrate a logic and a degree of harmony of previous efforts, are summarized in Table 6. This performance criteria with respect to speed is recommended as part of the procedure providing a direct input to analyses of weaving sections. Also associated with the speed of weaving is a lane service volume, serving as a dependent variable; this aspect is discussed later on in the chapter.

As a side comment, it may be noted that the speed listed under the column of "freeway proper" (approaching weaving section) in Table 6 is a uniformly decreasing speed by 5-mph increments per each change of level of service, indicating a steeper curve for speed reduction with level of service, compared with freeway speeds for open highway conditions currently noted, as in the last two columns of Table 4. A logical explanation and as supported by field studies shows this to be the case due to apparent more rapid degeneration of speed within the more turbulent weaving section than on the open freeway section.

It may be further noted that the speed measure of weaving traffic, for one-sided weaving sections as a level of service control, is 5-mph below the freeway (nonweaving) speed. This is generally indicative of the condition where there is little or no geometric constraint upon entering and exiting traffic and the weaving section is operationally balanced, or nearly so; i.e., levels of service of weaving and nonweaving traffic are the same, or nearly so.

With regard to two-sided weaving sections, since the freeway (through) movement is also part of the weaving movement, the speed of freeway traffic and weaving traffic essentially would be the same. Experience shows that for properly designed and well-balanced weaving sections, that the speed of combined weaving and freeway traffic coincides. Weaving area operations studies further indicate that the speed of weaving has a tendency to match the level of speed of "freeway proper" traffic, as indicated in the last column of Table 6.

TABLE 4

SUMMARY OF VARIOUS PERFORMANCE CRITERIA
FOR BASIC FREEWAY SECTIONS

AVERAGE RUNNING SPEED ON FREEWAYS--MPH *

Level of Service	Highway Capacity Manual 1965	Capacity Analysis Techniques--Fwys. FHWA-RD-74-24, 1974	Transp. Research Circular 212 1980	New Highway Capacity Manual Draft--1983
A	55 **	55 **	50	57
B	50	50	50	55
C	45	45	48	50
D	35-40	35-40	40	40
E	25-30	25-30	30	30

* Single number indicates $\overline{>}$; double number, normally shows range.

** Approximate conversion from "Operating Speed".

Note: Values apply to 70-mph design speed freeways.

Table 5

SUMMARY OF VARIOUS PERFORMANCE CRITERIA
FOR WEAVING SECTIONS

AVERAGE RUNNING SPEED OF WEAVING TRAFFIC--MPH *

Level of Service	Highway Capacity Manual 1965	Weaving Area Study--PINY NCHRP 3-15, 1973	Techniques for Design of Weaving Sections ITE Journal, 1979	Transportation Research Circular 212 1980
A	45-50 **	60	† 50 (55)	45-50 ≠
B	40-45	55	45 (50)	40-45
C	35-40	50	40 (45)	35-40
D	30-35	33-38	35 (40)	30-35
E	25-30	20-30	25-30 (30)	25-30

* Single number usually indicates "upper" (beginning or better) limit for LOS.

† First row of numbers for one-sided; second row for two-sided sections.

** Approximate conversion from operating speed--deduced through "operational quality."

≠ Range for weaving and nonweaving traffic when both at approximate same LOS.

Note: Values based on 70-mph design speed highways; also generally considered applicable to 60-mph design speed highways.

TABLE 6

PERFORMANCE CRITERIA
FOR WEAVING SECTIONS ON FREEWAY

SPEED CONTROLS FOR LEVELS OF SERVICE

AVERAGE RUNNING SPEED--MPH*

LEVEL OF SERVICE	FREEWAY PROPER	ONE-SIDED WEAVING SECTION	TWO-SIDED WEAVING SECTION
	THRU MOVEMENT, APPROACHING AND, FOLLOWING RECOVERY, LEAVING WEAVING SECTION	WEAVING TRAFFIC ONLY	WEAVING & MAJOR ROUTE TRAFFIC
A	55	50	55
B	50	45	50
C	45	40	45
D	40	35	40
E	30	25-30	30

* EITHER MEASURED OR INDICATIVE OF SPACE MEAN SPEED (SMS)

Service Volume Element

As part of the weaving model, an essential element is the application of the service volumes as a primary measure of the overall weaving section. In the past as well as in some of the current research and applications, there has been a tendency to use the levels of service per lane volumes normally associated with freeway proper traffic to be applied to weaving sections. Also, since merging and diverging traffic is an important aspect of weaving area operations, service volumes associated with ramp entrances and exits should be considered in playing a part in the determination of weaving section levels of service. Both freeway and ramp junction lane service volumes are considered and reviewed here to establish and justify levels of service measures for weaving sections, as summarized in Tables 7 and 8.

Another aspect in calculating levels of service of various facilities, the need to account for fluctuations of traffic within the hourly volume has been considered essential in recent years to account for the higher rates of flow generated during the shorter periods within the hour (which have a significant impact upon operations and provide a more worthwhile measure of quality of operation). The method by which such expanded "hourly rate of flow" is determined is through the application of the peak-hour factor (PHF). Normally, 5-, 6- or 15-minute highest periods of flow within the peak-hour are utilized for this purpose. Although the shorter intervals have been used in the past for freeway facilities, the 15-minute period has been designated in the development of the new Highway Capacity Manual as the prescribed, consistent period for all types of facilities including freeways. Accordingly, the 15-minute basic measurement is utilized in this research project for weaving sections and associated freeways.

A PHF is determined by the ratio of the full peak-hour volume divided by 4 times the highest 15-minute volume within the hour. The PHF is always less than unity and approaches 1.00 when flow during the entire hour is uniformly consistent (full) throughout the hour which tends to occur at maximum hourly discharge, or "capacity."

To utilize the peak-hour factor and account for the "hourly rate of flow" for design or traffic operation it is essential that the service volume representative of the full hour is multiplied by the PHF in order to reflect the higher rate of flow to be accounted for in evaluation of operation and design.

The PHF is normally applied separately to the service volume in various capacity analyses, on the basis that the PHF can either be estimated within some degree of accuracy or actually measured from traffic counts. In the case of weaving sections the complexity of operation, as reflected by the degree of operational balance with respect to intermix of weaving and non-weaving movements, makes it difficult to identify a specific PHF. Analysis of data with respect to peak-hour factors on weaving sections (values reported in Table 1 based on 6-minute periods) has indicated an erratic pattern as shown in Figure 7. Moreover, in examining separate PHF's for the separate elements of weaving and nonweaving traffic produces further irregularities.

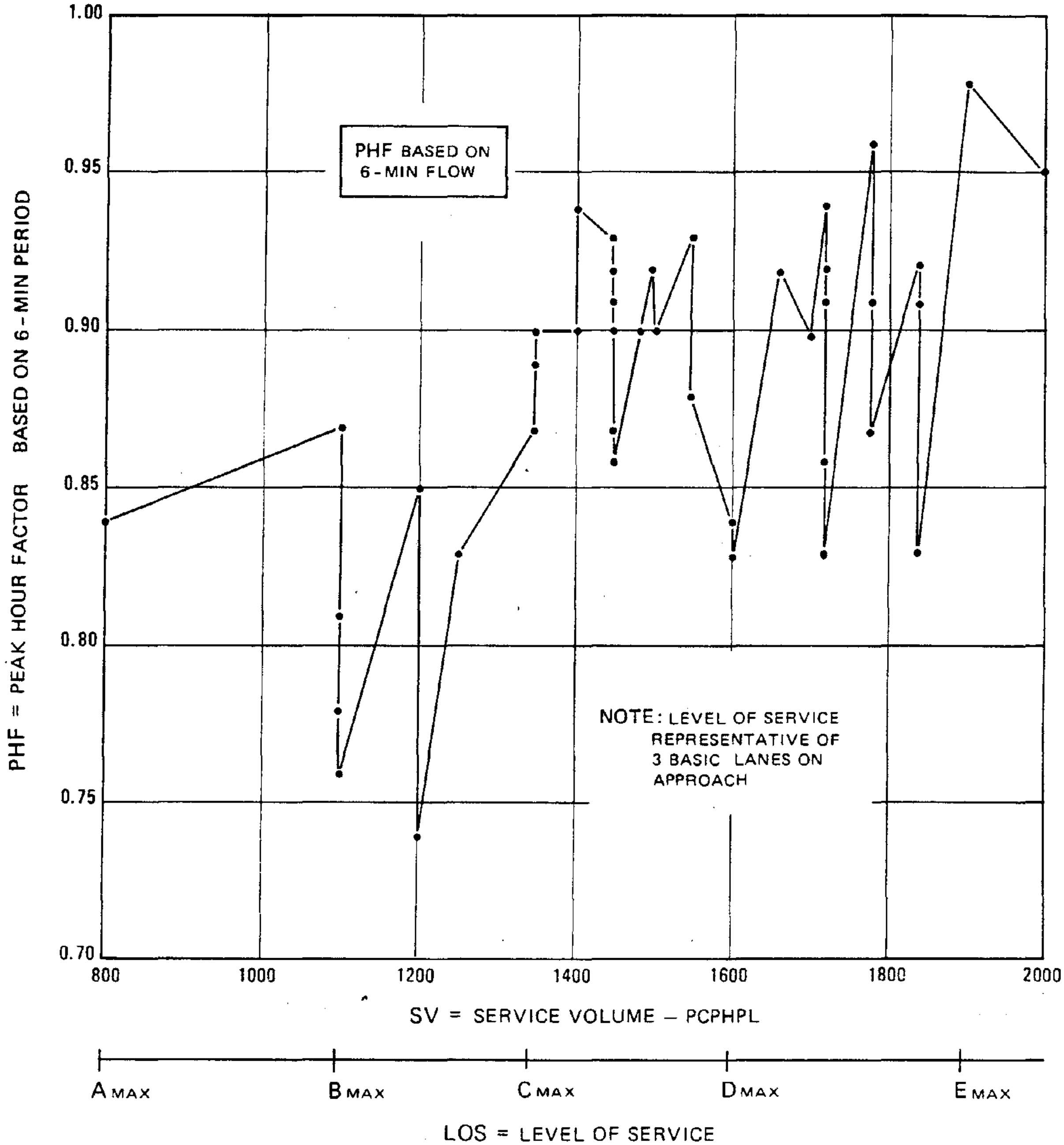


Figure 7. COMPOSITE PEAK HOUR FACTOR ON WEAVING SECTIONS PROVIDED BY BPR DATA BASE – PREDICATED ON 6-MIN, FLOW

The PHF on any facility is affected externally by city size, trip lengths, system effects, and pattern of trip generations; but, despite its variation during the lower levels of service it is modified in a definite manner by the relative amount of traffic and facility of movement on the freeway. Taking advantage of this phenomenon it is reasonable to predict representative PHF's associated with service levels C, D and E. Previous observations on freeways show that the PHF for level of service E (at capacity) approaches 1.00 and for level of service C values in the range of 0.80 to 0.87 are representative.

An attempt was made to find PHF relationships specifically for weaving sections, particularly with respect to the 15-minute rather than the 6-minute period. This was accomplished with interpolation by using the data from Appendix B of the 1965 HCM of the same 1963 BPR data base as in Table 1 but with selected observations of more detailed volume data breakdown. The computed 15-minute PHF's for the specific weaving sections are plotted in Figure 8, with regression indicating more consistency than for 6-minute periods.

The results of Figure 8 seem to provide some justification of using built-in PHF's for service volumes in evaluation of levels of service. However, because of flow rate differences within the hour between weaving and non-weaving traffic and other inconsistencies, values toward the lower limit of standard error in the regression of Figure 8 have been selected. Further reason to use a general PHF of lower value is that the service volumes normally utilized in the analysis of weaving sections are compatible with

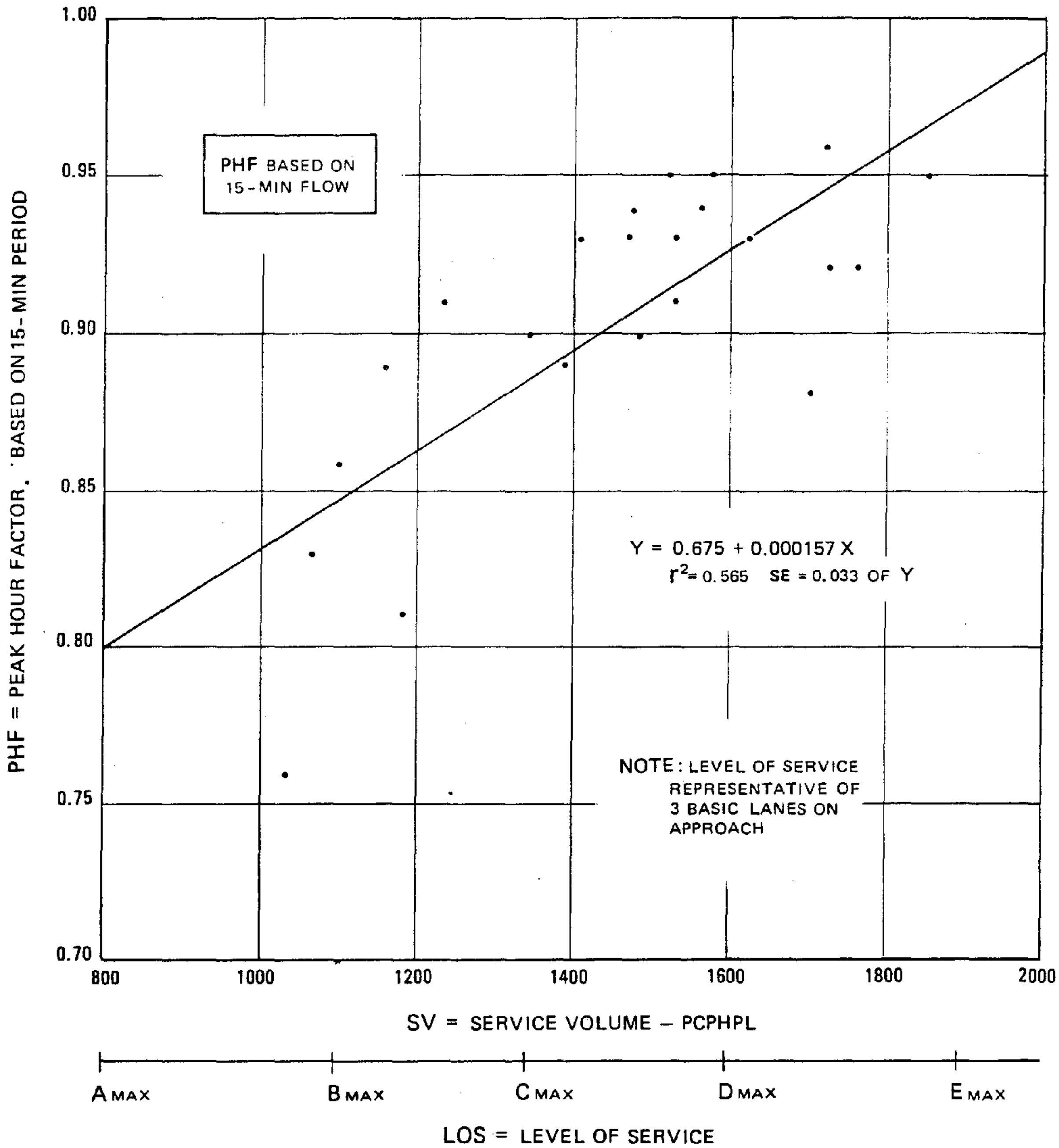


Figure 8. **COMPOSITE PEAK HOUR FACTOR ON WEAVING SECTIONS DERIVED FROM BPR DATA BASE – PREDICATED ON 15-MIN, FLOW**

70-mph design speed highways, yet some facilities may be classified at 60-mph for which service volumes are inherently lower. Considering this feature as well, and making allowance for some factor of safety, values are taken to be 0.85, 0.90 and 0.95 for service levels C, D and E, respectively. These factors are reflected in the comparative values of Tables 7 and 8, and are incorporated in the level of service criteria for this project in Table 9.

The reasonable consistency of service volumes in Tables 7 and 8 from several sources and the consolidation of these to a specific set of service volumes in Table 9 provide the means for evaluation of operation and design of weaving sections.

Table 7

SUMMARY OF VARIOUS PREFORMANCE CRITERIA
FOR BASIC FREEWAY SECTIONS

SERVICE VOLUMES ON FREEWAY PROPER--PCPHPL *

Level of Service	Highway Capacity Manual 1965		Transportation Research Circular 212 1980		New Highway Capacity Manual Draft - 1983	
	Peak-Hour Factor †		Peak-Hour Factor †		Peak-Hour Factor †	
	1.00	Variable	1.00	Variable	1.00	Variable
A	800	800	800	800	680	680
B	1160	1160	1300	1300	1160	1160
C	1600	1360	1700	1440	1660	1410
D	1800	1620	1925	1730	1920 1800 §	1730 1620
E	2000	1900	2000	1900	2000	1900

* Average values per lane for 3 lanes in one direction; values less for 2 lanes and more for 4.

† Representative PHF, commensurate with level of service, is incorporated ("built-in") for the basic SV Value: .85 for LOS C, .90 for LOS D, and .95 for LOS E. in the second row of figures of each column.

§ Revised value being considered for final draft.

Note: Values based on 70-mph freeways.

Table 8

SUMMARY OF VARIOUS PERFORMANCE CRITERIA
RAMP ENTRANCES AND EXITS ON FREEWAYS

RAMP SERVICE VOLUMES--PCPHPL *

Level of Service	Highway Capacity Manual 1965		Capacity Analysis Techniques--Freeways FHWA-RD-74-24, 1974		Transportation Research Circular 212 1980	
	Peak-Hour Factor †		Peak-Hour Factor †		Peak-Hour Factor †	
	1.00	Variable	1.00	Variable	1.00	Variable
A	1050	1050	1050	1050	780	780
B	1250	1250	1250	1250	1250	1250
C	1750	1490	1750	1450	1600	1350
D	1850	1660	1850	1650	1850	1570
E	2000	1900	2000	1850	2000	1900

* Average values per lane for 3-lane freeway directional lanes--each service volume is average of a merging and diverging movement (with merging 1000 pcphpl smaller than diverging in each case).

† Representative PHF is "built-in" to the base SV Value, using factors of 0.83 to 0.95.

Note: Pertains to junctions with 2-, 3- and 4-lane freeway lanes; applicable to 70-mph design speed freeways; also to 60- and 50-mph speeds.

TABLE 9

PERFORMANCE CRITERIA
FOR WEAVING SECTIONS ON FREEWAYS

LANE SERVICE VOLUMES

APPLICABLE TO ALL TRAFFIC--WEAVING AND NONWEAVING

LEVEL OF SERVICE	SV--MAXIMUM SERVICE VOLUME (AT INDICATED LEVEL OF SERVICE)--PCPHPL* 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

* PREDICATED ON UNIFORM FLOW 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.

Combined Level of Service Criteria

The level of service criteria presented in Tables 6 and 9 are shown jointly and graphically displayed in Figure 9; the graph serves as a convenient reference in facilitating further analysis on the project.

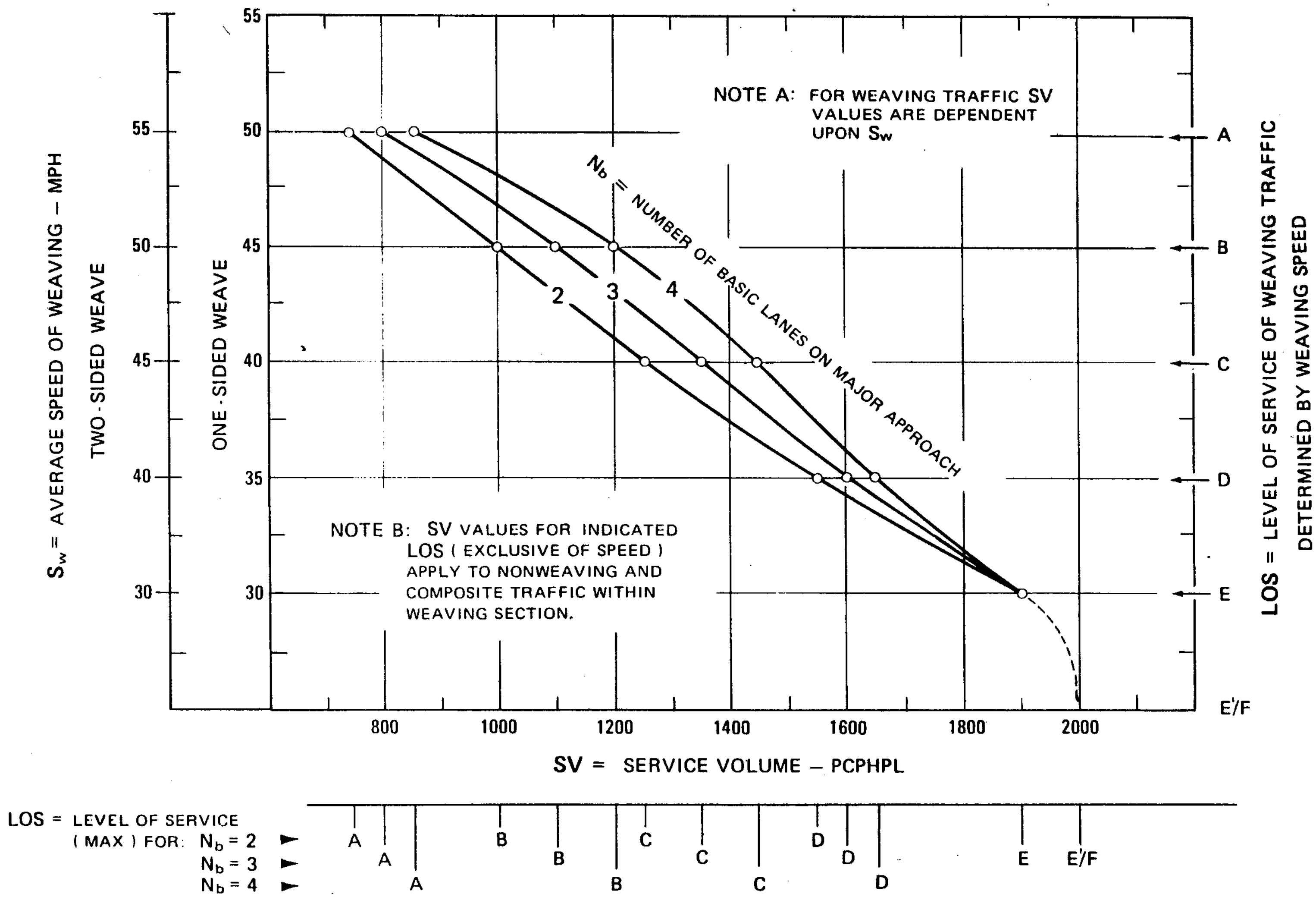


Figure 9. **LEVEL OF SERVICE CRITERIA FOR WEAVING SECTIONS AVERAGE SPEED AND SERVICE VOLUME RELATIONSHIP**

Chapter 6

DEVELOPMENT OF WEAVING MODEL ELEMENTS

The major elements of the model were detailed by statistical analysis to the extent feasible from information available in the overall data base. In some instances, due to a relatively large number of variables involved, the required quantity of data was in effect reduced or "thinned out," with a tendency in certain cases to weaken the statistical process; however, as stated at the inception of the project, those portions with limited data were to be developed by rational formulations in consonance with statistical procedures to broaden or complete the process. The total effort was structured to produce a homogeneous result utilizing both techniques.

The approach here, was not to "discover" a weaving analysis procedure which may emerge from statistical analyses but to utilize statistical procedures as an assist or adjunct along with analytical engineering processes to verify and refine a formulated model, deduced or postulated from operational observations and design experience.

Weaving Volume/Length/Speed Relations

The weaving model, which relies heavily on the data of the weaving operation studies, has to do with the interrelationship of the weaving volume with the length of weaving section and the resulting speeds. The hourly data as compiled in Tables 1, 2, and 3, along with supplementary information from Table A-1 in the Appendix, were found to be specifically oriented toward determining the relationship. A total of 42 experiments and 57 data points were utilized for this purpose. Data actually employed are summarized in Tables 13 and 14.

For convenience of analysis and design, the coordination of the weaving volume with the length of weaving, in terms of 5-mph increments of average speed of weaving movement, was taken to be a logical measure which also corresponds to level of service speed criteria set out in Table 6.

To achieve a relationship among these variables, regression analyses were performed, using 5-mph bands of average running speed of weaving traffic; thus, each regression line was represented by a 5-mph weaving speed. The groups of measured speeds as shown in Table 10 were utilized to represent each 5-mph speed line.

Table 10

SPEED GROUPS USED IN REGRESSION ANALYSES TO ESTABLISH WEAVING SPEED/VOLUME/LENGTH RELATIONS

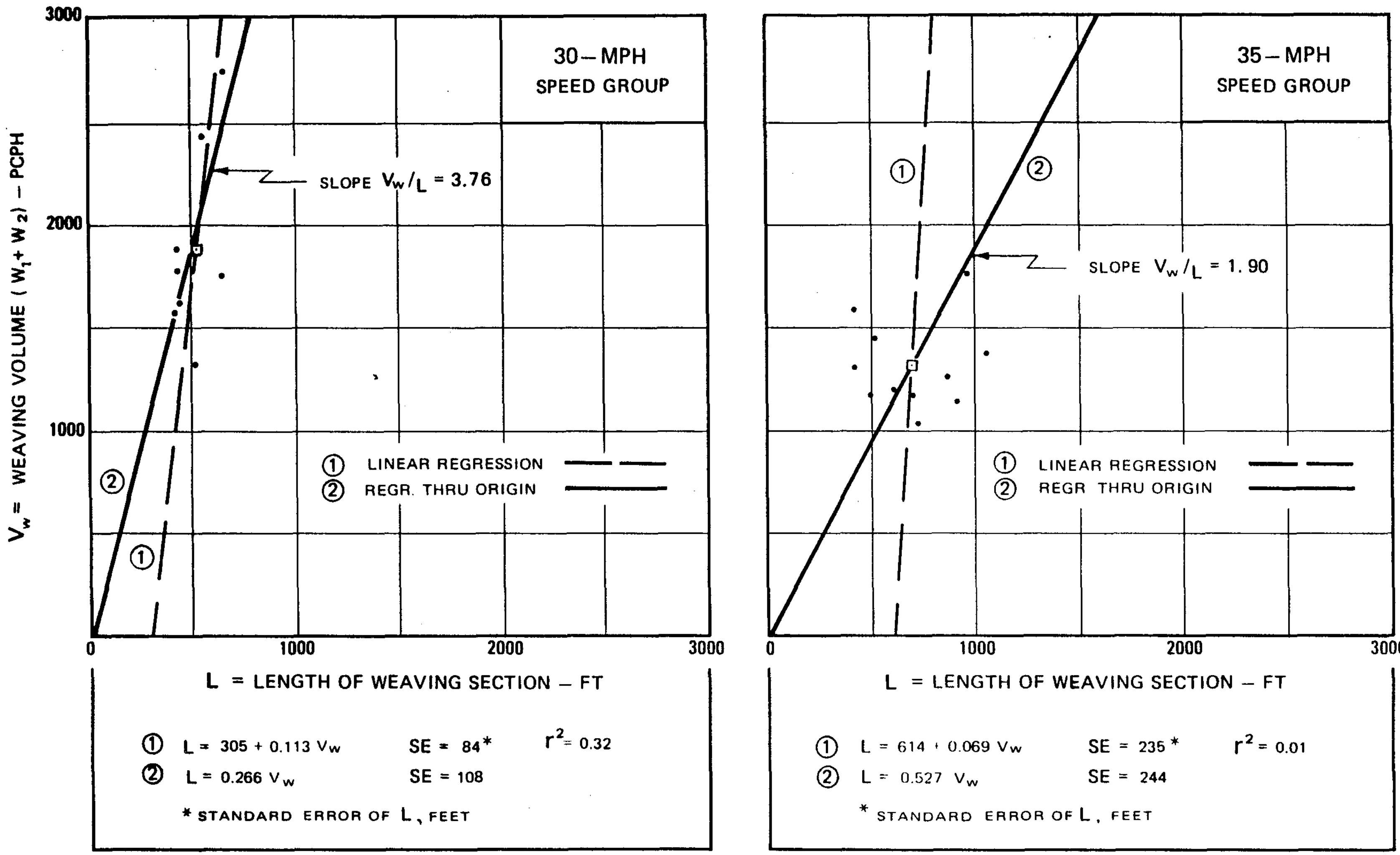
Representative Speed* of Weaving Traffic for Regression MPH	Range of Measured Speeds* of Weaving Traffic from Data Base MPH
25	22.5 - 27.4
30	27.5 - 32.4
35	32.5 - 37.4
40	37.5 - 42.4
45	42.5 - 47.4
50	$\lesssim$ 47.5

* Average Running Speed, derived from Space Mean Speed.

Regression was performed for weaving speeds of 25 and 30, 35, 40, 45, and 50-mph for weaving volume, V_W, vs. length of weaving section, L. Two types of relations were calculated--a least-squares line which furnished the statistical characteristics with respect to the available data points, and a regression line through the origin (V_W = 0, L = 0).

Actually, in the latter case, should an exit immediately follow an entrance, there would be some short distance between the two; but, because this would never be a "real" case, the theoretical distance of L = 0 was considered more direct and appropriate to use with V_W = 0 as the origin point for regression. Another consideration, in passing a regression line through the origin, is that preferably there should be some observations near the origin to ascertain the shape of the line; however, since such points on weaving sections of freeways are not available nor feasible to obtain, the rationale employed clearly points to the following procedure.

The condition is apparent that when practically no length is available for weaving, no weaving movement can take place; that is, the speed line which indicates the relationship between V_W and L, theoretically and from a practical standpoint, passes through the origin. Accordingly, a set of regression lines, as shown in Figures 10-12 for one-sided, and Figure 23 for two-sided weaving sections, were developed through the origin. These were taken to be indicative of the relationship of weaving volume to length of weaving section for each 5-mph weaving speed. To achieve better conformance to the variability in the orientation of the data points, regressions were run with L as the dependent variable for the lower speeds and V_W as the dependent variable for the higher speeds. The slope of line in all cases is consistently expressed as a ratio of V_W to L. Other statistics are shown with each set of regressions on the graphs.



-A- -B-

Figure 10. **REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP**

30– AND 35-MPH SPEED GROUPS — BASED ON 5-MPH SPEED BANDS

ONE-SIDED WEAVING SECTIONS

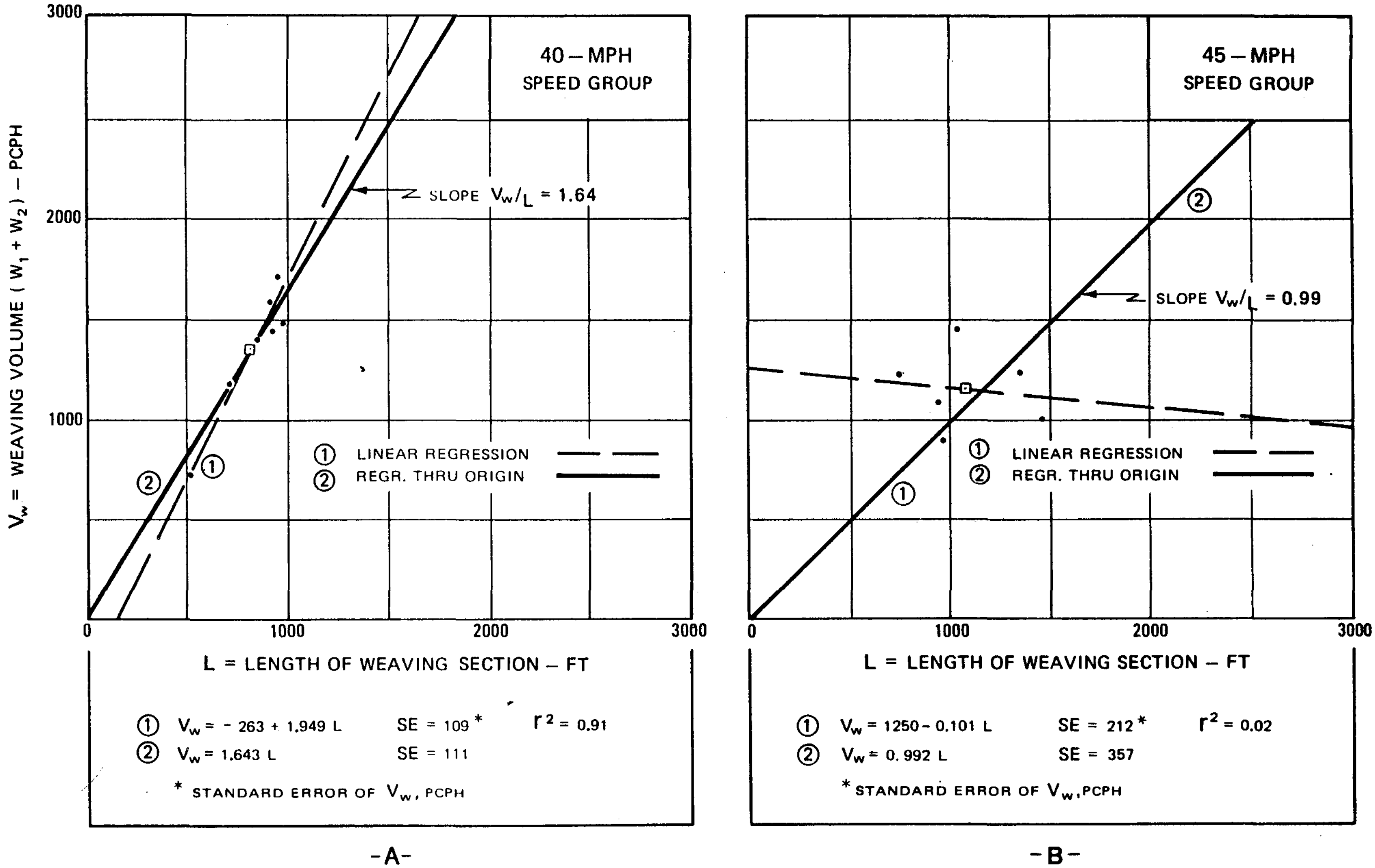
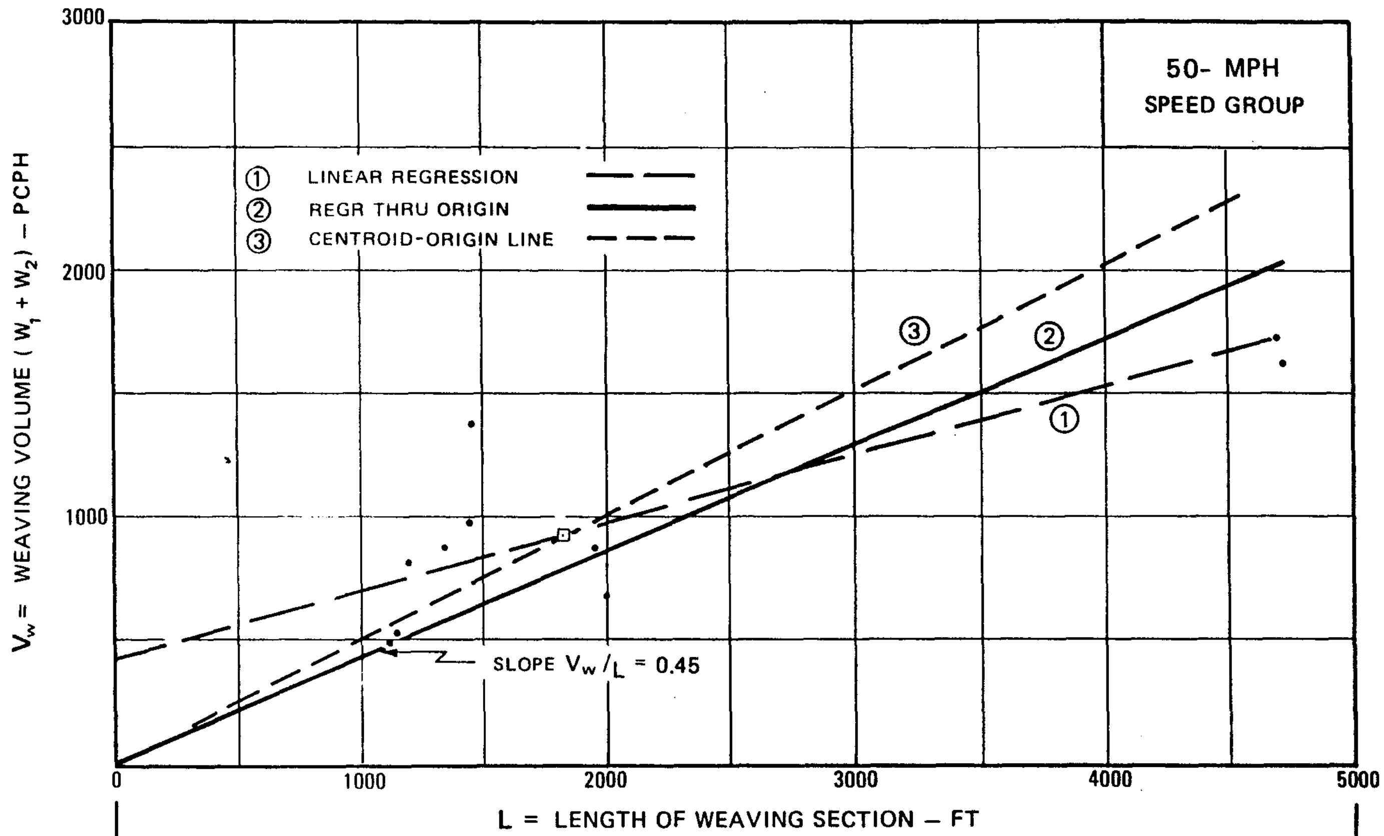


Figure 11. **REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP**

40- AND 45-MPH SPEED GROUPS — BASED ON 5-MPH SPEED BANDS

ONE-SIDED WEAVING SECTIONS



① $V_w = 423 + 0.274\ L$ SE = 279 * $r^2 = 0.58$

② $V_w = 0.447\ L$ SE = 345

③ $V_w = 0.506\ L$ SE = 370

* STANDARD ERROR OF V_w, PCPH

Figure 12. REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP
50-MPH SPEED GROUP — BASED ON 5-MPH SPEED BANDS
ONE-SIDED WEAVING SECTIONS

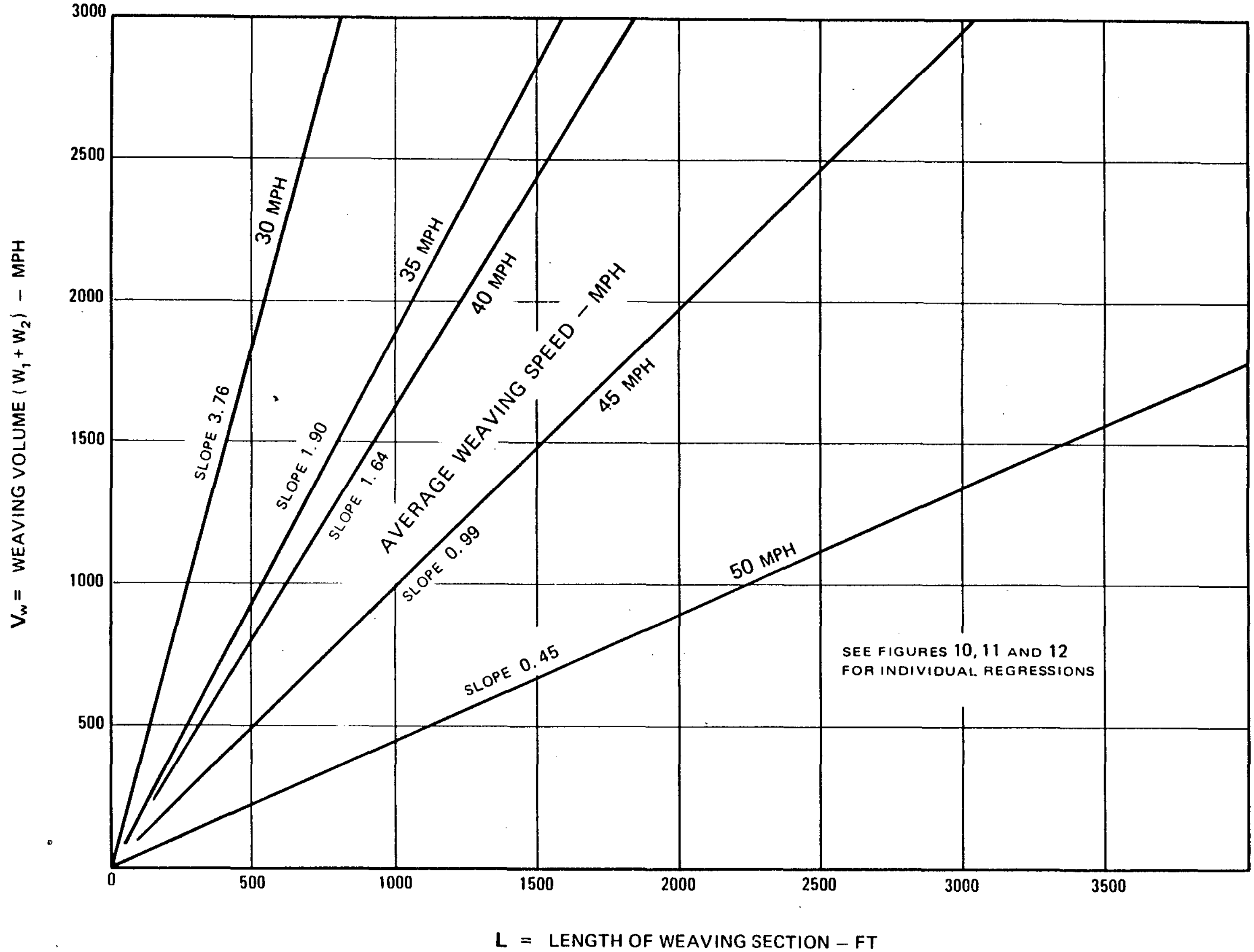


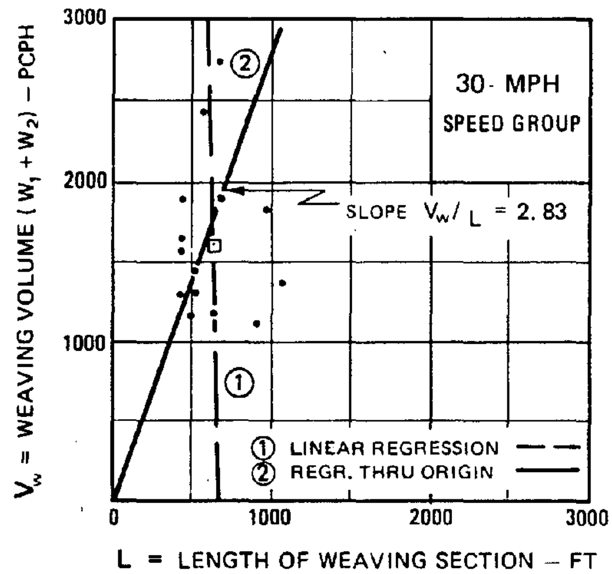
Figure 13. **COMPOSITE OF WEAVING VOLUME / LENGTH / SPEED REGRESSIONS**
BASED ON 5-MPH SPEED GROUPS OF 30 TO 50 MPH
ONE - SIDED WEAVING SECTIONS

One-Sided Sections

Regression analyses were run separately for one-sided and two-sided weaving sections. The results for the initial group of one-sided sections are diagrammed and summarized in Figures 10-12, showing the regression lines, data points, equations and related statistical elements. The actual data points used have been isolated and summarized in Table 13, listing the 40 points utilized in accordance with the speed divisions noted in Table 10. Of the five speed groups tested a favorable correlation of r^2 in the range of 0.32 to 0.91 was achieved with respect to 30-, 40-, and 50-mph data sets. The other two, for 35- and 45-mph groups, showed no correlation. However, the three that did are considered reasonably representative of the overall data set.

The linear regression lines passing through the origin for each speed and indicated slope are summarized in Figure 13. Although the trend for each speed is quite evident and some degree of progression is present with increase of speed, a more uniform dispersion or change in progression of lines would be expected with a larger data base.

To obtain a better insight to the array of curves in Figure 13, and to check further the distribution of data with respect to the speed divisions, an additional analysis was made utilizing 10-mph overlapping speed bands. Although such analysis could not be used directly to establish workable relationships, it was considered worth investigating for the purpose stated. In this case the 5-mph speed groups were selected to be representative of 10-mph speed bands. For example, the 35-mph speed line was derived from speed data band of 30 to 40 mph, the 40-mph speed line was derived from speed data band of 35 to 45 mph, etc. The results of this analysis and related statistics are shown in Figures 14 and 15.



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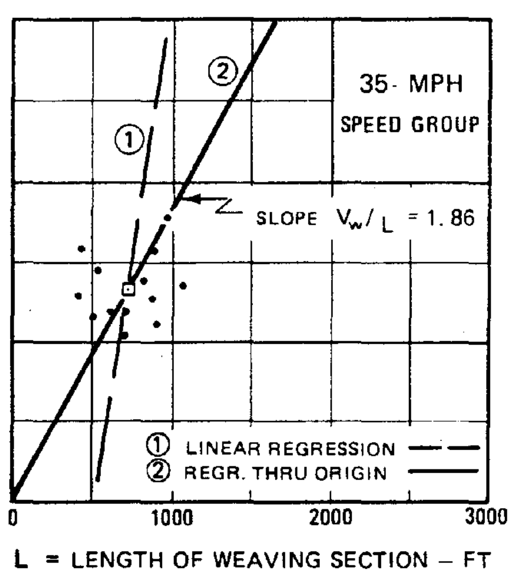

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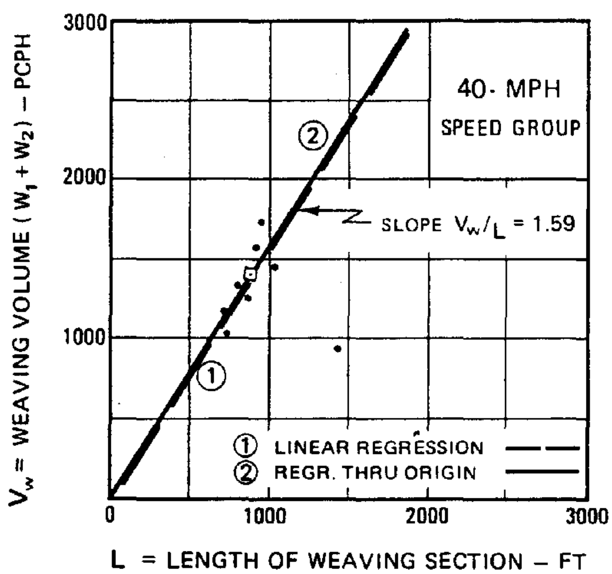


-C-

30 – MPH

① $L = 670 - 0.029\, V_w$ SE = 218* r^2= 0.0

② $L = 0.353\, V_w$ SE = 283

35 – MPH

① $L = 516 + 0.160\, V_w$ SE = 221* r^2= 0.03

② $L = 0.538\, V_w$ SE = 226

* STANDARD ERROR OF L, FEET

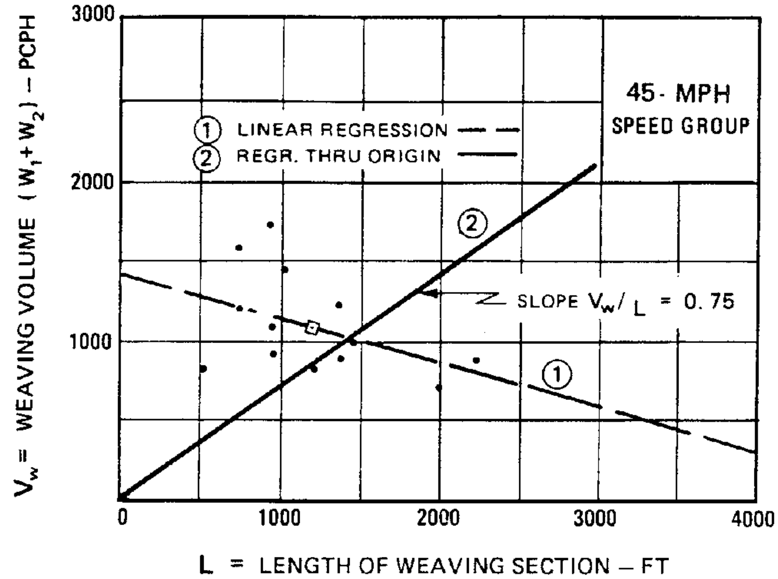
40 – MPH

① $V_w = -4.80 + 1.592\, L$ SE = 154† r^2= 0.59

② $V_w = 1.587\, L$ SE = 143

† STANDARD ERROR OF V_w, PCPH

Figure 14. **REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP**
30, 35- AND 40- MPH SPEED GROUP — BASED ON 10-MPH SPEED BANDS
ONE-SIDED WEAVING SECTIONS

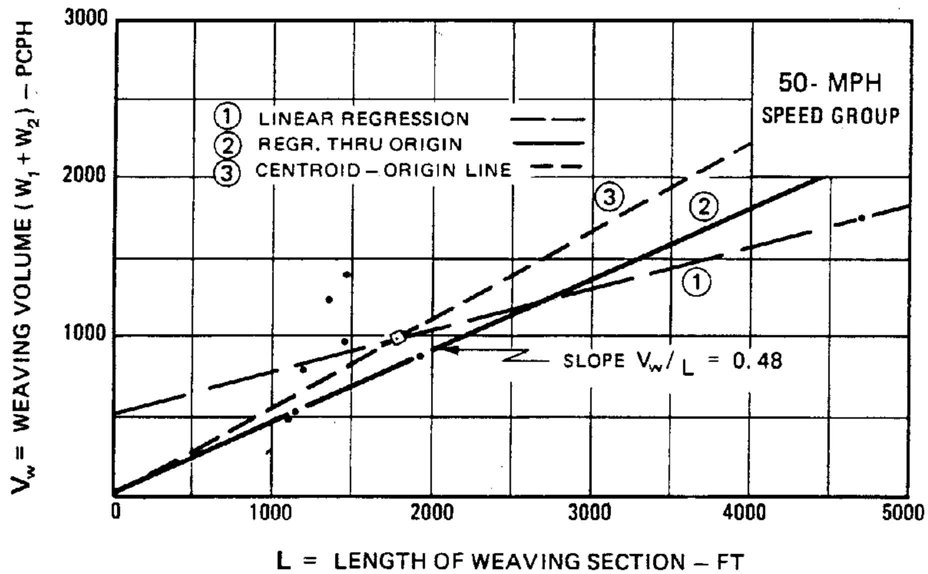


① $V_w = 1414 - 0.277\,L$ SE = 311* $r^2 = 0.17$

② $V_w = 0.748\,L$ SE = 616

* STANDARD ERROR OF V_w PCPH

– A –



① $V_w = 531 + 0.262\,L$ SE = 290* $r^2 = 0.54$

② $V_w = 0.483\,L$ SE = 399

③ $V_w = 0.564\,L$ SE = 436 * STANDARD ERROR OF V_w PCPH

– B –

Figure 15. **REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP**

45-MPH AND 50-MPH SPEED GROUP – BASED ON 10-MPH SPEED BANDS

ONE-SIDED WEAVING SECTIONS

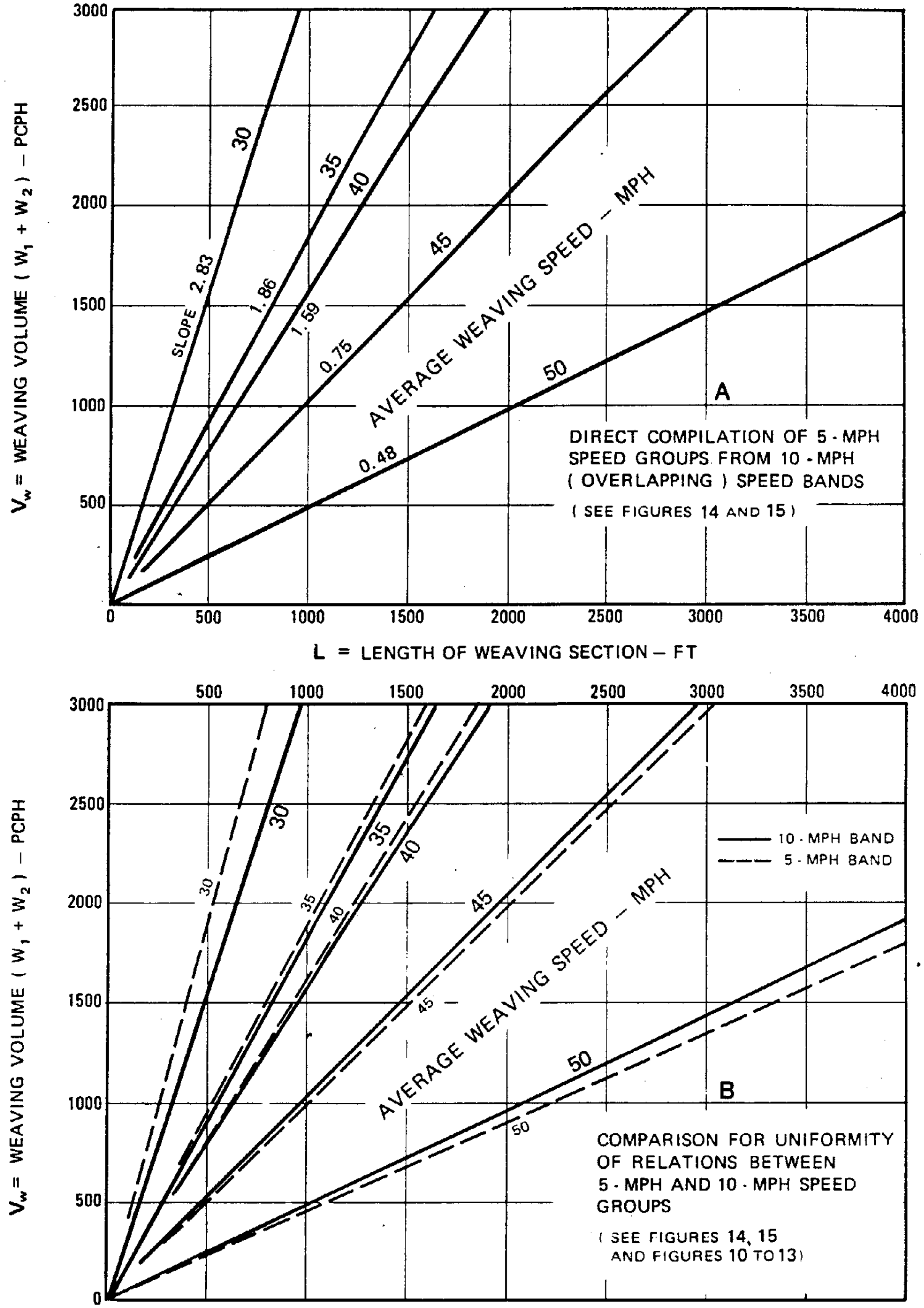


Figure 16. **COMPOSITE OF WEAVING VOLUME / LENGTH / SPEED REGRESSIONS**

BASED ON 5-MPH SPEED GROUPS DERIVED FROM 10-MPH (OVERLAPPING) SPEED BANDS

ONE-SIDED WEAVING SECTIONS

Despite the grossness in the 5-mph speed line selection and greater intermix of data points, the results are surprisingly close to the more refined 5-mph bands initially analyzed.

The summary from the 10-mph regressions are compiled in the upper part of Figure 16, and its direct comparison with results from the 5-mph bands is shown in the lower part of Figure 16. The comparisons of relations between the two is quite indicative of the uniformity of the data base despite its relatively small size. The comparison lends further confidence to the initial results summarized in Figure 13. With this accomplished and giving some credence to the applicability of results from the 10-mph speed bands, an attempt was made to achieve a more uniform distributional pattern among the speed curves.

<u>Slope Adjustment of Regression Lines.</u>--The slopes of speed regression lines summarized in Figure 13 based on the 5-mph bands, and those compiled in the upper part of Figure 16 for 10-mph bands were plotted, slope vs. speed of weaving, in Figure 17. A second level of regression, using a curvilinear form, employing both exponential and geometric equations, were fitted to the five sets of points. To account for the greater significance for the 5-mph speed bands, a double weight was attributed to these points compared with the 10-mph speed bands in performing the regressions. Good correlation was achieved, with r^2 of more than 0.90 and standard error of slope of 0.20 or less, in producing a relationship of smoothed distribution of slopes derived for a more uniform pattern to be used in the nomograph. These smoothed or refined lines of regression are replotted in Figure 18 demonstrating the regularity achieved as a result of this procedure. (The comparison of modeled speeds with actual, measured speeds are later demonstrated to show reasonable correlation and justification for this adjustment).

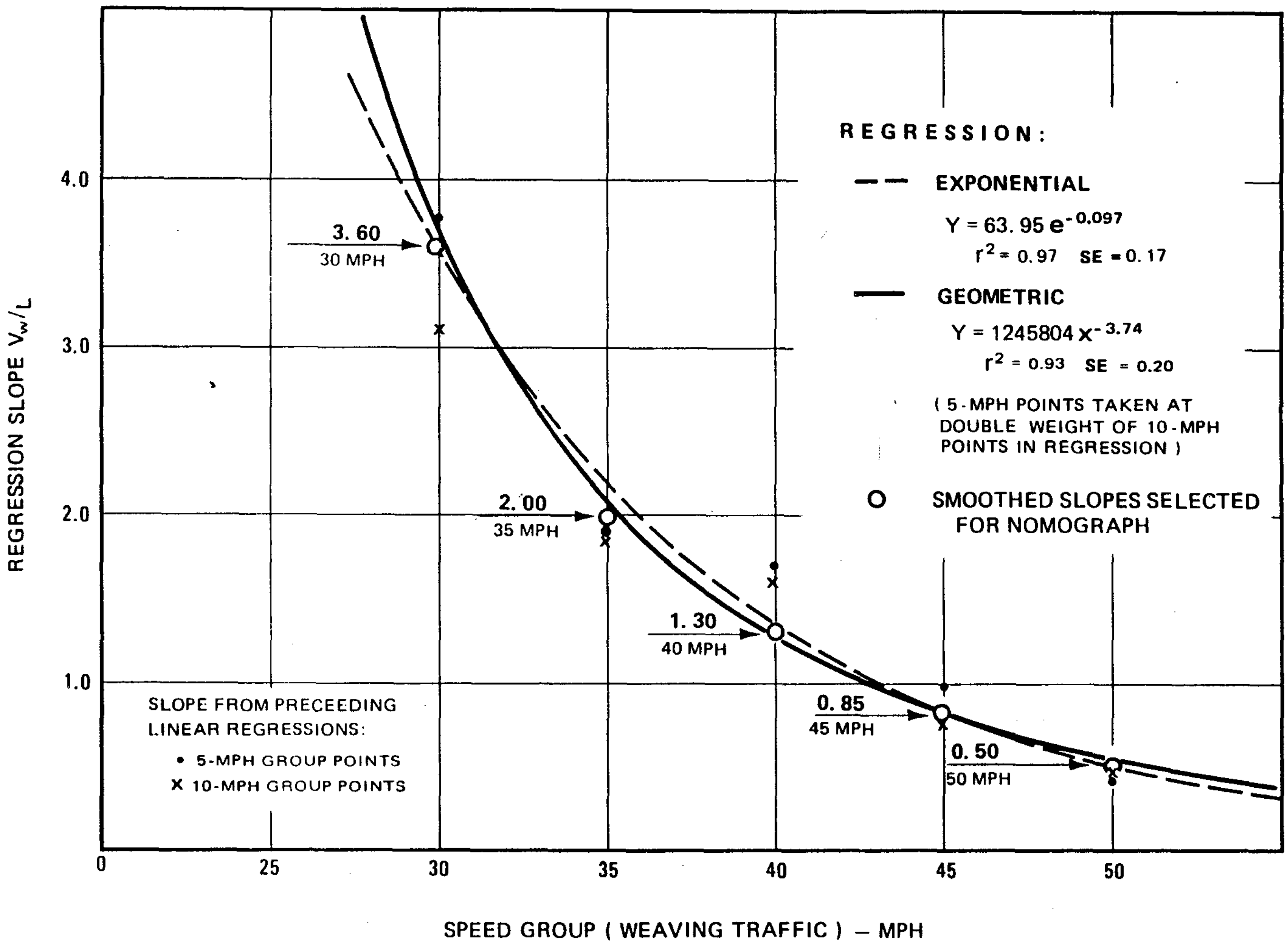


Figure 17. **SMOOTHED DISTRIBUTION OF REGRESSION SLOPES FOR WEAVING LENGTH / VOLUME / SPEED RELATIONS**

ONE-SIDED WEAVING SECTIONS

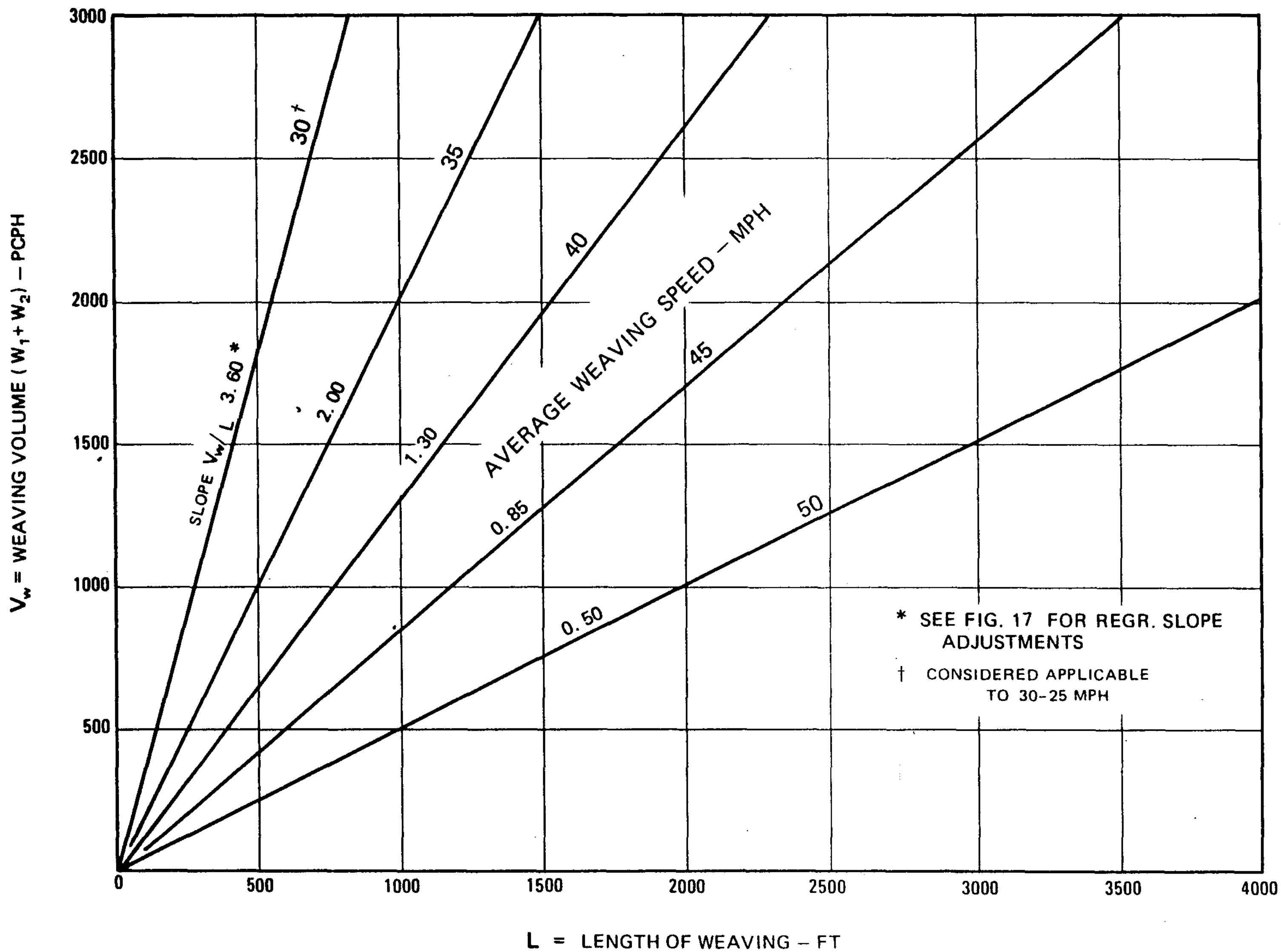


Figure 18. **REFINED LINES OF REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP**
5-MPH SPEED GROUPS OVER RANGE OF 30 TO 50 MPH
ONE-SIDED WEAVING SECTIONS

Out-of-Realm of Weaving Curve.--As part of the weaving model, the "out-of-realm" of weaving relationship between V_w and L, was considered as a fundamental element. The form and position of the curve, first introduced in the 1957 AASHO Policy on Arterial Highways in Urban Areas, based on a rational determination from limited observations, which indicated that when such volume-length combinations were exceeded it was not necessary to design the facility as a weaving section. The 1965 HCM, after some experience following the AASHO Policy adopted this relationship. Although there is no record of controlled studies having been carried out to specifically determine the position of this curve, there have been general observations of volume-length combinations to demonstrate "dissipated" weaving effects.

The relationship withstood the test of time having been utilized as a control in the development of the Interstate System; nor was it disproved by subsequent studies, including PINY's NCHRP 3-15 project. The relationship as adopted by the 1965 Highway Capacity Manual referred to it as the "out-of-realm" of weaving curve, and delineated by the following dimensions:

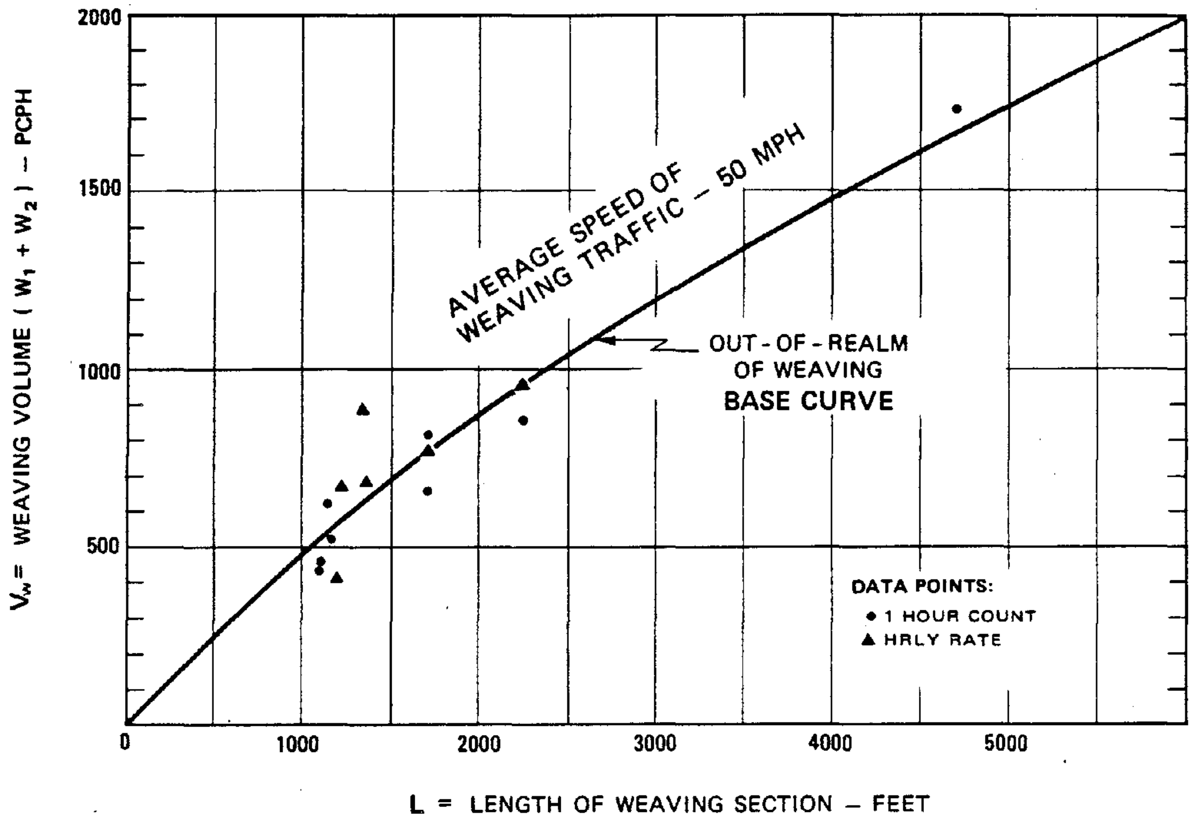
WEAVING TRAFFIC VOLUME, V_w pcph	MIN. LENGTH OF SECTION, L feet
500	1,000
1,000	2,400
1,500	4,000
2,000	6,000

The Highway Capacity Manual refers to the curve, plotted from these points, as having the characteristics where "values which fall below or to the right of the curve are considered to be out of the realm of weaving and are representative of uninterrupted-flow conditions. Values which fall above and to the left of the curve are taken to represent a weaving situation."

Although the curve is specifically delineated for purposes of analysis and design, obviously a sharp line for the condition described could not precisely divide weaving from no weaving. Actually, the curve may be considered as a line representative of a "zone" within which "weaving" is dissipated to "no weaving." There is no exact line of division, nor does there have to be one for practical purposes. The important aspect is that there is a limit, which can be closely defined, at which weaving effects are sufficiently dispersed to be approximately equivalent to a freeway uninterrupted-flow condition.

The out-of-realm of weaving curve, as developed in accordance with above reference, is shown plotted in Figure 19. The relationship represented occurs where traffic from the weaving configuration would assume or closely approach the through flow of freeway traffic, generating speeds of the order of 50 to 55-mph.

The general form of the curve in Figure 19, embodies some of the general characteristics found in the regression analysis for the 50-mph speed line in Figures 12 and 15-B. Regression slopes (V_W/L through the origin are near 0.50 which approximate the initial slope of the curve in Figure 19. The slope of the linear regression (least-squares) line, identified as line (1) in Figures 12 and 15-B, indicate a general slope approximating 0.25, which is the overall continuing



PLOTTED DATA POINTS – ONE-SIDED WEAVING

SITE/DATA POINT	AVERAGE SPEED - MPH		WEAVING LENGTH-FT	WEAVING VOL.- PCPH	MEASURE-MENT
	S_W	S_C*			
P-8.4	50.4	51.1	1355	680	HRLY RATE†
P-8.6	47.7	50.0	1355	880	HRLY RATE
P-11.1	52.4	55.4	1200	650	HRLY RATE
P-11.7	48.1	52.1	1200	400	HRLY RATE
I-2	52.6	55.8	1100	460	1-HR COUNT
I-2.1	50.8	56.2	1100	440	1-HR COUNT
I-6	48.1	52.1	2225	860	1-HR COUNT
I-6.1	49.4	53.4	2225	960	HRLY RATE
I-8.7	51.7	55.8	1700	820	1-HR COUNT
I-8.9	50.9	55.1	1700	765	HRLY RATE
I-8.12	51.0	55.0	1700	655	1-HR COUNT
I-11	50.5	56.5	1150	525	1-HR COUNT
I-11.2	51.0	56.1	1150	620	1-HR COUNT
B-65	45.1	45.1	4700	1730	1-HR COUNT

* Average speed all traffic on weaving section.
† Converted to hourly rate from 18-min. count.

Figure 19. DATA POINTS CONFORMING TO OUT-OF-REALM OF WEAVING CURVE

slope of the curve in Figure 19. A further analysis of the out-of-realm curve, utilizing applicable points from the data base are tabulated and plotted along the curve in Figure 19. The plotted data points indicate a degree of conformance to the out-of-realm of weaving curve.

The curve as defined indicates a limiting point of 2000 pcph of weaving volume (V_W) at a distance of 6000 feet of length (L). Since under actual conditions weaving volumes may occur well above 2000 pcph, some extrapolation is necessary if a usable procedure is to be formulated. To provide a reasonable guideline for application, the relationship of weaving volume to weaving length in the graph was projected upward to 3500 pcph of weaving volume and to 8000 feet of length, as shown in Figure 20. Similar limits have been developed and utilized in the 1965 HCM and were found to be generally within the bounds required in application for analysis and design.

Curve Adjustment of Volume-Length Relationship.--To complete and refine the relationship of V_W vs. L for the 5-mph incremental speeds and their associated levels of service, the regression lines of Figure 18 should incorporate the established base curve of Figure 19 for out-of-realm of weaving. Figure 20 demonstrates the technique in harmonizing the straight lines of regression to reflect the influence and transition of the base curve into the overall chart, and to consider the extension of relationships beyond the limits of the data base, for which the majority of data points fall below the dotted line (1)-(2)-(3). The rational formulation in this regard, applied as an extension of the statistical approach, provides the refinement and expansion of interrelationships for purposes of design and for analysis leading to improvement or redesign of facilities.

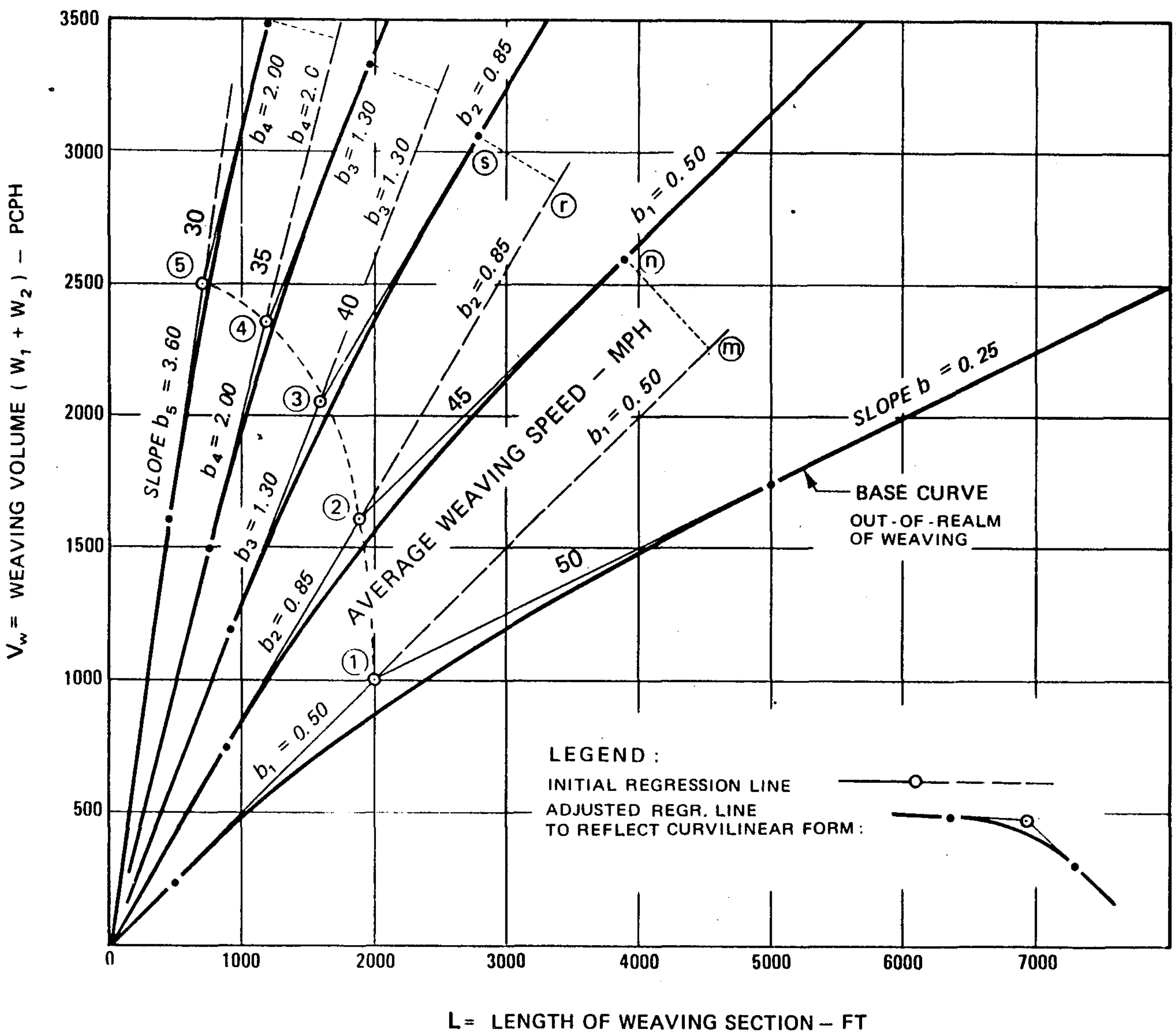
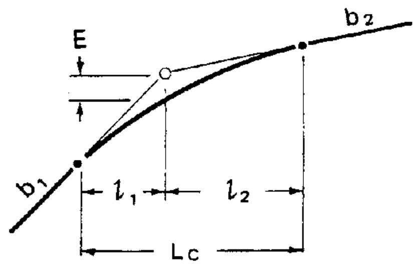


Figure 20. TECHNIQUE FOR FINAL ADJUSTMENT OF REGRESSION LINES OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIPS

ONE-SIDED WEAVING SECTIONS



$$E = \frac{l_1 l_2 (b_1 - b_2)}{2 L_c}$$

COORDINATES OF SLOPE BREAK POINTS			ASYMMETRIC SKEWED PARABOLA LENGTH ELEMENTS - FT., HORIZONTAL		
P.I.	X	Y	L_c	l_1	l_2
①	2000	1000	4500	3000	1500
②	1900	1600	3000	2000	1000
③	1577	2050	1875	1250	625
④	1175	2350	1200	800	400
⑤	694	2500	750	500	250

Figure 21. **SUPPLEMENTARY INFORMATION FOR ADJUSTING REGRESSION CURVES IN FIGURE 20**

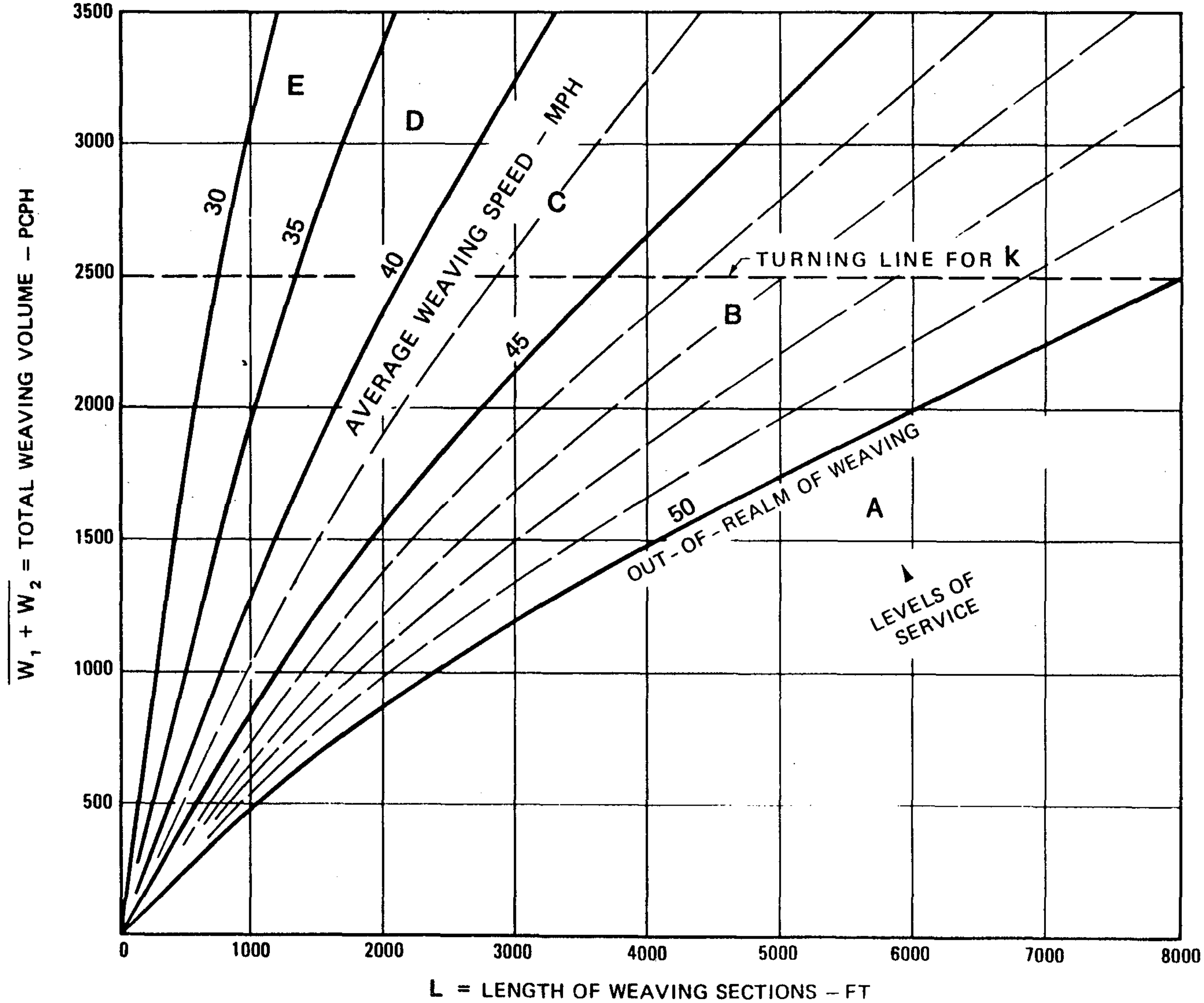


Figure 22. ADJUSTED WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP USED IN CONJUNCTION WITH k CALCULATIONS

ONE… D WEAVING SECTIONS

The technique utilized in configurating the curves in Figure 20 was a gradual transformation of the out-of-realm of weaving base curve progressively through the series of intermediate speed lines to a straight line (not shown) at 25-mph. This was accomplished by utilizing a series of parabolic curves with P.I. points (1) to (5), selected in consideration of data points used in the statistical analysis. Slope breaks, rationally selected, b_1 through b_5, are progressively transferred from (m) to (n), from (r) to (s), etc., as part of systemmatic progression. The form and details of the parabolic curves are shown in Figure 21, including the configuration for the out-of-realm of weaving curve. When applied to Figure 20, a series of gradually transitioned curves is produced. The curves are further shown in Figure 22, including level of service designations and additional breakdown of speeds for the purpose of deriving k values (weaving intensity factors). Derivations of k factors are discussed under a separate heading.

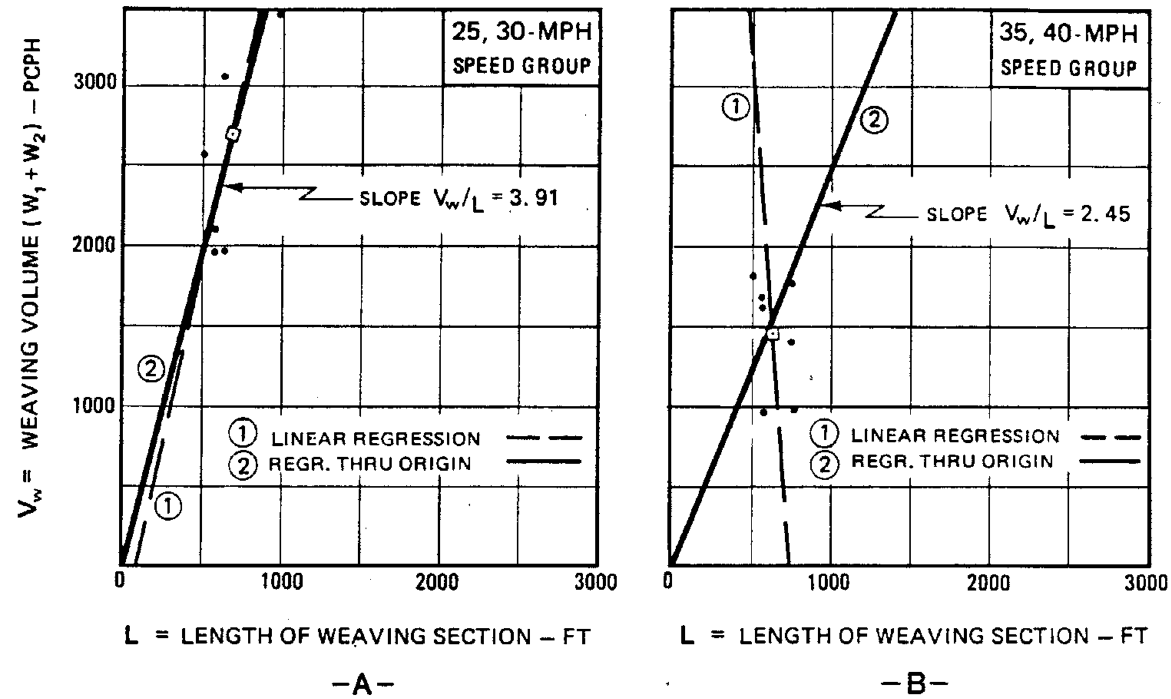
Two-Sided Weaving Sections

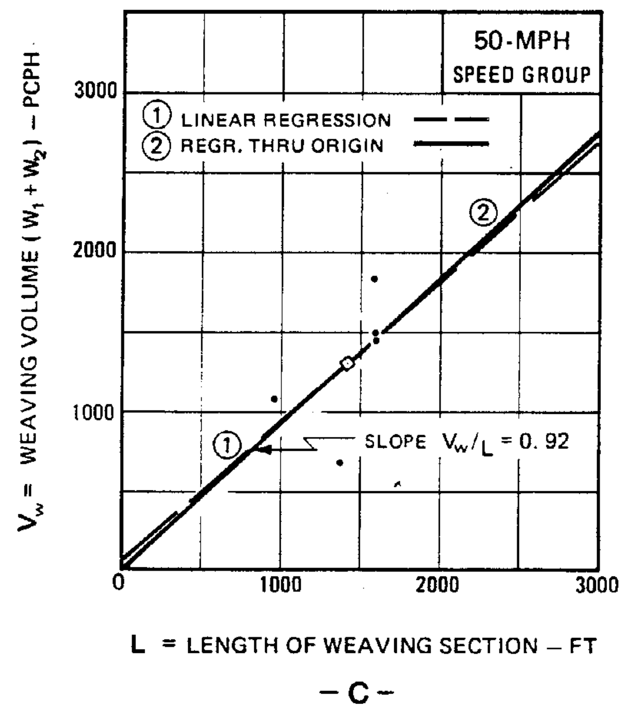
As in the case of one-sided weaving sections, similar analysis procedures were followed in an attempt to determine weaving volume/length/speed relations for two-sided sections. Studies of two-sided sections available for this project were all accomplished through the BPR research reported in Table 1. Additional breakdown of data (in the form of hourly rates expanded from 18-minute highest periods within the peak hour) was incorporated to a limited degree from Table A-1 to expand the data base. Supplementary to the information in Tables 1 and A-1, Table 14 provides the listing of 17 data points with associated speeds and other key data, which were used in regression analyses of V_W vs. L for several speed groups. Speed bands and the method of determining them was accomplished in a manner similar to one-sided sections previously discussed.

Because the data were so limited, a combination of some of the speed groups was necessary in order to have sufficient points for regressions to provide some semblance of results and direction toward a relationship. As before, two forms of linear regression were accomplished: a least-squares line which gave an indication of the statistical characteristics with respect to the available data, and a regression line through the origin ($V_W = 0$, $L = 0$). Three speed groups as shown in Figure 23 were utilized--25 and 30 mph, 35 and 40 mph, and 50 mph. r^2 correlations of 0.69 and 0.33 were achieved for the first and last, while no correlation was evident for the middle group. Standard errors of 115 and 192 for L were realized for the first two groups, and 355 for V_W for the last group.

Although this provided only three speed lines (instead of desired five) because of the combinations, the compilation of regression lines through the origin as plotted in the upper part (A) of Figure 24 shows a semblance of relationships to the initially compiled regression lines for one-sided sections. Assuming that there are some similarities between one-sided and two-sided weaving sections, certain comparisons and approximate conclusions may be drawn: (1) at near capacity operations, with speeds in vicinity of 30 mph, both types of sections seem to have similar characteristics in terms of weaving volume and relative length; (2) on 50-mph two-sided sections, volume to length relations tend to approximate those at 45-mph on one-sided sections (i.e. a similar weaving volume for a given length on a two-sided section would be handled at about 5-mph higher speed than on a one-sided section); (3) this speed differential may be extended to the next higher (50-mph corresponding to out-of-realm of weaving) speed for a one-sided section, so that in its place a 55-mph limiting curve would be logical for the two-sided section; and (4) in the mid-portion of the graph it is evident that if the 40-mph curve of the two-sided curve is moved down to approximate the slope of 35-mph curve of the one-sided section, again approximately a 5-mph speed differential would result, with a relative effect of the 35-mph one-sided curve being equivalent to a 40-mph two-sided curve.

The reorientation of speed slopes described in the paragraph above are shown in the lower part (B) of Figure 24, which is a rational deduction from the graph above, with the result that (except near capacity) two-sided volume-length relations occur at 5-mph higher speeds than for one-sided sections. This is a logical rationalization which later is verified by testing data sets from two-sided weaving sites. With this deduction and conclusion, the refined and adjusted lines of regression, except for speed designations, is made the same for two-sided as for one-sided sections for convenience of handling the model and nomograph development. Accordingly, the adjusted array of regression lines for two-sided sections is shown in Figure 25 by utilizing the slopes of Figure 18. The curvilinear form of the relationship along the lines previously worked out, is shown in Figure 26. The designated speeds, levels of service, and further breakdown of speed curves, places the relationship toward its final form, and for the next task of k factor derivations.





25, 30-MPH $r^2 = 0.69$

① $L = 69 + 0.232\ V_w$ SE = 124
② $L = 0.256\ V_w$ SE = 115*

35, 40-MPH $r^2 = 0.05$

① $L = 731 - 0.07\ V_w$ SE = 112
② $L = 0.408\ V_w$ SE = 192*

50-MPH $r^2 = 0.33$

① $V_w = 20 + 0.910\ L$ SE = 410
② $V_w = 0.923\ L$ SE = 355†

STANDARD ERROR OF:
* L FEET
† V_w PCPH

Figure 23. **REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP**
5-MPH SPEED GROUPS
TWO-SIDED WEAVING SECTIONS

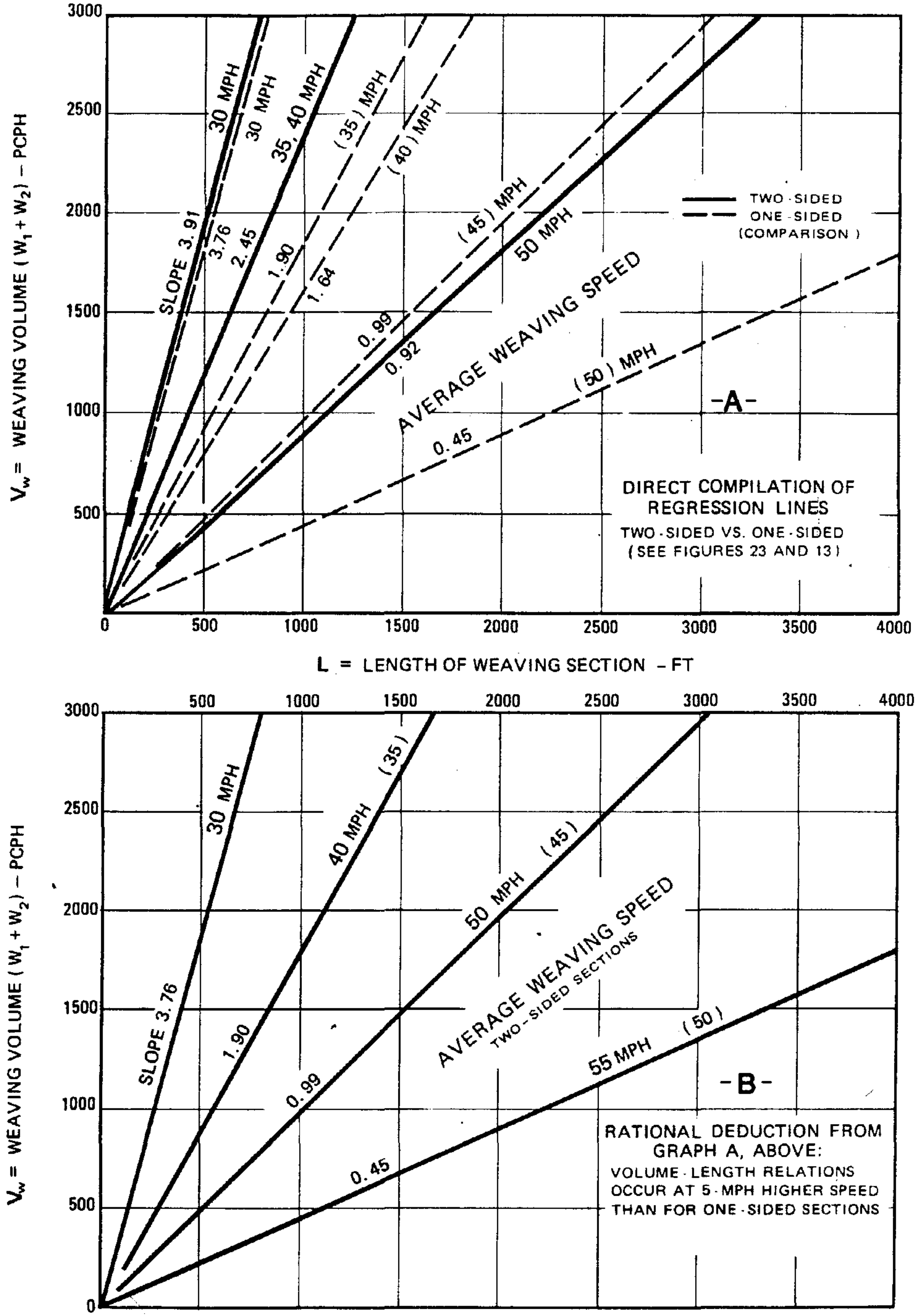


Figure 24. COMPOSITE OF WEAVING VOLUME / LENGTH / SPEED REGRESSION

TWO-SIDED WEAVING SECTIONS

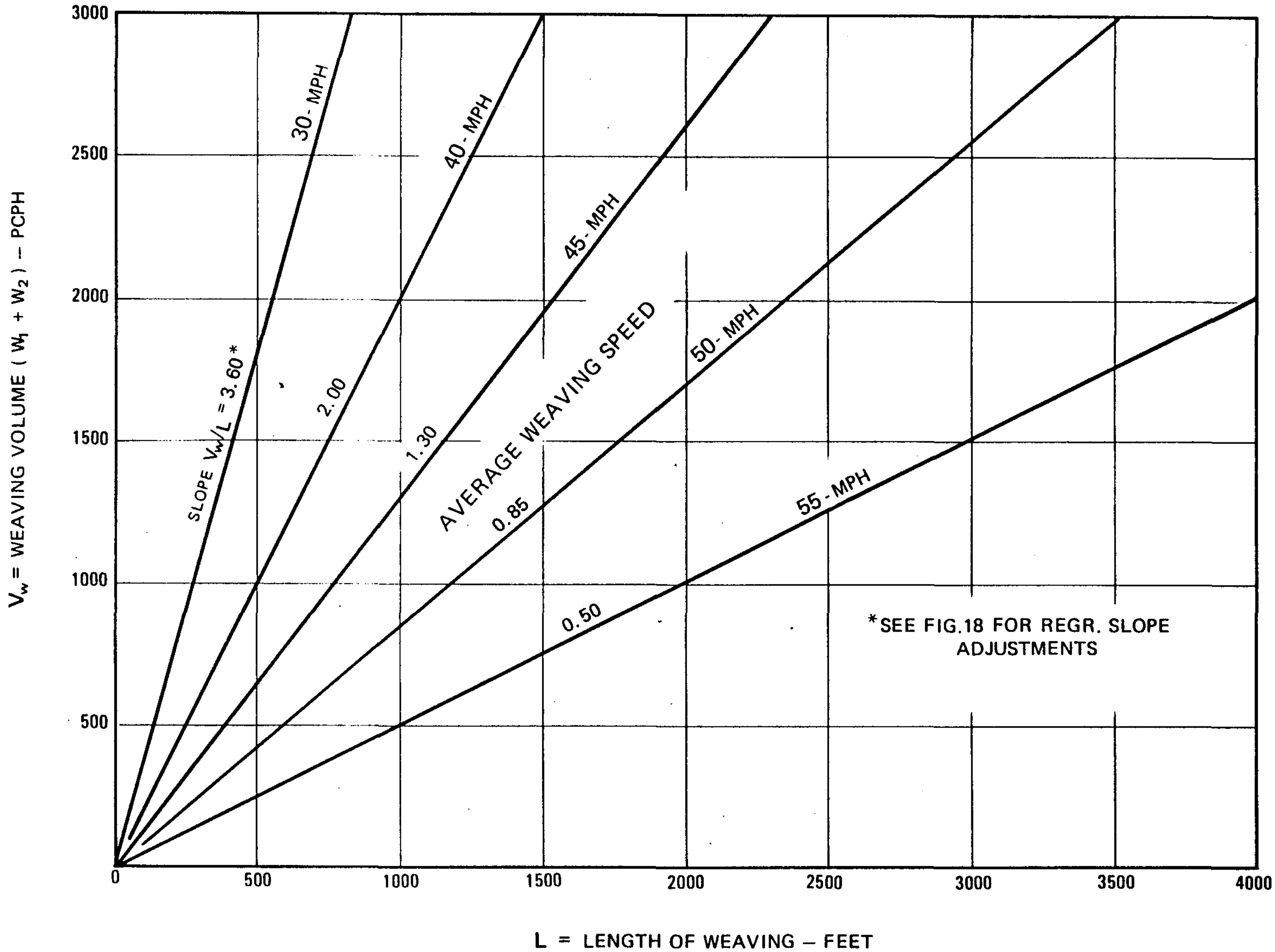


Figure 25. **REFINED LINES OF REGRESSION OF WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP**

5 - MPH SPEED GROUPS OVER RANGE OF 30 TO 55 MPH

TWO - SIDED WEAVING SECTIONS

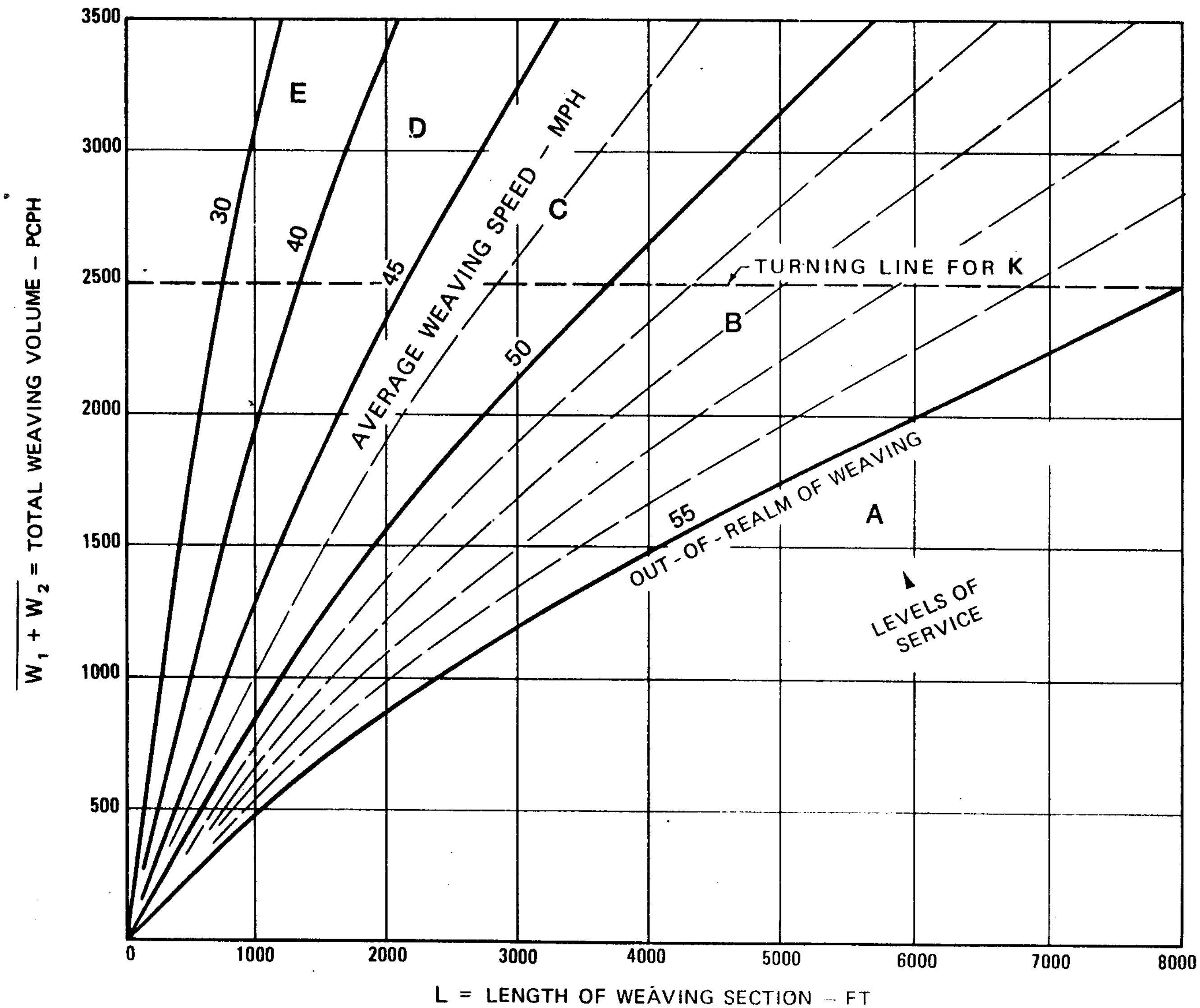


Figure 26. **ADJUSTED WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP USED IN CONJUNCTION WITH K CALCULATIONS**

TWO-SIDED WEAVING SECTIONS

Width-Volume Relations

The above discussion dealt with the weaving portion of traffic and its speed behavior as affected by available length along the freeway within which the weaving maneuver is accomplished. The results were derived from records of actual facility performance, providing a base of information. In conjunction with these representative relations of the weaving traffic element, certain variables are embodied within the results which are not directly identified but play an important operational role. Of the more important features, in this regard, are: geometric effects of entering and exiting ramps; nonweaving traffic; widths of traveled way; and lane arrangements within the weaving section.

Accepting the findings covered in the previous sections as basic parts of the model, other variables and model components have been designed for further integration to permit more complete analysis of weaving sections. An important element which interplays with some of the features mentioned has to do with the width-volume relationship pertaining to the overall weaving section as a segment of the freeway.

The rational formulation for this component, with more recent modifications, has a long history originally dating back to the 1950 HCM. In its near original form it was passed on to the 1965 HCM. Recently it was modified by Leisch (1978) and now further calibrated in this report. Aspects of its original formulation and reworking in the 1965 HCM are thoroughly discussed and evaluated by PINY (1973), p.p. 203-222, indicating that there are inconsistencies and problems with the relationship.

The change in the formula as presented, first, as part of the model, and here as its reoriented version (which later is verified by k factor determination) is described as a follow up of the presentation of the 1965 HCM version.

In the 1965 Manual, the analysis of a weaving section was accomplished by two separate steps: first, determination of length based on weaving volume and desired level of service, and second, determination of the overall width of weaving section based on total volume, including the extra effect of weaving traffic, and desired level of service. For a complete solution of a weaving section problem, both length and width requirements had to be met, although independently analyzed. When disparity between the two occurred the weaving solution result was then considered at an operational level corresponding to the more stringent control.

The rational width formula in the 1965 Manual which can be progressively expressed in three forms, with the limited insights and studies that were used for its development at that time, has been found to be correct in form for certain specific conditions--but not, as discovered through this research, to be applicable generally for all conditions. In the 1965 Manual, the formula is given as follows. (The volumes are reduced by truck effects and any other constraints and the service volume reduced by an appropriate peak-hour factor, to place the units in terms of passenger cars per hour.)

$$N = \frac{V_{o1} + V_{o2}}{SV} \quad \frac{W_1 + k\ W_2}{SV} \qquad \text{--------}\ (1)$$

$$N = \frac{V_o + V_o + W_1 + k\ W_2}{SV} \qquad \text{--------}\ (2)$$

$$N = \frac{V + (k-1)\ W_2}{SV} \qquad \text{--------}\ (3)$$

N = Total number of lanes in the weaving section (fractional lanes)

V_{o1} = Larger outer flow (nonweaving) in pcph

V_{o2} = Smaller outer flow (nonweaving) in pcph

W_1 = Larger weaving flow in pcph

W_2 = Smaller weaving flow in pcph

V = Total volume of all traffic within weaving section in pcph

k = Weaving intensity factor, normally a value of 3 (max.) but reducing to a limit of 1 at higher levels of service.

SV = Average service volume per lane in accordance with the number of lanes on the major approach, equivalent to that on freeway proper (Table 9.1 HCM) in pcphpl.

Equation (1) implies that the nonweaving traffic would have its own requirements and could be thought in a sense to operate separately, just as the weaving traffic would have its requirements and considered to operate in a hypothetical but separate mode, at the same time the two would operate in parallel and each would do so at a common level of service. (In the very early but limited research efforts,where such operational balance was achieved, the rational formulation and a k factor of the order of 3 were found to be applicable; the research, however, was not carried far enough.) Any intermixing of the different traffic elements, although it may be acknowledged, is not reflected in the formula.

Equation (2) implies basically the same results. By placing the values together in the numerator, conceivably there could be intermixing of some of the volume elements. However, an identical or a common level of service would prevail for each movement, and the k factor would remain a specific value, producing the same results as in Formula (1).

Equation (3) maintains the general features of the other equations, but in this form the specific influence of weaving becomes clearly apparent, over and above the V/SV term representing uninterrupted flow. Here, too, a common service volume or level of service is implied for all traffic including weaving, and with a definitive weaving intensity factor; also, as in other cases, N would be a fractional value to maintain a common service volume equivalent to open highway operations on the freeway.

In this research project although the volume-width requirements are expressed by a similarly structured formula (Formula 3) its components constitute several differences in: definition of terms--N and SV, and the use of a k factor that is fully correlated between the weaving volume-length relation and the total volume-width relation, which feature accounts for certain degrees of intermixing of weaving and nonweaving traffic. The formula used here is written as:

$$N = \frac{V + (k-1)\,W_2}{SV'} \qquad \text{--------}\ (4)$$

Where:

N = Total number of lanes in the weaving section, expressed in whole (integer) number of lanes.

V = Total volume of all traffic passing through the weaving section in pcph.

k = Weaving intensity factor, used as an expansion factor in conjunction with the smaller weaving volume to reflect the effect of weaving turbulance and corresponding need to compensate for it by providing additional width. The correlated k values have been determined to be in the range of 3 to 1 for one-sided and 6 to 1 for two-sided weaving sections.

SV' = Service volume per lane as a composite value for the overall weaving section (determined as a weighted average of weaving and nonweaving traffic with respect to relative volumes and availability of lanes for each), related to the basic SV values and number of lanes on the major approach to the weaving section, prescribed for various levels of service in Table 9 in pcphpl.

Note: More detailed explanation of k and SV' values is presented in the next section.

The formula described is used primarily for analysis to determine the service level of operation of the overall weaving section and its interrelationship to the service level of the weaving element of traffic.

Another make-up of this basic formula is expressed somewhat differently for the condition of establishing or testing an "operationally balanced" weaving section; in essence this means that the weaving traffic and the nonweaving traffic are so balanced in terms of traffic and geometric elements (and hence the composite operation of the weaving section) that the same or nearly the same overall level of service is achieved. This overall level of service is that which is initially determined by the weaving volume/length relationship.

The application of the formula is intended primarily for design or redesign of freeway facilities, and in which the resulting fractional value of N must be rounded to a whole number in the final solution.

The version of the formula in this case is:

$$N' = \frac{V + (k-1)W_2}{SV} \qquad \text{--------} \ (5)$$

Where:

N' = Total number of lanes in the weaving section, expressed fractionally.

V = Total volume of all traffic passing through the weaving section in pcph.

k = Weaving intensity factor, used as an expansion factor in conjunction with the smaller weaving volume. The correlated k values are identical to those described in the previous formula.

SV = Service volume for the overall weaving section, balanced so that the service volume is the same for the weaving and nonweaving traffic elements. The specific level of service, and thus service volume, is prescribed by the weaving movement predicated on the weaving volume/length relationship. The value of SV is determined with the aid of Tables 6 and 9, or Figure 9, in pcphpl.

Weaving Intensity Factor

The two versions of the width-volume formula, (4) and (5), described above can be utilized to determine the range of limits of applicable k values, as well as specific values for various combinations of weaving elements; and in the process to determine k which would provide, in essence, a continuum within the model by integrating its two major elements--weaving length-volume relation with the overall width-volume relation.

PINY Report NCHRP 3-15, 1973 performed an extensive analysis of k factors as an expansion mechanism presented in the 1965 Highway Capacity Manual (HCM) and arrived at definite conclusions that: "... the prescribed limit for k of 3.0 is obviously incorrect...no clear upper limit can be discerned from the data...that the basic structure of the HCM expansion mechanism is in error...computed values of k have little relationship to the HCM predicted values of k."

PINY's analysis calculated k factors from the BPR data base using the basic formula for the width-volume relation, formula (3) stated in the previous section, converted to the form:

$$k = \frac{N\,(SV)}{W_2} + \left(1-\frac{V}{W_2}\right) \qquad \text{------(6)}$$

In doing so, for each experiment, N, V and W_2 were known, and SV was computed from Table 9.1 of the HCM for the appropriate LOS, which was found by comparing the average speed of all vehicles within the weaving section to the standards given in Table IV.4 of PINY report. The values as calculated by PINY showed no relationship to the weaving chart, Figure 7.4 in the HCM; instead, the results indicated that some k factors not only fell below 1.0 but several were minus values, while upper limits reached upward of 8.0. As a result of the disparity in these values, including "impossible" factors of less than 1.0 and those that were minus, PINY investigated other relationships, including k values with respect to V_w, W_1, as well as V_w/V and W_2/W_1 which showed definite trends; however, the conclusion was that should a "true" expansion mechanism exist, it probably would involve sequential expansion of these in some combination and would be unduly complex and require considerable amount of additional data.

Although PINY "proved" by the procedure it employed that the k values utilized in the HCM do not fall into a neat and uniform pattern as displayed in Figure 7.4 therein, the derivation of k as determined by the Leisch study presented below, show different results. The disparity stems from the interpretation of the basic formula, and the intended relationship of k within the formula. PINY has taken Formula (3), using integer number of lanes, and treated the equation as a unit, with SV as a single value related to the average speed of all traffic within the weaving section. The expression as arranged in Formula (6) is highly sensitive to calculation of k, so that the translation of SV values from an average speed of the section, which intermixes very distinct characteristics of "weaving" and "nonweaving" traffic, would be expected to produce inconsistent and actually incorrect results.

To find k values as intended by the model, an independent computation was carried out on this project utilizing the same basic expression of Formula (6) derived by

PINY, but the definition of terms used are those associated with Formula (4). Another, alternate method of determining k values was also accomplished by the expression of Formula (6) but with the definition of terms associated with Formula (5).

The two methods represent different conditions, the first utilizes complete data of each experiment, and applies a composite SV value embodying both weaving and nonweaving traffic; while the second method uses all the data except N, assuming a balanced section in relation to level of service for both weaving and nonweaving traffic, employing in the process a resulting fractional number of lanes. The two methods are fundamentally different but produce the same results.

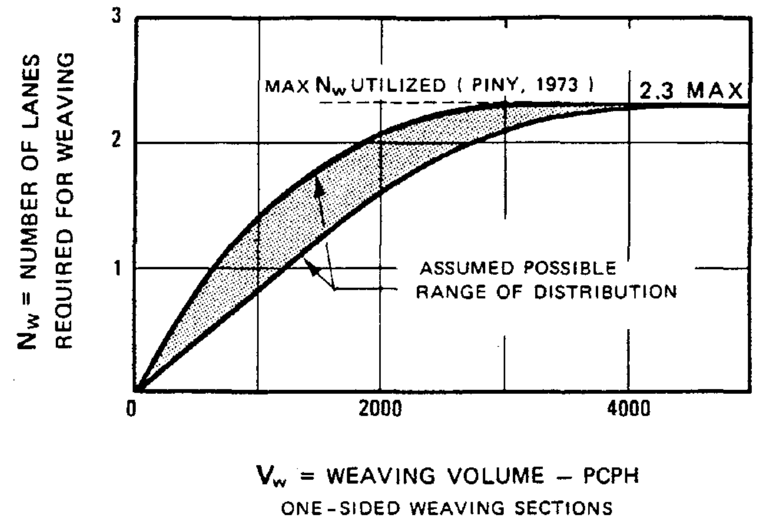
As part of the k calculation process the number of lanes required or apt to be utilized by the weaving movement (N_W) is an essential input. The derivation of N_W values are presented in the next several paragraphs, followed by the explanation of k calculations as structured in Tables 11 and 12.

Although NCHRP Report did not utilize k factors within its procedure, it did consider the separation of weaving traffic from nonweaving traffic. In this regard, the PINY report has derived the number of lanes required as a maximum for ramp weaves and for major weaves; the information is summarized in Table X1-1 and is the result leading to the recommended procedure therein. The maximum values derived are dependent upon the configuration of the weaving section, and are 2.3 lanes required for ramp weaves and 3.6 lanes required for major weaves. Intermediate values for specific cases, not requiring the maximum number of lanes, are functionally related to the ratio of V_W to V and expressed proportionally through equations by the term N_W/N.

The maximum number of lanes required for weaving, as derived by PINY, were adopted as an input to this project. In using maximum values of 2.3 lanes for one-sided and 3.6 lanes for two-sided weaving sections and in developing intermediate values as required for the derivation of k factors reported in Tables 11 and 12, the general framework for accomplishing it is shown in Figure 27. Since N_W is a function of volume relating to both V_W and V and their interaction, an attempt was made to find a resonable, although not as precise a relationship, by using a single variable of V_W as a surrogate in determining intermediate values of N_W.

Figure 27 utilizes the two variables and a possible range of distribution of values within the curved bands, structured for testing a series of individual curves for an optimum relationship. The results were accomplished by trial and error of precalculating k values for a generally known relationship (hypothesized) set of k's. What was considered to be the most "balanced" set of values following a process of iteration, prescribed the curves in Figure 28, from which N_W values were finally read and used in Tables 11 and 12 to derive the k values shown.

The calculation process for k values as structured in Tables 11 and 12, utilized data from experiments of Tables 1, 2, and 3, supplemented by complimentary points selected from Tables A-1 and A-2. Basically, all the points used in the initial regression analyses to establish the weaving volume/length/speed relations in Figures 10-12 and 23, were utilized in computation of k values. The level of service criteria from Tables 6 and 9, or Figure 9, and N_W values from Figure 28,



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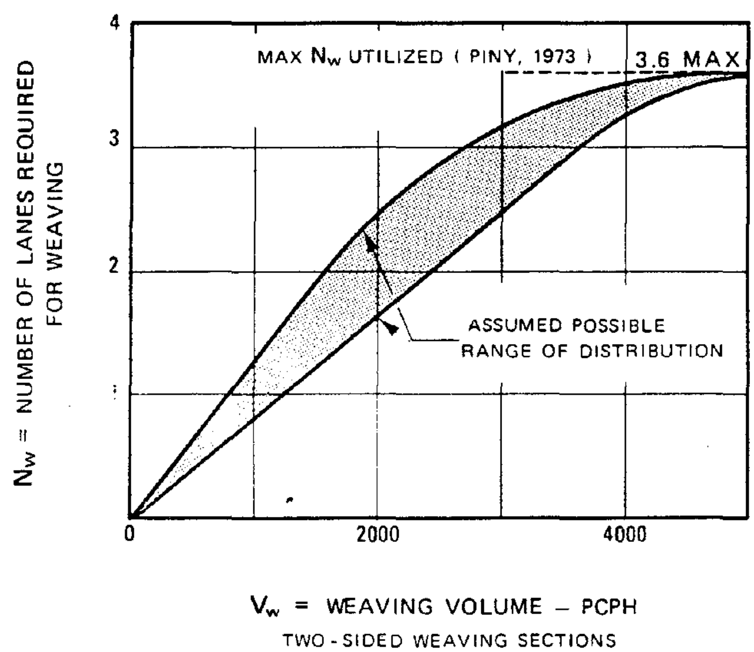


-B-

Figure 27. ELEMENTS AND ASSUMPTIONS FOR DEVELOPMENT OF RELATIONSHIP OF N_w TO V

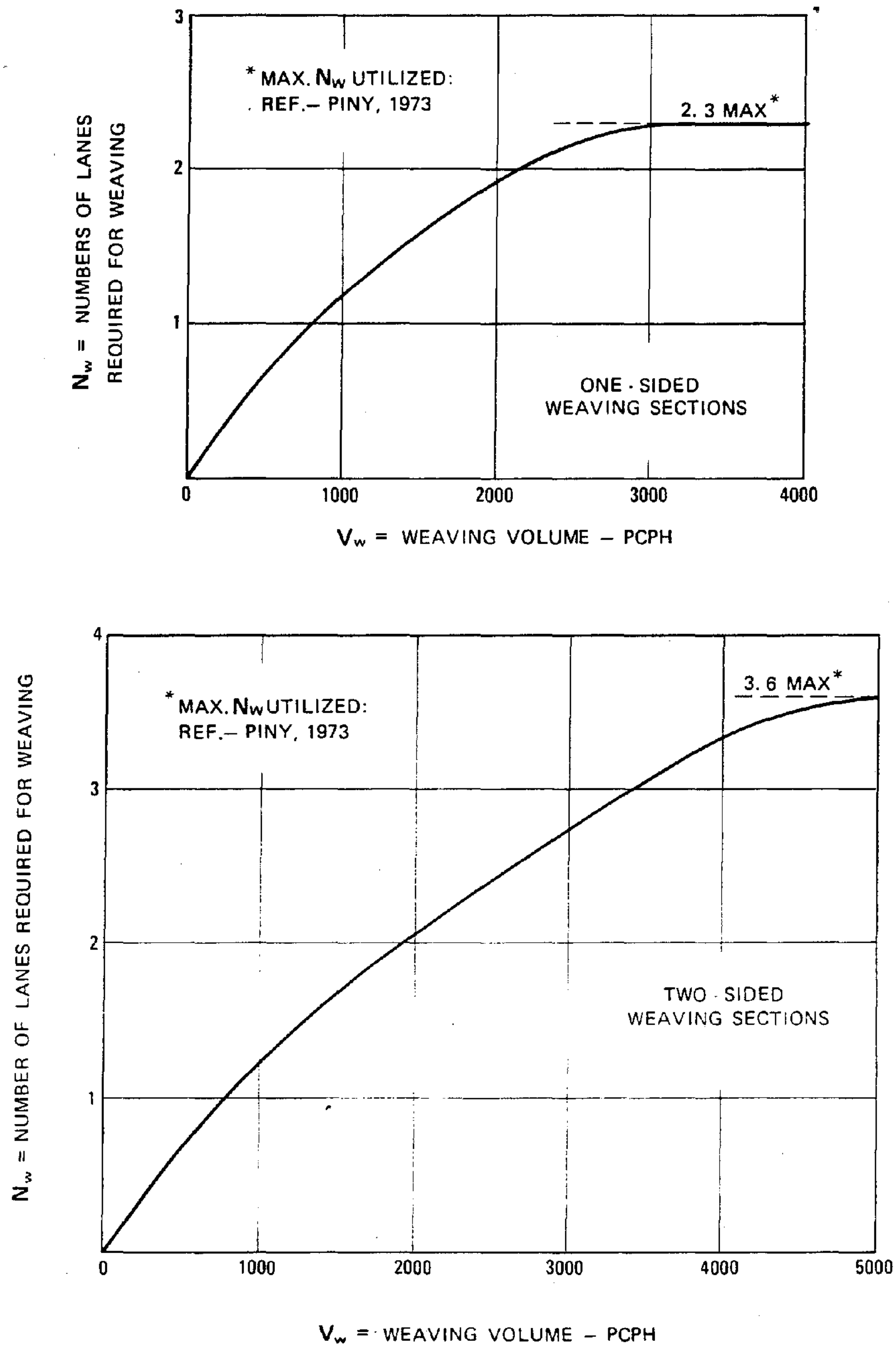


Figure 28. **NUMBER OF LANES REQUIRED FOR WEAVING AS RELATED TO WEAVING VOLUME**

ONE - AND TWO - SIDED WEAVING SECTIONS

were employed in conjunction with modeled speeds, read directly from the graphs of Figures 22 and 26, to arrive with the set of k values shown.*

For all practical purposes, as postulated, k factors fell within a general range of 1 to 3 for one-sided weaving sections and 1 to 6 for two-sided sections. Of the 50 points calculated, for one-sided sections there were 8 points in the general range of 3.5 to 4.0 which were discarded; of the 25 points calculated for two-sided sections, 3 points exceeded values of 6.5. These were considered as outliers with an obvious explanation for odd results. Tables 13 and 14 were compiled to provide a convenient summary of points and associated k values used in further analysis.

In refining the model and in utilizing the results for constructing the nomographs, it was necessary to examine the correlation of k values with various variables. This was attempted as shown in Figure 29 by plotting k vs. V_W (weaving volume), k vs. R (ratio of weaving volume), and k vs. S_W (weaving speed). For the most part the array of points were well scattered; however, for k vs. S_W for one-sided sections, and for k vs. R for two-sided section, a degree of correlation was implied. This provided the impetus for further examination and possible regression analyses in an attempt to establish more definitive relations.

---

* Tables 11 and 12 present a systematic means of computation. Observed data for each site are shown in columns 1 through 10, and 23 and 24. Remaining columns are part of the computational procedure, utilizing the modeled speed of column 11 as the basis, with each level of service subdivided into five parts to achieve closer results. Columns 21, 22, 25 and 26, as well as lower part of column 3 in parenthesis, indicate calculated values based on the structure of Formula (6). Computations represent an imbalanced section with a composite SV in the upper part, and a balanced section with a common SV in the lower part of each line of tabulation.

TABLE 11

COMPUTATION OF k (WEAVING INTENSITY) FACTORS FROM PROJECT DATA BASE

ONE-SIDED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED MEAS. MPH	WEAVING SPEED CHART MPH	LOS_W CHART	SV_W RANGE PCPH/L	SV_W FINITE PCPH/L	N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE SV PCPH/L	COMPOSITE LOS	$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED	k CALCULATED	COMMENTS
30-M.P.H. ONE-SIDED																										
B-6	30	2 (1.63)	2	425	1595	15	1580	635	32.2	30	E_{MAX}	1900	1900	1.62 1.62	0.38 0.01	41 1900	A E_{MAX}	1547 1900	D_{MAX} E_{MAX}	4.87 4.88	-1.51 -1.51	0.402	0.991	3.36 3.37	3.36	C-D ROAD
B-7	30	4 (3.54)	3	445	5420	3625	1785	835	26.6	28	F or E_{CAP} E_{CAP}	2000	2000	1.73 1.73	2.27 1.81	1600 2000	D_{MAX} E_{MAX}	1773 2000	E_3 E_{MAX}	8.49 8.48	-5.50 -5.50	0.467	0.329	2.99 2.98	2.99	AT OR NEAR LOS F
B-8	30	4 (3.50)	3	449	5245	3355	1890	820	29.8	26	E_{CAP}	2000	2000	1.82 1.82	2.18 1.68	1540 2000	D_4 E_{MAX}	1749 2000	E_2 E_{MAX}	8.53 8.54	-5.40 -5.40	0.434	0.360	3.13 3.14	3.13	AT OR NEAR LOS F
B-9	30	5 (4.00)	4	659	6480	4855	1625	760	28.4	30	F	2000	2000	1.57 1.57	3.43 2.43	1420 2000	D_1 E_{CAP}	1599 2000	D_4 E_{CAP}	10.52 10.52	-7.52 -7.52	0.468	0.251	3.00 3.00	3.00	
B-24	30	5 (3.95)	4	659	6220	3470	2750	580	29.9	25	F	2000	* 2000	2.22 2.22	2.78 1.73	1248 2000	C_1 E_{MAX}	1583 2000	D_4 E_{MAX}	13.64 13.62	-9.72 -9.72	0.211	0.442	3.92 3.90	3.91	k DISCARD HIGHLY IMBALANCED
B-33	30	5 (5.04)	4	521	7775	6460	1315	425	29.6	33.5	E_2	1900/ 1650	1725	1.30 1.30	3.70 3.74	1746 1725	E_2 E_1	1740 1725	E_2 E_2	20.47 20.46	-17.29 -17.29	0.323	0.169	3.18 3.17	3.17	

* SEE NOTE LAST PAGE OF TABLE

TABLE 11 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED MEAS. MPH	WEAVING SPEED CHART MPH	LOS_W CHART	SV_W RANGE PCPH/L	SV_W FINITE PCPH/L	N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE SV PCPH/L	COMPOSITE LOS	$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
B-41	30	4 (2.68)	3	556	3545	1105	2440	1150	26.9	25	F	2000	2000	2.13 2.13	1.87 0.55	590 2000	A F	1340 2000	C_{MAX} F	4.66 4.66	-2.08 -2.08	0.471	0.688	2.58 2.58	2.58	LOS V_w E/F
M-1	30	6 (4.58)	4	650	6880	5125	1755	520	28.6	32	E_3	1900/ 1650	1800	1.73 1.73	3.27 2.85	1567 1800	D_3 E_3	1648 1800	D_{MAX} E_3	15.84 15.85	-12.23 -12.23	0.296	0.26	3.61 3.62	3.62	ODD LANE CONFIG.
													35 - M.P.H. ONE- SIDED													
B-3	35	4 (4.36)	3	917	5240	4110	1130	395	34.6	40	D_{MAX}	1600/ 1350	1350	1.32 1.32	2.68 3.04	1534 1350	D_4 C_3	1473 1350	D_3 C_3	14.92 14.90	-12.27 -12.27	0.351	0.216	2.65 2.63	2.63	
B-5	35	2 (1.42)	2	425	1300	5	1295	550	33.5	32	E_3	1900/ 1550	1750	1.42 1.42	0.58 0.003	9 1750	A E_3	1245 1750	A E_3	4.53 4.52	-1.36 -1.36	0.425	0.996	3.17 3.16	3.16	C - D ROAD
B-6a	35	2 (1.63)	2	425	1595	15	1580	635	32.2	30	E_{MAX}	1900	1900	1.62 1.62	0.38 0.01	41 1900	A E_{MAX}	1547 1900	D_{MAX} E_{MAX}	4.87 4.88	-1.51 -1.51	0.402	0.991	3.36 3.37	3.36	
B-10	35	2 (1.34)	2	503	1175	10	1165	515	34.4	34	E_1	1900/ 1550	1625	1.33 1.33	0.64 0.01	16 1625	A E_1	1086 1625	C_2 E_1	4.22 4.23	-1.28 -1.28	0.442	0.991	2.94 2.95	2.95	C - D ROAD
B-11	35	4 (5.10)	4	1054	6425	5055	1370	495	33.0	40	D_1	1650/ 1400	1400	1.49 1.49	3.51 3.61	1440 1400	D_1 C_3	1428 1400	D_1 C_3	14.42 14.42	-11.98 -11.98	0.363	0.213	2.44 2.44	2.44	APPARENT UPSTREAM SPEED CONSTRAINT

* SEE NOTE LAST PAGE OF TABLE

TABLE 11 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED MEAS. MPH	WEAVING SPEED CHART MPH	LOS_W CHART	SV_W RANGE PCPH/L	SV_W FINITE PCPH/L	N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE SV PCPH/L	COMPOSITE LOS	$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED	k CALCULATED	COMMENTS
B-17	35	4 (4.14)	3	710	5275	4105	1170	520	36.7	37.5	D_2	1600/ 1350	1475	1.36 1.36	2.64 2.78	1555 1475	D_4 D_2	1528 1475	D_4 D_2	11.75 11.74	-9.14 -9.14	0.444	0.222	2.61 2.60	2.60	
B-18	35	4 (3.15)	3	725	3695	2670	1025	330	36.3	39.5	C_{MAX}	1350/ 1100 1600/ 1350	1375	1.21 1.21	2.79 1.94	957 1375	B_3 C_{MAX}	1083 1375	B_{MAX} C_{MAX}	13.13 13.13	-10.20 -10.20	0.322	0.277	2.93 2.93	2.93	
B-20	35	2 (1.45)	2	868	1310	45	1265	455	36.5	38	D_1	1500/ 1250	1375	1.42 1.42	0.58 0.03	78 1375	A D_1	999 1375	B_{MAX} D_1	4.38 4.38	-1.88 -1.88	0.360	0.966	2.50 2.50	2.50	C-D ROAD
B-32	35	4 (4.31)	3	822	5595	4195	1400	515	36.1	37	D_2	1600/ 1350	1500	1.51 1.51	2.49 2.80	1685 1500	E_1 D_2	1615 1500	D_{MAX} D_2	12.54 12.55	-9.86 -9.86	0.368	0.250	2.68 2.69	2.69	
B-34	35	4 (4.55)	3	621	6145	4955	1190	290	34.4	35	D_{MAX}	1550	* 1550	1.35 1.35	2.65 3.20	1870 1550	E_{MAX} D_{MAX}	1762 1550	E_3 D_{MAX}	21.30 24.32	-20.19 -20.19	0.244	0.194	4.11 4.13	4.12	k DISCARD V_W AND V IMBALANCED
P2.8	35	4 (4.87)	3	968	6300	4540	1760	270	34.5	36.5	D_3	1500/ 1250	1450	1.74 1.74	2.26 3.13	2009 1450	E_{MAX} D_3	1766 1450	E_4 D_3	26.16 26.15	-22.33 -22.33	0.153	0.279	3.83 3.82	3.82	"
P10.4	35	4 (3.28)	2	527	4420	2980	1440	390	33.9	32.5	E_2	1900/ 1550	1700	1.53 1.53	2.47 1.75	1206 1700	C_4 E_2	1395 1700	D_2 E_2	14.31 14.30	-10.33 -10.33	0.271	0.326	3.98 3.97	3.97	"

*SEE NOTE LAST PAGE OF TABLE

TABLE 11 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED MEAS. MPH	WEAVING SPEED CHART MPH	LOS_W CHART	SV_W RANGE PCPH/L	SV_W FINITE PCPH/L	N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE SV PCPH/L	COMPOSITE LOS	$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
40-M.P.H. ONE-SIDED																										
B-3.2	40	4 (3.84)	3	917	4250	3300	950	250	39.2	42.5	C_2	1350/ 1100	* 1225	1.15 1.15	2.85 2.69	1158 1225	C_1 C_2	1177 1225	C_2 C_2	18.84 18.82	-16.00 -16.00	0.266	0.233	2.84 2.82	2.83	
B-3.7	40	4 (3.17)	3	917	2915	2280	635	170	41.7	47	B_2	1100/ 800	* 980	0.84 0.84	3.16 2.33	722 980	A B_2	776 980	A B_2	18.26 18.25	-16.15 -16.15	0.264	0.218	2.11 2.10	2.10	
B-15	40	2 (1.62)	2	900	1595	0	1595	535	39.9	37	D_2	1550/ 1250	1425	1.61 1.62	0.39 0	0 1425	A D_2	1147 1425	C_3 D_2	4.29 4.31	-1.98 -1.98	0.335	1.00	2.31 2.33	2.32	C-D ROAD
B-17.2	40	4 (3.63)	3	710	4350	3390	960	250	37.7	40	D_1	1600/ 1350	1350	1.12 1.12	2.88 2.51	1177 1350	C_2 D_1	1226 1350	C_3 D_3	19.61 19.62	-16.40 -16.40	0.260	0.221	3.21 3.22	3.21	
B-27	40	2 (1.42)	2	844'	1365	5	1360	415	39.3	38	D_2	1550/ 1250	1370	1.42 1.42	0.58 0.003	9 1370	A D_2	975 1374	B_{MAX} D_2	4.70 4.69	-2.29 -2.29	0.305	0.996	2.41 2.40	2.40	C-D ROAD
P-2.4	40	4 (5.00)	3	968	5960	4480	1480	170	39.8	39	D_1	1550/ 1250	* 1300	1.55 1.55	2.45 3.45	18.29 1300	E_4 D_1	1624 1300	D_{MAX} D_1	38.21 38.24	-34.06 -34.06	0.115	0.248	4.15 4.18	4.16	K DISCARD Vw AND V INBAL-ANCED
P-5.8	40	4 (3.08)	2	950	3680	1960	1720	550	42.3	37	D_1	1550/ 1250	1475	1.70 1.70	2.30 1.38	852 1425	B_2 D_2	1096 1425	C_2 D_2	7.97 7.98	-5.69 -5.69	0.320	0.467	2.28 2.29	2.28	
P-10.1	40	3 (2.23)	2	527	2430	1700	730	235	41.5	39	C_{MAX}	1550/ 1250	1300	0.92	2.08	817 1300	B_3 C_{MAX}	965 1300	B_4 C_{MAX}	12.32 12.34	-9.34 -9.34	0.321	0.448	2.98 3.00	3.00	

* SEE NOTE LAST PAGE OF TABLE

TABLE 11 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED		LOS_W CHART	SV_W		N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE		$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
									MEAS. MPH	CHART MPH		RANGE PCPH/L	FINITE PCPH/L					SV PCPH/L	LOS							
M-2	40	4 (2.89)	3	921	3350	1900	1450	345	40.0	37.5	D_3	1550/ 1250	1400	1.53 1.53	2.47 1.36	769 1400	A_{MAX} D_3	1010 1400	B_{MAX} D_3	11.72 11.73	-8.71 -8.71	0.238	0.433	3.01 3.02	3.01	V_W AND V IMBAL-ANCED
45-M.P.H.																										
B-28	45	5 (5.20)	4	1032	6800	5360	1440	415	43.9	39	D_1	1650/ 1400	1450	1.50 1.50	3.50 3.70	1531 1450	D_1 C_{MAX}	1507 1450	D_2 C_{MAX}	18.15 18.17	-15.39 -15.39	0.288	0.212	2.76 2.78	2.77	
B-28.2	45	5 (5.58)	4	1032	7200	5760	1440	410	45.4	39.5	D_1	1650/ 1400	1425	1.54 1.54	3.46 4.04	1665 1425	D_{MAX} D_1	1591 1450	D_4 D_1	19.40 19.39	-16.56 -16.56	0.285	0.200	2.84 2.83	2.83	
P-2.1	45	4 (4.66)	3	968	4560	3660	900	100	42.7	44.5	C_1	1250/ 1000	* 1025	1.09 1.09	2.81 3.57	1303 1025	C_4 B_4	1194 1025	C_2 B_4	47.77 47.77	-44.60 -44.60	0.111	0.197	3.17 3.17	3.17	LOW R AND VR
P-2.10	45	4 (3.53)	3	968	3280	2550	730	90	45.2	46	B_3	1000/ 750	* 970	0.90 0.90	3.10 2.63	823 970	A_{MAX} B_3	856 970	B_1 B_3	38.03 38.05	-35.44 -35.44	0.123	0.223	2.59 2.61	2.61	
P-5.1	45	4 (2.51)	2	950	2480	1390	1090	260	44.1	42.5	C_2	1250/ 1000	1125	1.27 1.27	2.73 1.24	509 1125	A C_2	705 1125	A C_2	10.84 10.86	-8.54 -8.54	0.239	0.440	2.30 2.32	2.31	
P-7.7	45	3 (2.22)	2	750	2390	1190	1200	260	44.7	38	D_2	1550/ 1250	1356 1350	1.34 1.34	1.66 0.88	717 1350	A D_2	1002 1350	A D_2	11.56 11.53	-8.19 -8.19	0.217	0.502	3.37 3.34	3.35	V_W AND V IMBAL-ANCED

* SEE NOTE LAST PAGE OF TABLE

TABLE 11 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED		LOS_W CHART	SV_W		N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE		$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
									MEAS. MPH	CHART MPH		RANGE PCPH/L	FINITE PCPH/L					SV PCPH/L	LOS							
P-8.7	45	5 (3.18)	4	1355	3400	2180	1220	310	47.3	45	B_{MAX}	1200	1200	1.36 1.36	3.64 1.82	599 1200	A B_{MAX}	762 1200	A B_{MAX}	1230 1231	-9.97 -9.97	0.254	0.359	2.32 2.34	2.34	
P-8.10	45	5 (2.71)	4	1355	2610	1710	900	350	44.4	47	B_2	1200/850	1060	1.10 1.10	3.90 1.61	439 1060	A B_2	576 1060	A B_2	8.22 8.21	-6.46 -6.46	0.389	0.315	1.73 1.72	1.73	
P-8.11	45	5 (3.49)	4	1355	3800	2610	1190	420	44.1	45	B_{MAX}	1200/850	1200	1.31 1.31	3.69 2.18	707 1200	A B_{MAX}	836 1200	A B_{MAX}	9.95 9.97	-8.05 -8.05	0.353	0.313	1.90 1.92	1.91	
P-14.3	45	5 (3.06)	4	1467	2620	1650	970	120	47.4	47	B_2	1000/750	*900	1.23 1.23	3.77 1.83	438 900	A B_2	552 900	A B_2	22.98 22.95	-20.83 -20.83	0.124	0.370	2.15 2.12	2.13	
P-14.4	45	5 (3.56)	4	1467	3130	2140	990	150	45.5	47	O	1000/750	*900	1.18 1.18	3.82 2.38	560 900	A B_2	640 900	A B_2	21.35 21.36	-19.86 -19.86	0.150	0.312	1.49 1.50	1.50	
50-M.P.H. ONE-SIDED																										
B-65	50	3 (4.30)	2	4700	4300	2570	1730	405	45.1	49.5	A	1000/750	1000	1.73 1.73	1.27 2.57	2024 1000	E_{CAP} B_{MAX}	1434 1000	D_3 B_{MAX}	10.62 10.62	-9.62 -9.62	0.234	0.402	1.00 1.00	1.00	
P-8.6	50	5 (2.93)	4	1355	2720	1840	880	330	47.7	48	B_2	1200/850	990	1.07 1.07	3.93 1.86	468 990	A A	580 990	A A	8.79 8.79	-7.24 -7.24	0.375	0.324	1.55 1.55	1.55	

*SEE NOTE LAST PAGE OF TABLE

TABLE 11 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED		LOS_W CHART	SV_W		N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE		$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
									MEAS. MPH	CHART MPH		RANGE PCPH/L	FINITE PCPH/L					SV PCPH/L	LOS							
P-11.3	50	3 (2.63)	2	1200	2200	1380	820	300	49.3	485	B_1	1000/ 750	850	1.01 1.01	1.99 1.62	694 850	A A	747 850	A_{MAX} A	7.47 7.45	-6.33 -6.33	0.366	0.373	1.14 1.12	1.13	
P-14.1	50	5 (3.34)	4	1467	3300	1960	1370	80	50.2	43	C_1	1250/ 1000	1050	1.47 1.47	1.47 1.87	1333 1050	D_1 B_2	701 1050	A B_2	43.81 43.84	-40.70 -40.70	0.058	0.411	3.10 3.14	3.12	VERY LOW R, OUT OF REALM OF MODEL (?)
P-15.1	50	4 (3.77)	3	2000	2960	2280	680	200	42.6	50+	A	800	800	0.92 0.92	3.08 2.85	740 800	A A	754 800	A A	15.08 15.08	-13.80 -13.80	0.294	0.230	1.28 1.28	1.28	APPARENT UPSTREAM SPEED CON-STRAINT
I-2	50	3 (5.67)	3	1100	4250	3790	460	30	52.6	50+	A	750	750*	0.62 0.62	2.38 5.05	1592 750	D_{MAX} A	1418 750	D_1 A	141.77 141.75	140.67 140.67	0.065	0.108	1.10 1.08	1.09	LOW R AND VR, OUT OF REALM OF MODEL
I-6	50	2 (3.32)	2	1950	2540	1680	860	140	48.1	50	A	750	750	1.08 1.08	0.92 2.24	1823 750	D_4 A	1244 750	C_{MAX} A	17.77 17.79	-17.11 -17.11	0.163	0.339	0.65 0.68	0.67	
I-8	50	3 (3.10)	2	1450	2715	1745	970	105	52.0	47	B	1000/ 750	900	1.16 1.16	1.84 1.94	948 900	B_4 B_3	930 900	B_4 B_3	26.56 26.57	-24.85 -24.85	0.108	0.357	1.71 1.72	1.72	
I-8.3	50	3 (2.09)	2	1450	1800	810	990	140	51.4	47	B_1	1000/ 750	900	1.19 1.19	1.81 0.90	448 900	A B_2	627 900	A B_2	13.44 13.44	-11.86 -11.86	0.141	0.550	1.58 1.58	1.58	
I-11	50	4 (4.68)	3	1150	3705	3180	525	215	50.5	50	A	800	800	0.70 0.70	3.30 3.98	964 800	B_2 A	935 800	B_2 A	17.40 17.41	-16.23 -16.23	0.410	0.142	1.17 1.18	1.17	

* FOR LOW R VALUE SV EQUIVALENT TO N_b OF 2 LANES (RATHER THAN 3 OR 4) IN ACCORDANCE WITH MODEL.

TABLE 12

COMPUTATION OF k (WEAVING INTENSITY) FACTORS FROM PROJECT DATA BASE

TWO-SIDED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED MEAS. MPH	WEAVING SPEED CHART MPH	LOS_W CHART	SV_W RANGE PCPH/L	SV_W FINITE PCPH/L	N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE SV PCPH/L	COMPOSITE LOS	$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
25, 30 - M.P.H TWO- SIDED																										
B-42	25,30	4 (2.32)	3	625	2545	595	1950	955	21.6	31	E_{MAX}	1900/ 1600	1870	2.00 2.00	2.00 0.32	300 1870	A E_{MAX}	1085 1870	B_{MAX} E_{MAX}	4.54 4.52	-1.66 -1.66	0.490	0.766	2.88 2.88	2.88	
B-43	25,30	4 (3.07)	3	625	3590	540	3050	705	29.6	25+	E/F	1900/ 1600	1900	2.79 2.79	1.21 0.28	446 1900	A E_3	1460 1900	D_2 E_3	8.28 8.27	-4.09 -4.09	0.231	0.850	4.19 4.18	4.19	
B-47	25,30	4 (3.76)	4	980	4800	1125	3675	495	24.3	<30	E/F	1900	1900	3.17 3.17	0.83 0.59	1355 1900	C_4 F	1787 1900	E_3 F	14.44 14.43	-8.70 -8.70	0.135	0.766	5.74 5.73	5.74	
B-48	25,30	4 (3.63)	4	980	4615	1140	3475	425	27.1	<30	E/F	1900	1900	3.03 3.03	0.97 0.60	1175 1900	B_{MAX} E/F	1725 1900	E_2 E/F	16.24 16.23	-9.86 -9.86	0.122	0.753	6.38 6.37	6.37	
B-49	25,30	4 (3.65)	4	564	5050	2935	2115	415	26.3	30	E/F	1900	1900	2.11 2.11	1.89 1.54	1553 1900	D_3 E/F	1736 1900	E_2 E/F	16.73 16.71	-11.17 -11.17	0.196	0.419	5.56 5.54	5.55	
B-517	25,30	4 (3.42)	4	564	4630	2760	1870	240	32.9	31	E_{MAX}	1900	1900	1.93 1.93	2.07 1.49	1333 1850	C_3 E_{MAX}	1583 1850	D_4 E_{MAX}	18.60 18.60	-12.62 -12.62	[illegible]	[illegible]	5.98 5.97	5.98	
B-518	25,30	4 (3.63)	4	564	5050	3090	1960	330	29.4	30	E_{MAX}	1900/ 1650	1850	2.00 2.00	2.00 [illegible]	1545 1900	D_3 E_{MAX}	1723 1900	E_1 E_{MAX}	20.90 20.90	-14.30 -14.30	0.168	0.388	6.60 [illegible]	[illegible]	k SLIGHT-LY HIGH SOME IMBALANCE

TABLE 12 (cont'd)

1 TEST NO.	2 SPEED GROUP MPH	3 N	4 N_b	5 L FT	6 V TOTAL PCPH	7 V_N PCPH	8 V_W PCPH	9 W_2 SMALL WEAV. PCPH	10 WEAVING SPEED MEAS. MPH	11 WEAVING SPEED CHART MPH	12 LOS_W CHART	13 SV_W RANGE PCPH/L	14 SV_W FINITE PCPH/L	15 N_W REQ'D	16 N_N AVAIL. OR REQ'D	17 SV_N PCPH/L	18 LOS_N	19 COMPOSITE SV PCPH/L	20 COMPOSITE LOS	21 $\frac{N \cdot SV}{W_2}$	22 $1-\frac{V}{W_2}$	23 R	24 VR	25 k CALCULATED	26	27 COMMENTS
B-52	25,30	4 (3.62)	3	497	4830	2280	2550	285	29.7	<30	E/F	2000/ 1900	1900	2.42 2.42	1.58 1.20	1443 1900	D_2 E/F	1720 1900	E_2 E/F	24.14 24.13	-1595 -15.95	0.112	0.539	8.19 8.18	8.18	k DIS-CARDED GEOMETRIC CONSTRAINT
35, 40 - M.P.H. TWO-SIDED																										
B-51	35,40	4 (2.82)	4	564	3590	1910	1680	330	38.3	33	E_3	1900/ 1650	1825	1.77 1.77	2.23 1.05	857 1825	A E_3	1286 1825	C_2 E_3	15.59 15.60	-9.88 -9.88	0.136	0.462	5.71 5.72	5.71	
B-51.1	35,40	4 (2.10)	4	564	2430	1470	960	370	41.7	42	D_3	1650/ 1400	1550	1.15 1.15	2.85 0.95	516 1550	A D_3	814 1550	A D_3	8.80 8.80	-5.57 -5.57	0.335	0.395	3.23 3.23	3.23	
B-51.3	35,40	4 (2.65)	4	564	3360	1900	1460	270	39.0	35	E_2	1900/ 1650	1775	1.58 1.58	2.42 1.07	785 1775	A E_2	1176 1775	B_{MAX} E_2	17.42 17.42	-12.44 -12.44	0.185	0.435	4.98 4.98	4.98	
B-51.5	35,40	4 (2.68)	4	564	3410	1890	1520	330	35.8	34	E_2	1900/ 1650	1800	1.63 1.63	2.37 1.05	798 1800	A E_2	1207 1800	B_{MAX} E_2	14.63 14.62	-9.33 -9.33	0.217	0.446	5.30 5.29	5.29	
B-51.6	35,40	4 (3.05)	4	564	4010	2260	1750	430	35.8	31.5	E_3	1900/ 1650	1860	1.83 1.83	2.17 1.22	1041 1860	A E_3	1416 1860	C_{MAX} E_3	13.17 13.19	-8.33 -8.33	0.246	0.436	4.84 4.86	4.85	
B-52.3	35,40	4 (2.72)	3	497	3380	1560	1820	240	34.5	30	E_{MAX}	1900/ 1600	1900	1.90 1.90	2.12 0.82	743 1900	A E_{MAX}	1292 1900	C_4 E_{MAX}	21.53 21.53	-13.08 -13.08	0.132	0.538	8.45 8.45	8.45	k DIS-CARDED GEOMETRIC CONSTRAINT

TABLE 12 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED MEAS. MPH	WEAVING SPEED CHART MPH	LOS_W CHART	SV_W RANGE PCPH/L	SV_W FINITE PCPH/L	N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE SV PCPH/L	COMPOSITE LOS	$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
B-54	35,40	3 (2.22)	2	738	2400	635	1765	295	37.6	36	E_2	1900/ 1550	1690	1.84 1.84	1.16 0.38	547 1690	A E_3	1249 1690	C_{MAX} E_3	12.70 12.72	-7.14 -7.14	0.167	0.735	5.56 5.58	5.57	
B-54.1	35,40	3 (3.14)	2	738	3980	2270	1710	690	33.9	37	E_1	1900/ 1550	1700	1.81 1.81	2.19 1.33	1037 1700	A_4 E_1	1337 1700	C_{MAX} E_1	7.75 7.74	-4.77 -4.77	0.404	0.430	2.98 2.97	2.98	
B-54.2	35,40	3 (1.93)	2	738	2030	625	1405	250	37.9	40	D_{MAX}	1550/ 1250	1550	1.53 1.53	1.47 0.40	425 1550	A D_{MAX}	999 1550	B_{MAX} D_{MAX}	11.99 11.97	-7.12 -7.12	0.178	0.692	4.87 4.85	4.86	
B-54.7	35,40	3 (1.65)	2	738	1550	460	1090	290	35.3	42.5	D_2	1550/ 1250	1400	1.32 1.32	1.68 0.33	274 1400	A D_1	770 1400	B_1 D_2	7.97 7.97	-4.34 -4.34	0.266	0.703	3.63 3.63	3.63	APPARENT RAMP SPEED CONSTRAINT
B-60	35,40	3 (4.97)	2	4665	5460	2480	2980	970	33.8	50	B_{MAX}	1100/ 800	1100	2.72 2.72	0.28 2.25	1938 1100	E_{MAX} B_{MAX}	1824 1100	E_4 B_{MAX}	5.64 5.64	-4.63 -4.63	0.326	0.546	1.01 1.01	1.01	k MODELS OK; BUT LOS, V_w, V IMBAL-ANCED
B-63	35,40	3 (4.24)	2	4650	4525	1740	2785	1150	34.5	50.5	B_{MAX}	1100/ 800	1070	2.61 2.61	0.39 1.63	4462 1070	F B_{MAX}	1511 1070	D_3 B_{MAX}	3.94 3.95	-2.95 -2.95	0.413	0.615	0.99 1.00	1.00	"
B-63.5	35.40	3 (4.30)	2	4650	4600	1800	2800	1160	30.3	50.5	B_3	1100/ 800	1070	2.62 2.62	0.38 1.68	4737 1070	F B_3	1535 1070	D_4 B_3	3.97 3.97	-2.97 -2.97	0.414	0.609	1.00 1.00	1.00	"

TABLE 12 (cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
TEST NO.	SPEED GROUP MPH	N	N_b	L FT	V TOTAL PCPH	V_N PCPH	V_W PCPH	W_2 SMALL WEAV. PCPH	WEAVING SPEED MEAS. MPH	WEAVING SPEED CHART MPH	LOS_W CHART	SV_W RANGE PCPH/L	SV_W FINITE PCPH/L	N_W REQ'D	N_N AVAIL. OR REQ'D	SV_N PCPH/L	LOS_N	COMPOSITE SV PCPH/L	COMPOSITE LOS	$\frac{N \cdot SV}{W_2}$	$1-\frac{V}{W_2}$	R	VR	k CALCULATED		COMMENTS
50-M.P.H. TWO-SIDED																										
B-53	50	4 (2.53)	3	1583	2615	790	1825	180	47.8	45.5	C_3	1350/ 1100	1325	1.93 193	2.07 0.60	382 1325	A C_3	837 1327	A_{MAX} C_3	18.60 18.62	-13.53 -13.53	0.099	0.698	5.07 5.09	5.08	
B-53.1	50	4 (2.16)	3	1583	2080	630	1450	160	49.2	48.5	C_1	1350/ 1100	1175	1.62 1.62	2.38 0.54	265 1175	A C_1	634 1175	A C_1	15.85 15.86	-12.00 -12.00	0.110	0.697	3.85 3.86	3.86	
B-53.4	50	4 (2.67)	3	1583	2820	960	1860	150	46.2	45.5	C_{MAX}	1350/ 1100	1325	1.95 1.95	2.05 0.72	468 1325	A C_{MAX}	886 1325	B_1 C_{MAX}	23.63 23.59	-17.80 -17.80	0.081	0.661	5.83 5.79	5.81	
B-53.5	50	4 (2.18)	3	1583	2120	650	1470	160	46.0	48	C_2	1350/ 1100	1200	1.64 1.64	2.36 0.54	275 1200	A C_2	654 1200	A C_2	16.35 16.36	-12.50 -12.50	0.109	0.693	3.85 3.86	3.86	

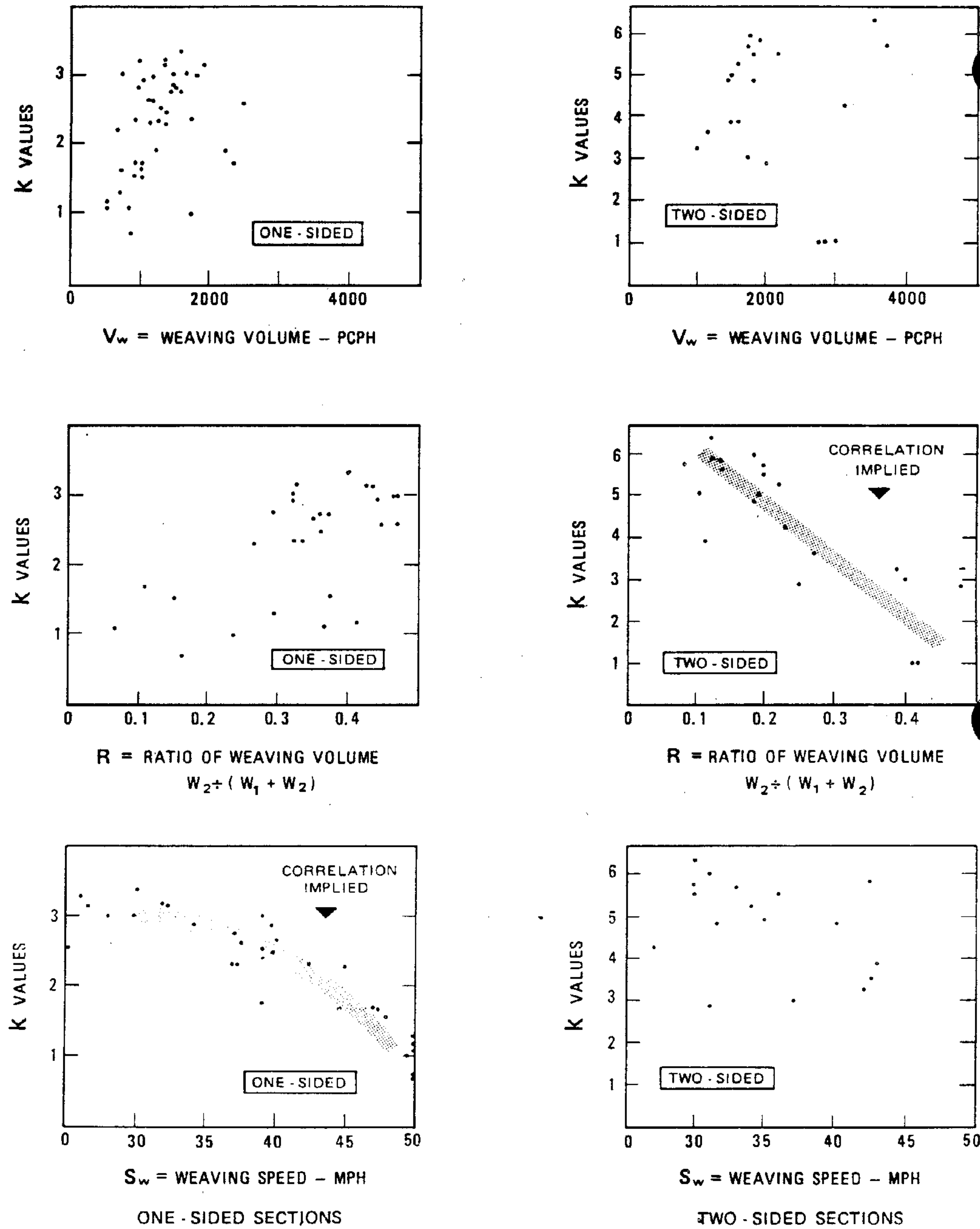


Figure 29. EXAMINATION OF K (WEAVING INTENSITY FACTOR) CORRELATION PROBABILITIES WITH SEVERAL VARIABLES

One-Sided Sections

In examining the k factors in Table 11 with a variety of plots of the points with respect to the speed of weaving, it became evident that the k's logically separated into two sets--those representing high R values, and those representing low R values, [$R = W_2 \div (W_1 + W_2)$ in which W_1 is the larger and W_2 the smaller weaving volume]. The appropriate division occurs with one set having R values of 0.25 to 0.50 and the other having R values of $\lesssim 0.20$. Because of relatively small number of points and slight overlap between the two groups, values from 0.25 to 0.20 would be considered to lie between the two curves. The high and low R points are identified by symbols of solid and open circles, respectively in Table 13.

The plot of each set of data points is shown in Figure 30. A regression line--using an N^{th} order equation to the second power--was fitted separately to the high R set in the top and to the low R set in the bottom part of the figure. Excellent correlation was achieved with r^2 of 0.85 and 0.91, respectively, and corresponding standard errors for K of 0.25 and 0.27.

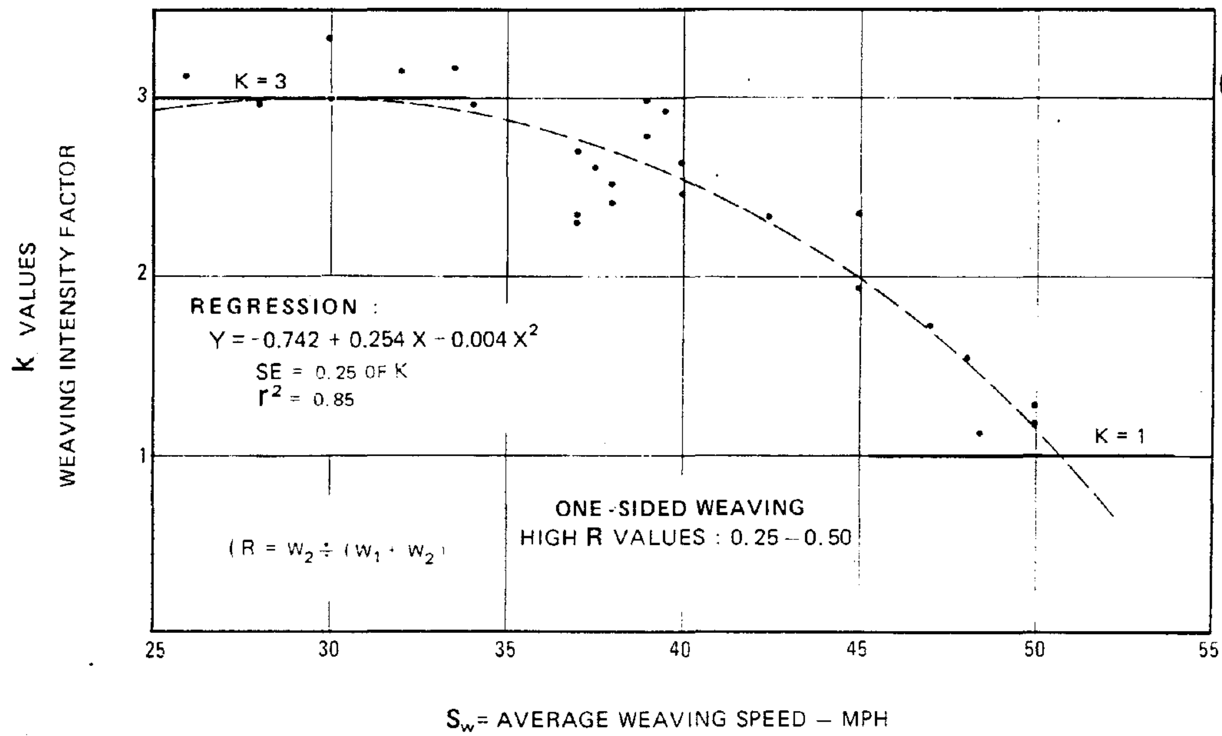
The regression curves with minor adjustments were hand-fitted in the vicinity of k limits of 1 and 3 as shown in Figure 31, thus permitting their adjusted form to be used in application with direct reading of k values for various speeds of weaving traffic. The two plots (high R's and low R's) were thus combined and turned over top-to-bottom for orientation toward their ultimate use in the nomograph. To allow for a transitional effect in the use of R below 0.25, the lower curve (considering the range of values used in its derivation) was designated $R \lesssim 0.20$ as shown in Figure 32 for its final application. Thus, values from 0.25 to 0.20 would be interpolated between the two curves. In its completed form for the nomograph, Figure 33, the k values with the two R curves are shown adjusted horizontally to the k turning-line speed scale; the turning line for k is indicated in its selected position in Figure 22 from which the speed scale is calibrated.

Two-Sided Sections

In referring to the correlation implied between k and R for two-sided weaving sections in Figure 29, and in examining the k factors in Table 12 and their summary in Table 14, the postulated values indicate a definite trend from 3 to 6 between weaving speeds of 30 to 45 mph. Beyond 45 mph k values must and do transition to a value of 1 to meet uninterrupted-flow conditions at approximately 55 mph.

Several forms of regressions were run for the data points (30-45 mph) as shown in Figure 34. Particularly good results were achieved using geometric and exponential relations, with a correlation coefficient of 0.86 and standard error of 0.10 of k for the latter. The regression curve shown by the solid line, was hand-adjusted at each end to practical limitations of k for the indicated speed range. The open circled points high-lighted on the graph were selected as the controlling values for further development. To do so it was necessary to relate these values to the speed of weaving traffic, along with the transition of k factors to a value of beyond 45 mph.

This was accomplished in Figure 35. The graph was formatted from preliminary investigation of the nomograph structure. Speed of weaving was introduced as the abscissa, transferred from the turning line for k of Figure 26. Values of k and R were interrelated to produce coincidental (horizontal) lines from 30 to 45 mph. As shown in the upper part of Figure 35, an indication of transitions of k factors to a value of 1 were sketched approximately from a plot of several points noted in Table 14. Due to limited data and a more likely gradual change in k values, the smoother simulated transitions, as shown in the lower part of Figure 35, were drawn to represent the relationship for the nomograph.



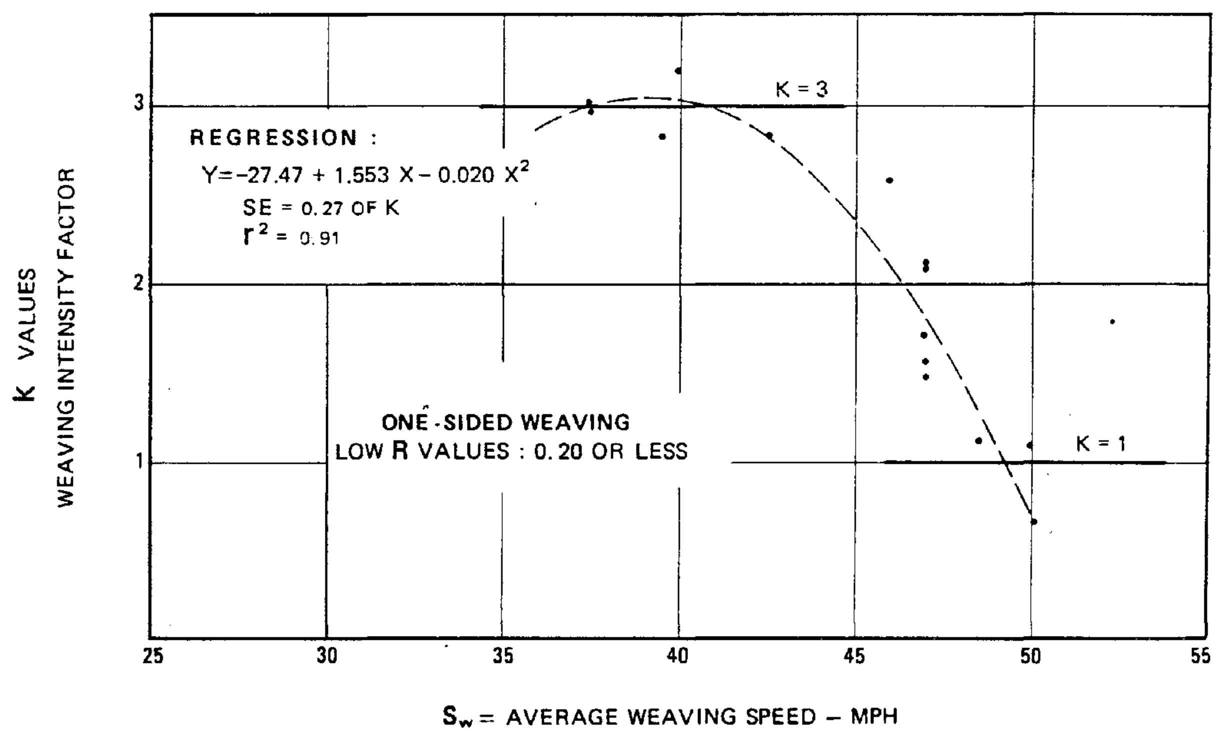
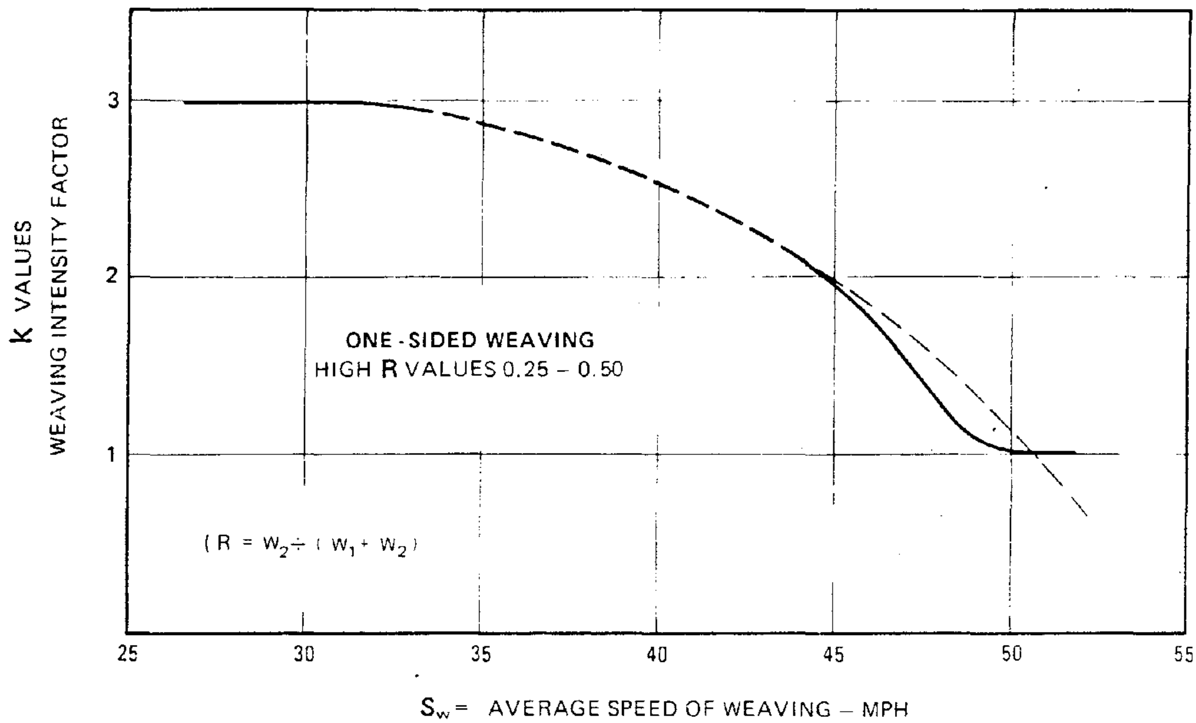


Figure 30. **REGRESSION OF k VALUES AS RELATED TO SPEED OF WEAVING TRAFFIC**

ONE-SIDED WEAVING SECTIONS



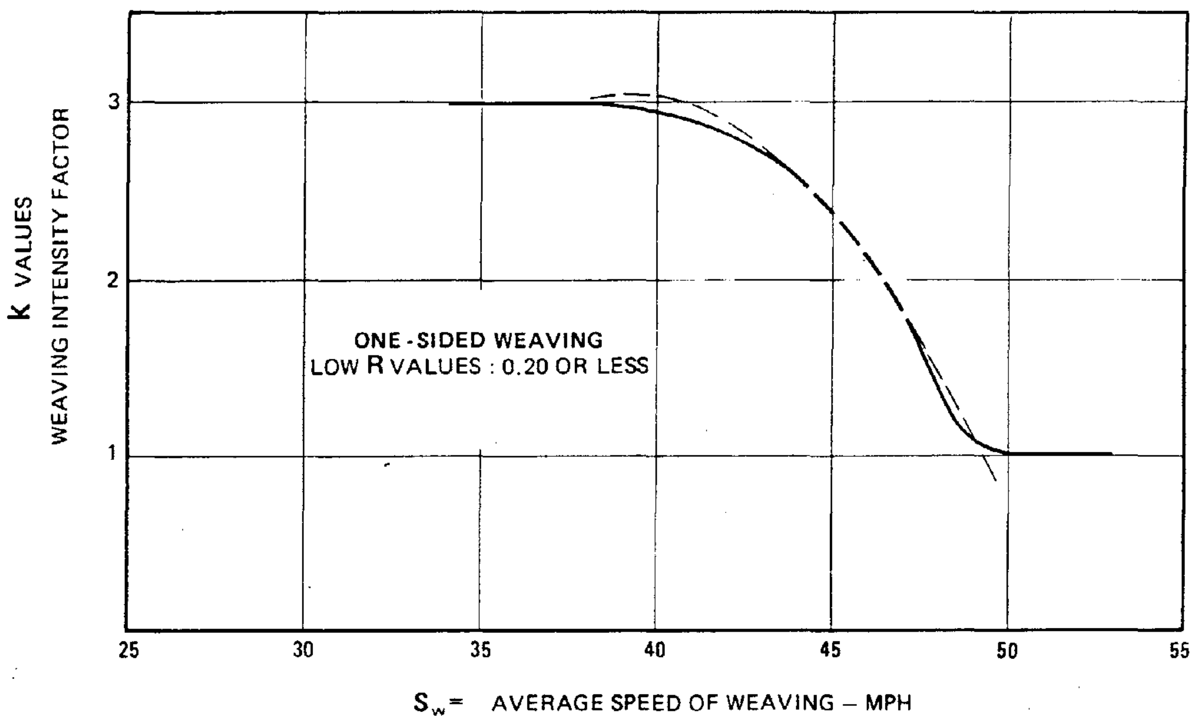
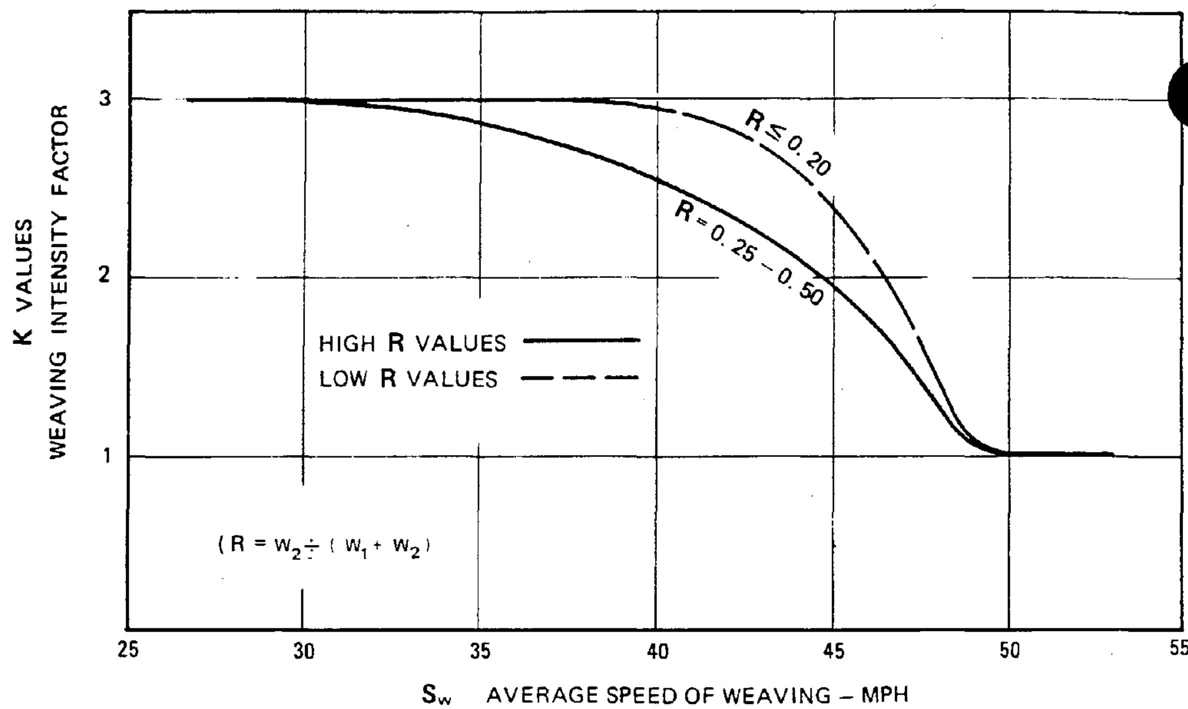
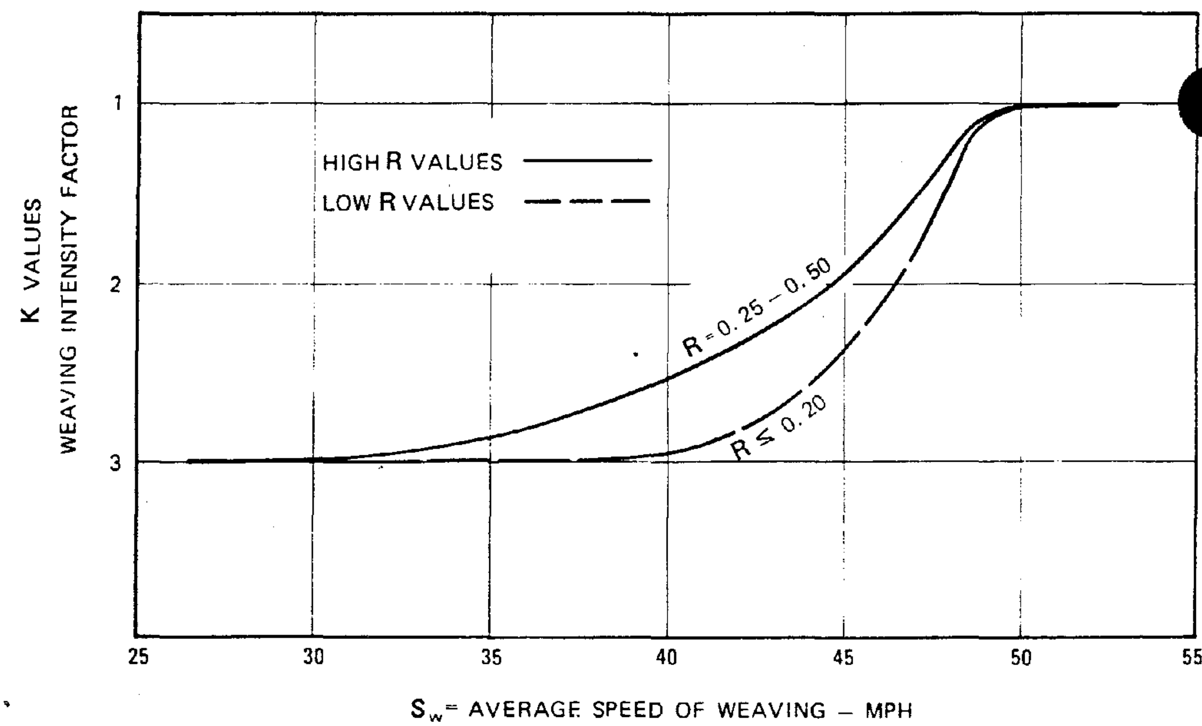


Figure 31. K VALUES AS RELATED TO SPEED REGRESSION LINES ADJUSTED FOR APPLICATION

ONE-SIDED WEAVING SECTIONS



A–COMBINED PLOT OF K FOR HIGH AND LOW R VALUES



B – REVERSE PLOT OF K FOR COMBINED R VALUES

Figure 32. K VALUES AS RELATED TO SPEED OF WEAVING, COMBINED PREPARATORY FOR NOMOGRAPH

ONE-SIDED WEAVING SECTIONS

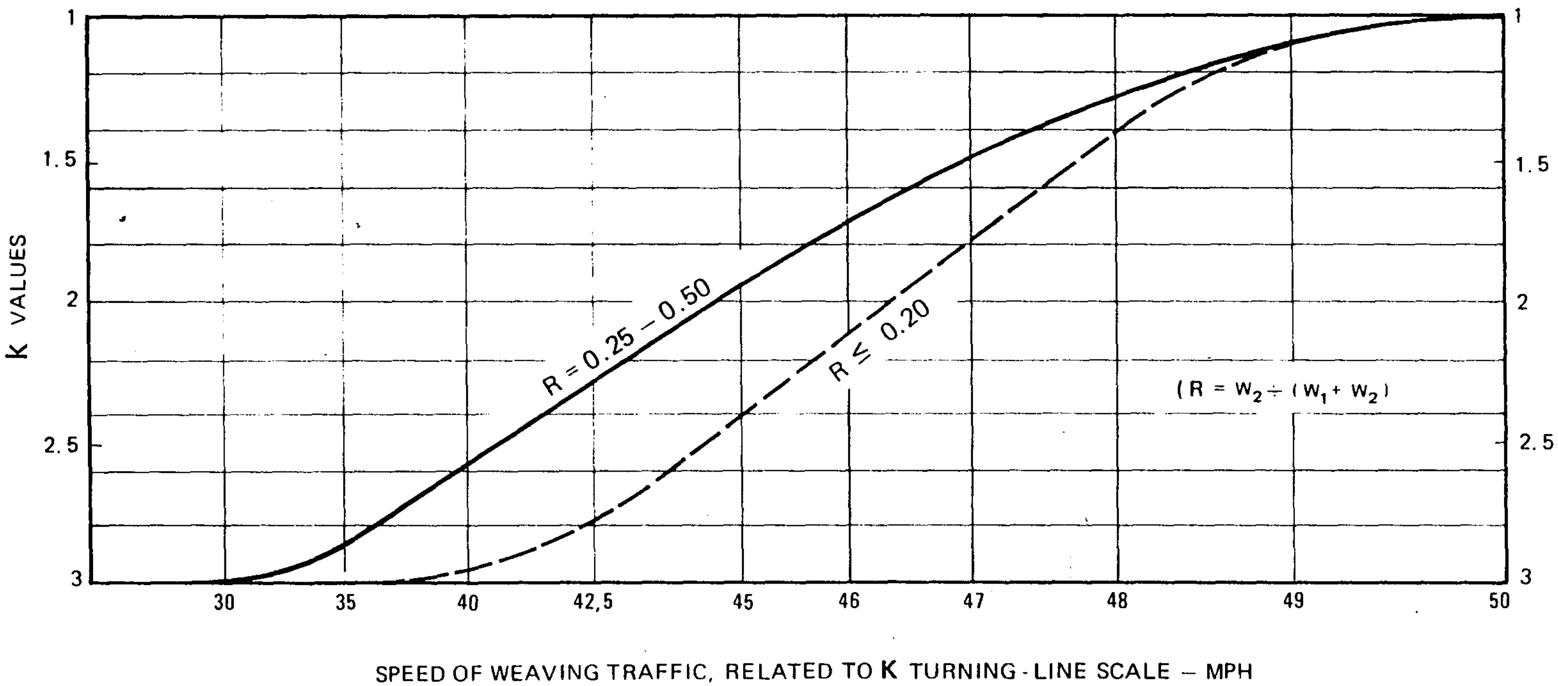


Figure 33. **PLOT OF K VALUES FOR USE IN NOMOGRAPH**

ONE-SIDED WEAVING SECTIONS

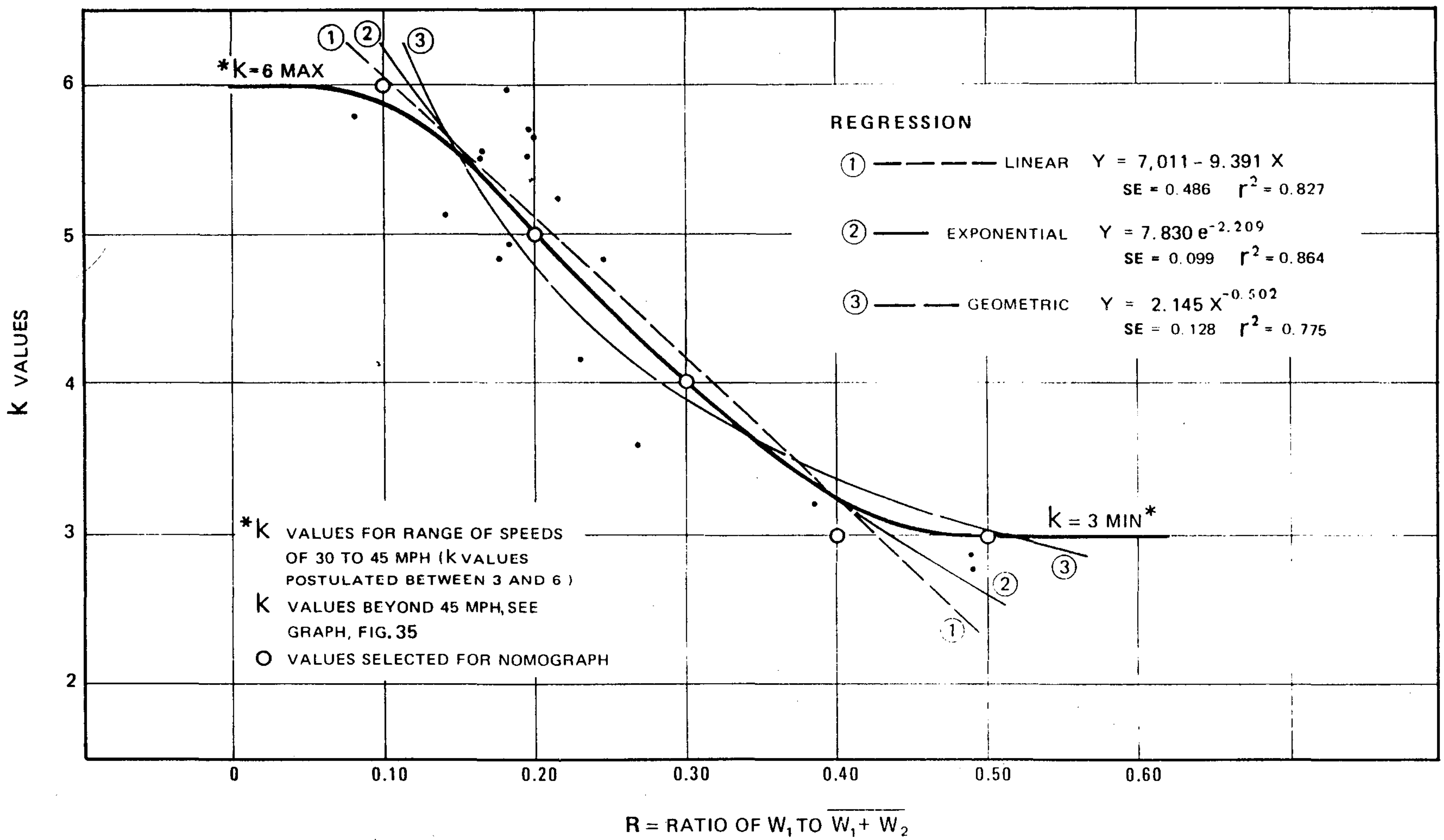


Figure 34. **DERIVATION OF k VALUES AS RELATED TO WEAVING RATIO**

REGRESSION LINES ADJUSTED FOR APPLICATION

TWO-SIDED SECTIONS

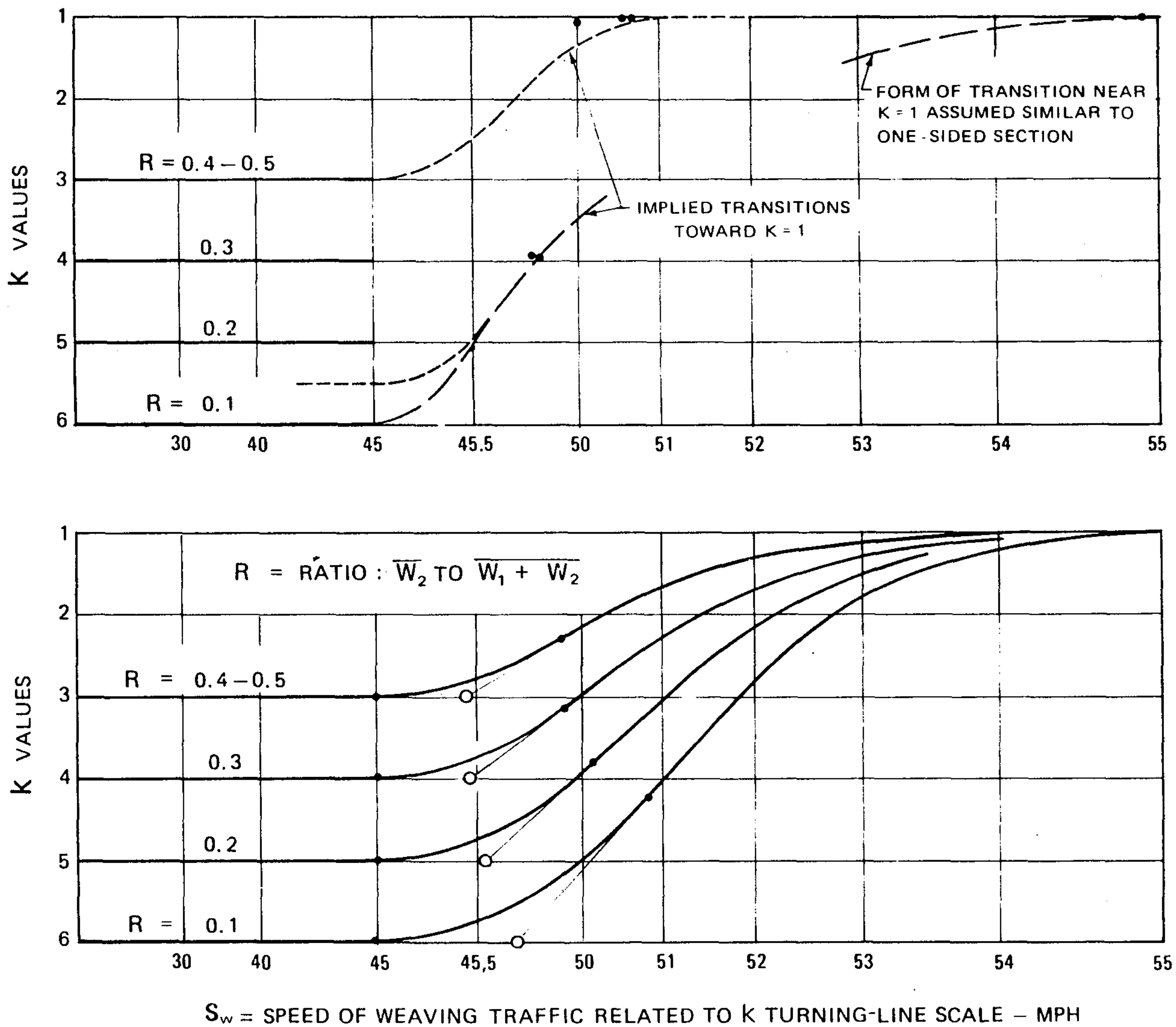


Figure 35. **DEVELOPMENT AND PLOT OF K VALUES FOR NOMOGRAPH**

TWO-SIDED WEAVING SECTIONS

TABLE 13

SUMMARY OF K VALUES AND INDEX TO DATA POINTS FOR ANALYSIS

ONE-SIDED WEAVING SECTIONS

SITE NO.	WEAVING SPEED Average--mph Actual	Modeled	N	L feet	V_w pcph	R	VR	WEAVING FACTOR k Calculated	DATA USED FOR See Key *	REMARKS
B-41	26.9	25+	4	556	2440	0.471	0.688	2.58	▲ ● √	LOS V_w:E/F
B-24	29.9	25+	5	659	2750	0.211	0.442	3.91	▲	K not used; see note §
B-8	29.8	26	4	445	1890	0.434	0.360	3.13	▲ ●	At or near LOS F
B-7	26.6	28	4	445	1785	0.467	0.329	2.99	▲ ● √	At or near LOS F
B-6	32.2	30	2	425	1580	0.402	0.991	3.36	▲ ● √	C-D Road
B-9	28.4	30	5	449	1625	0.468	0.251	3.00	▲ ● √	
B-6a	32.2	30	2	425	1580	0.402	0.991	3.36	▲ ● √	C-D Road
M-1	28.6	32	6	650	1755	0.296	0.255	3.61	▲ √	odd lane configuration
B-5	33.5	32	2	425	1295	0.425	0.996	3.16	▲ ● √	C-D Road
P-10.4	33.9	32.5	4	527	1440	0.271	0.326	3.97	▲ √	K not used; see note †
B-33	29.6	33.5	5	521	1315	0.323	0.169	3.17	▲ ● √	
B-10	34.4	34	2	503	1165	0.442	0.991	2.95	▲ ● √	C-D Road
B-34	34.4	35	4	621	1190	0.244	0.194	4.12	▲ √	K not used; see note φ
P-2.8	34.5	36.5	4	968	1760	0.153	0.279	3.82	▲ √	K not used; see note †
B-32	36.1	37	4	822	1400	0.368	0.250	2.69	▲ ● √	
B-15	39.9	37	2	900	1595	0.335	1.000	2.32	▲ ● √	C-D Road
P-5.8	42.3	37	4	950	1720	0.320	0.467	2.28	▲ ● √	
B-17	36.7	37.5	4	710	1170	0.444	0.222	2.60	▲ ● √	
M-2	40.0	37.5	4	921	1450	0.238	0.430	3.01	▲ √	V_w and V imbalanced
B-20	36.5	38	2	868	1265	0.360	0.966	2.50	▲ ● √	C-D Road
B-27	39.3	38	2	844	1360	0.305	0.996	2.40	▲ ● √	C-D Road
P-7.7	44.7	38	3	750	1200	0.217	0.502	3.35	▲	V_w and V imbalanced
P-2.4	39.8	39	4	968	1480	0.115	0.248	4.16	▲ √	K not used; see note †
P-10.1	41.5	39	3	527	730	0.321	0.448	2.99	▲ ● √	
B-28	43.9	39	5	1032	1440	0.288	0.212	2.77	▲ ● √	

KEY: * ▲ Regression of $V_w/S_w/L$

● K Value--Large R

o K Value--Small R

√ Speed Comparison Diagram

§ K discarded--Highly imbalanced, LOS F operation, outside scope of model.

† K discarded--Highly imbalanced, large disparity in LOS of V_w and V

φ K discarded--Highly imbalanced in LOS of V_w vs. LOS of V; also low VR and/or R.

TABLE 13 (cont'd)

SITE NO.	WEAVING SPEED Average--mph Actual	Modeled	N	L feet	V_w pcph	R	VR	WEAVING FACTOR k Calculated	DATA USED FOR See Key*	REMARKS
B-18	36.3	39.5	4	725	1025	0.322	0.277	2.93	▲ ● √	
B-11	33.0	40	5	1054	1370	0.363	0.213	2.44	▲ ●	Appar. upstream speed constr't.
B-3	34.6	40	4	917	1130	0.351	0.216	2.64	▲ ● √	
P-5.1	44.1	42.5	4	950	1090	0.239	0.440	2.31	▲ ● √	
P-2.1	42.7	44	4	968	900	0.111	0.197	3.17	▲ √	Low R and VR
P-14.1	50.2	44	5	1467	1370	0.058	0.411	3.12	▲	Very low R, outside Model
P-8.7	47.3	45	5	1355	1220	0.254	0.359	2.33	▲ ● √	
I-8	52.0	47	3	1450	970	0.108	0.357	1.72	▲ o √	
P-14.4	45.5	47.5	5	1467	990	0.152	0.312	1.50	▲ o √	
P-8.6	47.7	48	5	1355	880	0.375	0.324	1.55	▲ ● √	
P-11.3	49.3	48.5	3	1200	820	0.366	0.373	1.13	▲ ● o √	
B-65	45.1	49.5	3	4700	1730	0.234	0.402	1.00	▲ o √	
I-6	48.1	50	2	1950	860	0.163	0.339	0.67	▲ o √	
I-11	50.5	50	4	1150	525	0.410	0.142	1.17	▲ ● √	
P-15.1	42.6	50>	4	2000	680	0.294	0.230	1.28	▲ ●	Appar. Speed Constraint
I-2	52.3	50>	3	1100	457	0.065	0.108	1.09	▲ o √	

Additional Points for Calculation of k Values

B-28.2	45.4	39.5	5	1032	1440	0.285	0.200	2.83	o	
B-17.2	37.7	40	4	710	960	0.260	0.221	3.21	o	
B-3.2	39.2	42.5	4	917	950	0.266	0.223	2.83	o	
P-8.11	44.1	45	5	1355	1190	0.353	0.313	1.91	●	
P-2.10	45.2	46	4	968	730	0.123	0.223	2.60	o	
P-8.10	44.4	47	5	1355	900	0.389	0.315	1.73	●	
P-14.3	47.4	47	5	1467	970	0.124	0.370	2.13	o	
I-8.3	51.4	47	3	1450	990	0.141	0.550	1.58	o	
B-3.7	41.7	47	4	917	636	0.264	0.218	2.10	o	

KEY: * ▲ Regression of $V_w S_w / L$
● k Value--Large R
o k Value--Small R
√ Speed Comparison Diagram

TABLE 14

SUMMARY OF K VALUES AND INDEX TO DATA POINTS FOR ANALYSIS

TWO – SIDED WEAVING SECTIONS

SITE NO.	WEAVING SPEED Average--mph Actual	Modeled	N	L feet	V_w pcph	R	VR	WEAVING FACTOR k Calculated	DATA USED for See Key *	REMARKS
B-43	29.6	25+	4	625	3050	0.231	0.850	4.19	▲ o √	
B-47	24.3	<30	4	980	3675	0.135	0.766	5.73	▲ o √	
B-48	27.1	<30	4	980	3475	0.122	0.753	6.37	▲ o √	
B-52	29.7	<30	4	497	2550	0.112	0.529	8.18	▲ √	K not used; † External constr't.
B-49	26.3	30	4	564	2115	0.196	0.419	5.55	▲ o √	
B-51.8	29.4	30	4	564	1960	0.168	0.388	6.60	▲ √	K not used; Imbalanced
B-52.3	34.5	30	4	497	1820	0.132	0.538	8.45	▲ √	K not used; † External constr't.
B-42	31.6	31	4	625	1950	0.490	0.766	2.88	▲ o √	
B-51	38.3	33	4	564	1680	0.196	0.468	5.71	▲ o √	
B-51.5	35.8	34	4	564	1520	0.217	0.446	5.29	▲ o √	
B-54	37.6	36	3	738	1765	0.167	0.735	5.57	▲ o √	
B-54.2	37.9	40	3	738	1405	0.178	0.692	4.86	▲ o √	
B-51.1	41.7	42	4	564	960	0.385	0.395	3.23	▲ o √	
B-54.7	35.3	42.5	3	738	1090	0.266	0.703	3.63	▲ o	Appar. ramp speed constr't.
B-53	47.8	45.5	4	1583	1825	0.099	0.698	5.08	▲ o √	Transition k of 6 to 1
B-53.5	46.0	48	4	1583	1470	0.109	0.693	3.86	▲ o √	Transition k of 6 to 1
B-53.1	49.2	48.5	4	1583	1450	0.110	0.697	3.86	▲ o √	Transition k of 6 to 1

Additional Points for Caclulation of k Values

B-51.7	32.9	31	4	564	1870	0.182	0.404	5.98	o	
B-51.6	35.8	31.5	4	564	1750	0.246	0.436	4.85	o	
B-51.3	39.0	35	4	564	1460	0.185	0.435	4.98	o	
B-54.1	33.9	37	3	738	1710	0.404	0.430	2.98	o	
B-53.4	46.2	45.5	4	1583	1860	0.081	0.660	5.81	o	
B-60	33.8	50	3	4665	2980	0.326	0.546	1.01	o	Transition k of 3 to 1
B-63.5	30.3	50.5	2	4650	2800	0.414	0.609	1.00	o	Transition k of 3 to 1
B-63	34.5	50.5	3	4650	2785	0.413	0.615	1.00	o	Transition k of 3 to 1

KEY: * ▲ Regression of $V_w/S_w/L$
o k Values
√ Speed Comparison Diagram

† Both data points of high k from same site; apparent constraint on outer movements, also E/F weaving

Configuration of Weaving Sections and Lane Balance

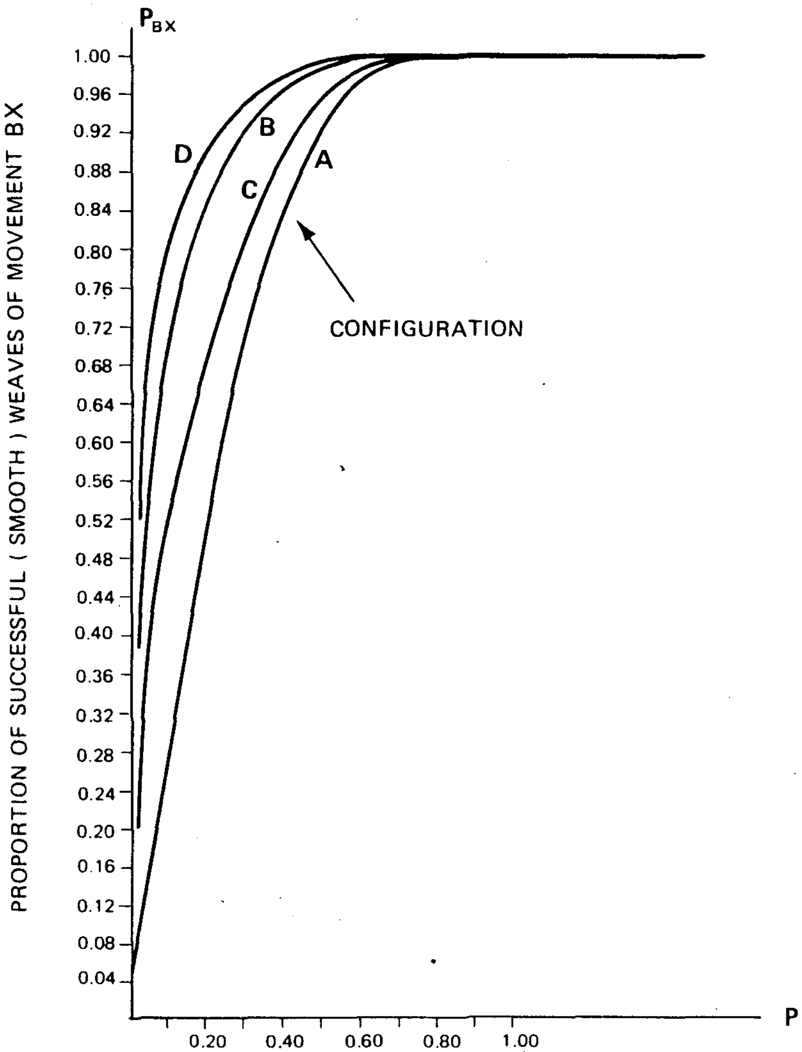
Lane configuration within the weaving section has a pronounced effect upon efficiency of operation. Lane arrangement in terms of continuity and what may be termed "lane balance" at the entrance to and exit from the weaving section are features when properly applied permit traffic to be served more adequately. Examples of configurations are identified in Figure 3 as to form, which for the most part have been dealt with in development of the various model elements. Configuration with respect to lane arrangement and lane balance as described in Figure 4 is a further feature which must be accounted for in determining more appropriately the operational characteristics of weaving sections.

The most significant effect of configuration with respect to lane arrangement and lane balance has to do with the influence of the number of lane changes made in the act of weaving. Lane configuration is not a factor which has been explicitly considered in the 1965 HCM weaving procedures. Moreover, the manner in which the BPR data was collected, as well as other subsequent data compiled on weaving sections, has not specifically addressed this problem. Speed variations between weaving and nonweaving traffic along with lane-change distributions, however, were evident in some cases for different volume to lane relations within these data. The means of facilitating and simplifying weaving operations by providing lane continuity and lane balance has been recognized by the authors of this report. This primarily has to do with the means of minimizing number of lane changes and providing an "optional" lane at the exit point of the weaving section as demonstrated in Figure 4. The full extent of operational improvement with this feature is not known nor has it been measured directly in the field.

PINY, however, in its NCHRP Report 3-15, has made some rationalizations, and formulations including a lane-changing model, to gain some insights into the effects of configuration. The lane-changing model demonstrates the quality of service being provided by a configuration. This is measured by the number of percentage of "successful" or "unforced" weaves apt to take place within the weaving section. As shown in Figure 36, four different configurations were compared in the PINY report for various lane-changing probabilities using movement BX as the prime measure of "successful" (smooth) weaves. Based on various configurations (A through D) and their probabilities (p) of achieving successful weaves, only a certain percentage (noted as P_{BX}) would be predicted to accomplish the weaving within the section. The remainder of weaving vehicles, not situated in the proper lanes toward the end of the section, would have to force their maneuver to complete the weave with degrading effect. Based on this, P_{BX} is taken as an indicator of the quality of weaving operation.

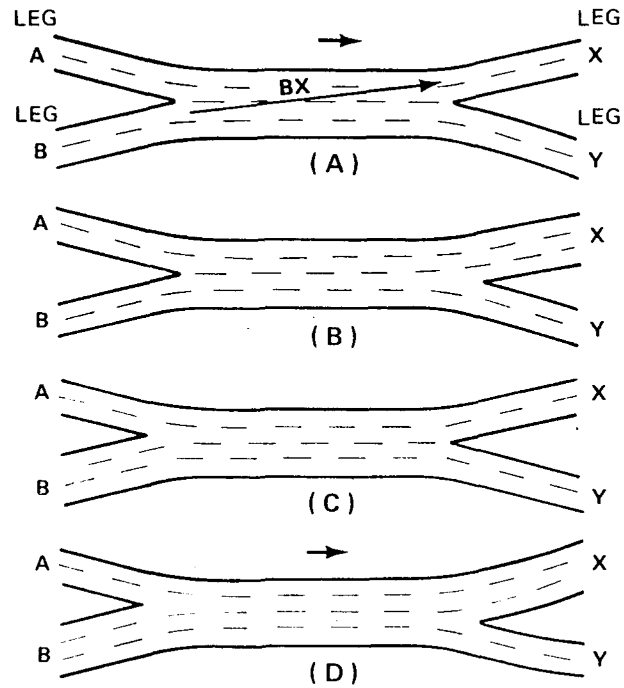
The analyses of the four configurations, compared for various probabilities of achieving certain percentages of successful weaves (P_{BX}) is summarized by a graphical relationship in Figure 36. The results indicate configuration D as the most efficient, followed by B, C and A.. Consideration of configuration D as the best and configuration A as the worst in performance is reinforced by the overall design to minimize the number of lane shifts through application of lane balance and lane continuity referred to in Figure 4.

The distinction between the two basic configurations, which may be accounted for in analysis and design of weaving sections may be identified by the provision of these two features of design. Assuming that lane continuity would be inherent to



COMPARISON OF WEAVING CONFIGURATIONS FOR VARIOUS PROBABILITIES OF SUCCESSFUL MOVEMENT BX

COMPARISON OF WEAVING SECTIONS



FOUR ALTERNATIVF WEAVING CONFIGURATIONS OF FOUR LANES

SOURCE: DIRECT REPRODUCTION FROM NCHRP REPORT 3-15, FIGS. IV-3 AND IV-4, PINY, NOV. 30, 1973.

Figure 36. **EFFECT OF CONFIGURATION OF WEAVING SECTIONS ON QUALITY OF OPERATION**
AS ANALYZED BY POLYTECHNIC INSTITUTE OF NEW YORK

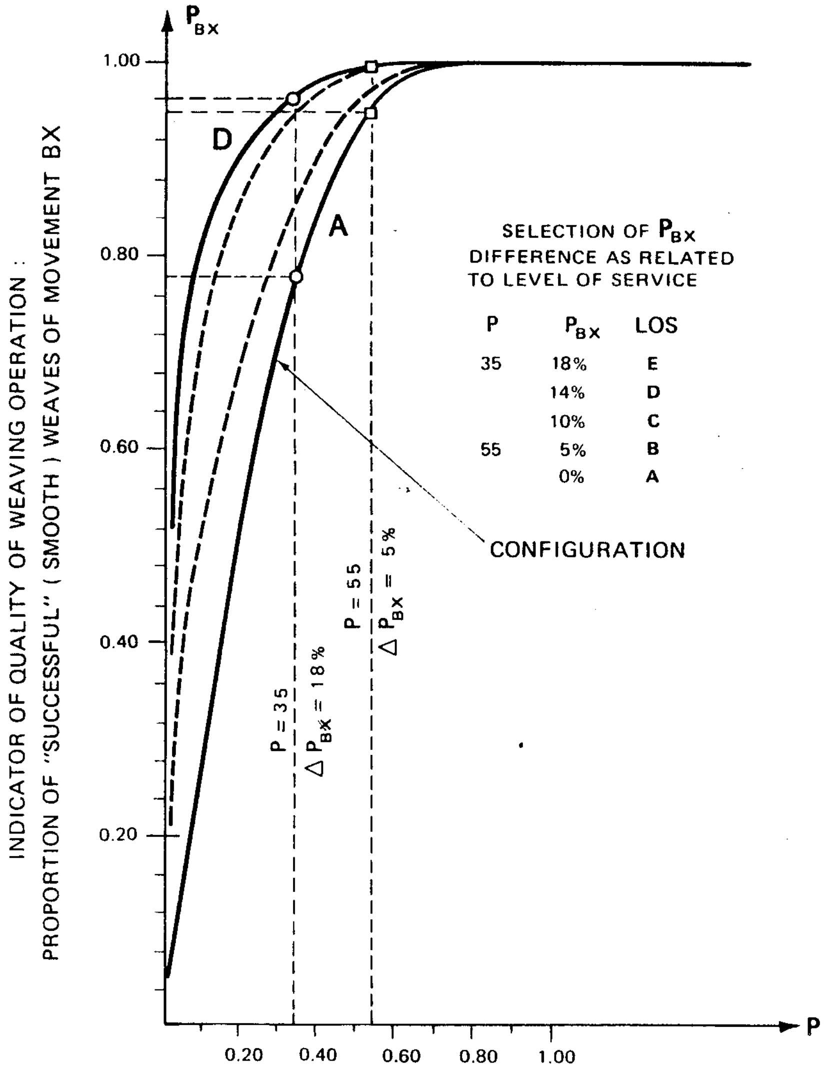
the main roadway through the weaving section, the remaining configuration element of lane balance--its provision or absence--can be utilized as an additional measure by which to adjust the operational quality of weaving sections.

Lane continuity pertains to the provisions of basic number of lanes on the facility and allows a through driver to maintain normally his lane position in negotiating the weaving section. Lane balance, which is an extension of lane continuity, is the arrangement of lanes at ramp exits and entrances with a uniform pattern which provides a degree of operational flexibility. With respect to exits, lane balance simply means the provision of "one more lane going away" (the combined number of lanes on the freeway and ramp after the exit should be one more than on the freeway preceding the exit); also, not more than one preceding lane should be dropped at a time. At entrances, the requirement is that the number of lanes must "add up," with the merged or combined number on the freeway equal to, or one less, after the merge.

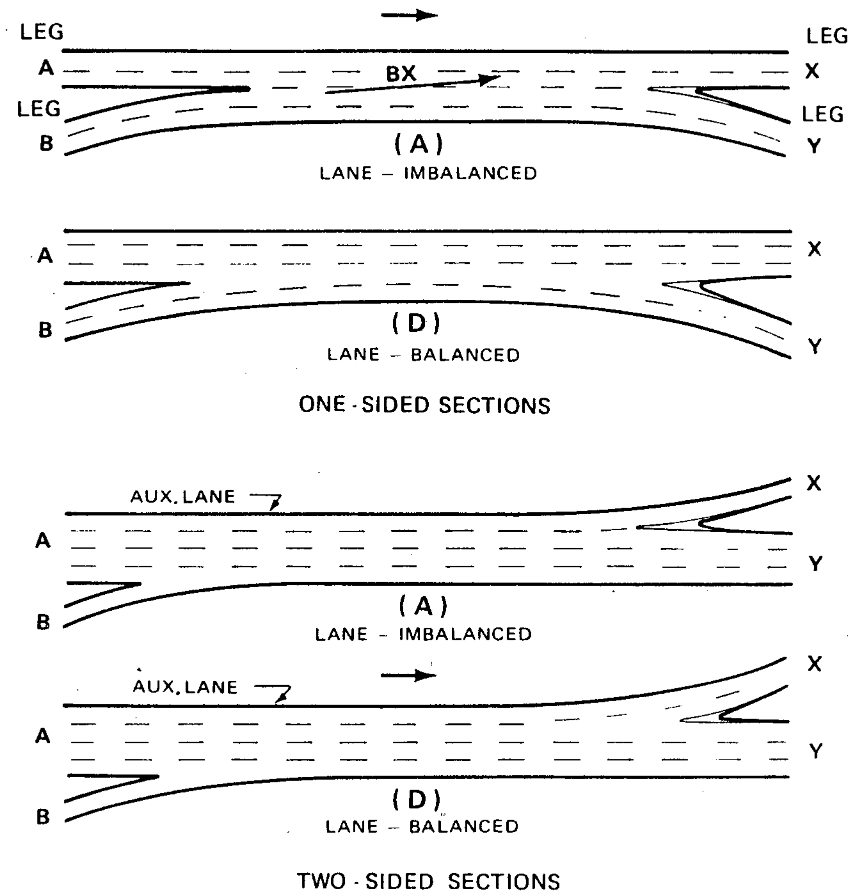
As part of weaving section analysis, lane balance has the facility to function as a single feature or surrogate in accounting for the effect of weaving section configuration upon operational quality of the section. Although in somewhat diagrammatic form, configurations A and D serve to demonstrate a lane imbalanced and a lane balanced condition, respectively. The difference in the quality of operation between representative configurations A and D can be measured on the graph in Figure 36 for various probabilities of weaving occurrance. The difference in proportion of successful weaves (P_{BX}) between the two configurations can be translated into a measure of the amount of weaving traffic, for example, one configuration can accommodate over the other; or, how much longer or shorter one section may be than the other.

A further expansion of this analysis is shown in Figure 37. Here the weaving sections have been redrawn to represent geometry as used in actual practice. Weaving sections denoted by A represent lane-imbalanced configurations. Weaving sections designated by D represent lane-balanced configurations. The upper pair of sections depict one-sided, and the lower pair of sections, two-sided weaving. Since the analysis indicated that sensitivity of P_{BX} to length is considerable, with longer lengths producing greater opportunities for successful weaves, and since greater width provides more freedom in this regard, these aspects would tend toward higher probability values (p) with higher levels of service. Analysis of relations in the graph of Figure 37, p values of 0.35 and 0.55 for levels of service E and B were considered appropriate. These produced proportional differences in P_{BX} in the range of 18 percent for LOS E to 5 percent for LOS B. The significance of these relations would indicate that in a weaving section of a given length and width, a lane-imbalanced section carries 18 percent less weaving traffic than a lane-balanced section at LOS E, and 5 percent less weaving traffic to maintain LOS B.

In applying this information to the developed weaving volume/length/speed curves in Figures 22 and 26, it was assumed that the developed curves are representative of lane-balanced sections. The data base from which these curves were derived is a mixture of lane-imbalanced and lane-balanced sections and, even though the great majority of the data comprised lane-imbalanced sections, the derived curves were assumed to represent lane-balanced sections. This was done to be more on the conservative side for purposes of using the relationship for design purposes or for improvement and reconstruction of existing sections; that is, producing a safer design or one of higher standard in actual application.



COMPARISON OF WEAVING CONFIGURATIONS
FOR VARIOUS PROBABILITIES OF
SUCCESSFUL MOVEMENT BX



ALTERNATIVE WEAVING CONFIGURATIONS

SOURCE : ADAPTED FROM NCHRP REPORT 3-15, FIGS, IV-3 AND IV-4, PINY, NOV 30, 1973.

Figure 37. **EFFECT OF CONFIGURATION OF WEAVING SECTIONS ON QUALITY OF OPERATION AS RELATED TO LANE ARRANGEMENT AND LANE BALANCE**

To account for the lane-imbalanced sections, the curves of Figures 22 and 26 were recalculated to a form which reduced the weaving volume (V_W) by 18, 14, 10, 5 and 0 percent (from Figure 37) for each curve representing LOS E to LOS A, respectively, relative to each length of weaving section (L). This additional family of curves representing lane-imbalanced weaving sections have been added to the previously developed curves as shown in Figures 38 and 39. These two graphs provide the major elements in formulation of nomographs in the next chapter.

Speed Relations

The several traffic elements which make up the weaving section yield different speeds, depending upon various interrelationships, and can be altered by changing geometric or traffic volume and pattern characteristics. Data base summaries, Tables 1, 2, and 3, and Tables A-1 and A-2, show measurements of average speeds of weaving, nonweaving, and all (composite) traffic for each experiment or subexperiment. Speed relations between individual experiments are quite variable and sensitive to lane imbalances, traffic constraints and intermixing of weaving and nonweaving volumes, geometric features, and a multitude of variables which generally are not measured or of which the analyst may have no direct knowledge.

Except for speed of weaving traffic relationships, which are representative as an average across the data base, and which on that basis show a degree of uniformity, is incorporated into the major nomographs. Other speed relations are not included and are analyzed and considered in a supplementary fashion in the next chapter, and eventually are incorporated into the analysis procedure.

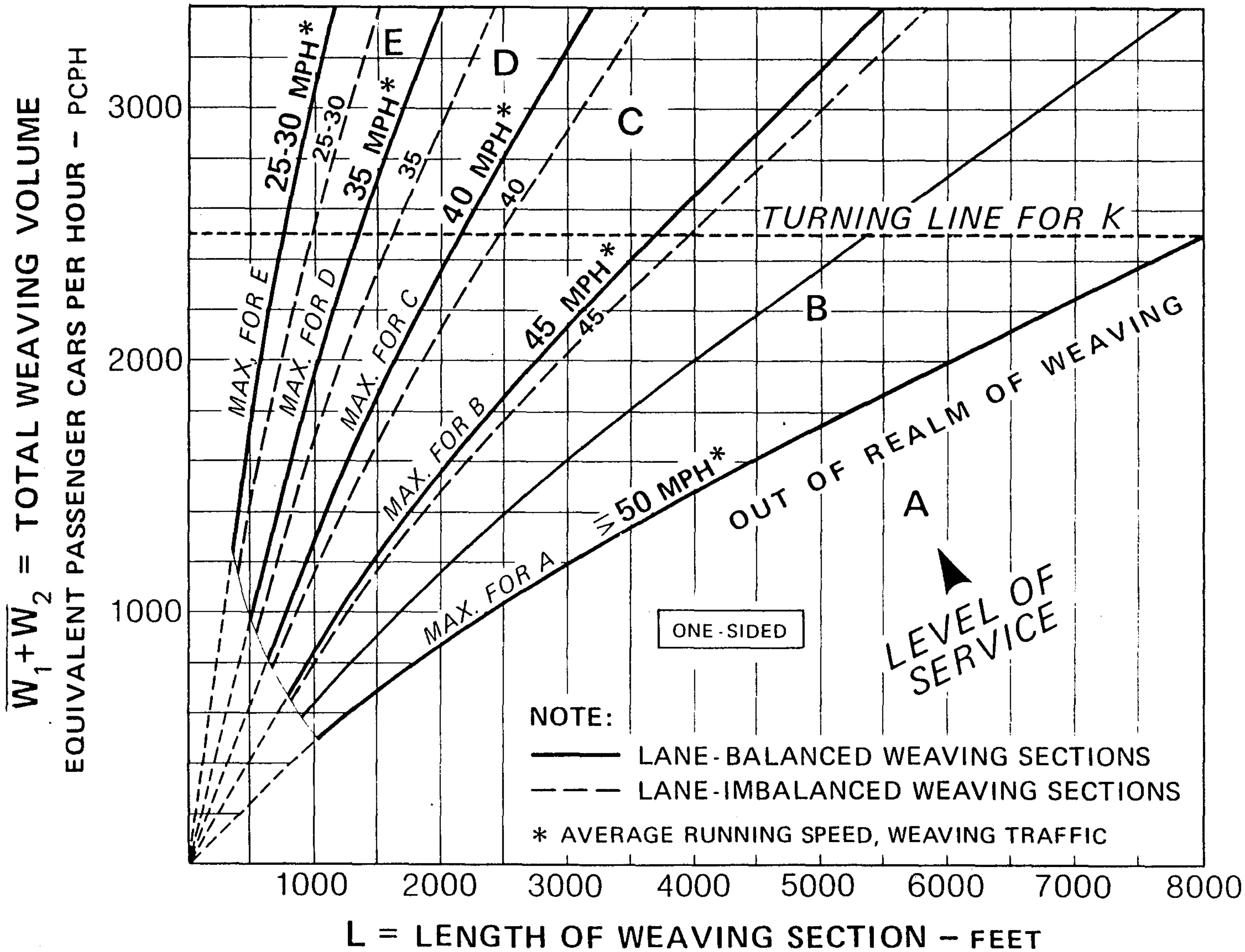


Figure 38. FINALIZED WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP
DESIGN ANALYSIS CURVES INCLUDING LANE BALANCED AND IMBALANCED SECTIONS
[illegible]SIDED WEAVING SECTIONS

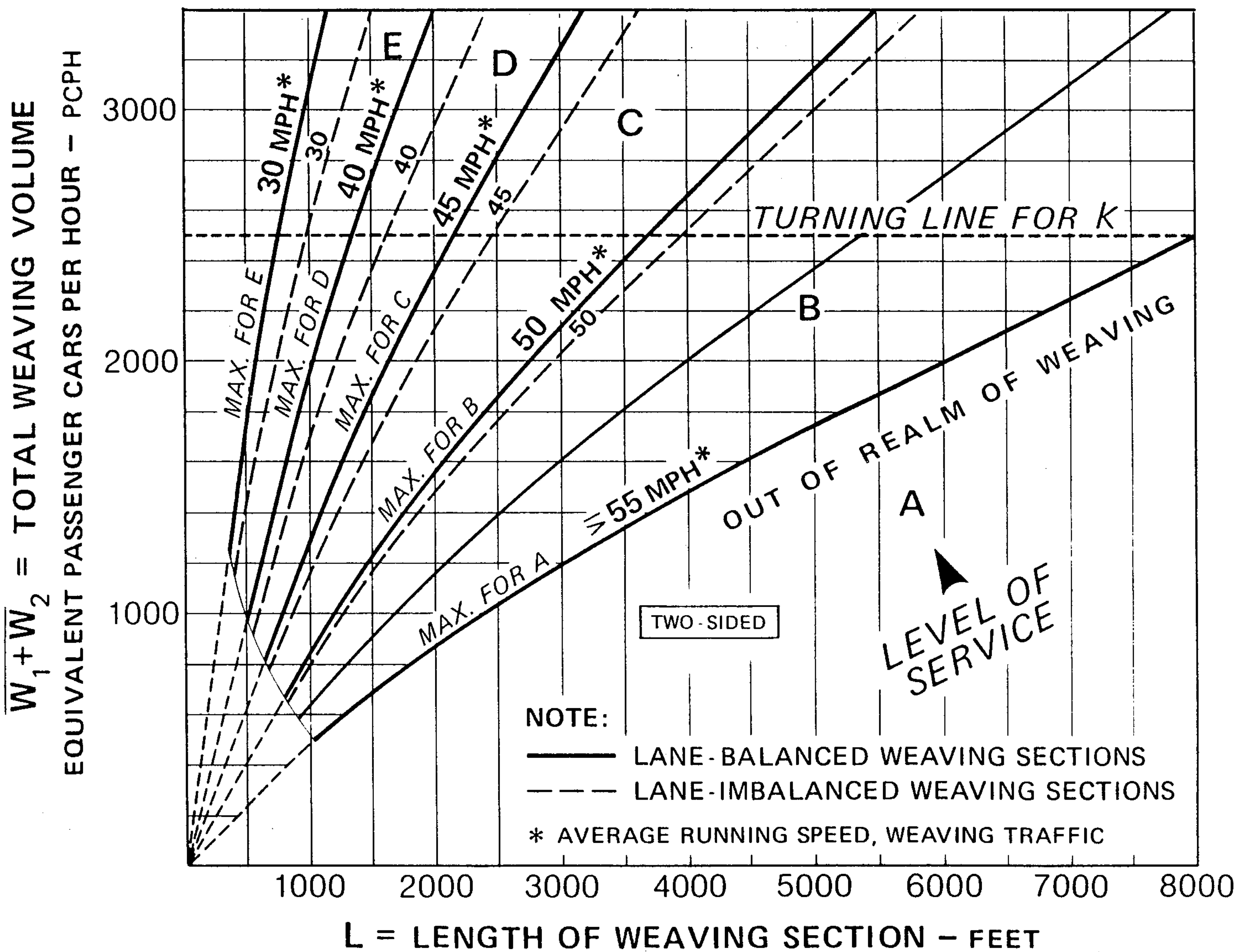


Figure 39. FINALIZED WEAVING VOLUME / LENGTH / SPEED RELATIONSHIP DESIGN ANALYSIS CURVES INCLUDING LANE BALANCED AND IMBALANCED SECTIONS

TWO-SIDED WEAVING SECTIONS

Chapter 7

NOMOGRAPH DEVELOPMENT AND SPEED CALIBRATIONS

In this section of the report the primary results of the previous chapters are presented in the form of two composite graphs which permit the solution of all forms of weaving problems on freeways. The multitude of analysis steps, subdiagrams, calculations, tabulations and other illustrative material were utilized to produce the major part of the end product embodied in the nomographs of Figures 40 and 41.

Construction of Nomographs

Two separate nomographs were found essential since the configuration and identifications of weaving sections were determined to have sufficiently different affect upon operational characteristics. The two graphs, supplemented by several simple speed graphs described later, permit the analysis and design of the full range of types and configurations of weaving sections of the variety described in Chapter 2.

In addition to the field data providing information for weaving sections, a significant aspect to the development of an effective procedure for analysis and design depended upon a sound basis of level of service measures. The formulation of a specific set of weaving speeds and/or service volumes and their application set the necessary criteria, outlined in Tables 6 and 9, and in Figure 9, as a point of departure in development of the weaving model. The calibration of the levels of service measures, as an end product of the procedure in problem solving by the nomograph, is remarkably well correlated in Figure 44.

The construction of each nomograph constituted in part the assembly of the model elements, the relationships of which were developed in the previous chapter. The familiar terminology in current use and that generally prepared for the new HCM have been maintained where feasible. The focal point of the nomograph (taking the one-sided weaving as an example) consists of the graph embodying the weaving volume/length/speed relationship as first derived in Figure 22 and then expanded to include configuration of lane balance in Figure 38. This formed the lower left half of the nomograph. Since the k value, representing the weaving intensity factor, a function of the weaving volume and its speed, as well as an expansion element within the weaving volume for determination of overall lane requirements, the relationship was developed in Figures 30-32; it was finalized in the graph of Figure 33 in appropriate format for coordination and attachment above the previous portion of the nomograph.

The next two elements in the central portion of the graph are graphic representations of the numerator of the right half of the equation $N = [V + (k-1)W_2] \div SV$, accounting for the product and the difference of the terms involved. The last three elements at the bottom right incorporate the denominator of the previous equation as a divisor utilizing the service volume (SV) values from Table 9 and Figure 9. A separate diagram is provided for each set of service volumes in accordance with the major set of width of approach to the weaving section of 2, 3 and 4 lanes. As described in Chapter 5, LOS values have built into them a representative set of peak-hour factors so that a uniform hourly rate indicative of (approximately) 15-minute peak period within the hour is reflected in the results. Also, the nomograph is so structured that the SV values represent composite values in consonance with k values, providing the necessary consistency in problem solving.

Application of nomographs is simple and direct. Solutions for numerous conditions are feasible. Different sets of variables or givens can be used to find the missing feature(s) as part of the answer sought. The nomographs with supplementary instructions and adjunct graphs further expand their application, permitting the handling of all forms of weaving sections covered in Chapter 2 and serving as a special analysis and design tool.

The dotted solution lines with arrows passing through the nomographs give a general indication of their use. The example in the nomograph of Figure 40 shows one application where it is required to find the spacing between a ramp entrance and a ramp exit for a given weaving volume at a specified level of service, and the number of total lanes required when other volume elements are given. The projected line through the nomograph demonstrates the process. The specified weaving volume for LOS C operation calls for a weaving section length of 1300 feet. Then an upward projection from the intersection point upward along and following the trend of the LOS or speed lines to the horizontal "turning line for k" permits successively the further extension of the solution line through the nomograph. In this case for an operationally balanced design, the final line at the extreme right is projected downward for the 4-lane freeway in the problem from LOS C line (SV=1450) to read slightly over 5 lanes. With nominal rounding, the design is a 5-lane weaving section, 1300 feet long, with operation at LOS C. This is only a general indication of one of a number of ways of using the nomographs. A complete coverage of various examples is presented in the Users Guide, a companion volume to this report.

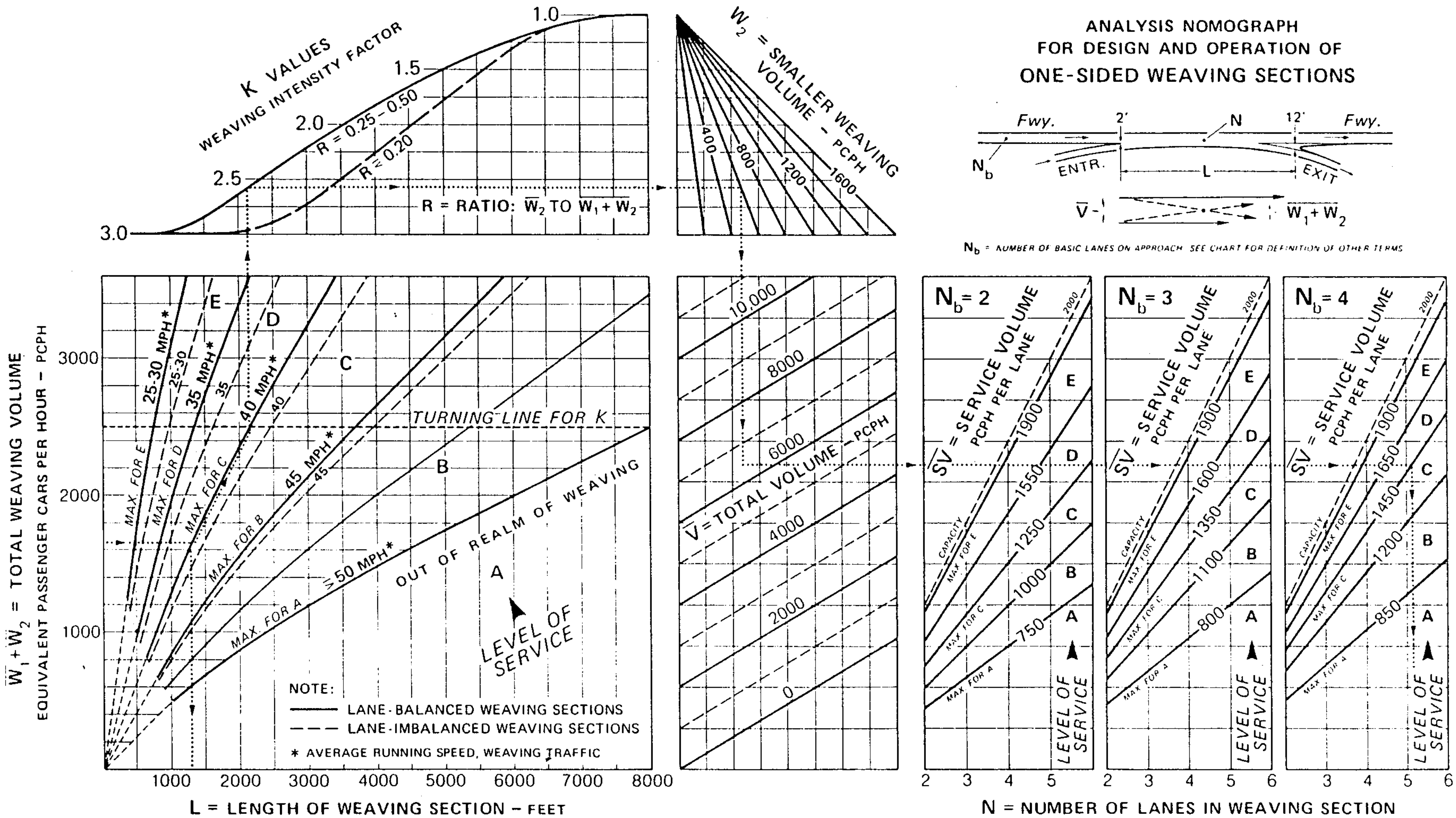


Figure 40. NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS – ONE-SIDED CONFIGURATIONS

NOMOGRAPH 1

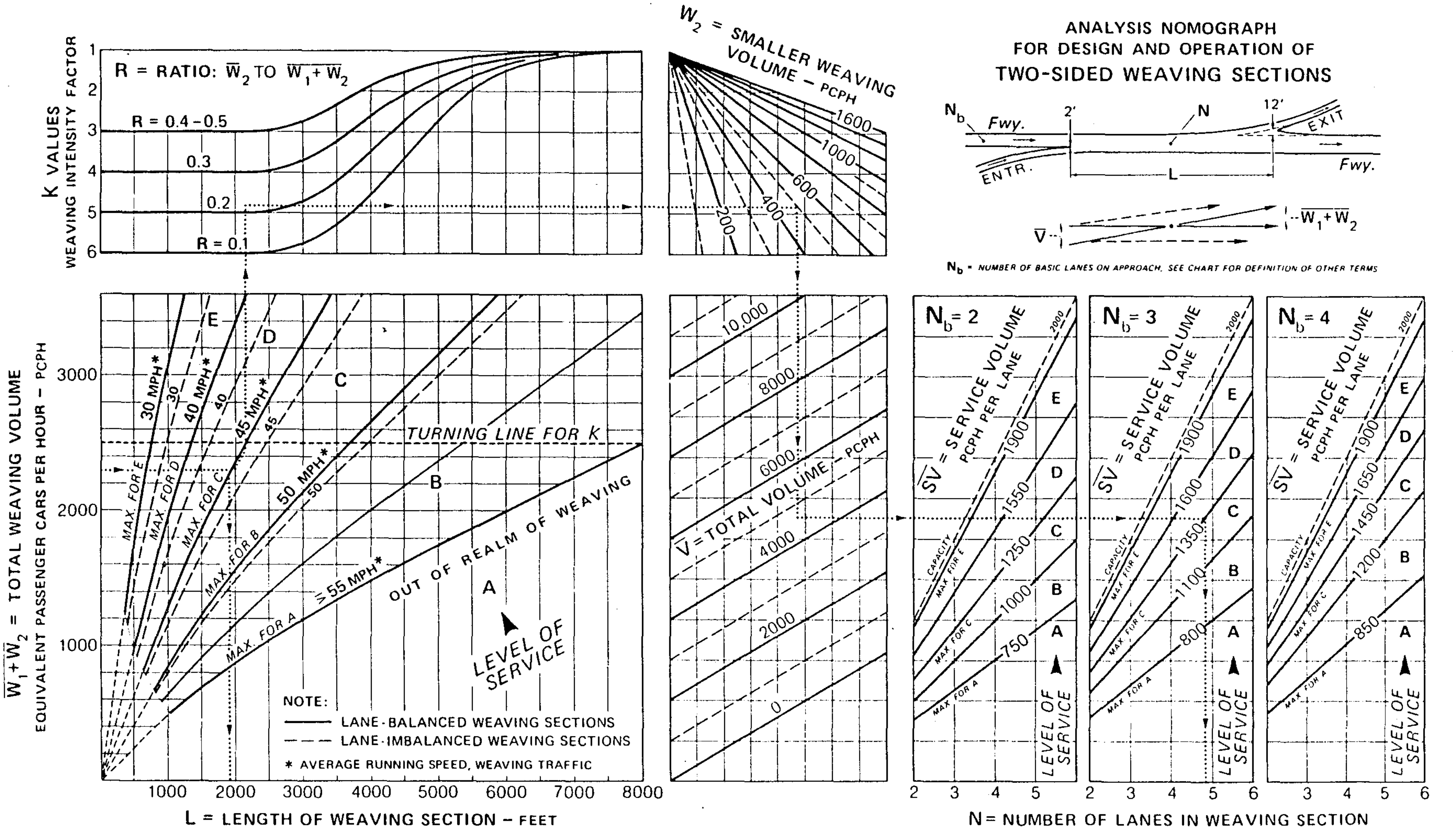


Figure 41. NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS—TWO-SIDED CONFIGURATIONS

NOMOGRAPH 2

Calibration of Speed Relations

Several tests were made for apparent degree of accuracy of results of the developed method. In addition to a series of individual tests performed in the preparation of various nomograph elements, the following further tests lend credence to the process developed through the weaving model and resulting nomographs. A comparison of actual weaving speeds observed with modeled weaving speeds for one-sided and two-sided nomographs are shown in Figures 42 and 43. This comparison relates to the lower left portion of the nomographs, Figures 40 and 41, respectively. Despite some inconsistencies in the regressions previously demonstrated, the segmenting of data to 5-mph bands, the extremely limited data for two-sided weaving sections and the interpolative procedure used therewith, and the further adjustment of speed lines to a slightly curvilinear relationship, a highly acceptable result has been achieved. The distribution of data points comparing measured weaving speeds with modeled speeds are well distributed along a 45-degree line, with an indicated standard error of 2.7 mph for both one-sided and two-sided sections. A further separate test by regression for their relation in each case produced a nearly 45-degree line with the same standard error of 2.7 mph.

A most significant test in the make-up of the overall nomograph, including the basis for the level of service selected, is demonstrated in analysis of Figure 44. First of all, it should be recognized that any procedure, no matter how sophisticated and detailed, may be of little value or ineffective unless one of its major ingredients, as a prerequisite, is a logical, consistent, and fully compatible method for the basis of level of service measure. The compatibility

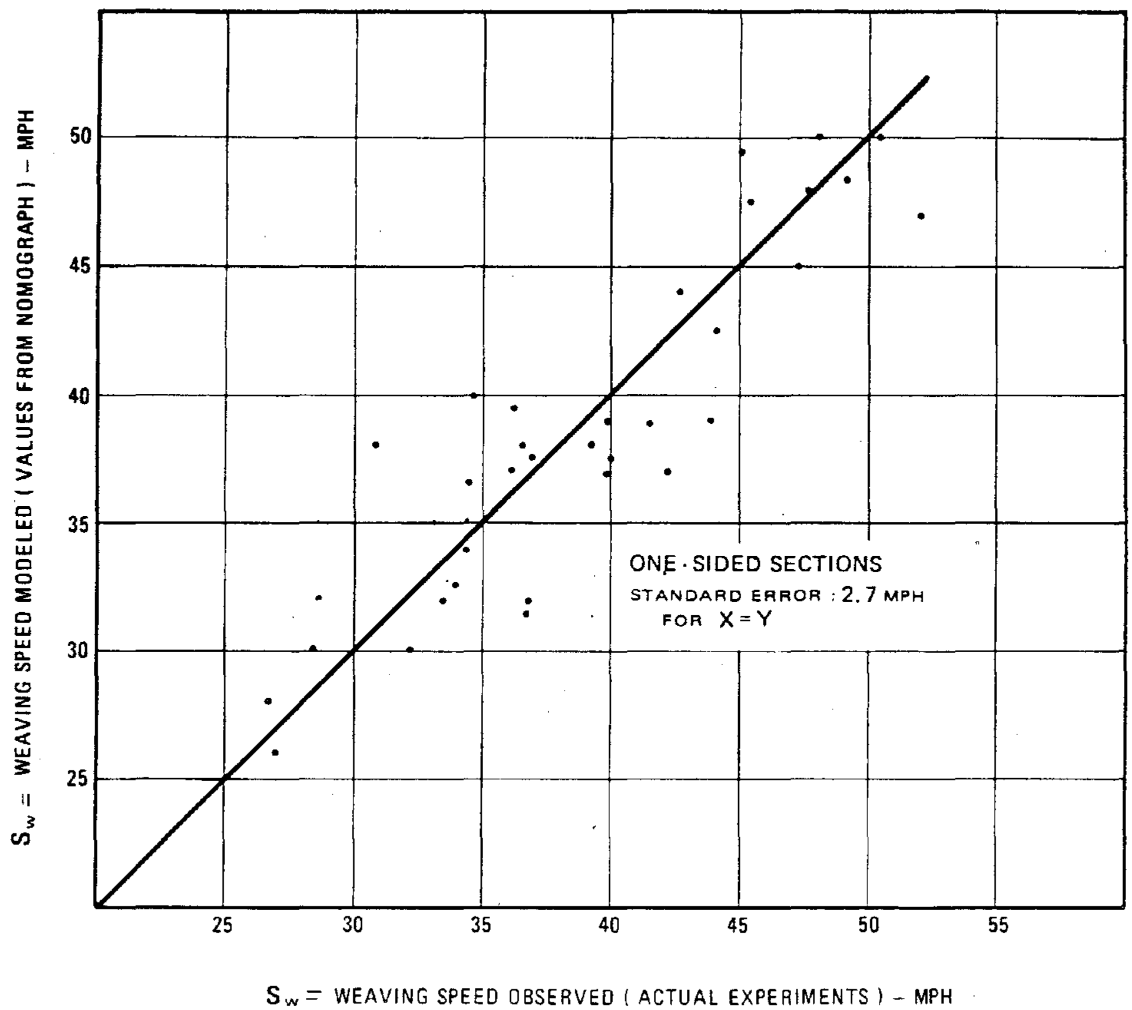


Figure 42. **COMPUTED (MODELED) VS. OBSERVED AVERAGE WEAVING SPEEDS**

DATA POINTS AS USED IN VOLUME / LENGTH / SPEED REGRESSION ANALYSIS

ONE - SIDED WEAVING SECTIONS

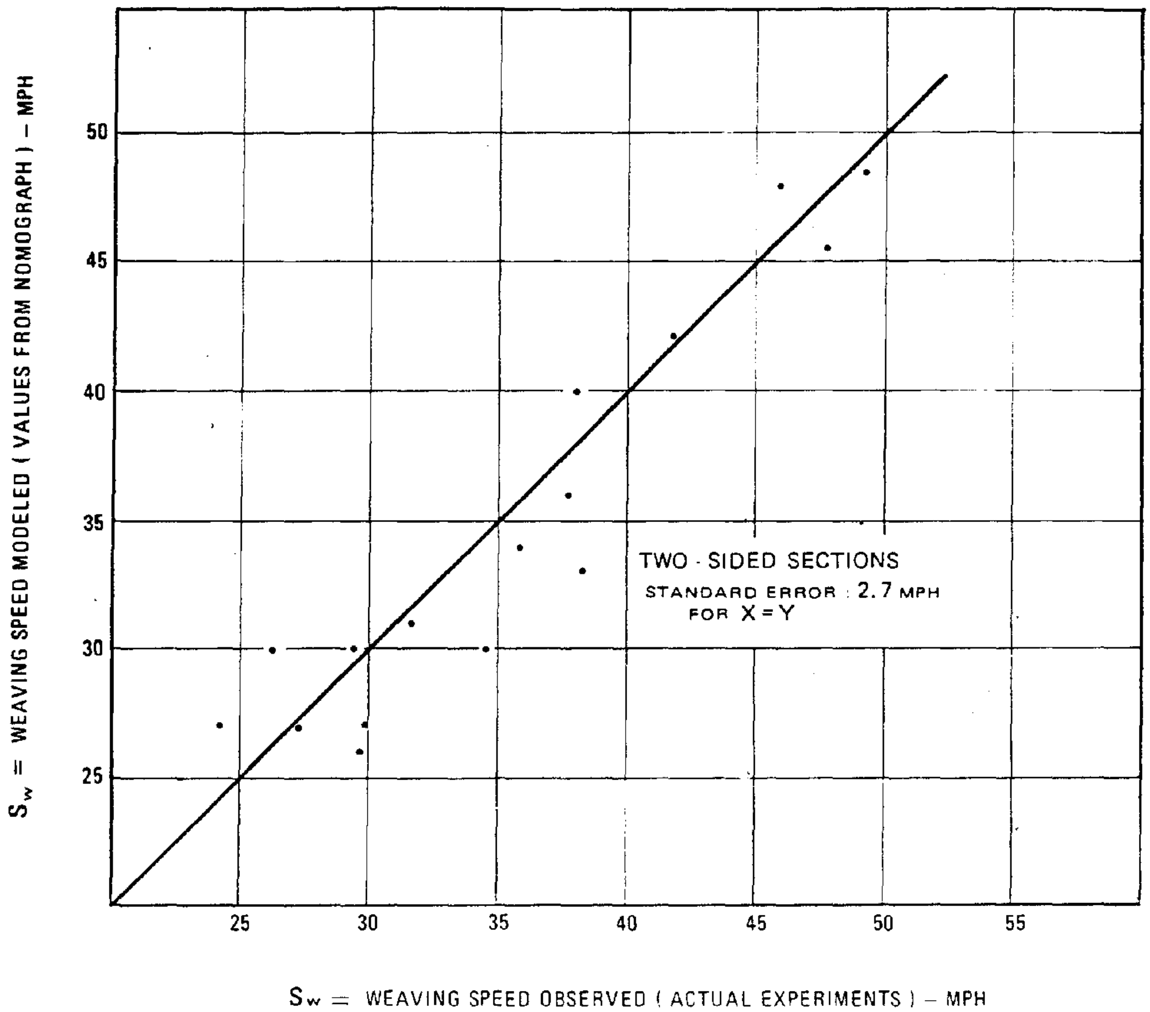


Figure 43. **COMPUTED (MODELED) VS. OBSERVED AVERAGE WEAVING SPEEDS**

DATA POINTS AS USED IN VOLUME / LENGTH / SPEED REGRESSION ANALYSIS

TWO - SIDED WEAVING SECTIONS

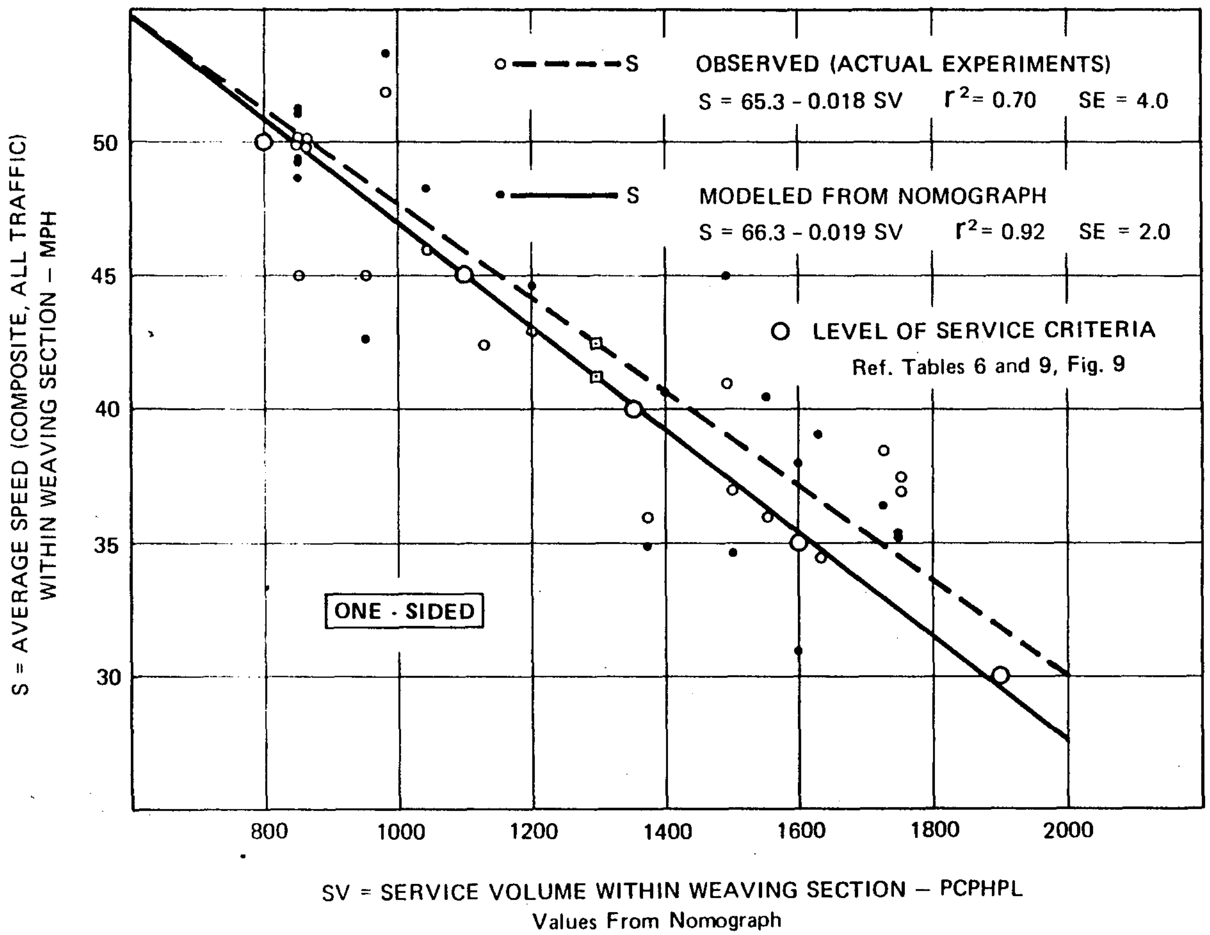


Figure 44. **RELATIONSHIP OF AVERAGE SPEED TO SERVICE VOLUME**
COMPOSITE VALUES WITHIN WEAVING SECTION – ONE-SIDED

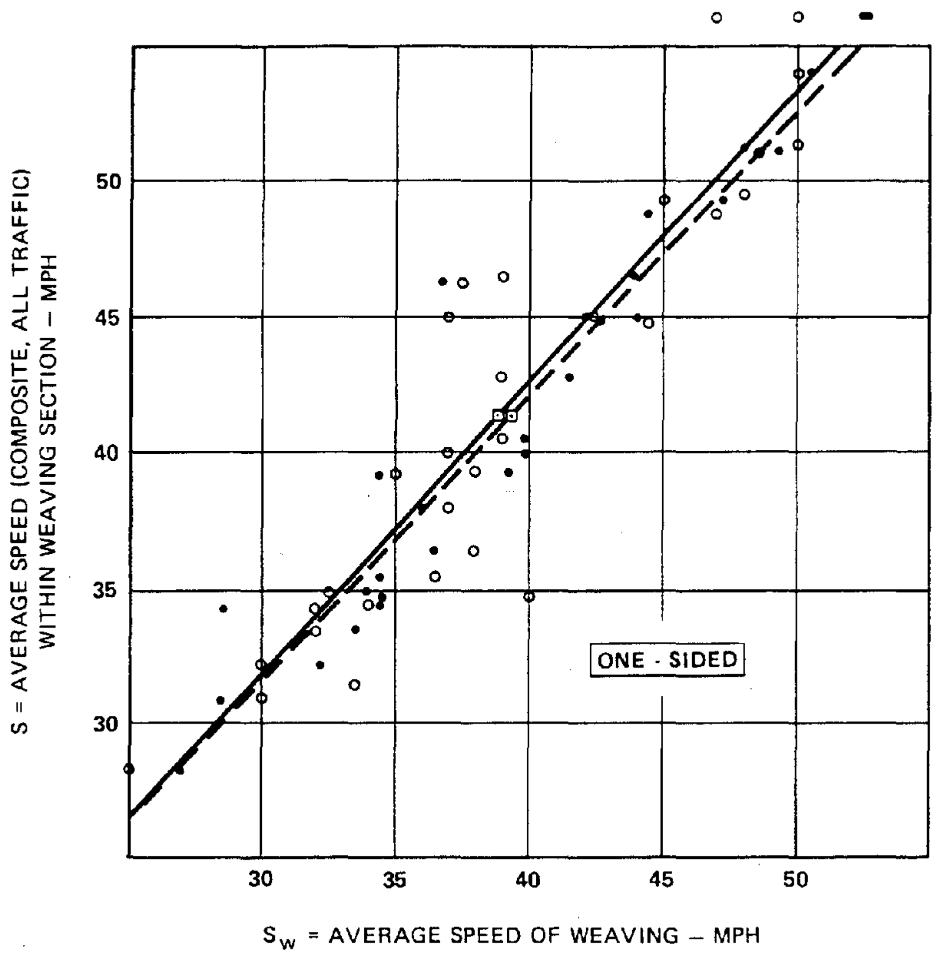
must reflect and harmonize with the LOS measure along other elements of the freeway. At the same time, it must be simple and not burdensome--which was accomplished through analysis and extensive testing (although not fully detailed in this report) as outlined in Chapter 5.

The relationship in Figure 44 shows dramatically the overall results achieved in modeling the data, in this case for one-sided weaving sections. First, all of the field experiments utilized in the study were "run" through the nomograph with the given data, and the LOS or more specifically the service volume, SV, was read at the lower right of the nomograph. Each SV value was then plotted against the actual corresponding average speed of all traffic, as recorded in the field, within the weaving section. (This speed is also referred to as the "composite" speed just as the SV value modeled in the nomograph is also the "composite" value representative of all traffic within the weaving section.)

The results of this relationship are shown by the dashed regression line in Figure 44 demonstrating good correlation. As a further more complete test of the model, including the use of S values, average composite speed of all traffic within weaving sections as related to the speed derived from the level of service criteria of Chapter 5 and incorporated into the modeled procedure, produced even a better fit shown by the solid line in Figure 44. In this case the regression shows excellent correlation with an r^2 of 0.92 and a standard error of just 2.0 mph. The large circles plotted on the graph indicate the conformity of the level of service criteria with the overall procedure.

The same type of analysis was attempted for two-sided weaving sections, but because of extremely limited data, and probably because of the inherent characteristic of freeway through volume being part of the weaving volume, did not produce similar results.

Another valuable relationship was developed for both one-sided and two-sided weaving sections of S (average, composite speed of all traffic) versus S_w (average speed of weaving) as shown in Figures 45 and 46. This was done for data as measured, and for S_w as modeled, indicating good correlation. These charts can be utilized as an adjunct to the major nomographs to achieve further calibration of results.



REGRESSION :

o — — — — — — S OBSERVED (ACTUAL EXPERIMENTS)

$S = 0.111 + 1.049\ S_W$

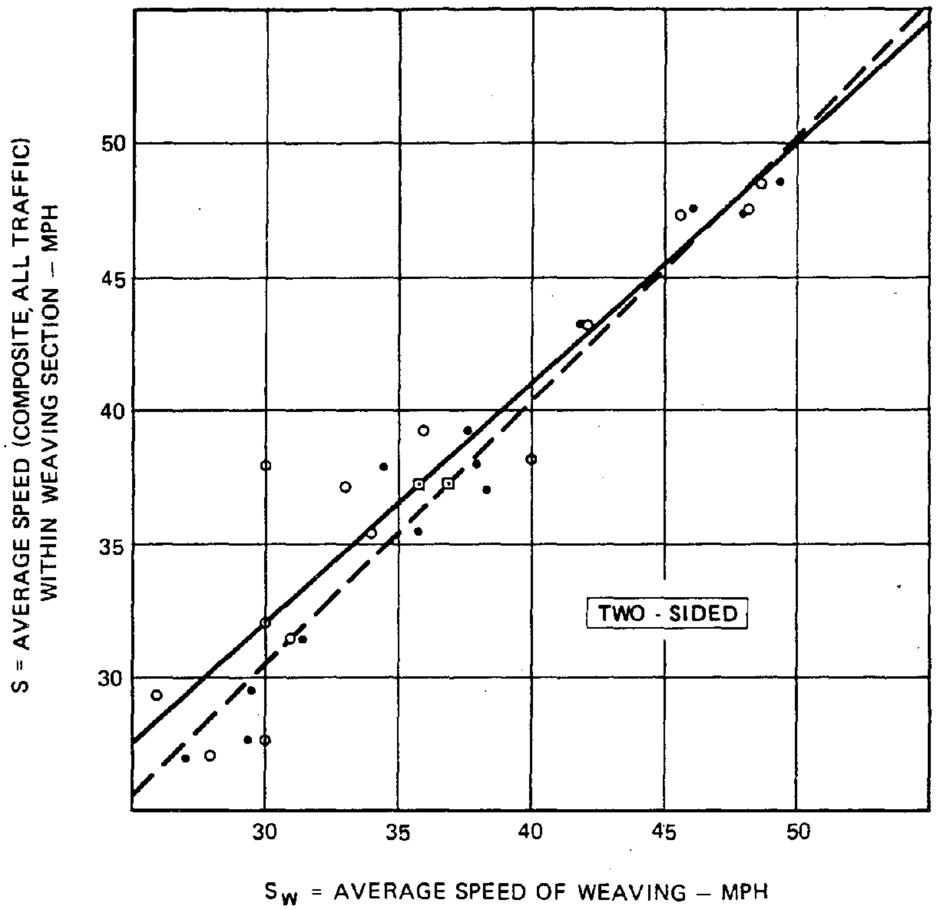
$r^2 = 0.93$ SE = 2.1 of S

• ———————— S MODELED FROM NOMOGRAPH

$S = -0.591 + 1.079\ S_W$

$r^2 = 0.85$ SE = 3.1 of S

Figure 45. RELATIONSHIP OF AVERAGE COMPOSITE SPEED TO AVERAGE WEAVING SPEED – ONE-SIDED



REGRESSION :

○ – – – – – – S OBSERVED (ACTUAL EXPERIMENTS)

$S = 0.675 + 0.970\ S_W$

$r^2 = 0.96$ SE = 1.5 of S

• ———————— S MODELED FROM NOMOGRAPH

$S = -0.011 + 0.975\ S_W$

$r^2 = 0.91$ SE = 2.2 of S

Figure 46. **RELATIONSHIP OF AVERAGE COMPOSITE SPEED TO AVERAGE WEAVING SPEED – TWO-SIDED**

Chapter 8

ADDENDUM--APPLICATION OF PROCEDURE

In order to have a better understanding of application of the developed procedure, this addendum is included with Volume 1 to demonstrate the technique of solving problems and the versatility in the use of nomographs.

As an extension of Chapter 7, which develops the major nomographs and deals with speed correlations, this additional section of the report expands on the speed relations, develops supplementary nomographs for speed calibration, (Figures 47 and 48), and presents a series of problems to more fully cover the application of the procedure for typically representative analysis and design situations. Figures 47 and 48 are to be used in conjunction with the major nomographs of Figures 40 and 41, further noted for convenience as Nomographs 1 and 2.

Supplementary Nomographs

In testing a group of actual examples from the data base, it was possible to develop for one-sided sections, using Figures 44 and 45, a procedure for augmenting the results from the main nomograph of Figure 40 in order to either obtain the speed, S, of the overall weaving section, or to adjust or better calibrate the speed of weaving, S_W. In conjunction with this explanation and study it was possible to develop the nomograph in Figure 47, noted as Nomograph 3, in order to expand on the procedure for application. Although the speed of weaving S_W and the composite speed of all traffic in the weaving section, S, are dealt with, the speed of nonweaving traffic, S_{nw}, for one-sided weaving sections has not been isolated at this time. This may be done with further analysis, although its value may be questioned if S is available, particularly since equivalent speeds on the freeway in conjunction with other ramp configurations have not been identified in the 1965 HCM or in the new HCM soon to be published.

With respect to two-sided sections, a similar nomograph was developed, shown in Figure 48 and noted as Nomograph 4. Its formulation was accomplished with limited material from the data base and a combination of information from Figure 46 and Figure 9. Although the latter is basically representative of level of service criteria, it was possible to deduce from previous tests that the SV to S relationship provided a reasonable conjunction of similar order of volume to speed along other general sections of freeway. With appropriate series of trial solutions, the basis for application of the two-sided Nomograph 4 was formulated. In the use of the nomograph it should be recognized that it is generally representative of 70- and 60-mph design speed highways. (For 50-mph continuous C-D road situations--for which no data are available--the nomograph may be used with caution.)

The case of local C-D roads, designed for simple weaving between two ramps, is generally handled by Nomograph 1 only, with S_w and corresponding LOS within the lower-left portion of the graph furnishing the result, providing that sufficient number of lanes are available. Nomograph 3 should be refered to, however, when the outer flow from one ramp to the other exceeds about 15 percent of the total C-D road volume.

Typical Problem Solutions*

Generally the solution of problems is considered in terms of two aspects--design problems and operational analysis problems. Although the situations seem different, in essence the overall solution and end result, if each is being prepared or intended to be constructed or reconstructed, is much the same or similar. Accordingly, the example problems which follow are not separated and are handled in the same manner for either condition.

Example 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 freeway 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.

Enter with a weaving volume of 600 + 1050 or $W_1 + W_2 = 1650$, proceed right to the 40-mph curve (maximum for C) and turn downward to read a minimum required weaving

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* Solutions covered in this section are also included with a more extensive presentation of problem examples in Volume 2.

length, L, of 1300 feet, (The fine dotted lines with arrows projected through the nomograph show the process in the 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 proceed 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 produces, with a downward projection, a total number of lanes, N, of 5.2. A rounding to 5 lanes would be close enough to maintain a balanced section. Theoretically, this barely places the operation into level of service D zone with no measureable change in weaving speed (S_w) and overall speed of weaving section (S) according to instruction 2 in Nomograph 3, thus maintaining a speed of 40 mph.

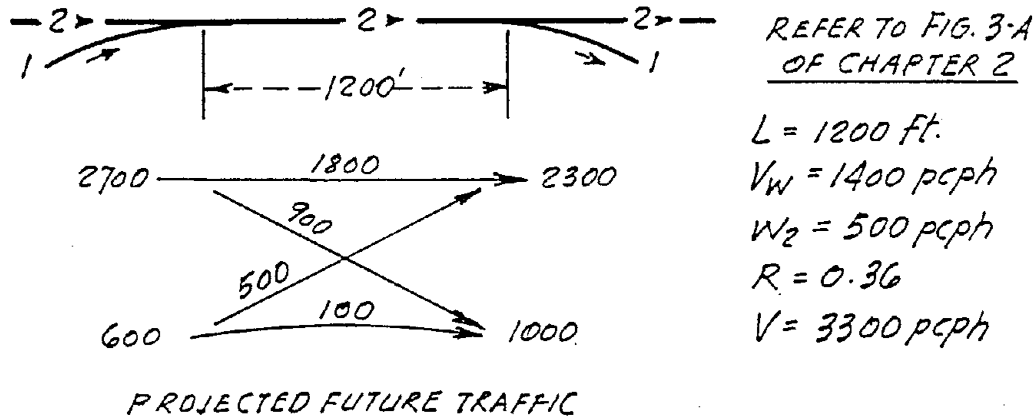
Example 2. In this case a two-sided weaving section is formed by an entering ramp on the right and an exiting ramp on the left as diagrammed in the upper part of Nomograph 2. The existing section is badly congested and is slated for improvement as required in length and width to produce an operationally balanced facility at level of service C. The total volume of V = 4650 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.

Following the solution arrows on the nomograph, it is noted that with $W_1 + W_2$ of 2300 and level of service C, the spacing between ramps has to be increased to at least 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 of N to 5 lanes would be appropriate, maintaining reasonable balance with possibly a very slight improvement in operation.

The resulting SV for 5 lanes approximates 1300 pcphpl which according to Nomograph 4 (as shown by the projection lines in accordance with instruction 2) yields an overall speed for all traffic in the weaving section of 46 mph, with 40 mph being maintained by the weaving movement (and the through traffic on the freeway).

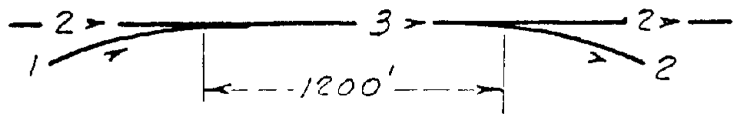
General statement for Examples 3, 4 and 5.--An existing freeway within the outskirts of an urban area is to be improved to accommodate increased traffic due to system reorientation and concentrated development projected along the corridor. Design studies produced several alternatives for consideration. As part of performing "capacity" analysis using projected future traffic, the existing configuration (Example 3) 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 (Chapter 2). The second alternative (Example 4) utilizes an auxiliary lane between the entering and exiting ramps as shown in Figure 3-B (Chapter 2). The third alternative incorporates a section of C-D road as in Figure 3-C (Chapter 2). The projected traffic in conjunction with weaving is to be accommodatd at LOS D and preferably LOS C. For convenience of demonstating 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 quickly analyzing alternative plans.

Example 3.--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?



Solution: Enter Nomograph 1 at the lower left and bottom with V_w = 1400 and L = 1200, and locate intersection at 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_1 = 500, down to V = 3300, right to N_b = 2 portion of graph and intersect N = 2 at SV = 1900 (representing V). The latter value indicates a highly constrained section with overall operation of weaving section at LOS E (capacity). In Nomograph 3, instruction 4, enter with SV = 1900 and read overall (composite) speed of weaving section, S = 30 mph in chart A, and corresponding weaving speed, S_w = 28 mph in chart B. Extremely poor conditions would prevail if this configuration were maintained in the future.

Example 4.--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.

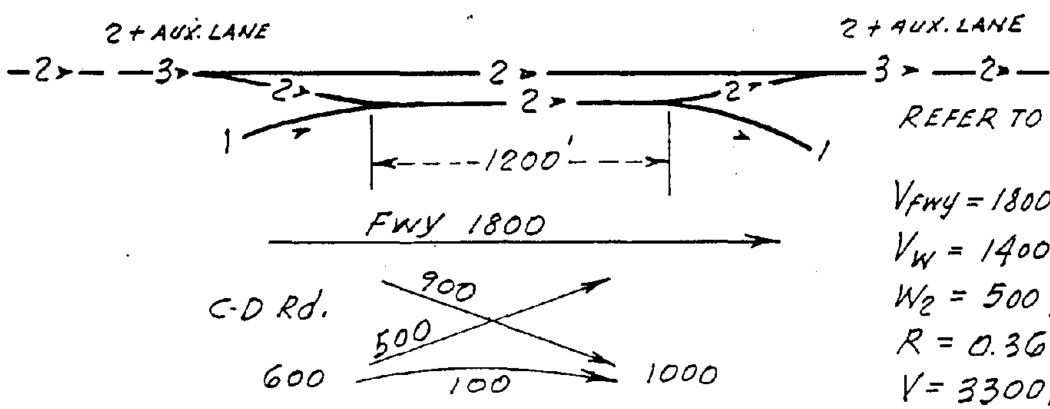


TRAFFIC DIAGRAM SAME AS IN PROBLEM 3

$L = 1200$ ft. $V_W = 1400$ pcph
$W_2 = 500$ pcph $R = 0.36$ $V = 3300$ pcph

Solution: Proceed through Nomograph 1 in the same manner as in Example 3, except that the horizontal projection from V = 3300 is intersected (within N_b = 2 section) with N = 3. This yields for the overall section an SV of about 1325, just within LOS D. Instruction 2 of Nomograph 3 applies, so that the initial reading of S_W = 40 mph remains the same and the overall speed, S, equals S_W or 40 mph. The result is sufficiently close to a balanced section, with considered operation at the limit of LOS C.

Example 5.--A more elaborate improvement, emphasizing greater freedom of operation on the freeway is presented in this example by separating the weaving movement from the freeway. The accompanying sketch demonstrates the plan.



REFER TO FIG. 3-C

$V_{Fwy} = 1800$ pcph
$V_W = 1400$ pcph
$W_2 = 500$ pcph
$R = 0.36$
$V = 3300$ pcph

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 $N_b = 2$ section) to intersect with $N = 2$, which yields an SV of about 1250. In the case of a local C-D road weaving section, Nomograph 3 normally is not used as indicated previously; thus, S_w with corresponding LOS is determined by the lower-left portion of Nomograph 1, which yields an S_w of 40 mph and corresponding LOS C. The through movement on the freeway, 1800/2 = 900 pcph per lane, indicates operation at LOS B and an average speed of about 55 mph.

The examples presented provide initial insight and familiarity in the use of nomographs. A greater number and variety of sample problems, including multiple weaving sections, have been added to the Users Guide, Volume 2 of this report.

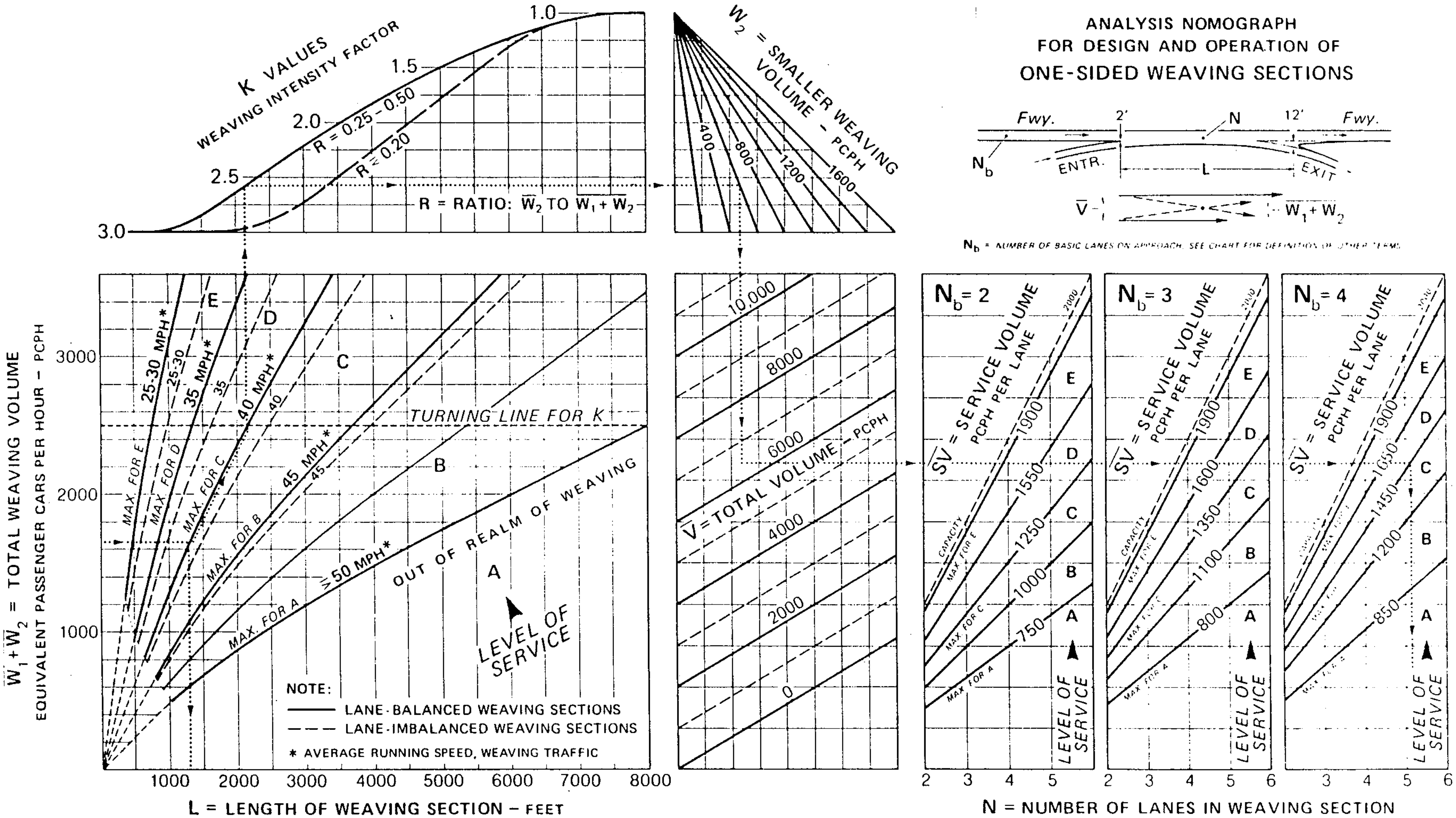


Figure 40. NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS – ONE-SIDED CONFIGURATIONS

NOMOGRAPH 1

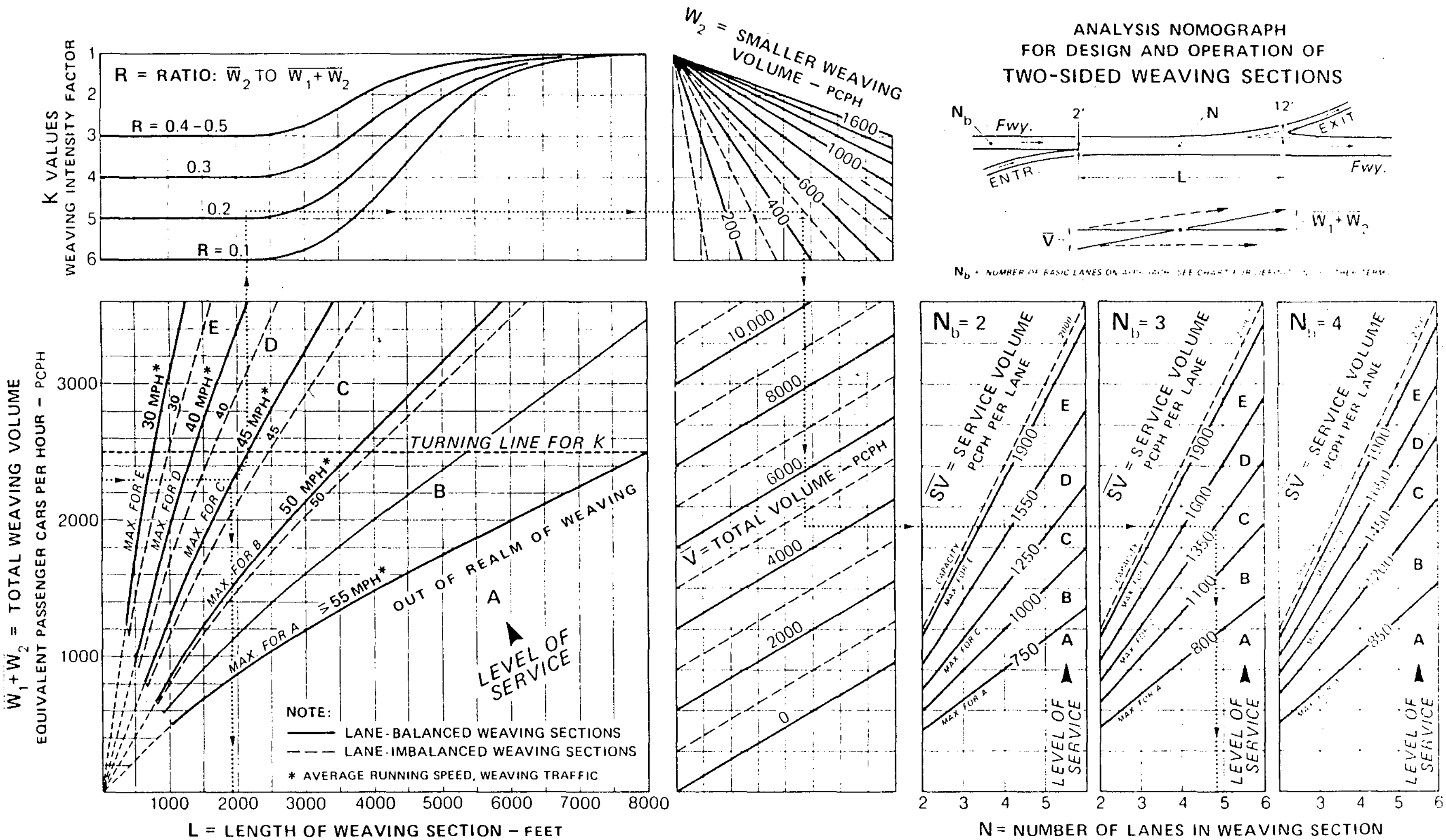
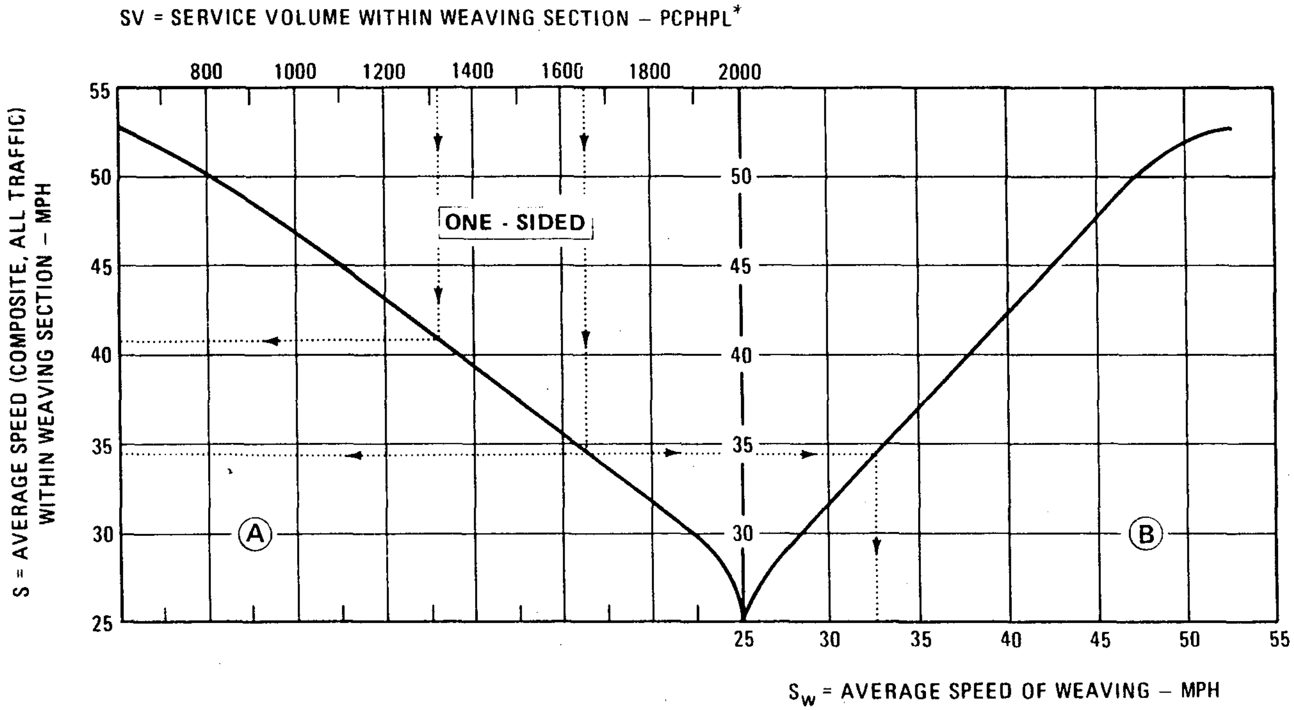


Figure 41. NOMOGRAPH FOR DESIGN AND ANALYSIS OF WEAVING SECTIONS—TWO-SIDED CONFIGURATIONS

NOMOGRAPH 2



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 WITHIN ½ LOS (±) OF V_w, S_w REMAINS THE SAME AND S EQUALS S_w.

} DO NOT USE NOMOGRAPH 3

3. WHEN V IS ONE OR MORE LOS BETTER THAN THAT OF V_w, S_w REMAINS THE SAME AND S IS READ FROM CHART Ⓐ.
4. WHEN V IS ONE OR MORE LOS WORSE THAN THAT OF V_w, S_w IS REDUCED AND BOTH S AND S_w ARE READ FROM CHARTS Ⓐ AND Ⓑ.

} USE NOMOGRAPH 3

NOTE:

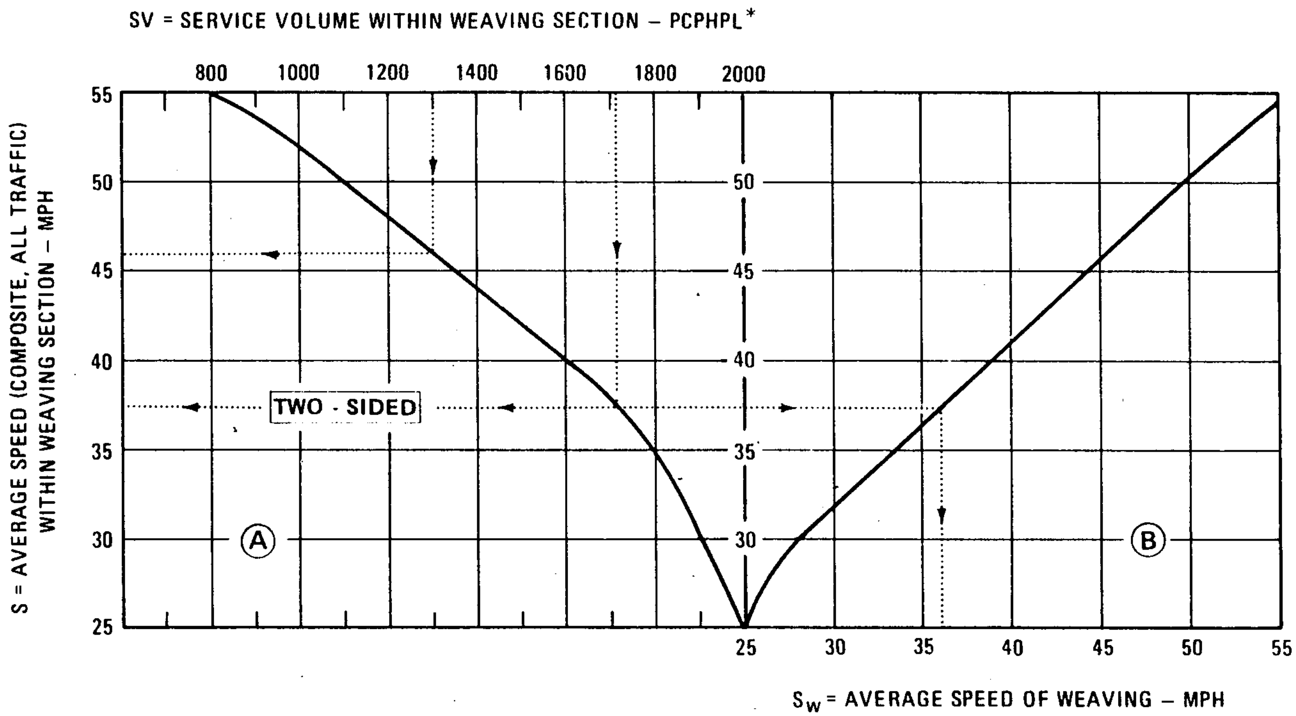
LOS OF V IS THE OVERALL LEVEL OF SERVICE AS A COMPOSITE WITHIN THE WEAVING SECTION, DETERMINED IN THE RIGHT PORTION OF NOMOGRAPH 1.

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

*SV READ FROM INITIAL SOLUTION OF NOMOGRAPH 1.

Figure 47. **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. } DO NOT USE NOMOGRAPH 4
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 Ⓐ. } USE NOMOGRAPH 4 CHART A
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 Ⓑ. } USE NOMOGRAPH 4 CHARTS A AND 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 2.

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

*SV READ FROM INITIAL SOLUTION OF NOMOGRAPH 2.

Figure 48. SUPPLEMENTARY NOMOGRAPH FOR SPEED CALIBRATION – TWO-SIDED WEAVE

NOMOGRAPH 4

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APPENDIX

TABLE A-1

DATA POINTS FOR WEAVING SECTION ANALYSIS.

ONE-HOURLY RATES OF FLOW EXPANDED FROM 18-min. COUNTS.

INFORMATION SELECTED AND FURNISHED BY NEW YORK POLYTECHNIC INSTITUTE – NOV. 15, 1983

DATA POINT	L FT	N	V_W $(W_1 + W_2)$	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
B-3.1	917	4	840	3276	42.6	53.8	0.343	0.204	3 4 5 / 1 1	40/45
B-3.2	917	4	948	3300	39.2	53.0	0.266	0.225	″	40
B-3.3	917	4	972	3912	38.5	45.3	0.346	0.199	″	40
B-3.4	917	4	996	4104	35.7	34.4	0.422	0.195	″	35
B-3.5	917	4	1296	3924	29.8	33.4	0.306	0.248	″	30
B-3.6	917	4	1056	3960	29.5	34.3	0.318	0.211	″	30
B-3.7	917	4	636	2280	41.7	50.4	0.264	0.218	″	40
B-3.8	917	4	588	2796	40.7	48.5	0.347	0.174	3 4 3 / 1 1	40
B-4.1	3760	4	1990	4810	38.1	35.5	0.417	0.311	3 4 3 / 1 2	40
B-4.2	3760	4	1710	4520	37.0	40.7	0.450	0.274	″	35
B-4.3	3760	4	2330	4900	35.6	34.6	0.429	0.322		35
B-4.4	3760	4	2470	4810	35.0	36.4	0.437	0.339		35
B-4.5	3760	4	2290	4630	34.5	31.7	0.415	0.331	″	35
B-4.6	3760	4	2550	4700	33.7	33.4	0.424	0.352	″	35
B-4.7	3760	4	2600	4770	32.1	32.8	0.419	0.353	3 4 3 / 1 2	30/35
B-7-8.1	445	4	1400	2740	33.5	56.7	0.257	0.338	3 4 3 / 1 1	35
B-7-8.2	445	4	1330	2950	32.0	50.0	0.353	0.311		30
B-7-8.3	445	4	1360	3060	31.7	51.9	0.382	0.308		30
B-7-8.4	445	4	1390	3260	31.5	52.4	0.317	0.299	3 4 3 / 1 1	30
B-7-8.5	445	4	1260	2930	31.3	52.3	0.341	0.301	3 4 3 / 1 1	30
B-7-8.6	445	4	1030	2860	31.0	52.8	0.282	0.265		30
B-7-8.7	445	4	1900	3430	27.7	44.5	0.411	0.356		25/30
B-7-8.8	445	4	1940	3250	27.6	44.4	0.443	0.374		25/30
B-7-8.9	445	4	1710	3710	27.5	42.1	0.462	0.315		25/30
B-7-8.10	445	4	1540	3320	25.6	45.4	0.481	0.317		25/30
B-7-8.11	445	4	1600	2720	33.4	52.9	0.419	0.370	3 4 3 / 1 1	35
B-9.1	449	5	1550	4930	31.2	50.0	0.329	0.239	4 5 4 / 1 1	30
B-9.2	449	5	1270	4310	33.5	53.2	0.402	0.228		35
B-9.3	449	5	1200	4200	32.6	49.7	[illegible]	0.222		30/35

TABLE A - 1 (cont'd)

DATA POINT	L FT	N	V_W (W_1+W_2)	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1+W_2}$	VR $\frac{W_1+W_2}{V}$	CONFIG	WEAVING SPEED GROUP
B-9.4	449	5	1470	4000	30.7	49.5	0.435	0.269		30
B-9.5	449	5	1140	4490	29.7	50.7	0.395	0.202		30
B-9.6	449	5	1560	4850	28.1	28.1	0.385	0.243		30
B-9.7	449	5	1470	4500	26.4	20.5	0.442	0.246	4 5 4 / 1 1	25/30
B-11.1	1054	5	1300	4880	35.9	50.5	0.554	0.212	4 5 4 / 1 1	35
B-11.2	1054	5	1350	5120	33.0	50.2	0.385	0.209		35
B-11.3	1054	5	1200	4810	32.5	51.4	0.358	0.200		30/35
B-12.1	910	5	550	6010	39.9	52.6	0.473	0.084	4 5 4 / 1 1	40
B-12.2	910	5	580	6120	36.5	48.3	0.466	0.087	4 5 4 / 1 1	35
B-12.3	910	5	610	6200	28.5	28.2	0.492	0.090		30
B-12.4	910	5	600	5980	17.3	20.5	0.433	0.091		25
B-13.1	2875	5	2860	5320	49.3	54.1	0.154	0.158	5 5 4 / 2 1	50
B-13.2	2875	5	2400	4510	41.9	45.2	0.242	0.347		40
B-13.3	2875	5	2960	5980	38.0	38.7	0.213	0.427		40
B-13.4	2875	5	3060	4560	29.6	28.7	0.275	0.402		30
B-13.5	2875	5	2690	4570	27.7	22.7	0.164	0.371		25/30
B-13.6	2875	5	2890	4690	17.2	19.6	0.215	0.381	5 5 4 / 2 1	25
B-14.1	963	5	750	5930	36.5	28.8	0.466	0.109	4 5 6 / 1 1	35
B-14.2	963	5	560	6830	35.5	33.6	0.500	0.076		35
B-14.3	963	5	790	5450	33.9	26.8	0.316	0.127		35
B-14.4	963	5	530	6410	30.5	28.0	0.472	0.076	4 5 4 / 1 1	30
B-16.1	935	5	790	5850	21.5	18.8	0.436	0.119	4 5 4 / 1 1	25
B-16.2	935	5	930	5880	18.2	17.7	0.387	0.137		25
B-16.3	935	5	970	6090	18.1	18.2	0.474	0.137		25
B-16.4	935	5	860	5680	14.2	16.4	0.349	0.131		25
B-16.5	935	5	880	5930	14.9	17.1	0.455	0.129	4 5 4 / 1 1	25
B-16.6	935	5	1140	5520	14.7	15.2	0.377	0.176	4 5 4 / 1 1	25
B-17.1	710	4	840	2690	38.0	56.2	0.274	0.238	3 4 3 / 1 1	40

TABLE A-1 (cont'd)

DATA POINT	L FT	N	V_W $(W_1 + W_2)$	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
B-17.2	710	4	960	3390	37.7	54.8	0.260	0.221		35/40
B-17.3	710	4	930	3810	37.5	54.9	0.462	0.196		35/40
B-17.4	710	4	1060	3590	37.2	55.7	0.326	0.238		35/40
B-17.5	710	4	1160	3970	34.9	50.6	0.397	0.226		35
B-17.6	710	4	1080	4100	36.6	46.4	0.500	0.207		35
B-17.7	710	4	1140	3920	34.5	50.6	0.421	0.225	3 4 3 / 1 1	35
B-18.1	726	4	1140	2830	36.9	58.0	0.342	0.287	3 4 3 / 1 1	35
B-18.2	726	4	810	2490	39.1	57.5	0.546	0.245		40
B-18.3	726	4	800	2290	35.7	56.7	0.350	0.259		35
B-18.4	726	4	530	2090	35.0	56.8	0.407	0.226	3 4 3 / 1 1	35
B-20.1	868	2	1010	10	37.9	55.2	0.386	0.990	1 2 1 / 1 1	35/40
B-20.2	868	2	1170	100	34.5	52.4	0.291	0.921		35
B-20.3	868	2	970	50	36.5	54.0	0.330	0.951		35
B-21.1	625	4	550	4440	36.5	43.9	0.418	0.110	3 4 3 / 1 1	35
B-21.2	625	4	510	4190	35.3	44.2	0.471	0.109		35
B-21.3	625	4	490	3610	35.1	47.8	0.429	0.120		35
B-21.4	625	4	520	4590	34.9	49.3	0.500	0.102	3 4 3 / 1 1	35
B-21.5	625	4	540	3660	32.0	52.0	0.463	0.129		30
B-21.6	625	4	530	3560	31.4	36.1	0.491	0.130		30
B-21.7	625	4	680	4540	26.8	27.9	0.471	0.130		25/30
B-21.8	445	4	1780	3510	26.6	37.2	0.444	0.336	3 4 3 / 1 1	25/30
B-23-24.1	659	5	2720	3654	33.6	44.9	0.107	0.427	4 5 4 / 2 1	35
B-23-24.2	659	5	2660	3546	33.0	41.8	0.147	0.429		35
B-23-24.3	659	5	2480	2690	32.4	41.1	0.165	0.480		30/35
B-23-24.4	659	5	2570	3240	32.2	42.6	0.206	0.442		30/35
B-23-24.5	659	5	2590	3070	31.6	39.8	0.201	0.456		30
B-23-24.6	659	5	2620	2980	31.2	42.1	0.240	0.468		30
B-23-24.7	659	5	2620	3010	31.0	43.5	0.126	0.465		30
B-23-24.8	659	5	3020	3170	29.9	43.8	0.159	0.488		30

TABLE A-1 (cont'd)

DATA POINT	L FT	N	V_W $(W_1 + W_2)$	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
B-23-24.9	659	5	2970	4140	29.1	40.1	0.111	0.416		30
B-23-24.10	659	5	2420	3280	29.1	43.6	0.219	0.425		30
B-23-24.11	659	5	2660	3160	27.9	44.1	0.212	0.451		25/30
B-23-24.12	659	5	2270	3010	25.8	44.1	0.187	0.470		25
B-23-24.13	659	5	2620	2940	25.4	44.4	0.198	0.471		25
B-23-24.14	659	5	2510	3820	20.9	34.9	0.163	0.402	4 5 4 / 2 1	25
B-28.1	1032	5	1240	4760	46.0	48.8	0.306	0.207	4 5 4 / 1 1	45
B-28.2	1032	5	1460	5760	45.4	47.1	0.285	0.200		45
B-28.3	1032	5	1140	5010	45.0	49.2	0.316	0.184		45
B-28.4	1032	5	1370	5000	44.7	46.3	0.336	0.215		45
B-28.5	1032	5	1450	5750	45.3	45.4	0.297	0.201	4 5 4 / 1 1	45
B-28.6	1032	5	980	4560	46.2	49.7	0.290	0.199		45
B-29.1	894	3	1560	2090	37.6	41.5	0.476	0.376	2 3 2 / 1 1	35/40
B-29.2	894	3	1420	2030	36.9	44.3	0.472	0.412		35
B-29.3	894	3	1640	2040	36.6	42.3	0.486	0.414		35
B-29.4	894	3	1380	2120	36.5	42.7	0.486	0.394		35
B-29.5	894	3	1440	1990	35.9	41.5	0.465	0.420		35
B-29.6	894	3	1510	2380	34.1	37.9	0.397	0.355		35
B-29.7	894	3	1710	2220	34.0	36.2	0.462	0.435	2 3 2 / 1 1	35
B-30.1	890	3	1110	2160	36.7	39.9	0.432	0.339	2 3 2 / 1 1	40
B-30.2	894	3	1020	2550	36.9	38.7	0.490	0.286		35
B-30.3	890	3	1100	2110	36.7	40.0	0.491	0.343		35
B-30.4	890	3	1160	2290	36.5	39.6	0.440	0.336		35
B-30.5	890	3	1140	1900	36.0	42.3	0.491	0.375		35
B-30.6	890	3	1240	2420	35.0	41.5	0.484	0.339	2 3 2 / 1 1	35
B-32.1	822	4	950	3940	46.6	44.5	05.66	0.191	3 4 3 / 1 1	40
B-32.2	822	4	640	3160	39.3	45.6	0.326	0.213		40
B-32.3	822	4	810	3240	39.2	44.5	0.253	0.212		40
B-32.4	822	4	1270	4210	38.2	40.6	0.260	0.232		40
B-32.5	822	4	1520	4370	24.4	26.5	0.408	0.258		25
B-32.6	822	4	1080	4510	16.2	15.8	0.399	0.234	3 4 3 / 1 1	25
B-32.7	822	4	720	2570	44.8	45.6	0.333	0.219		40

TABLE A-1 (cont'd)

DATA POINT	L FT	N	V_W $(W_1 + W_2)$	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
B-33.1	521	5	960	5190	34.7	45.0	0.398	0.159	4 5 4 / 1 1	35
B-33.2	521	5	1150	5050	34.6	44.2	0.348	0.185		35
B-33.3	521	5	1220	6170	33.0	39.6	0.270	0.165		35
B-33.4	521	5	1260	6740	31.0	36.4	0.341	0.157		30
B-33.5	521	5	1330	6350	29.8	33.4	0.262	0.173		30
B-33.6	521	5	1240	6260	28.0	29.9	0.363	0.165		30
B-33.7	521	5	1070	4350	34.7	45.0	0.459	0.197	4 5 4 / 1 1	35
B-34.1	621	4	940	3090	35.0	46.2	0.287	0.233	3 4 3 / 1 1	35
B-34.2	621	4	1230	3410	34.3	39.1	0.307	0.265		35
B-34.3	621	4	1120	2950	37.0	46.2	0.304	0.275		35
B-34.4	621	4	1200	2930	35.9	41.9	0.192	0.291		35
B-34.5	621	4	1130	3060	35.4	42.2	0.239	0.270		35
B-34.6	621	4	1260	2530	34.9	44.4	0.214	0.332	3 4 3 / 1 1	35
B-49-51.1	564	4	960	1470	41.7	44.7	0.355	0.395	4 4 3 / 1 2	40
B-49-51.2	564	4	1590	1560	40.1	42.2	0.138	0.505		40
B-49-51.3	564	4	1460	1900	39.0	42.3	0.185	0.435		40
B-49-51.4	564	4	1830	1900	37.3	40.2	0.158	0.491		35/40
B-49-51.5	564	4	1520	1890	35.6	35.2	0.217	0.446		35
B-49-51.6	564	4	1750	2260	35.8	37.3	0.206	0.436		35
B-49-51.7	564	4	1870	2760	32.9	37.7	0.162	0.404		30/35
B-49-51.8	564	4	1960	3090	29.4	26.6	0.168	0.388		30
B-49-51.9	564	4	2300	3060	23.6	26.6	0.170	0.429		25
B-49-51.10	564	4	2210	2760	21.5	31.4	0.222	0.447		25
B-49-51.11	564	4	2380	2420	20.5	14.0	0.184	0.497		25
B-49-51.12	564	4	2210	2560	18.5	11.9	0.195	0.463		25
B-49-51.13	564	4	2180	2900	17.0	15.6	0.202	0.429		25
B-49-51.14	564	4	1170	1410	15.8	15.5	0.162	0.453		25
B-49-51.15	564	4	1250	1960	14.6	13.3	0.206	0.389		25
B-49-51.16	564	4	2150	2600	14.1	11.9	0.135	0.454		25
B-49-51.17	564	4	1460	1680	11.7	13.1	0.253	0.465		25

TABLE A-1 (cont'd)

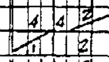
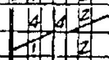
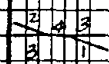
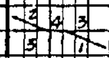
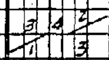
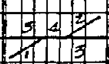
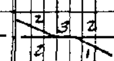
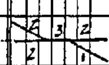
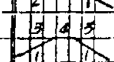
DATA POINT	L (FT)	N	V_W $(W_1 + W_2)$	V_{NW}	S_W (MPH)	S_{NW} (MPH)	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
B-49-51.18	524	4	890	950	40.2	45.2	0.371	0.484		40
B-49-51.19	564	4	1670	2010	38.4	45.1	0.343	0.454		40
B-49-51.20	564	4	1270	1760	34.3	39.7	0.228	0.419		35
B-49-51.21	564	4	1960	2990	30.4	35.7	0.173	0.396		30
B-49-51.22	564	4	1600	2560	12.2	20.3	0.250	0.404		25
B-52.1	497	4	2460	2100	30.0	34.6	0.085	0.539		30
B-52.2	497	4	2750	2240	27.3	31.2	0.120	0.551		25/30
B-52.3	497	4	1820	1560	34.5	41.3	0.132	0.538		35
B-52.4	497	4	2530	2340	32.8	36.8	0.091	0.524		30/35
B-52.5	497	4	2460	1970	29.6	31.2	0.098	0.555		30
B-53.1	1583	4	1450	650	49.2	47.6	0.110	0.697		50
B-53.2	1583	4	1610	680	47.8	46.0	0.075	0.703		45/50
B-53.3	1583	4	1860	660	47.6	44.2	0.118	0.732		45/50
B-53.4	1583	4	1860	960	46.2	42.9	0.081	0.660		45
B-53.5	1583	4	1470	650	46.0	48.8	0.109	0.693		45
B-54.1	738	3	2270	1710	38.5	33.9	0.405	0.570		40
B-54.2	738	3	1444	624	37.9	38.4	0.179	0.692		35/40
B-54.3	738	3	1624	660	37.7	34.9	0.178	0.711		35/40
B-54.4	738	3	1332	520	36.7	37.8	0.252	0.712		35
B-54.5	738	3	1932	564	36.6	34.4	0.168	0.774		35
B-54.6	738	3	1572	576	36.0	36.4	0.183	0.732		35
B-54.7	738	3	1692	456	35.3	35.4	0.244	0.705		35
B-63.1	4650	3	2270	1710	38.5	33.9	0.405	0.570		40
B-63.2	4650	3	2160	1410	37.7	33.3	0.421	0.605		35/40
B-63.3	4650	3	1740	1120	36.7	37.8	0.252	0.712		35
B-63.4	4650	3	2740	1800	33.5	31.9	0.434	0.598		35
B-63.5	4650	3	2800	1800	30.3	31.3	0.414	0.609		30
P-2.1	948	4	900	3660	42.7	44.6	0.111	0.197		40/45
P-2.2	948	4	930	3220	46.2	45.8	0.108	0.224		40
P-2.3	948	4	1230	3740	40.2	43.7	0.081	0.247		40

TABLE A-1 (cont'd)

DATA POINT	L FT	N	V_W (W_1+W_2)	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1+W_2}$	VR $\frac{W_1+W_2}{V}$	CONFIG	WEAVING SPEED GROUP
P-2.4	968	4	1480	4480	39.8	41.1	0.115	0.248		40
P-2.5	968	4	1240	3820	37.9	44.9	0.145	0.245		35/40
P-2.6	968	4	1640	4570	36.1	36.5	0.140	0.244		35
P-2.7	968	4	1290	3240	34.7	38.6	0.171	0.285		35
P-2.8	968	4	1760	4540	34.5	34.5	0.153	0.279		35
P-2.9	968	4	760	2380	45.4	47.0	0.092	0.212		45
P-2.10	968	4	730	2550	45.2	43.9	0.123	0.233		45
P-2.11	968	4	740	2860	42.2	43.6	0.108	0.206		40/45
P-2.12	968	4	730	2560	41.9	46.8	0.123	0.222	3 4 3 / 1 1	40
P-5.1	950	4	1090	1390	44.1	45.6	0.239	0.440	2 4 3 / 2 2	45
P-5.2	950	4	1550	1550	42.5	45.8	0.265	0.500		40/45
P-5.3	950	4	1560	2120	42.5	44.4	0.256	0.424		40/45
P-5.4	950	4	1550	1930	42.4	44.2	0.297	0.445		40/45
P-5.5	950	4	1620	2070	42.3	43.6	0.333	0.439		40/45
P-5.6	950	4	1520	1910	42.3	46.0	0.316	0.443		40/45
P-5.7	950	4	1620	200	41.5	44.8	0.321	0.448	2 4 3 / 2 2	40
P-5.8	950	4	1720	1940	42.3	47.4	0.320	0.467	2 4 3 / 2 2	40/45
P-7.1	750	3	1020	1380	50.6	63.0	0.167	0.449	2 3 2 / 1 1	50
P-7.2	750	3	1240	1250	50.0	61.7	0.342	0.496		50
P-7.3	750	3	1140	1340	46.5	53.7	0.147	0.460		45
P-7.4	750	3	990	1570	46.5	55.9	0.162	0.387		45
P-7.5	750	3	1130	1140	45.9	54.8	0.142	0.496		45
P-7.6	750	3	1660	2380	45.6	50.4	0.193	0.411		45
P-7.7	750	3	1200	1190	44.7	55.3	0.217	0.502		45
P-7.8	750	3	1290	1260	44.3	55.0	0.140	0.506		45
P-7.9	750	3	1560	2220	42.1	50.2	0.141	0.413		40/45
P-7.10	750	3	840	750	50.4	63.5	0.140	0.521		50
P-7.11	750	3	1150	1040	49.5	53.5	0.150	0.521		50
P-7.12	750	3	140	570	49.2	63.9	0.200	0.213		50
P-7.13	750	3	100	820	46.0	51.3	0.200	0.109	2 3 2 / 1 1	45
P-8.1	1555	5	730	1970	75.8	76.8	0.493	0.270	4 5 3 / 1 2	50
P-8.2	1555	5	410	1720	63.5	54.5	0.390	0.192		50

TABLE A-1 (cont'd)

DATA POINT	L FT	N	V_W $(W_1 + W_2)$	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
P-8.3	1355	5	320	1650	56.2	51.6	0.375	0.162		50
P-8.4	1355	5	680	2160	50.4	51.3	0.353	0.239		50
P-8.5	1355	5	680	2020	50.0	54.3	0.397	0.250	4 5 3 / 1 2	50
P-8.6	1355	5	880	1800	47.7	51.1	0.375	0.324	4 5 3 / 1 2	45/50
P-8.7	1355	5	1220	2180	47.3	51.3	0.254	0.359		45/50
P-8.8	1355	5	870	2100	45.7	48.5	0.402	0.293		45
P-8.9	1355	5	710	2060	45.1	46.5	0.479	0.256		45
P-8.10	1355	5	900	1710	44.4	46.6	0.389	0.315		45
P-8.11	1355	5	1190	2610	44.1	46.2	0.353	0.313		45
P-8.12	1355	5	960	2250	44.0	48.5	0.448	0.299		45
P-8.13	1355	5	750	1660	44.0	46.1	0.440	0.311	4 5 3 / 1 2	45
P-10.1	527	4	750	1700	41.5	43.9	0.321	0.448	2 4 3 / 2 1	40
P-10.2	527	4	490	1260	40.5	39.9	0.245	0.280		40
P-10.3	527	4	550	1550	37.1	39.9	0.349	0.262		35/40
P-10.4	527	4	1040	29[illegible]0	33.9	35.8	0.271	0.326		35
P-10.5	527	4	900	1800	31.5	32.7	0.211	0.333		30
P-10.6	527	4	330	950	31.4	29.9	0.212	0.258		30
P-10.7	527	4	440	1120	29.1	27.6	0.159	0.282		30
P-10.8	527	4	260	830	28.3	27.9	0.269	0.239		30
P-10.9	527	4	500	1100	25.2	25.7	0.220	0.313		25
P-10.10	527	4	600	1210	22.0	23.8	0.283	0.331		25
P-10.11	527	4	630	1170	35.6	44.5	0.270	0.350	2 4 3 / 2 1	40
P-11.1	1200	3	650	1300	52.4	56.8	0.400	0.333	2 3 2 / 1 1	50
P-11.2	1200	3	760	1760	51.1	54.0	0.342	0.302		50
P-11.3	1200	3	820	1380	49.3	52.9	0.366	0.373		50
P-11.4	1200	3	400	760	76.7	57.5	0.400	0.345		50
P-11.5	1200	3	260	780	59.2	55.0	0.423	0.250		50
P-11.6	1200	3	680	990	50.2	55.8	0.324	0.407		50
P-11.7	1200	3	440	1030	48.1	53.8	0.432	0.299	2 3 2 / 1 1	50

TABLE A-1 (cont'd)

DATA POINT	L FT	N	V_W $(W_1 + W_2)$	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
P-14.1	1467	3	1370	1960	50.2	55.1	0.056	0.411	2 3 2 / 1 1	50
P-14.2	1467	3	1190	1920	50.0	55.2	0.064	0.383		50
P-14.3	1467	3	970	1650	47.4	49.9	0.124	0.370		45/50
P-14.4	1467	3	990	2140	45.5	51.9	0.152	0.316	2 3 2 / 1 1	45
P-15.1	2000	4	680	2280	42.6	45.4	0.294	0.230	3 4 3 / 1 1	40/45

TABLE A-2

ADDITIONAL DATA POINTS FOR WEAVING SECTION ANALYSIS.

ONE-HOURLY RATES OF FLOW EXPANDED FROM 18 min COUNTS, PLUS ONE-HOURLY COUNTS.

BASIC INFORMATION FURNISHED BY FHWA – NOV. 1983

DATA POINT	L FT	N	V_W (W_1+W_2)	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1+W_2}$	VR $\frac{W_1+W_2}{V}$	CONFIG	WEAVING SPEED GROUP
I-2.1	1100	3	440	3680	50.8	54.9	0.10	0.11	3 3 3	50
I-2.2	1100	3	375	3800	54.0	61.5	0.04	0.12	"	50
I-2 *	1100	3	435	3790	52.6	59.5	0.06	0.11	"	50
I-6.1	1950	2	955	1665	49.4	55.7	0.14	0.36	2 2 2	50
I-6.2	1950	2	875	1280	47.6	53.4	0.22	0.34	"	45/50
I-6.3	1950	2	925	1395	48.2	54.1	0.25	0.40	"	50
I-6.4	1950	2	815	1910	46.4	51.6	0.25	0.30	"	45
I-6 *	1950	2	860	1675	49.1	54.4	0.16	0.34	"	50
I-8.1	1450	3	1130	2000	51.5	60.2	0.07	0.36	2 3 2	50
I-8.2	1450	3	915	890	51.3	59.8	0.17	0.52	"	50
I-8.3	1450	3	990	810	51.4	59.5	0.14	0.55	"	50
I-8.4	1450	3	825	925	50.1	59.3	0.17	0.50	"	50
I-8.5	1450	3	780	895	51.7	60.9	0.16	0.46	"	50
I-8.6	1450	3	795	840	50.3	58.2	0.16	0.50	"	50
I-8.7	1450	3	870	1200	51.6	58.8	0.06	0.42	"	50
I-8.8	1450	3	973	1245	52.9	59.9	0.15	0.44	"	50
I-8 *	1450	3	970	1745	52.0	60.1	0.11	0.36	2 3 2	50
I-8.9 *	1450	3	765	690	50.9	57.6	0.15	0.48	"	50
I-8.10 *	1450	3	720	830	50.8	59.3	0.15	0.46	"	50
I-8.11 *	1450	3	760	1005	51.6	59.6	0.17	0.43	"	50
I-8.12 *	1450	3	655	800	51.0	58.1	0.18	0.45	"	50
I-8.13 *	1450	3	865	1110	51.7	59.4	0.05	0.40		50
I-11.1	1150	4	410	3460	51.0	58.8	0.40	0.40	3 4 3	50
I-11.2	1150	4	620	2600	51.0	57.0	0.36	0.18	"	50
I-11.3	1150	4	580	3820	50.3	58.1	0.48	0.13	"	50
I-11.4	1150	4	520	2780	49.9	58.3	0.44	0.16	"	50
I-11.5	1150	4	600	4170	50.3	56.3	0.47	0.12	"	50
I-11.6 **	1150	4	415	1940	51.0	58.3	0.30	0.18	"	50

TABLE A-2 (cont'd)

DATA POINT	L FT	N	V_W $(W_1 + W_2)$	V_{NW}	S_W MPH	S_{NW} MPH	R $\frac{W_2}{W_1 + W_2}$	VR $\frac{W_1 + W_2}{V}$	CONFIG	WEAVING SPEED GROUP
I-11 *	1150	4	575	3180	50.5	57.2	0.41	0.16	"	50
M-1 *	650	6	1755	5125	28.6	40.0	0.42	0.26	4 6 4	30
M-1.1 **	650	6	1235	6585	26.3	39.3	0.48	0.16	"	25
M-1.2 **	650	6	1230	5595	53.4	43.6	0.13	0.18	"	35
M-2 *	921	4	1450	1900	40.0	—	0.24	0.43		40

* 1 HOUR DATA BASE;

** ADDITIONAL 1 HOUR COUNTS; ALL OTHER POINTS ARE RATES OF FLOW BASED ON 18 MIN. COUNTS.