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Design Capacity Charts for Signalized Street and Highway Intersections

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BUREAU OF PUBLIC ROADS
U. S. DEPARTMENT OF COMMERCE
E. A. STROMBERG, Editor

Design Capacity Charts
for Signalized Street and Highway Intersections

Introduction

By J. E. LEISCH,[1] Highway Engineer,
Urban Highway Branch,
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THE recently published *Highway Capacity Manual*[2] has furnished highway ıd traffic engineers with much-needed data r the design and improvement of streets ıd highways. This up-to-date informaɔn, which is largely based on field obrvations rather than on theory, should applied to all design problems to assure e provision of appropriate and adequate ghway facilities. The capacity of most reets or urban highways, except those the freeway class, is determined largely the volumes of traffic that can be handled the intersections. Part V of the Manual resents a method of analysis for the callation of capacity at signalized intersecons under various conditions. Although is method is quite complete and is consely stated in the Manual, its application, ith the numerous steps necessary to obtain e result, is apt to become involved for omplicated problems.

A graphic analysis method, based on 'art V of the Manual, is presented here facilitate the determination of capacities f signalized intersections. The value of harts is recognized in all fields of engineerng, and their application is well demontrated as a short cut for the use of umbersome formulas and detailed calcuations. Such charts are of considerable alue in visual demonstration of the effect f each variable included. The design caacity charts developed here for the analysis f various types of signal-controlled interections on two-way streets, one-way streets, nd expressways are presented with probem examples to demonstrate their use.

A highway intersection, like any other structure, must be designed for the loads t is required to carry. In the case of a signalized intersection the loads are estabished by the volume, density, composition, and distribution of traffic using the intersecting facilities. The geometric features of design are determined by these traffic loads and their relation to physical characteristics and economic considerations of the site or locality, and to the type of facilities involved.

The rational determination of highway capacity is now recognized as an important part of highway planning and design. The recently published* Highway Capacity Manual *provided, for the first time, a complete, practical method for the calculation of intersection capacities. The method developed was an arithmetic process, and for those who prefer a graphic procedure the charts presented in this article were devised. In addition to their convenience, the charts are of value in visual demonstration of the effects of the many variables involved.

Data Needed for Capacity Analysis

Knowing the design traffic loads and the physical and economic limitations, an intersection design can be made in one of two manners: (1) a geometric layout can be prepared and by capacity analysis checked for its suitability to carry the anticipated traffic; or (2) the design traffic loads can be used in capacity analyses to determine the necessary control dimensions and operating conditions. In either event a capacity analysis is required, for which proper data are essential. Often only the average daily traffic on each intersecting street is available. This can serve as a general guide but may be of little direct value in the intersection design. For proper capacity analyses the following information is needed:

Traffic volume and distribution.—Directional design volumes of traffic on each approach to the intersection, with breakdown as to through, left-turning, and right-turning movements, together with factors for anticipated future traffic increases. In urban and suburban areas, data are needed for simultaneous movements during both the morning and evening peaks to determine the critical conditions.

Trucks and busses.—Classification of these traffic volumes to show percentage of trucks and busses.

Bus stops.—Near-side or far-side location of bus stops and approximate number of busses using them during the peak hours.

Type of area.—Classification of intersection site conditions as downtown, intermediate, or outlying area.

Traffic signals.—Type and over-all control conditions of traffic signals used.

Miscellaneous.—Requirements for parking and for pedestrians, space limitations of pavement and right-of-way areas, and other physical controls.

Development of Capacity Charts

The design capacity charts are based on the information contained in part V, Signalized Intersections, of the Manual, particularly the data given in figures 24 and 26 (pp. 79, 84), and the section on adjustments for specific conditions (pp. 87–91). Any one intersection may have as many as eight conditions for which adjustments must be made in order to determine its capacity.

The charts presented here incorporate all of these adjustments, so that for any known condition the intersection capacity can be obtained directly without reference to the various Manual adjustment values. In constructing the charts all of the adjustments are precisely accounted for and no short-cuts or approximations are made. The results obtained by the use of these charts are the same as those from the long-hand method in the Manual. There is one added adjustment to the Manual data, as explained later, in the form of a factor to obtain "design" capacity.

The material on capacity of signalized intersections could have been combined on a few charts to cover all conditions for the various types of facilities, but such charts would be unduly complex. Accordingly, it was decided to prepare a larger number of charts, each containing the data for a selected condition. These charts are individually explained in the following discussion, and examples of their proper use are given in each case.

General Terms Used

In order to simplify the terms on the charts and in the examples, a system of symbols was adopted for the variable conditions that affect capacity, as follows:

$W/2$ Pavement width, in feet, of one approach to the intersection. For the two-way facilities it is normally, but not necessarily, one-half of the curb-to-curb width. For one-way facilities it is the normal curb-to-curb width, exclusive of separate turning lanes.

[1] Acknowledgment is made to D. W. Loutzenheiser, W. P. Walker, J. S. Biscoe, and J. A. Desch for assistance in the preparation and review of the manuscript.

[2] *Highway Capacity Manual*, by the Committee on Highway Capacity, Department of Traffic and Operations, Highway Research Board; published by the Bureau of Public Roads, 1950. Hereafter referred to in the text as the Manual.

T Trucks and busses on the one approach, expressed as a percentage of the total volume on that approach (exclusive of light delivery trucks).

R Right-turning vehicles (of all types) on the one approach, expressed as a percentage of the total volume on that approach.

L Left-turning vehicles (of all types) on the one approach, expressed as a percentage of the total volume on that approach.

B Location (or nonexistence) of a bus stop at the intersection, described as near-side stop, far-side stop, or no bus stop.

D Distance in feet that parking is prohibited in advance of the intersection, on the approach under consideration.

G/C Proportion of total time during the peak hour that the signal is green for the movement of traffic from the one approach, where *G* is the green interval in seconds and *C* is the total cycle (includ the green, amber, and red intervals) seconds.

K Design capacity of one approach, pressed in vehicles per hour.

P Possible capacity of one approa expressed in vehicles per hour.

These terms apply to all charts. Ac tional terms relative to special conditi are described as they occur in the text

Part I.—Two-Way Streets

DESIGN CAPACITY FACTORS

The basic data for intersection capacities of two-way streets, expressed in terms of average maximum volumes observed at street intersections, are shown in figure 1.[3] These data, to a large degree, represent a condition with a continual backlog of vehicles on the intersection approach so that some drivers waited through two or more cycle changes. In view of this, the Manual recommends the use of 90 percent of the values in figure 1 for what is termed practical capacity. At practical capacity, according to the Manual, traffic will pass through the intersection with few drivers having to wait longer than for the first green period. In examining these data, the Committee on Planning and Design Policies of the American Association of State Highway Officials considered that the constant factor of 90 percent for design was not representative for all cases. With recognition of the variable conditions of street width, type of area, and parking regulation, the Committee recommends that design capacity be determined by application of a factor in the range of 70 to 90 percent of the values obtained from the Manual data and shown here in figure 1. The percentages for conversion of the average values of figure 1 to design capacities, as used herein to construct the charts, are shown in table 1.

It may be noted that an 80- or 90-percent factor is used for the majority of cases. The 70-percent factor is used only for the narrower streets on which parking is permitted on both sides and only one lane is available for moving traffic in each direction.

To demonstrate the application of table 1, consider a two-way, 60-foot street, with parking on both sides, situated in an intermediate area. On this street four lanes (two in each direction) are available for movement of traffic. In figure 1, using a 60-foot street and curve for intermediate area with parking permitted, an average maximum volume of 1,440 vehicles per hour of green is given for one approach. In table 1, for intermediate area, four traffic lanes, and with two parking lanes, the adjustment factor is 80 percent. Design capacity of one approach on this street is $1{,}440 \times 0.80 = 1{,}150$ vehicles per hour of green.

In addition to this adjustment for design capacity, which is incorporated in the design capacity charts, it may be necess to make a further adjustment to refl the character and habits of drivers ir particular city or locality. Since the d in figure 1 are the average of all int sections measured, and are representat of many cities throughout the country, maximum volumes recorded at some int sections were either above or below average curves shown in figure 1. T relation between actual intersection cap ties in a given locality and those obtai by either the Manual method or the des capacity charts can be expressed as factor, which may be more or less th unity. This relation, referred to as "city factor," may be determined as scribed later on in the section on Spe Conditions, item 11, and applied as a fi adjustment to the results obtained fr the design capacity charts.

[3] This is figure 24 (p. 79) in the Manual.

Table 1.—*Conversion of average maximum volumes to design capacity volumes*

Parking conditions	Percentages to convert average maximum volumes [1] to design capacities, when the number of traffic lanes [2] is—			
	Two lanes	Four lanes	Six lanes	Eight lanes
Downtown areas:				
Without parking lanes	80	80	80	80
With two parking lanes	70	80	90	......
Intermediate areas:				
Without parking lanes	80	80	90	90
With two parking lanes	70	80	90	......

[1] From figure 1. [2] Exclusive of parking lanes; percentages apply to lane widths for moving traffic in range of 10-12 feet

Table 2.—*Factor* f *for conversion of design capacity to possible capacity*

Type of area	Factor *f*, when *W*/2 (in feet) is—						
	22 or less	24–26	28–30	32–34	36–38	40–42	44–48
No parking:							
Downtown	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Intermediate	1.4	1.3	1.25	1.2	1.2	1.2	1.2
With parking:							
Downtown	1.6	1.5	1.4	1.3	1.25	1.2	1.2
Intermediate	1.6	1.5	1.4	1.3	1.3	1.25	1.2

RELATION OF DESIGN CAPACITY TO POSSIBLE CAPACITY

Design capacity is by no means the ma mum volume that can be handled at n intersection, but is a value that prefera should be used in design to provide fav able operating conditions. Whereas des capacity represents a volume of tra that will pass through the intersect with few drivers having to wait lon than for the first green period, possi capacity represents the maximum volu of traffic that can pass through the int section with a continual backlog of wait vehicles. The latter condition would considered by most drivers as too congest since some drivers would be obliged wait through two or more signal cyc before proceeding through the intersecti Because of site conditions and right-of-w costs at some intersections, it may not feasible to provide facilities based on sign capacity. In such cases facilities a quate for possible capacity may be best that can be provided.

Possible capacity, according to the M ual, is 110 percent of the average maxim volumes reported in figure 1. Design pacity, on the other hand, as used her is expressed as 70, 80, or 90 percent the values in figure 1. The relation tween design capacity and possible capa

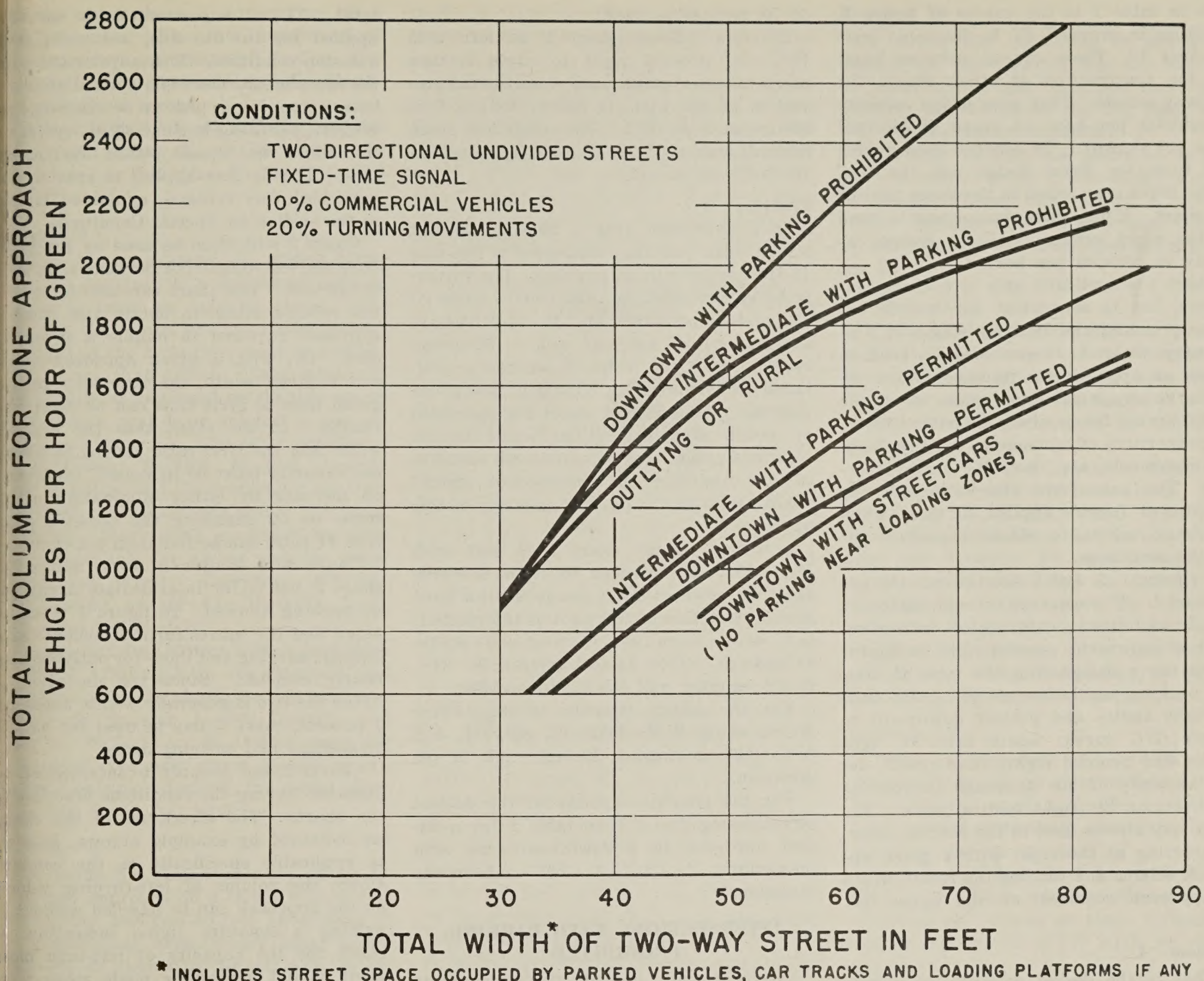

Figure 1.—Average maximum volumes at intersections on two-way streets, for different widths and by type of area and parking regulation.

the ratio of these percentage values. ɪis ratio provides a factor for determin-ɪg possible capacity directly from the chart ɪlues for design capacity. Table 2 shows ese factors, hereafter referred to as *f*, r various conditions and ranges of ap-ɪoach width.

The knowledge of possible capacity is ɪeded in many instances. Although an tersection may be designed for design ca-ɪcity, possible capacity will indicate the ɪlumes that can be handled (with some ɪngestion) on certain peak days during ɪe year. Or, knowing possible capacity, ɪ estimate can be made of the future point ɪ time when no further increase in traffic ɪn be handled.

Moreover, where separate turning lanes re provided, it may not be feasible, accord-ɪg to the distribution of traffic, to accom-ɪodate each movement at design capacity. ɪne of the turning movements may have ɪ be designed to operate at or near possible ɪapacity. Design capacity of a separate ɪrning lane is considered to be the same s its practical capacity. Since practical capacity on an average is 80 percent of possible capacity, the possible capacity of a separate turning lane is 1.2 times its practical capacity.

Experience has indicated that in some instances, particularly in highly developed areas, practical and economic considerations preclude widening or otherwise improving an intersection to accommodate the traffic demand without some congestion. Since the traffic for which an intersection is designed is a future volume (design volume), the intersection generally will operate satisfactorily initially even when designed for possible capacity. However, in the future when traffic builds up and equals the possible capacity, a new facility to accommodate further expansion of traffic becomes essential. Furthermore, when the traffic demand exceeds the possible capacity, operating conditions will not only be unsatisfactory but the total number of vehicles desiring to use the street cannot be served. Thus, the use of possible capacity in design, where the use of design capacity is not feasible, definitely limits the life of the facility to the date when the assumed volume is reached.

Possible capacity determined by use of the design capacity charts and table 2 is the same as that obtained by the Manual method. However, the design capacity as found by these charts, except for the narrow streets with parking on which only one lane is available for movement of traffic in each direction, is 0–10 percent lower than the practical capacity given in the Manual. The value of practical capacity, if desired, can also be obtained from the design capacity charts, as follows: (1) obtain design capacity from charts 2–6, (2) multiply by appropriate *f* in table 2, and (3) multiply the result by 0.80.

INTERSECTIONS WITH AVERAGE CONDITIONS

The first step in the development of the capacity charts was the conversion of average maximum volumes to design capacity volumes for average conditions. This was accomplished by application of the percentages in table 1 to the curves of figure 1, resulting in curves I–IV in the upper part of chart 1.[4] These curves serve as bases for the construction of other charts for two-way streets. They give design capacity in vehicles per hour of green (horizontal scale not shown). To convert such values into form for direct design use, the G/C ratio curves are plotted in the lower part of the chart. Using these, values can be read on the right vertical scale as design capacity in vehicles per hour.

Chart 1 is applicable only to average conditions, but is convenient for use in advance planning and in early stages of preliminary design. It can also be used to obtain an approximate value of design capacity at any intersection where all of the conditions are not precisely known but where the proportions of commercial vehicles, turning movements, etc., may be termed average. The subsequent charts include the adjustment factors applied to these average basic values, to obtain capacities for specific conditions.

Problems 1, 2, and 3 demonstrate the use of chart 1. The sequence through the chart may be as follows: enter at left with given width of approach; proceed right to appropriate curve designating the type of area and parking regulation; at this point turn at right angles and project downward to proper G/C curve; again turn at right angles and proceed right; read result, design capacity of one approach in vehicles per hour, on the right vertical scale. The chart may also be used in the reverse order, by entering at the right with a given approach volume and reading the result, width of approach required, on the upper left scale.

Problem 1

What is the design capacity of a two-way street, 66 feet wide curb-to-curb, with parking prohibited, in an intermediate area? Major intersections are signalized. Specific data regarding commercial vehicles, turning movements, etc., are not known, but conditions are assumed to be average. Half of the time during the hour can be allotted to green on this street.

Solution: Using $W/2=66/2=33$ and $G/C=0.50$, and following the arrows indicated in chart 1, it is found that design capacity $K=880$ v.p.h. in one direction. If parking were permitted, K would be 650 v.p.h.

Problem 2

A major street consisting of a narrow median and two 24-foot pavements, with no parking, in a downtown area, carries a volume of 950 v.p.h. in one direction during the peak hour. A signal is to be installed at a cross street. If conditions are assumed to be average, what should be the minimum green interval on the major street in order to accommodate 950 v.p.h., if a cycle of 70 seconds is used?

Solution: Enter chart 1 at left with $W/2=24$, proceed right to curve I, then down to lower graph until a horizontal projection of 950 v.p.h. is intersected; G/C is interpolated as 0.67. The minimum green interval with a 70-second cycle is, therefore, $70\times0.67=47$ seconds.

Problem 3

In a downtown area a two-way 58-foot street, with parking, intersects a two-way 44-foot street with no parking. The former is to accommodate a peak-hour volume of 530 v.p.h. in one direction. If conditions are assumed to be average, and a 60-second cycle is used (of which 6 seconds are allotted to amber) what should be the green interval on the 58-foot street for operation at design capacity? What would be the resultant green interval and design capacity of one approach on the 44-foot street? What would be the possible capacity of this approach?

Solution: Enter chart 1 at left with $W/2=58/2=29$, proceed to right to curve III, then down to lower graph until a horizontal projection of 530 v.p.h. is intersected; $G/C=0.57$. G on 58-foot street$=60\times0.57=34$ seconds. G on 44-foot street$=60-34-6=20$ seconds; and $G/C=20/60=0.33$.

For the design capacity of the 44-foot street, using $W/2=44/2=22$, curve I, and $G/C=0.33$, in chart 1, $K=420$ v.p.h. in one direction.

For the possible capacity of the 44-foot street, using $f=1.4$ from table 2 for a 22-foot approach in a downtown area with no parking, $P=420\times1.4=590$ v.p.h. in one direction.

INTERSECTIONS WITH PARKING PROHIBITED

Charts 2 and 3 include the adjustments for specific intersection conditions on two-way streets where parking is prohibited. The basic design capacity data are taken from curves I (downtown area) and II (intermediate area) in chart 1. The adjustments included are those enumerated in item I on page 88 of the Manual, covering proportions of trucks and busses, right turns, left turns, and type of bus stop. These and the following charts give the adjusted design capacity applicable for direct or final design use, whereas chart 1 is suitable primarily for preliminary investigation.

Chart 2, applicable to downtown areas with no parking allowed, permits graphical solution for a series of capacity adjustment factors. The basic scales at the left side and at the bottom are the same as in chart 1. The intermediate groups of curves cover the likely range in values for the capacity adjustments as enumerated in the Manual. In use, the sequence through the chart requires a right-angle change at the applicable value for each adjustment.

The T, R, and L adjustments are proportional corrections in terms of the vehicles involved, expressed as a percentage of the total. The B adjustment is a correc[tion] applied for the far-side, near-side, or [no] bus-stop condition. This adjustment co[vers] the cases where there is a normal numbe[r of] busses stopping to pick up or discharge [pas]sengers, resulting in some signal cycles [dur]ing which no busses utilize the bus-[stop] area. The B_x line applies to special ca[ses] with high bus volumes, explained later in the section on Special Conditions.

Chart 2 will often be used by procee[ding] from the left-side to bottom scales, as sh[own] by arrows. The chart can also be use[d in] the reverse order to obtain the widt[h of] approach required to handle a given [vol]ume. Or, with a given approach vol[ume] and a given width, the necessary rati[o of] green time to cycle time can be determ[ined] readily. In the event that the appr[oach] width and the G/C ratio cannot be alte[red] but capacity must be increased, the am[ount] of increase by either elimination of [left] turns or by changing the bus-stop co[ndi]tion, or both, can be found on the chart.

Chart 3 is similar in form and us[e to] chart 2, but is for intermediate areas [with] no parking allowed. In figure 1 it ma[y be] noted that the curves for intermediate a[reas] without parking and those for outlying a[reas] nearly coincide. Since the deviation [be]tween the two is generally within about 3 percent, chart 3 may be used for bot[h in]termediate and outlying areas.

Charts 2 and 3 apply to intersection [ap]proaches having the conditions describe[d on] the charts. The direct use of the ch[arts] as indicated by example arrows, how[ever,] is applicable specifically to the cond[ition] where the volume of left-turning veh[icles] on the approach can be handled witho[ut re]quiring a separate signal indication. [A] check for the capacity of left-turn m[ove]ment should always be made when [using] charts 2 and 3, as explained later on i[n the] section on Special Conditions, item 5. F[or] simplicity in demonstration and bette[r un]derstanding of chart use, examples 4–[ ] a[re] purposely selected so that the volum[e of] left-turning vehicles does not excee[d the] capacity of the left-turn movement. T[he] maximum volume of left-turning ve[hicles] that can be accommodated without a se[p]arate signal indication on major stre[ets is] generally in the range of 80 to 120 [v.p.h.] Further examples illustrate the use o[f this] important control.

Problem 4

What is the design capacity, in a [down]town area, of one approach on a 6[4-foot] street on which there is no parking, [when] the cycle is 60 seconds and green in[terval] is 27 seconds? Other pertinent dat[a are] shown in the upper part of chart 2.

Solution: Enter chart 2 at left [with] $W/2=32$ and follow the arrows acc[ording] to each condition; $K=780$ v.p.h. i[n one] direction.

Problem 5

Determine the design capacity an[d pos]sible capacity of one approach on a 4[ ]-fo[ot]

[4] The illustrative figures, incorporated in the text, and the graphic analysis charts, grouped for convenience on pp. 125-139, are independently numbered as separate series.

et on which there is no parking, in a ntown area, with other conditions at intersection as follows: $T=5\%$, $R=$, $L=10\%$, $B=$near-side stop, $G=36$ sec-, and $C=60$ seconds.

lution: With $W/2=23$ and $G/C=36/60$ 60, from chart 2, $K=700$ v.p.h. In 2, $f=1.4$; therefore $P=700\times1.4=980$ h.

blem 6

new two-way street on which there be no parking, in a downtown area, is nned to cross an existing street. According to the volume on the existing street, ercent of the cycle time must be allotted green on that street. Determine the led width of pavement on the new street he design peak-hour volume in one diion is 1,200 v.p.h., and other conditions as follows: $T=10\%$, $R=12\%$, $L=5\%$, no bus stop, and $C=$preferably not over seconds, with 6 seconds amber per cycle.

olution: Sixty-seven percent of the cycle e is available for amber and for green the new street. Therefore, $(G+\text{amber})\div C=0.67$, or $(G+6)\div70=0.67$; $G=41$ onds, and $G/C=0.59$.

Enter chart 2 at bottom with a peak-hour ume of 1,200 v.p.h. in one direction, and ceed through the chart, turning at $G/C=$), $B=$no bus stop, $L=5\%$, $R=12\%$, and 10%; $W/2=31.5$. If 11-foot lanes are be used, the new street should be the rest multiple, doubled for both direcns; $33\times2=66$ feet wide.

blem 7

Determine the design capacity of an insection approach on a street with a narv median and two 30-foot pavements, in intermediate area, where other condins are as shown in the example at the of chart 3.

Solution: Enter chart at left with $W/2=$ and follow the arrows according to each ndition; $K=650$ v.p.h. in one direction.

blem 8

In an outlying area a two-way, 40-foot rkway is to be crossed by a new highway. the critical approach of the existing rkway, the peak-hour traffic is 520 autobiles in one direction of which 80 turn ht and 45 turn left. On the critical apoach of the new highway the design volle is 1,030 v.p.h., of which 7% are trucks, d turning movements are 10% and 4% to e right and left, respectively. There will no parking and no bus stops at the inrsection on either facility. If 12-foot nes are to be used, how many lanes are reired on one approach of the new facility?

Solution: It is first necessary to deterne the proportion of green time required r the existing parkway. From chart 3, ng $W/2=20$, $T=0\%$, $R=80\div520=15\%$, $=45\div520=9\%$, and no bus stops, and inrsecting from a volume of 520 v.p.h., it is und that $G/C=0.43$.

Assume $C=60$ seconds and total amber riod is 6 seconds. Then, G for parkway traffic is $0.43\times60=26$ seconds, and G for traffic on the new highway is $60-26-6=28$ seconds.

To determine the required width of the new facility, enter chart 3 at the bottom with a design volume of 1,030 v.p.h. and proceed up and to the left using $G/C=28/60=0.47$, $B=$no bus stop, $L=4\%$, $R=10\%$, and $T=7\%$; $W/2=37$ feet. At least three 12-foot lanes, therefore, are required on the new highway in each direction of travel.

INTERSECTIONS WITH PARKING PERMITTED

Charts 4 (for downtown areas) and 6 (for intermediate areas) include the adjustments for specific intersection conditions on two-way streets with parking permitted.[5] Basic data are from curves III and IV of chart 1. The adjustments included are those enumerated in item I on pages 88 and 89 of the Manual. Charts 4 and 6 are similar to charts 2 and 3 in form and use, except that a new factor Z, for correction for bus stops, is introduced.

Chart 5 is a supplement to charts 4 and 6 to derive the adjustment factor for the combined correction for bus-stop condition and parking restriction. This correction is determined separately for near-side, far-side, and no-bus-stop condition. In chart 5A, for the near-side bus-stop condition, Z is determined directly from the $R+L$ values. In chart 5B, for the far-side bus-stop condition, Z is determined from D, G, and $R+L$ values, used jointly. In chart 5C, for the condition with no bus stops, the same three values are used jointly in a different relation. On determination of the Z value from chart 5 for the proper condition, use is then made of charts 4 and 6 in the manner previously described for charts 2 and 3.

As in the case of charts 2 and 3, the direct use of charts 4 and 6 applies to the condition where the volume of left-turning vehicles on the approach can be accommodated without requiring a separate signal indication. For simplicity in presentation, examples 9–13 were selected so that this condition is satisfied, although in actual practice a check for the capacity of left-turn movement should always be made when using charts 4 and 6, as later explained in the section on Special Conditions, item 5.

Problem 9

Determine the design capacity of one approach on a two-way, 84-foot street, with parking, in a downtown area, on which other conditions at the intersection are as listed at the top of chart 4.

Solution: Since the bus stop is on the far side, chart 5B is used: for $D=155$ feet, $G=34$ seconds, and $R+L=22\%$, $Z=17.5$. Using this and the other conditions listed, the arrows in chart 4 indicate a design capacity K of 950 v.p.h. on the one approach.

Problem 10

If all of the conditions in problem 9 remain the same except that the bus stop is placed on the near side, and there is no parking restriction on the far side, what will be the design capacity?

Solution: In this case chart 5A is used first to obtain (with $R+L=22\%$) a value of $Z=5.5$. Then, using chart 4, $K=860$ v.p.h. Shifting the bus stop from the far to the near side would decrease the capacity by 90 v.p.h.

Problem 11

If, in problem 10, the 155-foot parking restriction in advance of the intersection is retained, and all of the conditions remain the same except that the bus stop is completely removed, what will be the design capacity?

Solution: Chart 5C must be used, from which a value of $Z=12$ is obtained. Then, using chart 4, $K=910$ v.p.h. This is 50 v.p.h. more than with the bus stop on the near side (problem 10), but 40 v.p.h. less than with the bus stop on the far side (problem 9). The reason for the latter difference is that the bus-stop area on the far side (in problem 9) is used to some extent when no bus is standing, by vehicles proceeding through the intersection.

Problem 12

If the one approach of a two-way street with parking, in an intermediate area, is 32 feet wide, what is the design capacity when other controlling conditions are as listed at the top of chart 6?

Solution: Using chart 5A, with $R+L=29\%$, $Z=6$. Then, with the other conditions as listed, the arrows on chart 6 indicate a design capacity K of 770 v.p.h. on the one approach.

Problem 13

As shown in figure 2, an east-west, two-way street in an intermediate area is 52 feet wide and has parking permitted on the north side only. Two lanes are available for moving traffic on both the west and east approaches. The critical condition on the west approach occurs during the evening peak hour and on the east approach during the morning peak hour. What are the design and possible capacities of the two approaches under the conditions indicated? To what extent can capacity be increased on the east approach by eliminating parking for a half-block length ($D=$ 170 feet or more) in advance of the intersection?

Solution: For the west approach, since there is no parking, chart 3 is applicable and, with the conditions given in figure 2, $K=640$ v.p.h.

In table 2, for an approach width of 21 feet, no parking, in an intermediate area, $f=1.4$; then $P=640\times1.4=895$ v.p.h.

For the east approach, since there is parking, charts 5 and 6 are applicable. A value of $Z=-6$ is obtained first from chart 5C with $D=20$ feet or less and with $R+L=$

[5] In this article, as in the Manual, parking parallel to the curb is the only type considered. Diagonal parking would obviously have a much different effect on traffic flow.

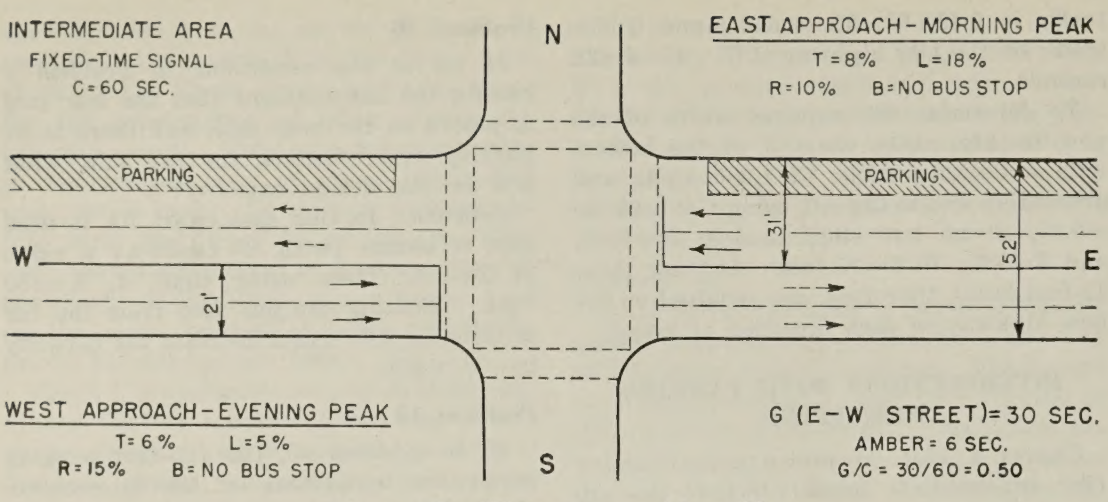

Figure 2.—Illustrative problem 13.

28%. (Since D is 20 feet or less, enter chart 5C with $D=20$ and proceed right along the upper scale to $R+L$.) Then, in chart 6, using $W/2=31$ and the other conditions shown in figure 2, $K=525$ v.p.h.

In table 2, for an approach width of 31 feet, with parking, in an intermediate area, $f=1.35$; $P=525\times1.35=710$ v.p.h.

If parking is eliminated on the east approach for a distance of 170 feet in advance of the cross walk, chart 5C is used with $D=170$ feet, $G=30$ seconds, and $R+L=28\%$; $Z=22$. Using this in chart 6, with the other conditions as before, $K=680$ v.p.h. and $P=680\times1.35=920$ v.p.h.

INTERSECTIONS WITH SEPARATE TURNING LANES AND NO SEPARATE SIGNAL INDICATION

Charts 7–9 cover intersections with separate turning lanes but with no separate signal indication. Chart 7 is used where there is a right-turn lane, chart 8 where there is a left-turn lane, and chart 9 where there are both right- and left-turn lanes.

These three charts incorporate the adjustments enumerated in item II on page 89 of the Manual. They provide graphic solutions for the design capacity of the separate turning lane and procedures for determination of the design capacity of one approach. Since the lengths of turning lanes are essential dimensions in the determination of capacity, the charts include means for determining such required lengths.

With Right-Turn Lane

Chart 7 gives the design capacity and required length of the separate right-turn lane, as well as instructions for obtaining the (total) capacity of the approach, when traffic in all lanes on the approach is permitted to move simultaneously on a common green indication. The following additional terms are introduced in chart 7.

D_2 Effective length of right-turn lane, in feet, for the storage of turning vehicles, exclusive of cross walk and taper.

V_2 Volume of traffic turning right on one approach, in vehicles per hour.

T_2 Trucks and busses turning right, expressed as a percentage of the total right-turn volume V_2 on one approach.

M_2 Design capacity of combined through and left-turn movement, exclusive of the movement on a separate right-turn lane; for use in chart 7 to obtain the (total) capacity of the approach.

K_2 Design capacity of the added lane for right-turn movement, in vehicles per hour.

The capacity of a right-turn lane is largely dependent on the proportion of truck traffic T_2 and the G/C ratio available for movement of traffic in the lane. Charts 7A and 7B show design capacity in terms of these factors. Right-turn lane capacity is also dependent on the radius of the turn, the amount of pedestrian interference, and the length of lane provided. From available data, distinction has been made for two general conditions in regard to radius and pedestrians. Chart 7A represents average curb return (corner radius at edge of pavement) and pedestrian interference, based on an average flow of 600 vehicles per hour of green. For better conditions with an adequate curb return and little or no pedestrian interference, chart 7B is constructed on the basis of an average of 800 vehicles per hour of green. Design capacity as expressed in the charts is 90 percent of these average values. In each case the intersection diagrams above the charts are indicative of the conditions represented.

Another control in capacity of an added turning lane is the length of that lane. If not long enough to store the vehicles that can make the turn on the proper green interval, the capacity otherwise possible cannot be attained. The Manual adjustments, in item II-3 on page 89, include a volume check in terms of D_2, the length of added turning lane. Chart 7C gives the solution for this length of added lane required to accommodate given volumes for different signal timings. In this form the length can be determined both for capacity volumes and for known smaller turning volumes for a specific condition. Since control values are in terms of passenger vehicles only, the adjustment for percentage of trucks and busses is included.

The required length of added right-turn lane is determined as the distance needed to store the average number of turning vehicles that will accumulate per cycle during the red and amber signals, recognizing the maximum that actually can move on the green signal. A length of 25 feet is used for each passenger vehicle, and 40 feet for each truck or bus.

The sloping lines in the lower part of chart 7C are curved to terminate at the left in logical minimum design values, according to the proportion of trucks and busses in the total traffic:

	feet
None	50
10–20 percent	65
30 percent or more	80

The minimum length of turning lane applies to the full width of turning lane. This full length is not available for use unless preceded by a taper of suitable length. While a taper length of 70 to 100 feet may be considered desirable for normal street conditions, a taper of at least 50 feet (about 5 feet of length per foot of turning lane width) should be provided. This taper is in addition to the minimum length of turning lane shown in chart 7C.

Included on chart 7 are instructions for determining the design capacity of the approach as the sum of separate values for the capacity of the through and left-turn lanes and that of the right-turn lane. Since the through-lane capacity is dependent upon the turning movements involved, the capacity for the whole is determined for a particular condition of turning movements. This value differs from a capacity sum of left plus through plus right in that it includes adjustment for any one of the three parts being at capacity while the other two are below capacity.

Since R and L are defined as percentages of the total approach volume, a simple proportion calculation is needed in step 3 of the instructions to find a right-turn volume V_2 on the arithmetic basis of through plus left. When V_2 is less than the right-turn lane capacity K_2, the design capacity is the sum of the values found in steps 1 and 3. If V_2 exceeds K_2, it is necessary to determine an adjusted volume for the combined through and left movement M'_2 based on the controlling value of the right-turn lane capacity as indicated in step 5. The formula shown is derived from the formula in step 3, with K_2 substituted for V_2. The design capacity of the approach, then, is the sum of the adjusted through-plus-left volume and the right-turn lane capacity.

The steps enumerated in chart 7 for design capacity of one approach are for the condition where each of the movements involved—left, through, and right—does not exceed the design capacity. Actually a perfect balance between these three movements will seldom, if ever, exist. It is likely that one or both of the turning movements may exceed the design capacity value may have to operate at or near possible capacity. In such cases, the value of K_2 in step 5 may be used as greater than design capacity, up to a maximum of the possible capacity. (This also applies to charts 8, 9, and 10.)

With Left-Turn Lane

Chart 8 gives the design capacity and the length of the separate left-turn lane, as well as instructions for obtaining the (total) capacity of the approach, and is similar in form to chart 7. Additional terms introduced are as follows:

D_3 Effective length of left-turn lane, in feet, for the storage of turning vehicles, exclusive of cross walk and taper.

V_3 Volume of traffic turning left on one approach, in vehicles per hour.

T_3 Trucks and busses turning left, expressed as a percentage of the total left-turn volume V_3, on one approach.

V_0 Volume of through traffic on the opposite approach, in vehicles per hour, that is in direct conflict, during the same period of time, with the left-turning movement on the approach in question.

T_0 Trucks and busses, expressed as a percentage of the total through volume on the opposite approach.

M_3 Design capacity of a combined through and right-turn movement, exclusive of the movement on a separate left-turn lane; for use in chart 8 in obtaining the (total) capacity of the approach.

K_3 Design capacity of the added lane for left-turn movement, in vehicles per hour.

The capacity of a left-turn lane is determined primarily by the volume of traffic opposing the left turn during the green signal indication. Normally, on major streets in downtown areas and on wide major streets in intermediate areas, it seldom will be possible for more than two vehicles to turn left per cycle (such turns usually have to be made on the amber signal). Using design capacity of turning lanes as 80 percent of possible capacity, the design capacity of a left-turn lane is, then, 1.6 vehicles per cycle. Chart 8B gives this relation in terms of vehicles per hour dependent upon the length of cycle.

On some streets, where the opposing through volume is relatively light, the capacity of a left-turn lane may be much greater than indicated above. For such a condition the average capacity of a left-turn lane per hour of green is estimated as the difference between 1,200 (item II-3-b, p. 89 of the Manual) and V_0, both figures expressed in terms of passenger vehicles. Design capacity is 90 percent of this difference. Chart 8A provides a solution for this condition, being the relation between V_0, G/C, and design capacity K_3. To express the capacity in terms of vehicles of all types, factors for the percentage of trucks and busses in the opposing through movement T_0 and that in the left-turn movement T_3 are applied. To determine the capacity of a left-turn lane, K_3 should be found on both charts 8A and 8B, and the larger of the two values used. In most cases on major streets, the values from chart 8B will govern.

Because of the interference of opposing through traffic, left-turning vehicles generally are delayed for longer periods of time than right-turning vehicles. The required green time per vehicle to make the turn is greater and the left-turn lane capacity is less than that for a right-turn lane. Moreover, when drivers not in the added left-turn lane await an opportunity to turn, those going right generally offer little interference to through traffic but those going left often block a through lane. Thus, within capacity conditions, a longer added lane for left turns is needed for a given volume than for an added lane for right turns of the same volume. Figure 8C shows required lengths of left-turn lanes based on storage space for 1.5 times the average number of turning vehicles that will accumulate per cycle. This is an assumed factor (50 percent increase over right-turn requirements).

With Both Right- and Left-Turn Lanes

Where lanes are added for both right and left turns, the determination of design capacity of an approach is made by steps as shown in chart 9. Design capacities of the added lanes, K_2 and K_3, are determined from charts 7 and 8 and, depending upon actual turning volumes involved, adjustments are made to find the proper through capacity M_1. M_1 is the design capacity of the lanes for through movement, exclusive of the movements on separate right- and left-turn lanes, for use in chart 9 to obtain the (total) capacity of the approach. Step 2 determines the through capacity from charts 2 or 3. In step 4 the through capacity, thus determined, is added to the turning volumes calculated in step 3. Step 5 adjusts for the through volume when one of the turning volumes exceeds design capacity, the basis being the same as described for chart 7. If both turning movements exceed design capacity, a separate step 5 solution should be made for each and the smaller of the two values obtained will govern the design capacity of the approach. Step 6 derives D_2 and D_3 from charts 7 and 8.

These six steps are for the determination of design capacity of one approach for the condition when no movement exceeds design capacity. Sometimes the traffic load may be such that the through movement can be accommodated at design capacity M_1 as determined in step 2, but the proportional volumes V_2 and V_3, as found in step 3, exceed the design capacities K_2 and K_3. In such a case it would be necessary to permit the turning movements to operate at above design capacity but not to exceed the possible capacity of each. Thus, the capacity of the approach may be equal to M_1+V_2 (not to exceed 1.2 K_2)$+V_3$ (not to exceed 1.2 K_3).

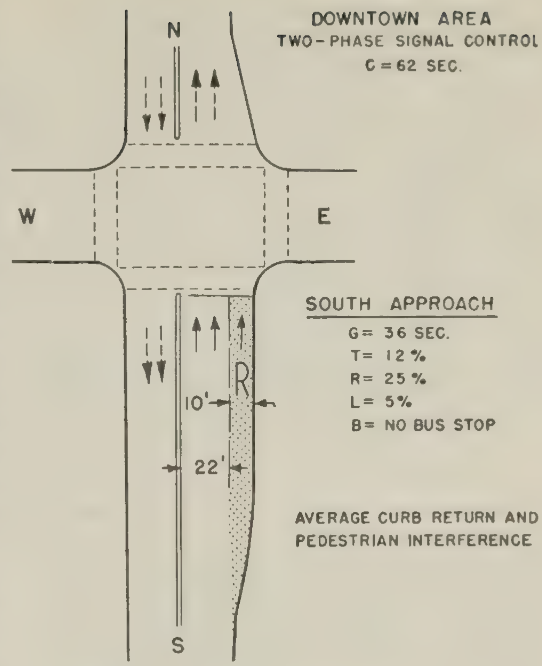

Figure 3.—Illustrative problem 14.

Problems 14–17, which follow, are illustrative of the uses of charts 7, 8, and 9.

Problem 14

What is the design capacity of the south approach for the conditions indicated in figure 3? What should be the length of the right-turn lane?

Solution: The percentage that the right-turning trucks are of the right-turn volume is not given, so T_2 is assumed to be the same as T, or 12%. Using $G/C=36/62=0.58$ and $T_2=12\%$, from chart 7A $K_2=305$ v.p.h.

From chart 2, using $W/2=22$, $T=12\%$, $R=0\%$, $L=5\%$, B=no bus stop, and $G/C=0.58$, the design capacity of combined through and left-turn movement M_2 (K on chart 2)$=830$ v.p.h. (see step 2 in chart 7).

On this basis, (from step 3, chart 7) the right-turn volume $V_2=(830\times25)\div(100-25)=275$ v.p.h.

Since this is less than K_2, the design capacity of the south approach $K=830+275=1{,}105$ v.p.h. (step 4 in chart 7).

The length of right-turn lane required, D_2 from chart 7C, using $V_2=275$ v.p.h., $C=62$ seconds, and $T_2=10$ to 20%, is 160 feet.

Problem 15

Determine the length of green interval required to handle the traffic at design capacity on the east approach of the intersection shown in figure 4.

Solution: Signal timing based on a combined volume of through and right-turn movement is obtained from chart 3 using $W/2=20$, $T=(15+40)\div(175+505)=8\%$, $R=175\div930=19\%$, $L=0\%$ (since left turn is on separate lane), B=no bus stop, and approach volume $=175+505=680$ v.p.h.; $G/C=0.57$.

Then check, in charts 8A and 8B, the capacity of the left-turn lane with this signal timing. Entering chart 8A with

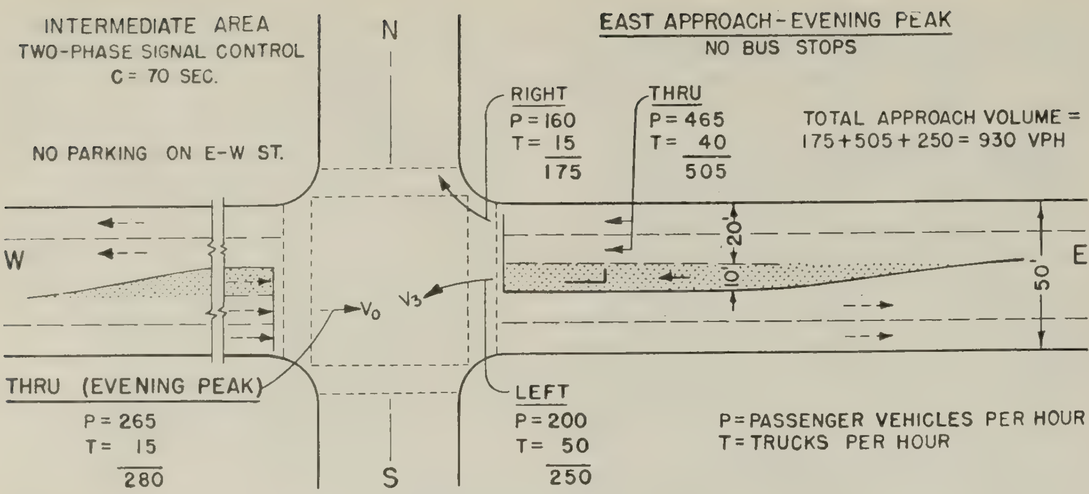

Figure 4.—Illustrative problems 15 and 16.

V_0=280 v.p.h. and proceeding to right and bottom with T_0=15÷280=5%, G/C=0.57, and T_3=50÷250=20% (see arrows), the design capacity of the left-turn lane is K_3=280 v.p.h. Chart 8A governs since in this case the value of 82 from chart 8B is much less. Thus, the indicated left-turning volume of 250 v.p.h. can be accommodated.

Therefore, for the east approach an adequate green interval G=0.57×70=40 seconds.

The required length of the left-turn lane to handle a volume of 250 v.p.h. is obtained from chart 8C. Using C=70 seconds and T_3=20%, D_3=205 feet.

Problem 16

If in problem 15 the G/C ratio of 0.57 is retained and other conditions (fig. 4) remain the same except that parking is permitted and a bus stop is placed on the near side, what will be the design capacity and possible capacity of the east approach?

Solution: The capacity of the combined through and right-turn movement is obtained from charts 5 and 6. Using chart 5A first, with $R+L$=19+0=19% (L used as 0% since it is on separate lane), Z=5 is obtained. Chart 6 is then used according to instructions in step 2 of chart 8. With $W/2$=20, T=8%, R=19%, L=0%, Z=5, and G/C=0.57, design capacity (exclusive of left turn) M_3 is found to be 380 v.p.h.

Left-turn movement L, according to the traffic distribution shown in figure 4, is 250÷930=27%. The left-turn volume V_3 on the basis of M_3 is (380×27)÷(100−27)=140 v.p.h. (see step 3 in chart 8).

Design capacity of east approach=380+140=520 v.p.h. With no parking and no bus stop (problem 15), design capacity is the sum of volumes indicated in figure 4, or 175+505+250=930 v.p.h.

In table 2, for $W/2$=20, with parking, in an intermediate area, f=1.6. Possible capacity of combined through and right-turn movement = M_3×1.6 = 380×1.6 = 610 v.p.h. Corresponding left-turn volume (from the formula in step 3, chart 8)=(610×27)÷(100−27)=225 v.p.h., which can be handled since K_3=280 v.p.h. (as determined in problem 15).

Possible capacity of east approach=610+225=835 v.p.h.

Problem 17

What is the design capacity of the east approach shown in figure 5? A large lumber mill to the north on the cross road accounts for the sizable proportion of vehicles and the high percentage of trucks turning right.

Solution: From chart 7B, K_2=280 v.p.h. Since chart 8B generally governs the capacity of the left turn on major multilane streets, it is used initially, obtaining K_3=95 v.p.h.

According to step 2 in chart 9, chart 3 is used, with $W/2$=22, T=6%, R=0%, L=0%, B=far-side bus stop, and G/C=30/60=0.50; M_1 is 610 v.p.h.

On this basis, V_2=(610×32)÷(100−32−8)=325 v.p.h., and V_3=(610×8)÷(100−32−8)=80 v.p.h. (see step 3 in chart 9). Thus V_2 is larger than K_2 and, in order that no movement shall exceed the design capacity, it is necessary to recalculate M_1 as shown in step 5 of chart 9: M'_1=280 (100−32−8)÷32=525 v.p.h.; then left-turn volume V'_3=(525×8)÷(100−32−8)=70 v.p.h., which can be handled since it is less than K_3.

Design capacity of the east approach (when no individual movement exceeds its design capacity)=525+280+70=875 v.p.h.

Required lengths of turning lanes are: from chart 7C, D_2=165 feet; from ch[art] 8C, D_3=70 feet.

In the event that a through volume [of] about 610 v.p.h. (as determined initial[ly]) had to be accommodated and other con[di]tions could not be altered, the 325 rig[ht-] turning vehicles could still be handled [but] at near possible capacity, since possible [ca]pacity of the right-turn lane would be K_2, or 1.2×280=335 v.p.h. (see note in ch[art] 9).

The capacity of the east approach, w[ith] the through movement operating at des[ign] capacity and the right-turn movement [at] near possible capacity, =$M_1+V_2+V_3$=61[0+]325+80=1,015 v.p.h.

INTERSECTIONS WITH SEPARATE TURNING LANES AND SEPARATE SIGNAL INDICATION

Chart 10, which is similar to charts [7,] 8, and 9, gives the design capacity a[nd] the required length of right- or left-tu[rn] lane, when traffic on this lane moves o[n a] green indication separate from that [of] other traffic on the approach; i. e., a rig[ht-] or left-arrow indication for the turn[ing] movement.

Additional terms introduced in chart 1[0] are as follows:

G' Green interval, in seconds, of s[ep]arate signal indication for the movem[ent] of traffic on a separate turning lane.

a Width of turning lane, in feet, [for] the movement of traffic on a separate s[ig]nal indication.

With a separate signal indication, [the] right- or left-turn movement is assumed [to] be free from interference of other tra[ffic] streams and pedestrian movements. [The] average capacity of the turning lane is [?00] vehicles per hour of separate green indi[ca]tion (item III, p. 89 of the Manual) fo[r a] lane 10 feet wide, and varies directly w[ith] the lane width. Design capacity is 90 p[er]cent of this value. Chart 10A gives a so[lu]tion for this capacity in terms of G'/C a[nd] the width of lane a. Since the control v[al]ues are in terms of passenger vehicles, [an] adjustment for the percentage of trucks a[nd] busses turning (T_2 or T_3) is included. [The] design capacity of the turning lane is [the] same whether the movement is to the ri[ght]

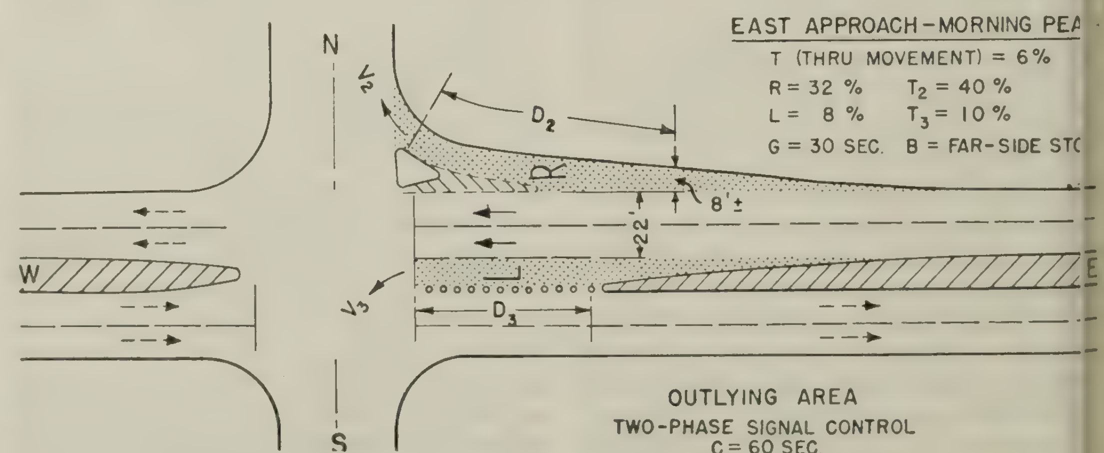

Figure 5.—Illustrative problem 17.

to the left and whether the lane is hin the normal pavement width or is added lane.

hart 10B provides the solution for the uired length of turning lane, identical h chart 8C. In the case of separate nal indication there is no opposing traf- as in chart 8C, but otherwise the con- ions are comparable. Usually the sep- te signal phase is green while other ough movements are stopped, and the rage lane must be long enough to pre- t blocking of a through lane. This calls a space greater than that needed to re the average number of vehicles ar- ing per cycle, since the number arriving some cycle intervals will be in excess the average. Accordingly, a length to re 1.5 times the average number of ve- les per cycle is used. This is an as- ned factor (50 percent increase over mal requirements).

The procedure for determining design ca- city of one approach is the same as that viously explained for charts 7 and 8. r clarity in the terms and charts, the ps are shown separately for right-turn d left-turn lanes.

Problems 18 and 19 demonstrate the use chart 10.

oblem 18

What is the design capacity of a right- rn lane, 11 feet wide, for which a sep- ate green indication of 20 seconds is used t of a 90-second cycle, and on which cks and busses comprise 15 percent of e total right-turning traffic? What should its length if a volume equivalent to de- gn capacity is to be accommodated?

Solution: From chart 10A, using $G'/C=$ /90=0.22, $a=11$, and $T_2=15\%$ (see ar- ws); $K_2=165$ v.p.h. From chart 10B, ing $V_2=165$ v.p.h., $C=90$, and $T_2=10$ to %; $D_2=175$ feet.

oblem 19

What should be the green interval for ch phase on the east approach of the tersection shown in figure 6 for opera- on at design capacity, if a total approach lume of 650 v.p.h. is to be accommodated? hat will be the green interval for the ovement of traffic on the cross street?

Solution: Volume of left-turning traffic 20 percent of 650=130 v.p.h. The volume through and right-turn movements to accommodated on a width of 22 feet is 0−130=520 v.p.h. The proportion of reen time required for this movement, om chart 2, with $W/2=22$, $T=11\%$, $R=$ %, $L=0\%$, B=far-side stop, and $K=520$, $G/C=0.40$. $G=80\times0.40=32$ seconds.

The proportion of green time required for e separate phase of left-turn lane is ob- ined from chart 10A. Using a volume of 0 v.p.h., $T_3=15\%$, and $a=12$ feet, obtain $/C=0.17$. Hence $G'=80\times0.17=14$ sec- nds.

Green time available for movement of affic on the cross street is 80−32−14−9 for amber) =25 seconds.

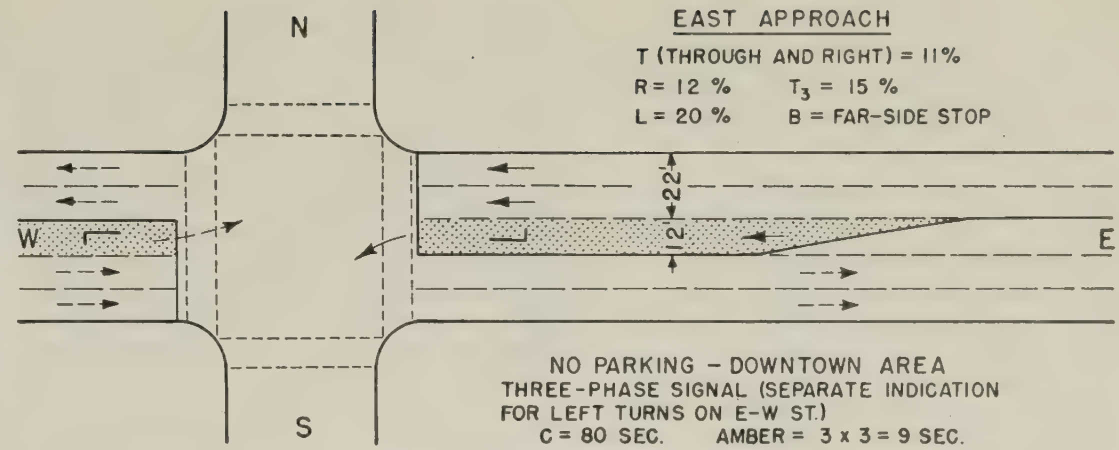

Figure 6.—Illustrative problem 19.

SPECIAL CONDITIONS

Charts 1–10 cover the general conditions found at four-way intersections under traf- fic-signal control. In addition there are numerous other conditions, the majority of which are discussed in the Manual as fur- ther adjustments. For each of these spe- cial conditions the chart procedure involves a series of steps or a special instruction to be followed.

1. *High Volume of Stopping Busses, With No Parking on Approach*

Where either a near- or far-side bus stop is provided, and where there is a high vol- ume of stopping busses, i. e., at least one bus loading or unloading at all times (one or two stopping to load and unload per cycle in one direction of travel), use chart 2 or 3 in the normal manner, except:

(*a*) Enter chart with $W/2$ equal to actual approach width minus 12 feet.

(*b*) Use T as a percentage of trucks only, exclusive of stopping busses.

(*c*) Use line B_x for bus-stop condition.

(*d*) To the design capacity obtained from the chart, add the number of stopping busses per hour in one direction to determine total design capacity.

Problem 20

If, in problem 4 (p. 108), all of the con- ditions remain the same except that 90 busses stop during the peak hour on the one approach and the percentage of trucks alone is 5 percent, what will be the design capacity?

Solution: Using chart 2, with $W/2=32-12=20$, $T=5\%$, bus-stop condition line B_x, $R=7\%$, $L=15\%$, and $G/C=0.45$, a value of 510 v.p.h. is obtained. Total $K=510+90=600$ v.p.h. in one direction.

2. *High Volume of Stopping Busses, With Parking on Approach*

Where either a near-side or far-side bus stop is provided and where there is a high volume of stopping busses as described in item 1 above, use charts 4 or 6 in the normal manner, except:

(*a*) Enter chart with $W/2$ equal to actual approach width minus 6 feet.

(*b*) Use T as percentage of trucks ex- clusive of stopping busses.

(*c*) Use line B_y for bus-stop condition. Do not use chart 5.

(*d*) Obtain result, but add to this the number of stopping busses per hour in one direction to determine total design capacity.

Problem 21

If, in problem 9 (p. 109), all of the condi- tions remain the same except that 80 busses stop during the peak hour on the one ap- proach, and the percentage of trucks alone is 4 percent, what will be the design ca- pacity? What will be the possible capacity of this approach?

Solution: Using chart 4, with $W/2=42-6=36$, $T=4\%$, bus-stop condition line B_y, $R=15\%$, $L=7\%$, and $G/C=0.52$, a value of 700 v.p.h. is obtained. Total $K=700+80=780$ v.p.h. in one direction.

From table 2, $f=1.2$. $P=(700\times1.2)+80=920$ v.p.h. in one direction.

3. *Widened Intersections, with No Parking*

Where the pavement approach is widened in advance of the intersection for a distance in feet equal to or greater than five times the green interval in seconds ($5G$), and the same pavement widening is continued be- yond the intersection for a distance in feet equal to $5G$ or more: Enter chart 2 or 3 with $W/2$ equal to total width of one ap- proach including the widening on that ap- proach; then use the chart in normal man- ner.

Problem 22

What is the design capacity of the south approach, widened through the intersection, as shown in figure 7?

Solution: Since the length of widening in advance of and beyond the intersection is greater than $5G$ ($5\times28=140$ feet), the full width of approach, 21+11=32 feet, is used to determine the capacity.

Using chart 3, for the conditions given, design capacity of south approach=625 v.p.h.

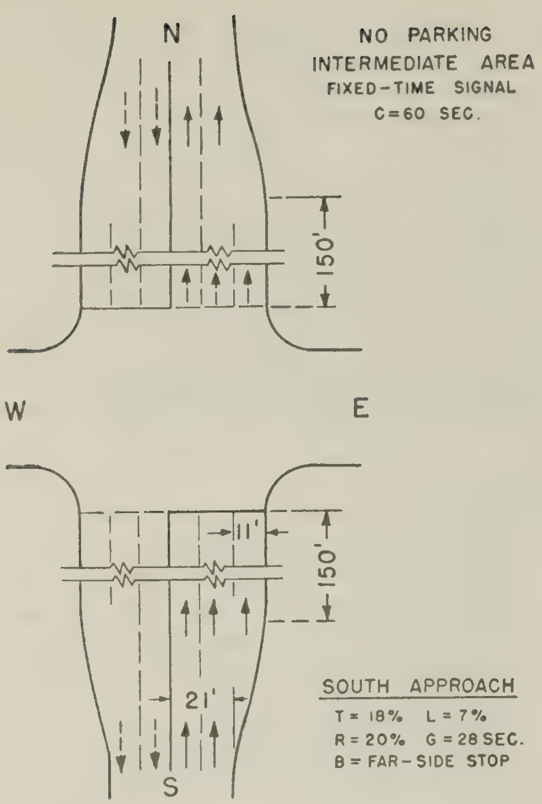

Figure 7.—Illustrative problem 22.

4. *Elimination of Parking at Intersections*

Where parking on a street is eliminated in advance of the intersection for a distance in feet equal to or greater than $5G$ and parking is also eliminated beyond the intersection for a distance equal to or greater than $5G$: Use chart 2 or 3, instead of chart 4, 5, or 6, as if there were no parking on the street.

Problem 23

To improve operation at a major intersection in a downtown area on a 42-foot street on which parking is permitted, it was decided to remove the bus stops and to prohibit parking for an effective distance in advance of and beyond this intersection. Other conditions on one approach are $T=15\%$, $R=20\%$, $L=10\%$, $G=30$ seconds, and $C=60$ seconds. Determine design capacity and possible capacity of one approach.

Solution: To be fully effective, parking must be eliminated on each side of the intersection for a distance of at least $5G$ or 150 feet.

From chart 2, using $W/2=21$ and other conditions as listed, $K=570$ v.p.h. $P=570\times 1.4$ (from table 2) $=800$ v.p.h.

5. *Check for Capacity of Left Turn*

Any intersection approach on a two-way street that does not involve a separate left-turn lane should be checked for capacity of the left-turn movement. This may be done in the same manner as for a separate left-turn lane, since the number of left-turning vehicles that can be accommodated with two-phase control, whether on a separate lane or not, is governed either by the volume of traffic opposing the left turn or by the length of cycle. Charts 8A and 8B should be used for such a check, which should be made for every intersection involving two-way streets. If the volume of left-turning vehicles exceeds the possible capacity as determined in charts 8A and 8B, serious congestion may result and the over-all capacity of the approach may be materially reduced. In such cases, the left-turn movement should be prohibited or, if feasible, accommodated on a separate signal indication.

Problem 24

Check whether the left-turn volume in problem 6 (page 109) can be handled satisfactorily.

Solution: Left-turn volume is 5% of 1,200, or 60 v.p.h. For the conditions given, it is found in chart 8B that 82 v.p.h. can be accommodated at design capacity; therefore, the solution in example 6 is satisfactory.

6. *Special Treatment of Turning Movements*

On the intersection approach of a two-way facility where the right-turn path is reasonably direct, and pedestrian interference is minor, the right-turn movement may be considered as part of the through movement; in which case, $R=0\%$ would be used in the chart solution.

On the intersection approach of a one-way facility where the turning conditions are as described above, either the right- or left-turn movement, or both, may be considered as part of the through movement. Such conditions are likely to occur at high-type, channelized intersections.

7. *Capacity Controlled by Intersection Exit*

Generally the capacity of the approaches controls the capacity of the intersection. At some locations, however, where all pavements of the intersection legs are not of the same width or where traffic backs up from an adjacent intersection, the capacity of the intersection may be dependent upon the exit lanes. The capacity of the exit pavement may be estimated as follows:

No parking on exit.—Enter chart 2 or 3 with $W/2$ equal to the width of exit pavement; proceed through chart in normal manner, but use T=percentage of trucks in through movement only, $R=0\%$, $L=0\%$, B=no bus stop (except where bus stop is on the far side, use B=far-side stop), and G/C equivalent to that used on the approach.

With parking on exit.—Enter chart 4 or 6 with $W/2$ equal to the width of exit pavement (including the parking width); proceed through chart in normal manner, but use T=percentage of trucks in through movement only, $R=0\%$, $L=0\%$, $Z=0$, and G/C equivalent to that used on the approach.

8. T *or* Y *Intersections*

The capacity of the approach on an tercepted street at T or Y intersect (east approach in figure 8) may be obtai from charts 2–6, as follows: Use the cha in normal manner except that the left-tu movement is considered to be the throu movement, since it is equivalent to through movement on a crossing (the o difference being the curved path), wh makes $L=0\%$. If parking is permitted the intercepted approach, use supplemen charts 5A and 5C, but $R+L$ is always eq to R only, because $L=0$.

Problem 25

What is the design capacity of the tercepted street (east approach), fr which traffic can turn only right and l into the north-south street, for the con tions indicated in figure 8?

Solution: In chart 2, using $W/2=20$, 10%, $R=40\%$, $L=0\%$, B=no bus stop, $G/C=0.40$, $K=460$ v.p.h. is obtained. T is the combined volume turning right left into the north-south street.

9. *Multiple-Type Intersections*

The capacity of any form of signaliz intersection, regardless of the number approach roads and extent of channeli tion, can be obtained from the charts examining each approach road separat The design of complex intersections, p ticularly those requiring multiphase c trol, may necessitate some study and t solutions before determining the final pl Multiple intersections often present seve possibilities in the pattern of operation in the number and arrangement of sig phases. Such alternate arrangements apt to result in different geometric layo thus affecting the size, shape, and locat of islands, widths of pavements, size storage areas, and over-all space requi ments for the intersection. The geome layout should be determined jointly w capacity analyses. Care should be ta

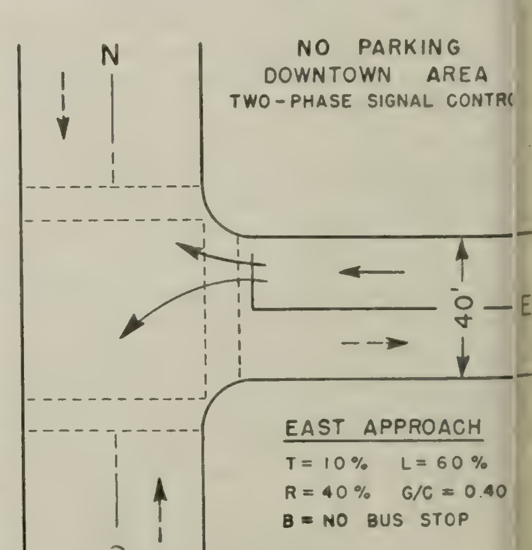

Figure 8.—Illustrative problem 25.

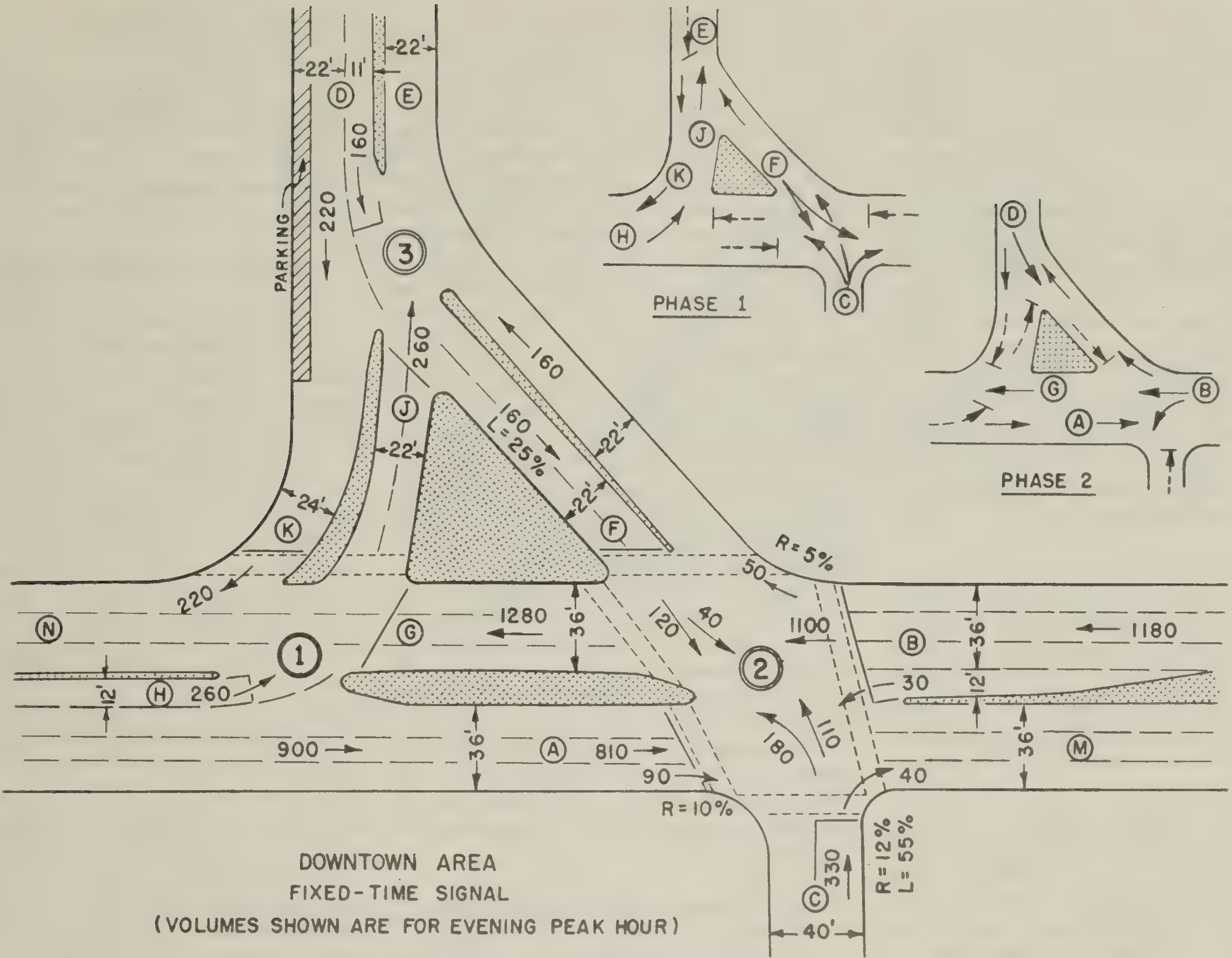

Figure 9.—Illustrative problem 26.

check the length and width of those traf- channels where vehicles will store dur-g certain signal phases to preclude the ndition of traffic backing up from one tersection point to another. The alter-te solutions will show differences in pacity, and in operational and economic lvantages, from which the most feasible an may be determined.

oblem 26

In figure 9 is shown a plan of a multiple tersection, selected from a study in which veral layouts were examined. The prob-m is to check the arrangement for opera-on at or near design capacity and to de-rmine the signal timing, using a 60-sec-d cycle, for the two-phase control indi-ted at the upper right of figure 9. There re no bus stops, and T is assumed to be 5 percent on all movements.

In order that the exit lanes (due to stored ehicles) do not limit the capacity of ap-roaches, a lagging green indication in sev-ral instances is considered necessary, as emonstrated below.

lovement H to E—phase 1

Approach H: From chart 10A, required $/C$=0.32, and $G=60\times0.32=19$ seconds. rom chart 10B, required length of left-rn lane is 180 feet.

Approach J: To prevent an excessive number of vehicles from storing at J and thereby limiting the capacity of this movement at H, a green indication at intersection 3 to lag behind that at intersection 1 is introduced. For a distance of 140 feet from H to J and an assumed speed of 15 m.p.h. (20 feet per second), the green lag= 140/20=7 seconds. This will preclude the storage of but a few vehicles at J. Thus, for approach J, $G=19+7=25$ seconds, and $G/C=0.42$.

Approach K—phase 1

Although there is parking about 70 feet in back of the stop line, it is not likely to have any effect on the capacity of the 24-foot pavement at intersection 1 due to the variable width involved. Moreover, since all traffic turns right on a rather direct path, the movement is considered to be a through movement without turns (see Special Condition, item 6). In chart 2, for $W/2=24$, no turns, etc., and $G/C=0.32$, (same as at H), design capacity=520 v.p.h., which is more than adequate for the load.

Approach G—phase 2

Using a 3-second amber period with each phase, the available green time per cycle is $60-19-6=35$ seconds, or $G/C=0.58$. From chart 2, design capacity=1,370 v.p.h., which is adequate since the load is 1,280 v.p.h.

Approach B—phase 2

During phase 1, approach G should be left clear, or nearly so, of vehicles from B to make room for the storage of movement C to G. During phase 2, this is accomplished by a lagging green at intersection 1 beyond that at intersection 2. For an assumed speed of about 20 m.p.h. (30 feet per second) and a distance of 200 feet, the lag is 7 seconds. Thus the green interval for approach B is 35—7=28 seconds, or $G/C=0.47$.

Through and right-turn movement: From chart 2, design capacity=1,100 v.p.h. This is satisfactory since the load, 1,100+50= 1,150 v.p.h., is only slightly above design capacity.

Left-turn movement: From chart 8B, design capacity of left-turn lane is about 95 v.p.h.; left-turn volume is 30 v.p.h. Required length of left-turn lane for this volume, from chart 8C, is 65 feet.

Approach A—phase 2

From chart 2, for a width of 36 feet and $G/C=0.47$, (same as at B), design capacity=1,070 v.p.h.; traffic load=900 v.p.h.

Approach C—phase 1

Available green time per cycle is 60—28—6=26 seconds, or $G/C=0.43$. It is first necessary to check the capacity of left turn in accordance with Special Conditions, item

5. From chart 8A, using V_o=120 v.p.h., T_o=15%, G/C=0.43, and T_3=15%, capacity of left turn is found to be 280 v.p.h., compared to a volume of 180 v.p.h. The capacity of the approach, as a whole, is obtained from chart 2. Since $L+(R/2)$ is greater than 35, R=10% and L=30% are used in the solution (see single-asterisk note in chart 2); and for the 20-foot approach, design capacity=370 v.p.h.; traffic load=330 v.p.h.

Storage space occupied by movement C to G on approach G during phase 1 may be obtained from chart 10B. For a volume of 180 v.p.h., the length required for storage, if in a single lane, is 135 feet.[6] In three lanes the length occupied would be about 45 feet. Available length on approach G is approximately 100 feet.

Approach F—phase 1

As above, G/C=0.43. The left-turn volume obviously can be handled. From chart 2, for an approach width of 22 feet, design capacity = 480 v.p.h. Since this is much in excess of the traffic load, the green interval on this approach could be decreased to give, in effect, a short advance green to movement C to G.

Length of storage on the two lanes of approach F for a volume of 160 v.p.h., from chart 10B, is 115÷2, or about 60 feet.[6] Available length is approximately 120 feet. This leaves sufficient space ahead of the stop line at D to consider the exit from approach D unimpeded in regard to capacity.

Approach D—phase 2

Movement D to K flows freely at all times. The green interval for left-turn movement D to F is 60−25−6=29 seconds (25 seconds is the green interval on approach J, previously determined), and G'/C=0.48. From chart 10A, design capacity of movement D to F is about 350 v.p.h. Since this is much in excess of the volume, the lagging green on approach J, phase 1, could be increased. Required length of left-turn lane, from chart 10B, is 120 feet.

Exit E—phase 1

Since exit E receives traffic from J and C simultaneously, the capacity of this combined movement should be checked as controlled by the exit (see Special Conditions, item 7). Total volume during phase 1 is 260+110=370 v.p.h. From chart 2, using $W/2$=22, no turns, etc., and G/C=0.42, design capacity of exit=620 v.p.h.

According to the above analysis, the intersection design is found to be satisfactory for operation during the evening peak hour. A similar capacity check should be made for the morning peak hour, which may show a different signal timing or a need for some modification in the geometric layout. Length of turning lanes and other storage areas would be based on the larger of the two values determined for the morning and evening peaks.

10. *Interpolation in Charts*

Where the intersection is in an area having characteristics between those of a downtown and an intermediate area, interpolation is made between the capacity values of charts 2 and 3, or charts 4 and 6.

Where the characteristics of the intersecting facility are between those of a street and an expressway, capacity values can be interpolated between those of charts for streets and those for expressways.

11. *Use of City or Local Factor*

In localities where driver characteristics, or other conditions, are believed to be different from those represented by the basic data in the Manual, a further adjustment to the Manual or chart values may be applicable. This adjustment can be expressed as a "city factor," established by relating actual hourly volumes measured at existing intersections loaded to their possible capacity (continual backlog of waiting vehicles on the approach during one hour), to the possible capacity, for comparable conditions, obtained from the Manual (1.10 times the value given in figure 24 therein and adjusted as necessary for specific conditions). Such field measurements should include a sufficient number and type of intersections to be representative for the city or locality as a whole. The ratio of measured possible capacities to those calculated by the Manual methods gives the "city factor." The numerical value of this factor may be a constant for all intersection approach conditions, or it may vary with the type of area and parking regulation.

Part II—One-Way Streets

Separate design capacity charts for one-way streets could have been developed but because of the definite relation between the capacity of two-way and one-way streets, this was considered unnecessary. Instead, a procedure is given for evaluation of intersection capacities of one-way streets by use of the charts for two-way streets.

DESIGN CAPACITY FACTORS

The basic data for intersection capacities of one-way streets, expressed in terms of average maximum volumes, are shown in figure 10.[7] This chart gives the same type of information for one-way streets as figure 1 for two-way streets. Since the same average conditions are represented in both, a definite relation can be established for the four upper curves of figure 10 and the comparable curves of figure 1. Thus, a series of factors to convert the maximum volumes accommodated by one approach on two-way streets to the maximum volumes on one-way streets can be obtained by making a ratio, for comparable conditions, of the volumes in figure 10 to the volumes in figure 1. For example, in figure 10, for an approach (one-way street) width of 34 feet, in an intermediate area, with no parking, a volume of 2,500 vehicles per hour of green is given; in figure 1 for the same approach width (68-foot two-way street) under the same conditions, a volume of 2,000 vehicles per hour of green is given. The conversion factor thus is 2,500/2,000=1.25.

Table 3 shows these conversion factors, i, for the range of approach widths up to 50 feet. It is to be emphasized that the parking on a one-way street represents parking on one side only. This condition is comparable to one approach of a two-way street, and so permits use of the two-way capacity charts. To find the design capacity of an approach on the one-way street, use charts 1–6, with $W/2$ equal to the whole width of the one-way street; then multiply the given K by appropriate i in table 3. Design capacities and required lengths of separate turning lanes on one-way streets are the same as those on two-way streets, for which charts 7–10 are used.

When parking exists on both sides of a one-way street the operating conditions are not similar and the two-way values and adjustments cannot be used. In such cases reference should be made to item IV on page 90 of the Manual for adjustments to the values in figure 10. It will be noted that the values in figure 10, for a given width of street, show one-way street capacity with parking on both sides to be about 70–75 percent of that with parking on one side in downtown areas, and about 80–85 percent in intermediate areas.

RELATION OF DESIGN CAPACITY TO POSSIBLE CAPACITY

The relation between design and possible capacities developed for two-way streets also is applicable to one-way streets. The factors f from table 2 apply directly when used with $W/2$ as the whole width of a one-way street. Factors for the condition "with parking" are applicable to parking on one side only of one-way streets. The procedure to obtain possible capacity of a one-way street is: (1) determine design capacity for an equivalent approach from charts 1–6; (2) multiply by factor i in table 3; and

[6] Storage space from chart 10B is based on 1.5 times the average number of vehicles storing per cycle. Actually the maximum that may be stored can be as high as two times the average number per cycle. Thus, where feasible, the length of such storage area should be predicated on chart 12E. In this problem, however, the space is adequate on either basis.

[7] Figure 26, p. 84 of the Manual.

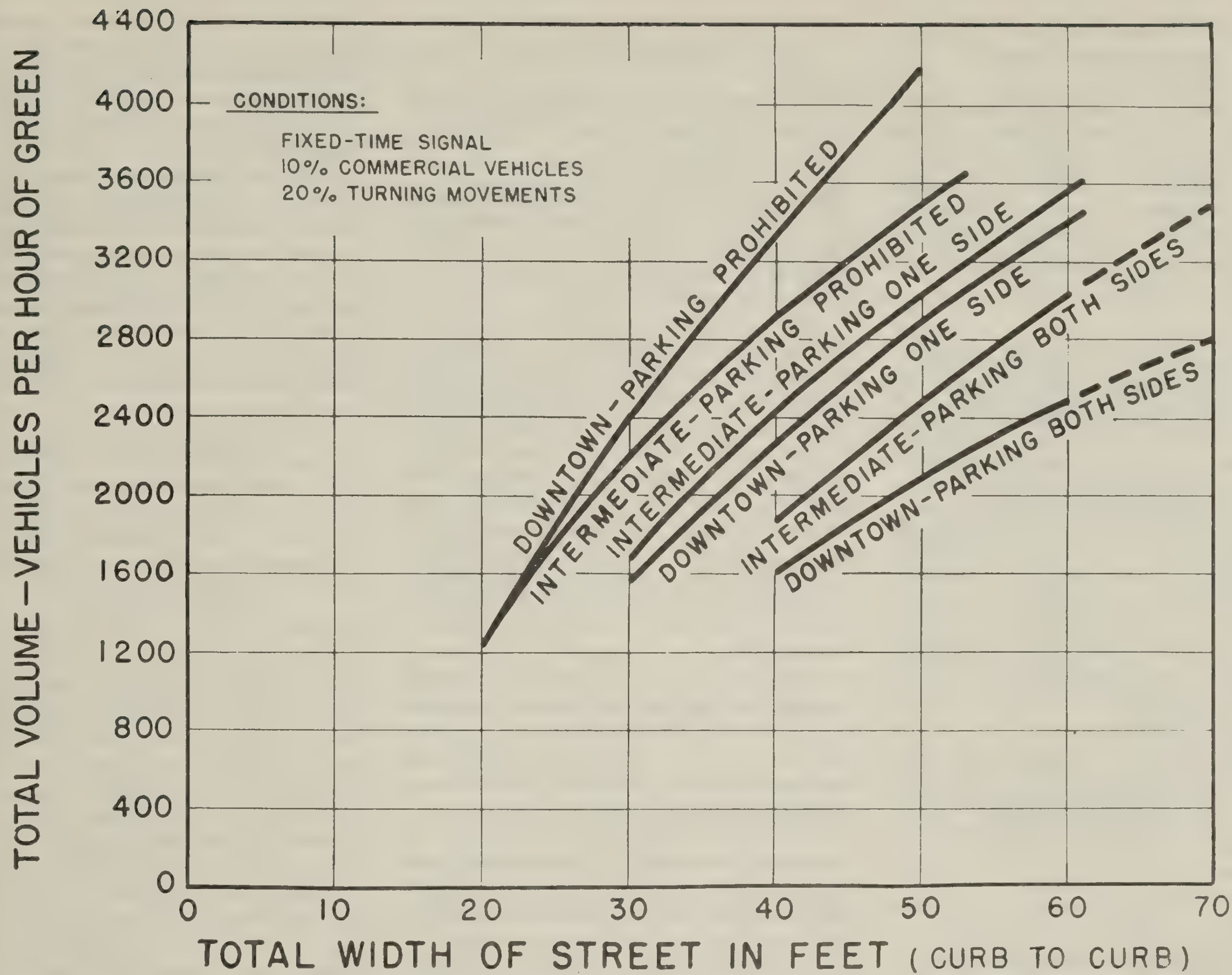

Figure 10.—Average maximum volumes at intersections on one-way streets, for different widths and by type of area and parking regulation.

:) multiply by factor f in table 2. Possi-le capacities of separate turning lanes on ie-way streets are the same as those on vo-way streets; i. e., $1.2K_2$ or $1.2K_3$.

PROCEDURE

The following procedures, employing arts 1–10 and tables 2 and 3, are used to termine the capacity of one-way streets. or ready reference, each major condition treated separately.

A.—Average Conditions

Proceed through chart 1 in the normal anner, with $W/2$ equal to the width of ie-way street, and obtain a capacity value. ultiply this by factor i, table 3, to obtain esign capacity of one-way street. If the iart is entered on the right with a given olume, in order to obtain either a value G/C or $W/2$, divide this volume by fac-or i before entering the chart.

roblem 27

An intersection on a one-way street, 30 eet wide between curbs, with parking on ne side, located in a downtown area, is assumed to be operating under average conditions. What is the design capacity if the signal is so timed that $G/C=0.60$? What will be the possible capacity?

Solution: In chart 1, using $W/2=30$, curve III, and $G/C=0.60$, read = 600 v.p.h. From tables 3 and 2, $i=1.25$ and $f=1.40$.

$K=600\times1.25=750$ v.p.h.

$P=750\times1.40=1{,}050$ v.p.h.

Problem 28

If, in problem 27, the approach volume to be accommodated is only 625 v.p.h., to what may the ratio of G/C be reduced?

Solution: Enter chart 1 with $W/2=30$, proceed to curve III, and project a line downward. Then enter the chart with a volume of $625\div1.25=500$ v.p.h., proceed to the left and intersect the vertical line previously projected; read $G/C=0.50$.

Table 3.—*Factor i to convert capacity value (charts 1–6) on one approach on a two-way street to that on a one-way street*[1]

$W/2$ = Approach width [2]	No parking		Parking on one side	
	Downtown	Intermediate	Downtown	Intermediate
Feet				
20	0.88	0.94	....	....
22	.94	1.00	....	....
24	.98	1.04	..	..
26	1.02	1.09	1.19	1.09
28	1.05	1.13	1.22	1.13
30	1.08	1.18	1.25	1.17
32	1.11	1.22	1.29	1.21
34	1.13	1.25	1.31	1.24
36	1.15	1.29	1.34	1.26
38	1.17	1.32	1.37	1.28
40	1.19	1.35	1.40	1.30
42	1.21	1.38	1.42	1.32
44	1.23	1.41	1.44	1.33
46	1.25	1.44	1.46	1.35
48	1.26	1.47	1.47	1.36
50	1.27	1.48	1.48	1.38

[1] For the same width of approach, type of area, and parking regulation.
[2] For one-way streets, the total curb-to-curb width, exclusive of separate turning lanes; for two-way streets, one-half (normally) of the curb-to-curb width.

B.—No Parking, in Downtown or Intermediate Area

Enter chart 2 or 3 with $W/2$ equal to the width of the one-way street. Proceed through the chart in normal manner, but instead of actual L use $(L/2)+5$. Multiply the result by factor i from table 3 to obtain design capacity of the one-way street. The single-asterisk note in charts 2 and 3 does not apply to one-way streets.

Problem 29

A 40-foot street in a downtown area is converted to one-way operation with no parking. Other conditions are T=18%, R=12%, L=20%, B=no bus stop, and 35% of the cycle time must be devoted to the cross street. What is the design capacity of the one-way street if two-phase signal control is used with C=60 seconds and each amber=3 seconds? What will be the possible capacity?

Solution: Green time that must be allotted to the cross street is 35% of 60=21 seconds. Green time available for the one-way street is $60-21-(2\times3)=33$ seconds, and $G/C=33/60=0.55$.

Using chart 2, with $W/2$=40, T=18%, R=12%, $L=(20/2)+5$=15%, B=no bus stop, and G/C=0.55, obtain a capacity value of 1,100 v.p.h. From tables 3 and 2, i=1.19 and f=1.40.

$K=1{,}100\times1.19=1{,}300$ v.p.h.

$P=1{,}300\times1.40=1{,}820$ v.p.h.

C.—With Parking on One Side, in Downtown or Intermediate Area

Enter chart 4 or 6 with $W/2$ equal to the width of the one-way street. Proceed through the chart in normal manner, except instead of actual L use $(L/2)+5$. Use supplemental chart 5 in normal manner, as for two-way streets. Multiply the result from chart 4 or 6 by factor i from table 3 to obtain capacity of the one-way street. The single-asterisk note on charts 4 and 6 does not apply.

Problem 30

If, in problem 29, all of the conditions remain the same except that parking is permitted on one side and D=20 feet, what will be the design capacity?

Solution: First use chart 5C, with $R+L=12+20=32$%, and D=20, obtaining $Z=-6$. Then, from chart 4, a capacity value of 640 v.p.h. is found. In table 3, i=1.40 for a 40-foot approach with parking on one side.

$K=640\times1.40=900$ v.p.h.

D.—With Separate Turning Lanes, No Separate Signal Indication

With right-turn lane: Follow the instructions given on chart 7, except in obtaining the capacity of the combined through and left-turn movement M_2 use $(L/2)+5$ instead of actual L in chart 2 or 3; multiply this by factor i from table 3.

With left-turn lane: Use chart 7, since chart 8 is not applicable to one-way streets. In obtaining the capacity of the combined through and right-turn movement, use L=5% (instead of 0%) in chart 2, 3, 4, or 6; multiply this by factor i from table 3.

With both right- and left-turn lanes: Follow the instructions on chart 9, except in obtaining the capacity of the through movement M_1 use L=5% (instead of 0%) in the solution on charts 2 and 3; multiply this by factor i from table 3.

Problem 31

If, in problem 29, all of the conditions remain the same, except that the approach is widened by addition of a left-turn lane with an adequate curb return (and there is little if any pedestrian interference), what will be the design capacity?

Solution: The design capacity of the left-turn lane, from chart 7B, using G/C=0.55 and T_3=18% (assuming the percentage of trucks is the same for all movements), is 360 v.p.h.

A capacity value for the combined through and right-turn movement, from chart 2, using $W/2$=40, T=18%, R=12%, L=5%, B=no bus stop, and G/C=0.55, is 1,220 v.p.h. From table 3, i=1.19. The design capacity of the through plus right-turn lanes$=1{,}220\times1.19=1{,}450$ v.p.h.

From step 3, chart 7, left-turn volume$=(1{,}450\times20)\div(100-20)=360$ v.p.h., which is the same as the design capacity found above. Design capacity of approach $=1{,}450+360=1{,}810$ v.p.h. The length of left-turn lane required, from chart 7C, is approximately 200 feet.

E.—With Separate Turning Lanes and Separate Signal Indication

With right-turn lane: Follow the instructions on chart 10, except for step 2 in the series on the right side of the figure substitute the following: Obtain design capacity of the combined through and left-turn movement M_2 in the usual manner fro[m] charts 2–6. Use $W/2$ as the normal wid[th] of approach, exclusive of turning lan[e], $(L/2)+5$ instead of actual L; and R=0[%]. Multiply the result obtained by factor [i] from table 3.

With left-turn lane: Follow the instru[c]tions on chart 10, except for step 2 in t[he] series on the left side of the figure subs[ti]tute the following: Obtain design capaci[ty] of the combined through and right-tu[rn] movement M_3 in the usual manner fr[om] charts 2–6. Use $W/2$ as the normal wid[th] of approach, exclusive of turning lane, a[nd] L=5%. Multiply the result by factor [i] from table 3.

F.—Special Conditions

The items listed under the heading Sp[e]cial Conditions for two-way streets (pa[ge] 113) also apply to one-way streets, exce[pt] that the charts are to be used as describ[ed] above in sections B–E.

Problem 32

What is the design capacity, in proble[m] 29, if all of the conditions remain the sa[me] except that a bus stop is provided at t[he] intersection on the one-way street with a[p]proximately 90 busses stopping per ho[ur], and T, exclusive of stopping busses, is 5%? What is the possible capacity?

Solution: According to item 1, page 1[13], $W/2=40-12=28$ feet. Using this in cha[rt] 2, with T=5%, R=12%, $L=(20/2)+5$= 15%, bus-stop condition line B_x, and G/C= 0.55, a capacity value of 890 is obtain[ed]. From tables 3 and 2, i=1.19 and f=1.40.

Design capacity$=(890\times1.19)+90$ buss[es] =1,150 v.p.h.

Possible capacity$=(1{,}060\times1.40)+$[90] busses=1,570 v.p.h.

Problem 33

What is the design capacity in proble[m] 25, page 114, if all of the conditions rema[in] the same, except that the 40-foot int[er]cepted street is converted to a one-wa[y] street for travel in the westerly directio[n]?

Solution: According to item 8, page 1[13], the left-turn movement is considered [to] be equivalent to the through movement, [b]ut that in the solutions $L=(0/2)+5$=5% (see section B above). Using chart 2 wi[th] $W/2$ = 40, T = 10%, R = 30% or more, L= 5%, B=no bus stop, and G/C=0.40, a capacity value of 880 is obtained. Fr[om] table 3, i=1.19. Design capacity of [th]e one-way east approach$=880\times1.19=1{,}0$[50] v.p.h.

Part III—Expressways

FEATURES OF EXPRESSWAYS

An expressway is defined as a divided arterial highway for through traffic with full or partial control of access and generally with grade separations at intersections.[8] The salient geometric features of an expressway are: a divided highway designed to high standards, insulated for the most part from the adjacent development; shoulder space for emergency use (no parking adjacent to the traveled way); bus stops (if any) on separate turnouts; a[nd] properly designed and controlled inters[ec]tions. Where partial control of access [i]s used, the expressway will intersect so[me] streets or highways at grade. These [in]tersections will require added turning la[nes] of adequate design, pedestrian cross-w[al]k

[8] Definition adopted by the American Association of State Highway Officials, June 25, 1949.

itrols, and in some instances traffic signal itrols for all traffic.

On expressways, where the above conditions are satisfied, intersection capacities expressed in terms of vehicles per hour green per unit of width will be higher than on ordinary streets or highways, and the capacity data represented on charts 10 are not applicable. Charts 11, 12, and 13 are design capacity adjustments for specific conditions on high-type facilities, based on the data in item V on page of the Manual. These charts are applicable to both rural and urban conditions, and to divided two-way highways or to one-way facilities. Two general conditions govern and are treated separately: charts and 12 are applicable where separate turning lanes exist; and chart 13 where widened approaches are used.

EXPRESSWAYS WITH SEPARATE TURNING LANES

Charts 11 and 12 give all of the necessary information for evaluating the expressway design capacity at signalized intersections having separate turning lanes the type of layout shown in the upper right-hand corner of chart 12). Added turning lanes are arranged for the exclusive use of turning vehicles, and other traffic cannot use them to proceed through the intersection. Added lanes designed to permit their use by through traffic are discussed in the next section, concerning widened intersections.

Chart 11 gives the solution for the design capacity of the through movement K_1 on the expressway at a signalized intersection. It is based on the Manual value of 1,000 passenger vehicles per hour of green per 10 feet of lane width. With adjustment for the percentage of trucks and busses and for the G/C value, the design capacity can be read directly for the width of through lanes ($W/2$ on the sketch in chart 12). This capacity value must be used jointly with separately determined capacities for right- and left-turn movements obtained from chart 12. The procedure is the same as that described for charts 9 and 10.

Chart 12 gives solutions for design capacities of separate turning lanes, in which charts A, B, and C are for controls without separate signal indication and chart D with a separate signal indication. Since the conditions are identical with those in chart 8, the design capacity of a left-turn lane is obtained from chart 12A or 12B, the larger value governing. Chart 12C is of the same form as that of chart 7B, but is based on a control value of 1,000 vehicles per hour of green per 10 feet of width instead of 800. A third adjustment is included in chart 12C in terms of three degrees of pedestrian interference. Chart 12D is the same as chart 10A except that the control value of 1,000 is used instead of 800.

The length of right- or left-turn lane, with or without separate signal indication, is given in chart 12E and predicated on the maximum number of vehicles that can be stored per cycle, which is assumed to be twice the average number. Since expressways are intended for rapid vehicular movement with a minimum of operational delay, the length of turning lanes should be predicated on the likely approach speeds of traffic during the green signal periods. For this purpose the turning lanes should be sufficiently long to permit turning vehicles to decelerate to the safe speed of the turn, with allowance for drivers to bring their vehicles to a stop if necessary. Minimum lengths of deceleration lanes to allow for such operation are given in table 4. Comparative values are obtained from chart 12E and from the second column of table 4 and the larger of the two should be used in design. The length of taper should never be less than that shown in the third column of table 4.

Table 4.—*Minimum lengths of speed-change lanes and taper to or from a stop position*

Highway design speed	For deceleration lanes			For acceleration lanes [1]		
	Length exclusive of taper	Length of taper	Total length	Length exclusive of taper	Length of taper	Total length
Miles per hour	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
30	15	100	115	....	140	140
40	40	125	165	75	175	250
50	90	150	240	280	200	480
60	130	175	305	550	250	800

[1] Applies only to conditions with widened approaches or to intersections without signal control.

On expressways, bus stops in the vicinity of cross streets should be located off the through lanes and on the far side of the intersection. When thus positioned at an intersection with corner islands, as in the sketch on chart 12, bus stops have little if any effect on intersection capacity. Thus, charts 11 and 12 apply to intersections with bus stops on the far side as well as to those with no bus stops. In the event that a near-side bus stop is provided, the capacity should be reduced according to the adjustment in item V-3B on page 91 of the Manual.

Another condition adjustment is shown in item V-2A (2) in the Manual, for right-turn movements as affected by frontage-road traffic. When a frontage road is sufficiently close to affect a right-turn movement, the capacity condition is the same as that of a left turn from an added lane without a separate signal indication, and values from charts 12A and 12B are applicable.

Intersections on expressways should be designed so that anticipated volumes will not exceed the design capacity. For certain combinations of traffic volumes and distributions, however, it may not be practicable to accommodate each approach movement at design capacity. One of the turning movements may have to operate above design capacity, but the excess should not be large. The relative amount can be determined by calculating possible capacity.

On expressways, possible capacity for any movement may be obtained by multiplying the design capacity by 1.2.

Problems 34–37 illustrate the use of charts 11 and 12.

Problem 34

On the expressway shown in figure 11, traffic from east to west during the peak hour is approximately 60% of the total two-way traffic on the expressway. On the east approach, what is the design capacity of the through lanes, the right-turn lane, and the left-turn lane, when trucks comprise 10% of each movement, C=65 seconds, and G=39 seconds?

Solution: Design capacity of the through pavement, K_1, using chart 11 with $W/2$=25, T=10%, and G/C=39/65=0.60, is 1,350 v.p.h.

Design capacity of the right-turn lane K_2, using chart 12C with G/C=0.60, a=11, T_2=10%, and light to moderate pedestrian interference, is 530 v.p.h.

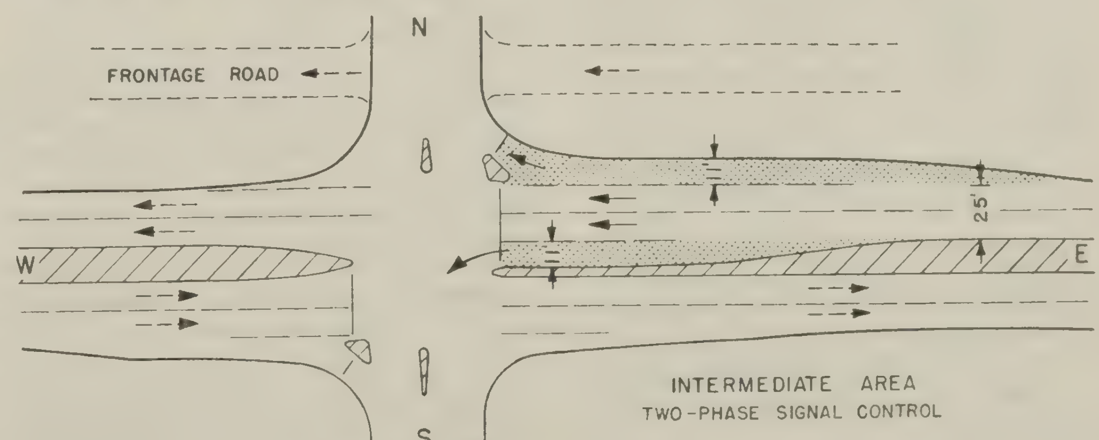

Figure 11.—Illustrative problems 34–37.

Design capacity of the left-turn lane K_3 is determined by the larger of the two values from charts 12A and 12B. The volume opposing the left turn V_0, as used in chart 12A, is 40% of the total peak-hour volume on the expressway, or $1{,}350 \times 40/60 = 900$ v.p.h. Using this in chart 12A gives a zero capacity. Minimum capacity in chart 12B, with $C=65$ seconds, is 88. Thus, the value in chart 12B governs and $K_3=90$ v.p.h. (using a rounded figure).

Problem 35

Determine the minimum signal timing and lengths of turning lanes of the east approach of the intersection shown in figure 11 if the design speed is 50 m.p.h. and the design volumes during the evening peak hour are as follows: through movement, 1,120 v.p.h. of which 5% are trucks; right-turn movement, 280 v.p.h. of which 30% are trucks; and left-turn movement, 90 v.p.h. of which 2% are trucks.

Solution: The proportion of green time, G/C, needed for the through movement is obtained from chart 11: Using $W/2=25$, $T=5\%$, and an approach through volume of 1,120 v.p.h., the required $G/C=0.47$.

For the right-turn movement chart 12C is used. Entering the chart at the bottom with a volume of 280 v.p.h., and using light to moderate pedestrian interference, $T_2=30\%$, and $a=11$, the required $G/C=0.38$.

It is apparent from the approach volumes indicated and from the distribution of traffic by direction, as shown in problem 34, that the capacity of the left-turn lane is not governed by the condition in chart 12A. Thus, using chart 12B, it is found that for a left-turn volume of 90 v.p.h. a cycle length C of 64 seconds is required.

The through movement, for which the required $G/C=0.47$, governs the design capacity of the east approach. Assuming that a 64-second cycle is satisfactory, $G=64 \times 0.47=30$ seconds and, if each amber period is 3 seconds, the signal timing will be 30 seconds green and 6 seconds amber, leaving 28 seconds red (green on the cross street).

In the event that a longer cycle had to be used, say 75 seconds, the design capacity of the left-turn lane (chart 12B) would be 77 v.p.h. The 90 v.p.h. could still be handled, although not as satisfactorily, since possible capacity would be $77 \times 1.2=92$ v.p.h.

The lengths of turning lanes, from chart 12E, required to handle the volumes indicated are:

Right-turn lane: Using $V_2=280$ v.p.h., $C=64$ seconds, and $T_2=30\%$; $D_2=300$ feet.

Left-turn lane: Using $V_3=90$ v.p.h., $C=64$ seconds, and $T_3=2\%$; $D_3=80$ feet.

The length of each turning lane required for speed change, from table 4, is 90 feet plus a taper of 150 feet. Thus, the right-turn lane should be 300 feet long plus a 150-foot taper, and the left-turn lane 90 feet long plus a 150-foot taper.

Problem 36

If, in problem 35, all of the conditions remain the same, except that a one-way frontage road is provided (dash lines in figure 11), what will be the design capacity of the right-turn lane on the east approach when a volume of 250 v.p.h. on the frontage road, of which 12% are trucks, receives a green signal at the same time as the expressway traffic?

Solution: In this case it is necessary to check the capacity of the right-turn lane as affected by the crossing of frontage-road traffic, which can be determined from charts 12 A and 12 B (see page 119, cols. 2–3).

Using $V_0=250$ v.p.h. in chart 12A as the volume conflicting with the right-turning movement, $T_0=12\%$, $G/C=0.47$, and T_3 (which in this case is the percentage of trucks in the right-turn movement) $=30\%$, the design capacity, as controlled by the frontage road traffic, is found to be 190 v.p.h.

This indicates that, with a frontage road, a right-turn volume of 280 v.p.h. cannot be accommodated, and three-phase control is needed at the intersection of the frontage road and the cross street.

Problem 37

If, in problem 35, all of the conditions remain the same, except that the left-turn volume on the east approach is 140 v.p.h., what will be the signal timing if the left turn is to be accommodated on a separate signal indication? The 28-second green interval on the cross street is to be retained to give pedestrians sufficient time to cross the street. Left-turn movement on the west approach also will move on this phase.

Solution: In problem 35 it is shown that a value of $G/C=0.47$ is required for the through movement, during which the right turn will also be accommodated. The separate phase for the left turn will require an additional $G'/C=0.13$, as determined from chart 12D with a volume of 140 v.p.h., $T_3=2\%$, and $a=11$ feet.

To retain the 28-second green period on the cross street, the length of cycle must be: $C=0.47C+0.13C+28+(3 \times 3)$ amber$=$ 93 seconds.

The green signal times are thus: For through and right-turn movement on the expressway, $93 \times 0.47=44$ seconds; for left turns on the expressway, $93 \times 0.13=12$ seconds; for the cross street, 28 seconds. Each of the three phases is followed by a 3-second amber period.

It may be noted that, while the 28-second green interval has been retained for the cross street, the proportion of green time (G/C) for movement of traffic on this street, because of lengthened cycle, has been decreased; thus, the capacity of the cross street is less than that in problem 35.

EXPRESSWAYS WIDENED THROUGH INTERSECTIONS

On expressways where the cross roads at grade are widely spaced it may be necessary to widen the expressway pavements at the intersections to prevent their capacity from being diminished at these points. Such treatment is illustrated b a sketch in the upper right-hand corne of chart 13, and from this chart the desig capacity can be determined or the numbe of lanes required to handle a given volum can be established.

In this condition the added lanes, show as e_2 and e_2 in the sketch, are carried throug the intersection, unobstructed by triangula islands. When the expressway is operatin at relatively low volumes, through traff will proceed through the intersection o the normal width of pavement, $W/2$, e clusive of widening. During such tim the added lanes e_2 and e_3 will function a speed-change lanes for turning vehicle At or near design capacity, however, throug traffic will be stored on the added lanes ar proceed through the intersection when th signal changes. Turning vehicles will al use these lanes at the same time. For th reason an adjustment in capacity must b made. This is accounted for in chart 1

An adjustment for bus stops is not i cluded in chart 13. Since this type intersection generally is used to maintai the high capacity available on other portio of the expressway without intersections grade, bus stops should be excluded fro all lanes intended for regular traffic us If bus stops are necessary at such location they should be provided on frontage roa or on separate turnouts.

Chart 13 is constructed on the same bas as chart 11 (see pp. 87 and 103 of t Manual), with a design capacity of 1,0 vehicles per hour of green per 10 feet width. The upper left and lower rig portions of chart 13 are identical wi chart 11. The added adjustments for tur ing movements are the same as in previo charts, the percentage reduction being 0.5 for right turns and 1.0L for left turns.

For this capacity condition the widened a proach pavement must be of sufficient leng to encourage its use by through traff as well as be adequate for deceleration a storage of turning vehicles. Controls f the required lengths are given in the not below the sketch in the upper right corn of chart 13. The widened length in fe in advance of the intersection, shown D_a, should be at least five times the gre interval in seconds (see Manual, p. 8 and also should be adequate for decelerati purposes, as indicated in the second colum of table 4. In addition it should have proper taper, as shown in table 4.

For the maneuvering of traffic, the wi ened pavement D_b beyond the intersecti should be of length somewhat longer than the approach side, for which a factor of 1 is assumed. Further, the length should checked for suitability for acceleration, a cording to the fifth column of table 4. T sixth column of table 4 gives the need length of taper.

Problem 38

An expressway with two one-way pav ments, separated by a median about 1 feet wide, intersects a cross road at gra

...d a signal must be installed. If the normal width of each expressway pavement is 33 feet, and at the intersection each pavement is widened by 12 feet on the left and on the right for an adequate distance in advance of and beyond the intersection, what is the design capacity of one approach, if $T=10\%$, $R=15\%$, $L=12\%$, and $G/C=$ 0.54?

Solution: The total width of approach is $W/2+e_2+e_3=33+12+12=57$ feet. Using this in chart 13 with the conditions given above, $K=2{,}260$ v.p.h. The wide median, in effect, separates the expressway into two one-way facilities; therefore, it is not necessary to check for the capacity of the left turn.

Problem 39

An urban expressway in rolling terrain, designed for a speed of 50 m.p.h., has two 12-foot lanes in each direction, and all cross streets are separated in grade except at one isolated intersection. The volume of traffic on the cross street can be accommodated by a two-phase traffic signal with 30% of the elapsed time allowed for the cross street, and a 20-second green interval for pedestrians.

If the intersection treatment is to be of the type shown in the upper right-hand corner of chart 13, determine the minimum number of lanes on the expressway, at the intersection, that will enable the intersection approaches to accommodate a volume of traffic equal to the capacity of the two 12-foot lanes where flow is uninterrupted. On the critical approach, during the peak hour, $T=15\%$, $R=18\%$, and $L=4\%$.

Solution: On the basis that 30% of the cycle is required for the cross movement with a green interval of 20 seconds, the shortest cycle that can be used is $20\div0.30=$ 67 seconds. Allowing 7 seconds for the amber periods, the green interval available for expressway traffic is $67-7-20=40$ seconds, and $G/C=40/67=0.60$.

The capacity of the expressway on the portions where the flow is uninterrupted, with 15% trucks in rolling terrain, is found to be 1,050 v.p.h. per lane,[9] or a one-way flow on the facility of 2,100 v.p.h. The total number of lanes on the one approach to handle this volume can be obtained from chart 13. Entering the chart at the bottom with a volume of 2,100 v.p.h. and using $G/C=0.60$, $L=4\%$, $R=18\%$, and $T=15\%$, the total approach width, $W/2+e_2+e_3$, is found to be 47 feet.

Four lanes will therefore be required on the one approach at the intersection, or an extra lane on each side of the normal pavement, to accommodate a volume equal to the uninterrupted capacity flow of the expressway.

Since the expressway is a two-way facility it is necessary to check separately in chart 12 for capacity of the left-turn lane. Obviously chart 12B governs, from which it is found for $C=67$ seconds that 86 left-turning vehicles can be handled. This is satisfactory since 4% of 2,100 is 84 v.p.h.

The minimum lengths of widened pavement, from the notes under the sketch on chart 13, should be: For D_a, 200 feet plus 150-foot taper; for D_b, 300 feet plus 200-foot taper.

[9] 1,500 X 0.70 = 1,050 v.p.h. Practical or design capacity of urban expressways is given as 1,500 vehicles per hour per lane on p. 47 of the Manual; 0.70 is a factor interpolated in table 9, p. 56 of the Manual, for the effect of commercial vehicles on practical capacity.

Part IV—Over-All Intersection Capacity

USE IN PRELIMINARY DESIGN

In planning or in preliminary design there often is need for a quick, approximate determination of intersection capacities. The problem usually resolves itself into one of two conditions: (1) where the intersecting volumes are known and street widths are established, to determine whether capacity is adequate; or (2) where the intersecting volumes and the width of one street are given, to determine the width of the intersecting street.

These problems can be solved with charts 1–13 by first determining the proportion of green time required for one approach, assuming a cycle length and appropriate amber periods; then calculating the resultant G/C for the cross-street approach; and finally determining, according to the cross-street volume, either its adequacy for capacity or its necessary width.

SOLUTION WITH HOURLY TRAFFIC VOLUMES

Chart 14 was devised for use in planning of systems or for early stages of design, as well as for review of preliminary plans, where a quick method is needed for determining intersection capacities or required street widths at a four-way intersection under signal control. Chart 14 combines the necessary information for both of the intersecting streets on one chart and gives results in terms of over-all capacity. It takes into account jointly, for average conditions, the intersection of any two facilities, regardless of the type of each (one-way or two-way street or expressway), type of area, and parking regulation. The left half of the chart is used for the approach on one street and the right half for the approach on the other (intersecting) street. A line projected between the inner sides of the two charts determines, at the point where it intersects the center axis, y-y, the adequacy of intersection capacity.

The two parts of chart 14 are identical except for the reverse plotting. The arrangement of each part is similar to that of chart 1, but the G/C ratio is made the outer scale and the volume is shown as the lower series of curves. In addition to the four area-parking conditions shown on chart 1, conditions for one-way streets and expressways are represented in the upper parts of chart 14 by other sloping lines. These are control values previously presented, including adjustments to obtain design capacity. Notes at the lower left show the proper $W/2$ value to be used for each case. The G/C ratio on the inner side scales is the proportion of time required on the one approach for operation at design capacity. With an assumption of 10 percent of the cycle time being used in the amber periods, design capacity is obtained when the total of two green intervals is 90 percent of the cycle (the sum of the two G/C values=0.90). The zero point on the y-y axis is located so that a straight line between any two G/C values passes through it when their sum is 0.90. The scale values above and below the zero point on the y-y axis show the proportion by which the sum of the G/C values is deficient or in excess of the design capacity condition. As indicated on the chart, a design capacity deficiency of 20 percent is about the possible capacity condition.

With chart 14, graphic solutions can be made for various combinations of control conditions to determine one missing factor. It must be remembered that this solution is for average conditions only, with assumptions that trucks and busses constitute 10 percent and turning movements on streets 20 percent (15 percent on expressways) of the total approach volume. Where specific conditions are otherwise, the solutions should be obtained from charts 2–13.

Problem 40

In a downtown area a two-way street (approach A) 62 feet wide with parking intersects a two-way street (approach B) 44 feet wide without parking. A fixed-time signal is used and conditions are assumed to be average. When the peak-hour volume on approach A is 400 v.p.h. in one direction and on approach B is 600 v.p.h. in one direction, is the capacity of the intersection adequate?

Solution: For approach A, enter chart 14 at the left with $W/2=62/2=31$, proceed to the right to the curve for downtown two-way street with parking, then down to an approach volume of 400 v.p.h., and to the right to $G/C=0.38$. For approach B, enter the chart at the extreme right with $W/2=$

nd a signal must be installed. If the normal width of each expressway pavement is 33 feet, and at the intersection each pavement is widened by 12 feet on the left and on the right for an adequate distance in advance of and beyond the intersection, what is the design capacity of one approach, if $T=10\%$, $R=15\%$, $L=12\%$, and $G/C=$ .54?

Solution: The total width of approach is $W/2+e_2+e_3=33+12+12=57$ feet. Using this in chart 13 with the conditions given above, $K=2{,}260$ v.p.h. The wide median, in effect, separates the expressway into two one-way facilities; therefore, it is not necessary to check for the capacity of the left turn.

Problem 39

An urban expressway in rolling terrain, designed for a speed of 50 m.p.h., has two 12-foot lanes in each direction, and all cross streets are separated in grade except at one isolated intersection. The volume of traffic on the cross street can be accommodated by a two-phase traffic signal with 30% of the elapsed time allowed for the cross street, and a 20-second green interval for pedestrians.

If the intersection treatment is to be of the type shown in the upper right-hand corner of chart 13, determine the minimum number of lanes on the expressway, at the intersection, that will enable the intersection approaches to accommodate a volume of traffic equal to the capacity of the two 12-foot lanes where flow is uninterrupted. On the critical approach, during the peak hour, $T=15\%$, $R=18\%$, and $L=4\%$.

Solution: On the basis that 30% of the cycle is required for the cross movement with a green interval of 20 seconds, the shortest cycle that can be used is $20 \div 0.30 =$ 67 seconds. Allowing 7 seconds for the amber periods, the green interval available for expressway traffic is $67-7-20=40$ seconds, and $G/C=40/67=0.60$.

The capacity of the expressway on the portions where the flow is uninterrupted, with 15% trucks in rolling terrain, is found to be 1,050 v.p.h. per lane,[9] or a one-way flow on the facility of 2,100 v.p.h. The total number of lanes on the one approach to handle this volume can be obtained from chart 13. Entering the chart at the bottom with a volume of 2,100 v.p.h. and using $G/C=0.60$, $L=4\%$, $R=18\%$, and $T=15\%$, the total approach width, $W/2+e_2+e_3$, is found to be 47 feet.

Four lanes will therefore be required on the one approach at the intersection, or an extra lane on each side of the normal pavement, to accommodate a volume equal to the uninterrupted capacity flow of the expressway.

Since the expressway is a two-way facility it is necessary to check separately in chart 12 for capacity of the left-turn lane. Obviously chart 12B governs, from which it is found for $C=67$ seconds that 86 left-turning vehicles can be handled. This is satisfactory since 4% of 2,100 is 84 v.p.h.

The minimum lengths of widened pavement, from the notes under the sketch on chart 13, should be: For D_a, 200 feet plus 150-foot taper; for D_b, 300 feet plus 200-foot taper.

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Part IV—Over-All Intersection Capacity

above and below the zero point on the y-y axis show the proportion by which the sum of the G/C values is deficient or in excess of the design capacity condition. As indicated on the chart, a design capacity deficiency of 20 percent is about the possible capacity condition.

With chart 14, graphic solutions can be made for various combinations of control conditions to determine one missing factor. It must be remembered that this solution is for average conditions only, with assumptions that trucks and busses constitute 10 percent and turning movements on streets 20 percent (15 percent on expressways) of the total approach volume. Where specific conditions are otherwise, the solutions should be obtained from charts 2–13.

Problem 40

In a downtown area a two-way street (approach A) 62 feet wide with parking intersects a two-way street (approach B) 44 feet wide without parking. A fixed-time signal is used and conditions are assumed to be average. When the peak-hour volume on approach A is 400 v.p.h. in one direction and on approach B is 600 v.p.h. in one direction, is the capacity of the intersection adequate?

Solution: For approach A, enter chart 14 at the left with $W/2=62/2=31$, proceed to the right to the curve for downtown two-way street with parking, then down to an approach volume of 400 v.p.h., and to the right to $G/C=0.38$. For approach B, enter the chart at the extreme right with $W/2=$ two facilities, regardless of the type of each (one-way or two-way street or expressway), type of area, and parking regulation. The left half of the chart is used for the approach on one street and the right half for the approach on the other (intersecting) street. A line projected between the inner sides of the two charts determines, at the point where it intersects the center axis, y-y, the adequacy of intersection capacity.

The two parts of chart 14 are identical except for the reverse plotting. The arrangement of each part is similar to that of chart 1, but the G/C ratio is made the outer scale and the volume is shown as the lower series of curves. In addition to the four area–parking conditions shown on chart 1, conditions for one-way streets and expressways are represented in the upper parts of chart 14 by other sloping lines. These are control values previously presented, including adjustments to obtain design capacity. Notes at the lower left show the proper $W/2$ value to be used for each case. The G/C ratio on the inner side scales is the proportion of time required on the one approach for operation at design capacity. With an assumption of 10 percent of the cycle time being used in the amber periods, design capacity is obtained when the total of two green intervals is 90 percent of the cycle (the sum of the two G/C values$=0.90$). The zero point on the y-y axis is located so that a straight line between any two G/C values passes through it when their sum is 0.90. The scale values

USE IN PRELIMINARY DESIGN

In planning or in preliminary design there often is need for a quick, approximate determination of intersection capacities. The problem usually resolves itself into one of two conditions: (1) where the intersecting volumes are known and street widths are established, to determine whether capacity is adequate; or (2) where the intersecting volumes and the width of one street are given, to determine the width of the intersecting street.

These problems can be solved with charts 1–13 by first determining the proportion of green time required for one approach, assuming a cycle length and appropriate amber periods; then calculating the resultant G/C for the cross-street approach; and finally determining, according to the cross-street volume, either its adequacy for capacity or its necessary width.

SOLUTION WITH HOURLY TRAFFIC VOLUMES

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$44/2=22$, proceed to the left to the curve for downtown two-way street without parking, then down to an approach volume of 600 v.p.h., and to the left to $G/C=0.47$. A straight line between the two values of G/C falls below the zero point on the y-y axis so capacity is adequate; in fact, there is about 6% excess capacity.

Adjusted signal timing, if desired, can be obtained by dividing each G/C by the portion of capacity required in respect to design capacity. In this case, with 6% excess capacity, the factor is $(100-6)\div 100=0.94$, and the signal timing would be: For approach A, $0.38\div 0.94=0.40$; for approach B, $0.47\div 0.94=0.50$; for amber (the remainder), 0.10.

Problem 41

If, in problem 40, all of the conditions remain the same except that approach B has to accommodate a peak-hour volume of 930 v.p.h. in one direction, to what extent must this approach be widened to make the intersection operate at design capacity?

Solution: For approach A, use the left portion of the chart as in the previous example, obtaining a value of $G/C=0.38$. From this point project a straight line through the zero point (design capacity) of line y-y to intersect the G/C scale on the right portion of the chart. From this point ($G/C=0.52$), proceed to the right to an approach volume of 930 v.p.h., then up to the curve for downtown two-way street without parking, and to the right to $W/2=30$. Approach B would have to be widened to 60 feet if the intersection is to operate at design capacity.

Problem 42

A two-way expressway (approach A) with two 24-foot pavements and added turning lanes intersects a 52-foot one-way street without parking (approach B). The intersection is situated in an intermediate area and is to be controlled by a fixed-time signal. The plan is in a preliminary design stage with only general traffic information of 1,400 v.p.h in one direction on approach A and 1,200 v.p.h. on approach B. Can these volumes be handled satisfactorily?

Solution: Enter chart 14 at left with width of approach A=24 feet, proceed to the right to the curve for expressway with turning lanes, then down to an approach volume of 1,400 v.p.h., and to the right to $G/C=0.56$. Enter the chart at right with a width of approach B=52 feet, proceed to the left to one-way street without parking in intermediate area, then down to an approach volume of 1,200 v.p.h., and to the left to $G/C=0.37$. A straight line between the two values of G/C shows that the intersection will operate at slightly above design capacity, or about 3% deficient; this is sufficiently close to consider the design satisfactory.

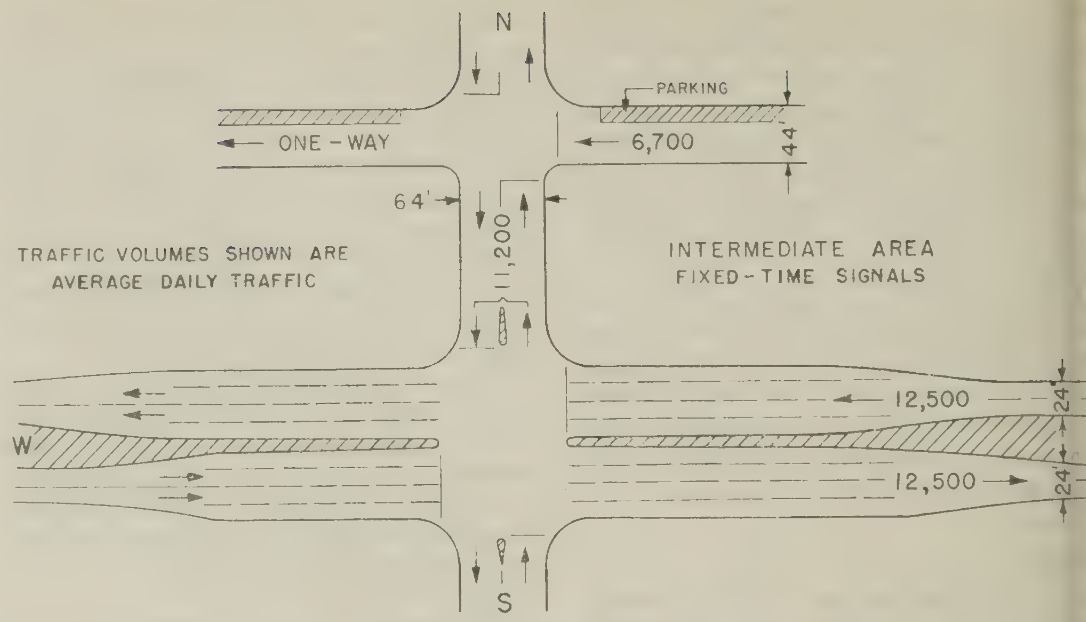


Figure 12.—Illustrative problems 43 and 44.

SOLUTION WITH AVERAGE DAILY TRAFFIC VOLUMES

In the first stages of preliminary design, when the pattern of highways and their intersections are being developed, street widths often must be tentatively established as a starting point. Only general traffic values are then available, customarily expressed in terms of average daily traffic volumes. Such information is of little value in final design of intersections, but in the absence of peak-hour volumes the average daily traffic volumes may be considered appropriate for preliminary design.

Where the design volumes are given in terms of average daily traffic it is necessary to convert them to peak-hour volumes in one direction of travel. Chart 15 gives this relation for average conditions. The peak-hour volume for design is assumed as 12 percent of the two-way average daily traffic, and as 55, 60, and 65 percent of the total peak-hour traffic as the predominant movement in one direction of travel for downtown, intermediate, and outlying areas, respectively. Chart 15 may be entered at the top with the total two-directional average daily traffic volume, or at the bottom with a one-way average daily traffic volume. Thus, the chart is applicable to both one- and two-way facilities. The vertical scale gives the design peak-hour volume in one direction of travel.

It will be noted that the assumption of the peak hour traffic as 12 percent of the two-way average daily traffic, and the use of three d values, results in different peak-hour percentages of the one-way average daily traffic, when the latter is one-half of the two-way daily volume. Thus, for one-way facilities, in chart 15, the resulting percentages that the peak-hour volume is of the one-way average daily traffic (obtained by dividing V by ½ ADT), are: downtown, 13.2; intermediate, 14.4; and outlying, 15.6.

Problem 43

Shown in figure 12 is a portion of preliminary plan on which an east-we four-lane expressway is planned to cro at grade a north-south major street. Th only traffic information available is in tern of average daily traffic, as indicated c the figure. The north-south street cann be widened, but right-of-way permits wi ening of the approaches on the expresswa Determine the number of lanes require at the intersection in each direction on th expressway if the intersection is to opera at design capacity.

Solution: It is first necessary to conve the average daily traffic volume to pea hour volume in one direction of travel. C the north-south street the two-direction daily volume of 11,200 vehicles in an inte mediate area, from chart 15, is equivale to a peak-hour volume in one direction 800 vehicles; and on the expressway th daily volume of 12,500 vehicles in or direction corresponds to a peak-hour volur of 1,800 vehicles.

Using the north approach on the maj street as approach A in chart 14, wi $W/2=64/2=32$, two-way street with n parking in intermediate area, and an a proach volume of 800 v.p.h., a value $G/C=0.46$ is obtained. From this point straight line is projected to the rig through the zero point of line y-y, inte secting a value of $G/C=0.44$ for approa B. From this point proceed to the rig to an approach volume of 1,800 v.p.h., th up to expressway with widened approache and read at the right a required approa width of about 50 feet.

The two-lane pavement in each directi on the expressway should therefore widened in advance of and beyond the inte section to $50/12=4.2$, or four lanes. T length of widened pavements should of sufficient length, as noted under t sketch in chart 13.

Problem 44

In figure 12, the north-south major street intersects a one-way street at a point several hundred feet north of the expressway. According to the average daily traffic volumes indicated and street widths provided, determine whether adequate capacity is available at this intersection.

Solution: The left portion of chart 14 is used for one approach on the north-south street, as in problem 43. The right portion of the chart is used for the east approach on the one-way street with $W/2=44$, one-way street with parking in intermediate area, and an approach volume of 960 v.p.h. (arrived from chart 15 as the equivalent of an average daily traffic in one direction of 5,700). A straight line between the two resulting values of G/C indicates, at the intersection of the y-y line, that more than adequate capacity is provided.

LIMITATIONS IN USE OF CHARTS 14 AND 15

Although charts 14 and 15 are convenient tools for preliminary design, the limitations in their use should be recognized:

1. Results are approximate, since average conditions are assumed.

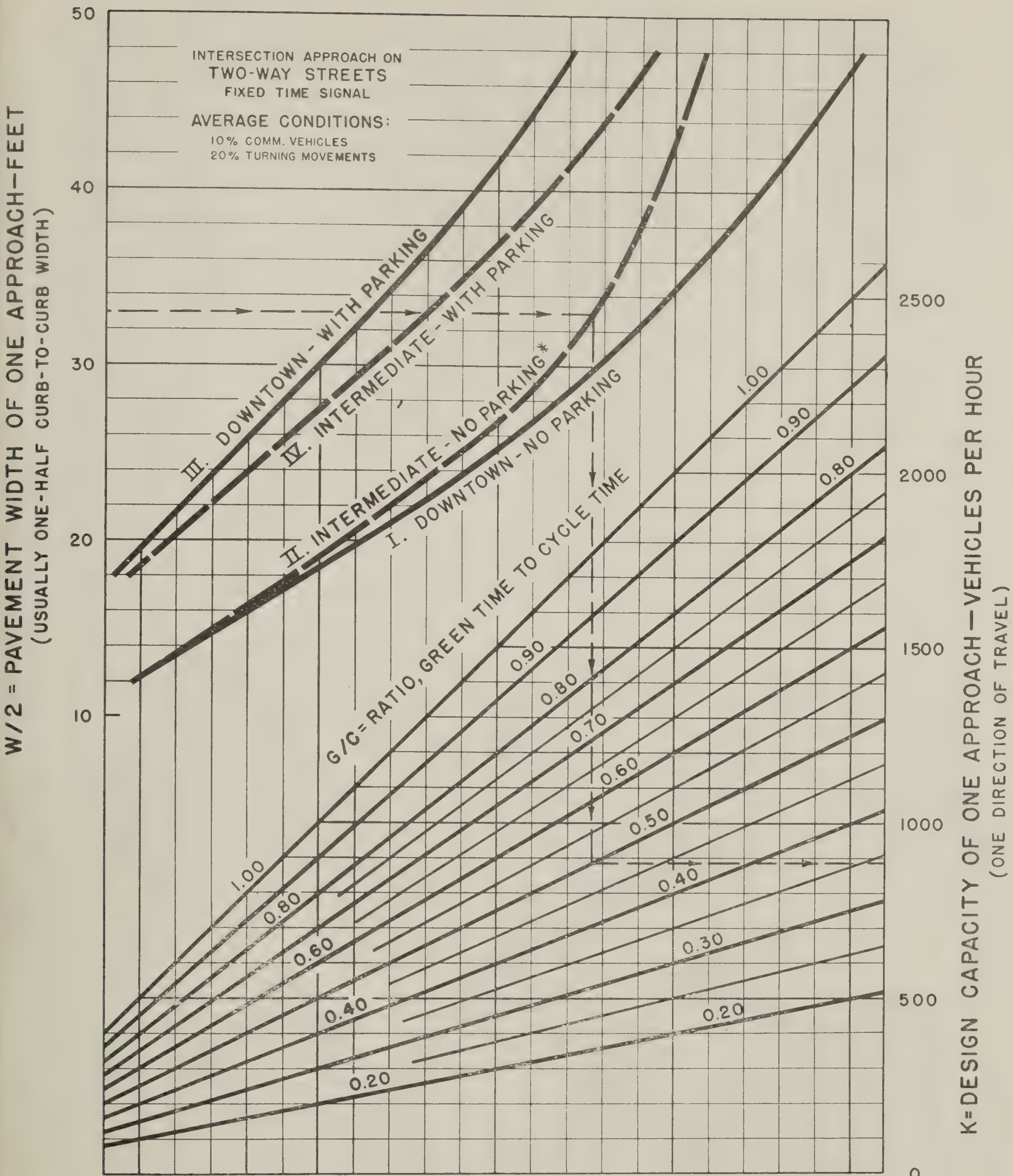
2. On two-way facilities it is assumed that the volume of left-turning vehicles can be accommodated without requiring three-phase signal control. Generally on major facilities not more than 80 to 120 left-turning vehicles per hour can be handled without a separate signal indication. Even in preliminary design, if it is known that the left turns on one approach will exceed about 100 vehicles per hour, the more detailed charts should be used.

3. Where average daily traffic volumes are used as the traffic basis, and corresponding one-way peak-hour volumes are taken from chart 15, it should be remembered that the peak-hour volumes on each approach may not occur simultaneously. At intersections involving two-way streets on which the signal timing remains the same throughout the day, the peak-hour volumes thus obtained and used may be appropriate. However, if the signal timing is different during the morning peak from that during the evening peak, because of load distribution, or if one or both of the intersecting streets are one-way, the peak-hour volumes based on average daily traffic may not be representative. If the designer has some knowledge of the peak distributions, he can make adjustments in the hourly approach volumes to arrive at the information needed for both the morning and evening peak hours, one or both of which may govern the design; if not, the direct use of chart 15 for each approach will give results in design on the safe side.

4. Chart 14 may not always apply to those intersections where a given minimum green interval must be maintained, as for a pedestrian crossing. However, the values of G/C obtained in the solution for any intersection can be tested with logical cycle lengths to determine whether the required green interval may be obtained.

5. For approximate results, chart 14 may also be used for T or Y intersections.

WIDTH OF ONE APPROACH—FEET

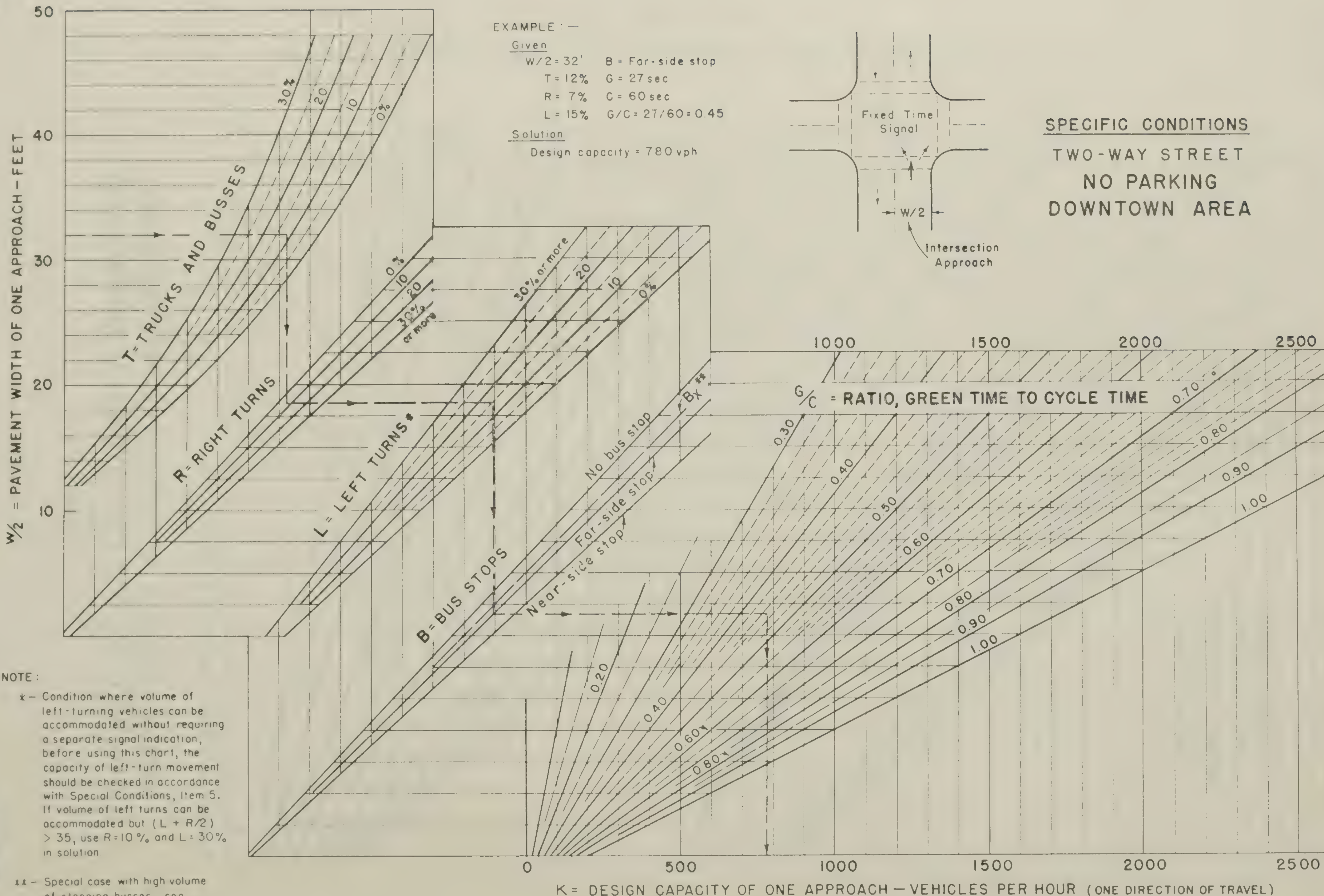


* Also applicable to outlying or rural areas.

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

TWO-WAY STREETS—AVERAGE CONDITIONS

CHART 1

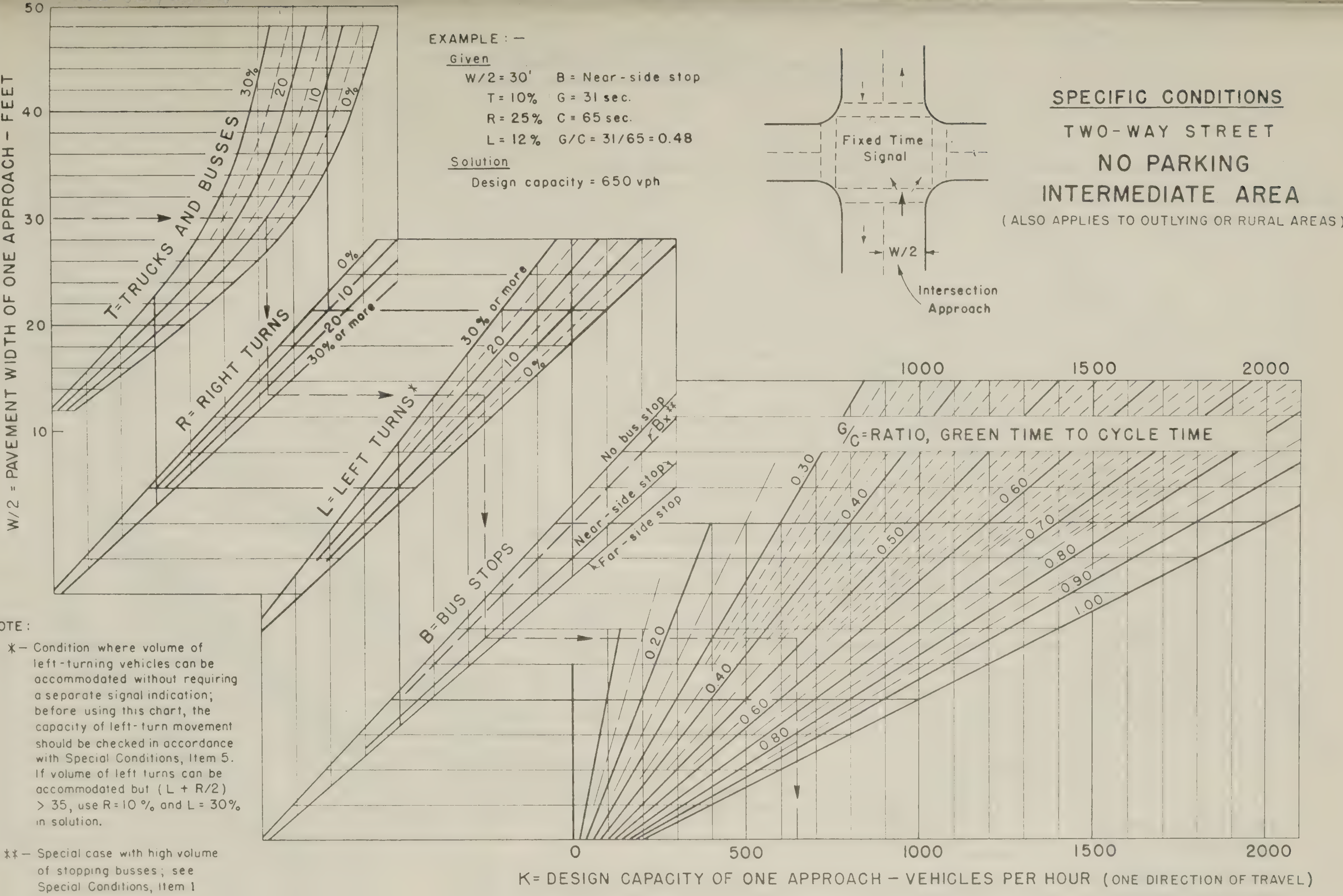


NOTE:

* – Condition where volume of left-turning vehicles can be accommodated without requiring a separate signal indication; before using this chart, the capacity of left-turn movement should be checked in accordance with Special Conditions, Item 5. If volume of left turns can be accommodated but (L + R/2) > 35, use R = 10% and L = 30% in solution

** – Special case with high volume of stopping busses, see Special Conditions, Item 1

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
TWO-WAY STREET — NO PARKING, DOWNTOWN AREA
CHART 2

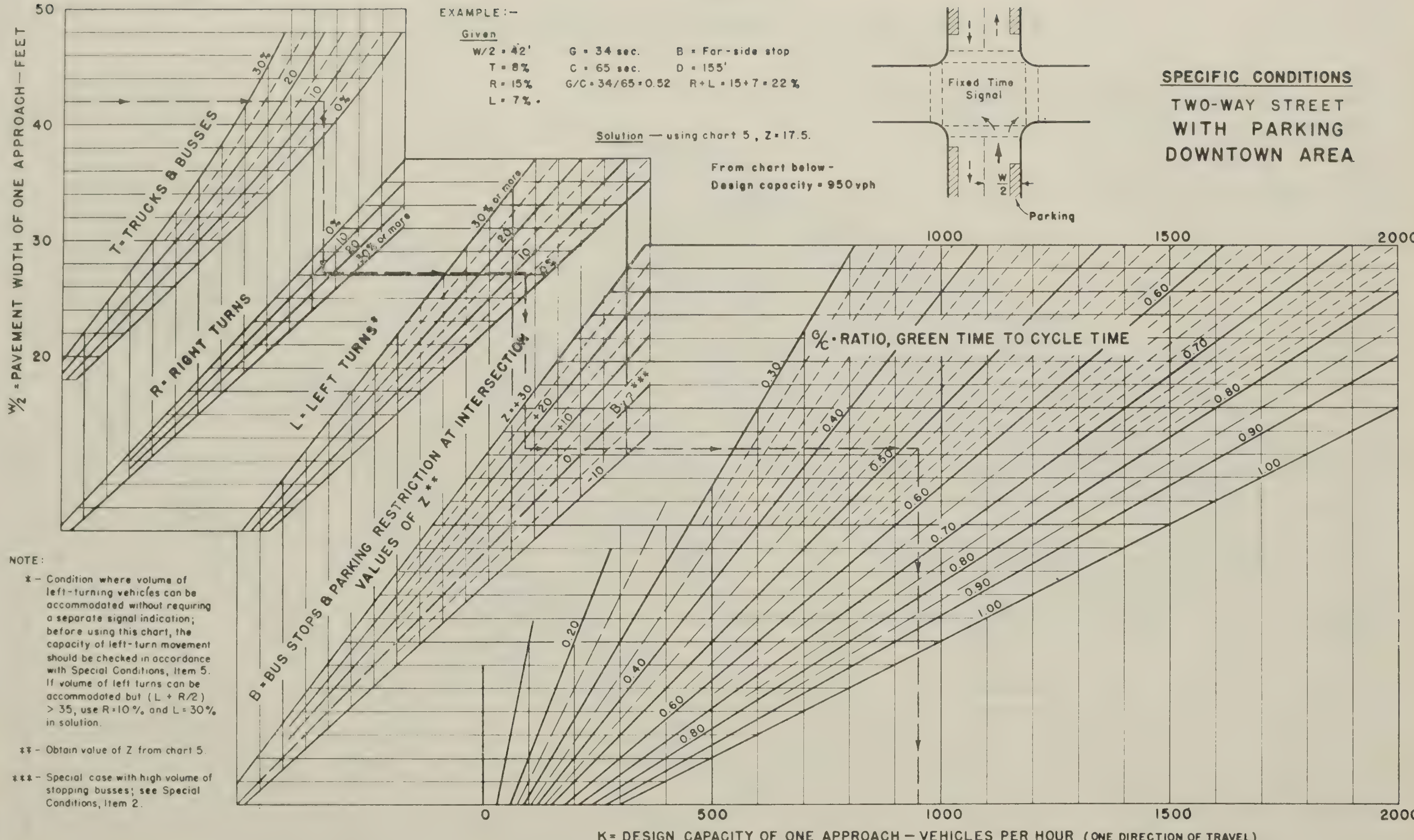


NOTE:

* — Condition where volume of left-turning vehicles can be accommodated without requiring a separate signal indication; before using this chart, the capacity of left-turn movement should be checked in accordance with Special Conditions, Item 5. If volume of left turns can be accommodated but (L + R/2) > 35, use R = 10% and L = 30% in solution.

** — Special case with high volume of stopping busses; see Special Conditions, Item 1

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
TWO-WAY STREET — NO PARKING, INTERMEDIATE AREA
CHART 3



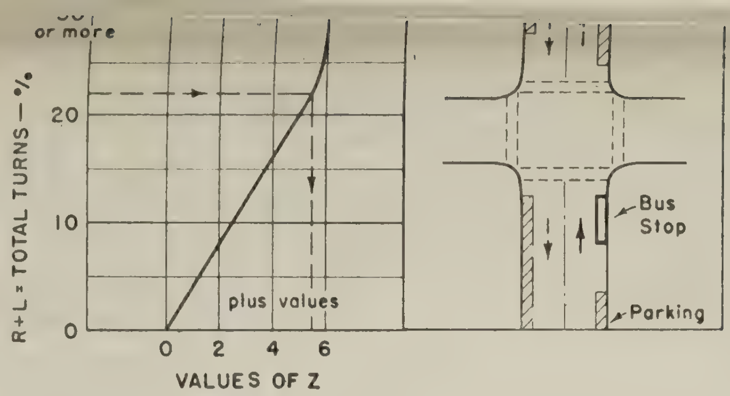
NOTE:

* – Condition where volume of left-turning vehicles can be accommodated without requiring a separate signal indication; before using this chart, the capacity of left-turn movement should be checked in accordance with Special Conditions, Item 5. If volume of left turns can be accommodated but (L + R/2) > 35, use R = 10% and L = 30% in solution.

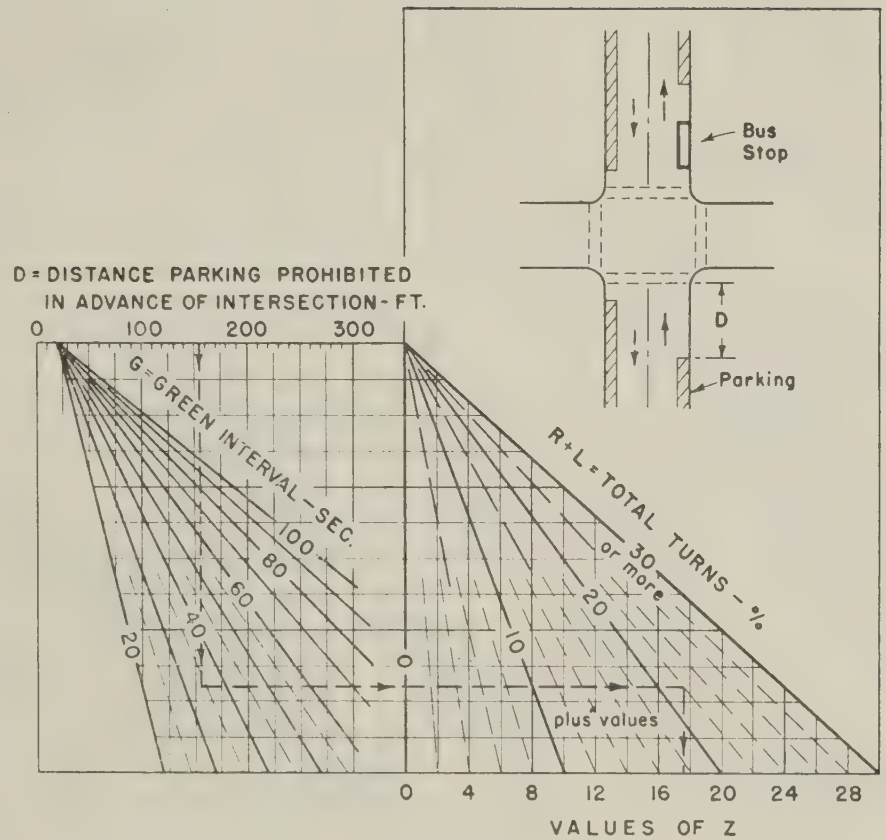
** – Obtain value of Z from chart 5.

*** – Special case with high volume of stopping busses; see Special Conditions, Item 2.

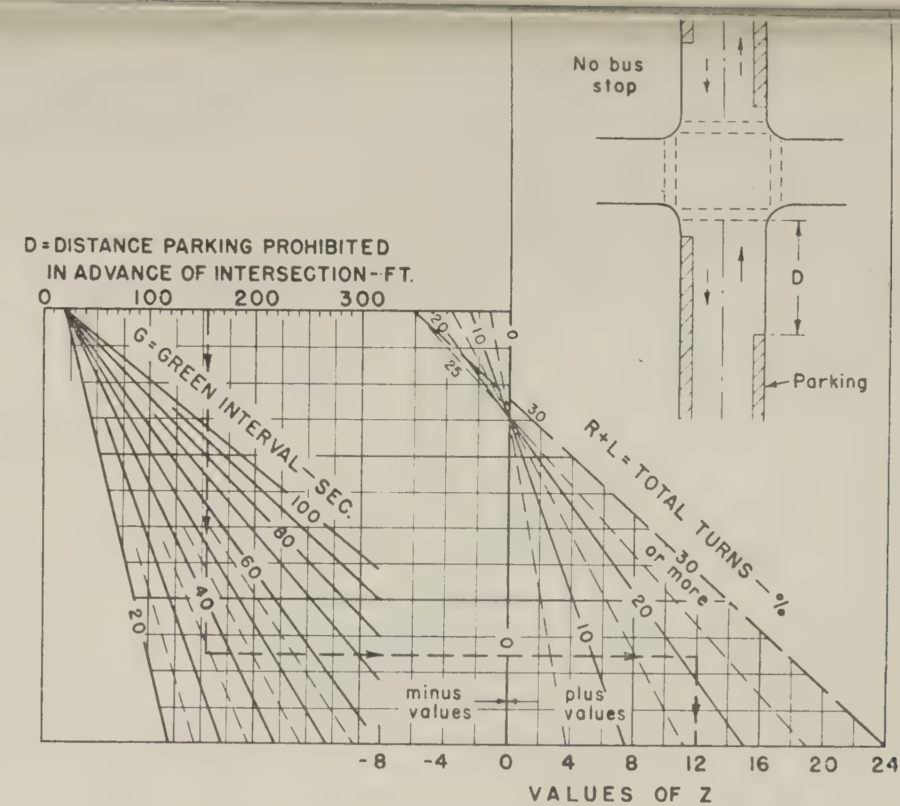
DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
TWO-WAY STREET — WITH PARKING, DOWNTOWN AREA
CHART 4



NEAR-SIDE BUS STOP
CHART A



FAR-SIDE BUS STOP
CHART B



NO BUS STOP
CHART C

NOTE:

Z = COMBINED CORRECTION FOR BUS STOP AND PARKING RESTRICTION IN PERCENT, FOR USE IN CHARTS 4 AND 6.

WHERE PARKING IS PROHIBITED FOR A LIMITED DISTANCE IN BOTH DIRECTIONS FROM THE CROSS STREET, SEE SPECIAL CONDITIONS, ITEM 4.

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
SUPPLEMENT TO CHARTS 4 AND 6
CHART 5

EXAMPLE:—

Given

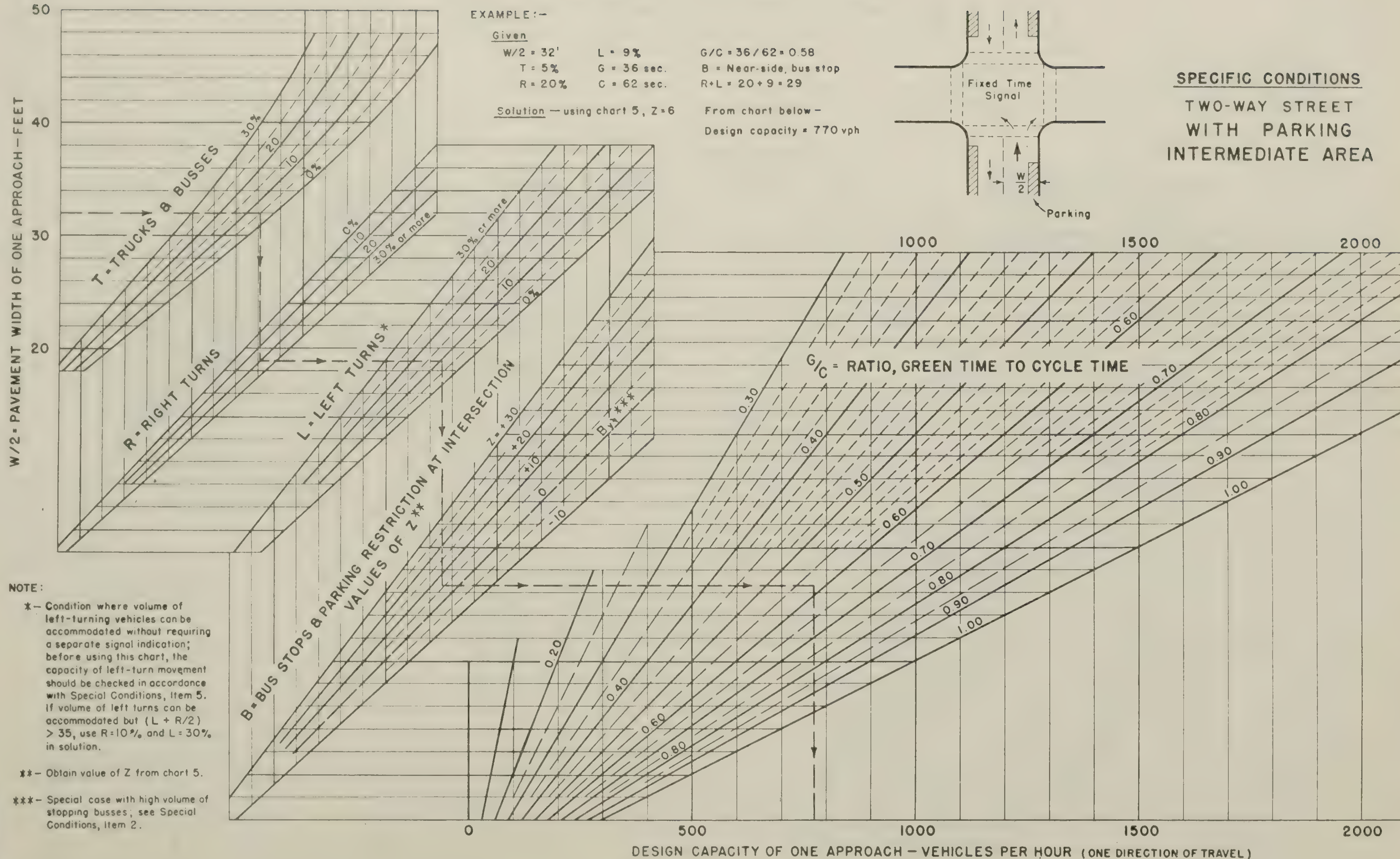
W/2 = 32'   L = 9%   G/C = 36/62 = 0.58
T = 5%   G = 36 sec.   B = Near-side, bus stop
R = 20%   C = 62 sec.   R+L = 20 + 9 = 29

Solution — using chart 5, Z = 6

From chart below —
Design capacity = 770 vph

SPECIFIC CONDITIONS

TWO-WAY STREET
WITH PARKING
INTERMEDIATE AREA



NOTE:

* — Condition where volume of left-turning vehicles can be accommodated without requiring a separate signal indication; before using this chart, the capacity of left-turn movement should be checked in accordance with Special Conditions, Item 5. If volume of left turns can be accommodated but (L + R/2) > 35, use R = 10% and L = 30% in solution.

** — Obtain value of Z from chart 5.

*** — Special case with high volume of stopping busses; see Special Conditions, Item 2.

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
TWO-WAY STREET — WITH PARKING, INTERMEDIATE AREA
CHART 6

TWO-WAY STREET WITH RIGHT-TURN LANE

NO SEPARATE SIGNAL INDICATION FOR TURNING MOVEMENT

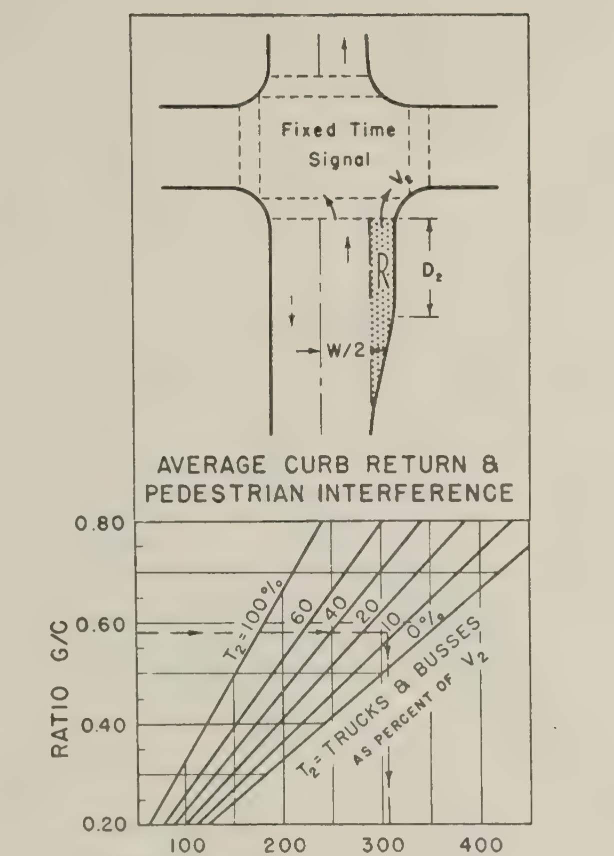


CHART A

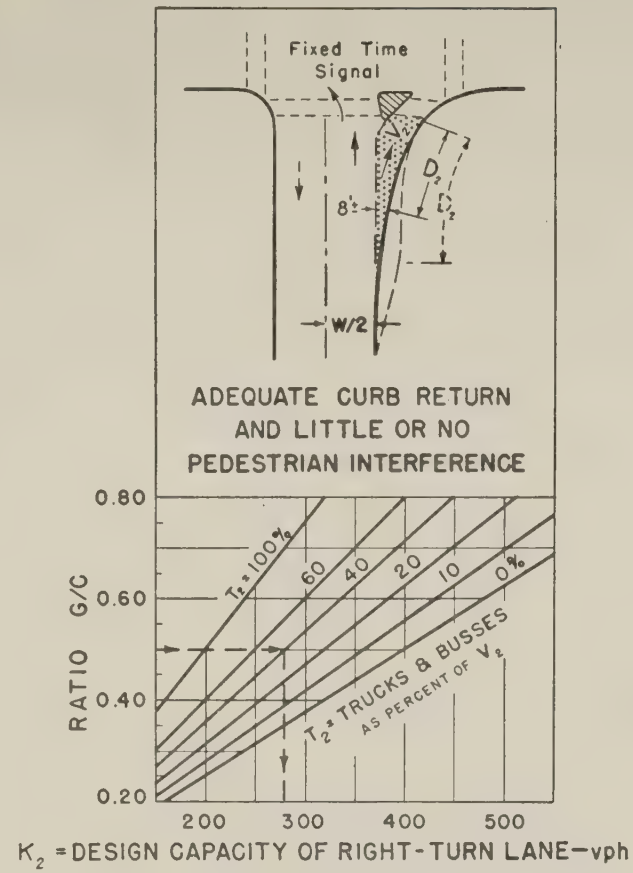


CHART B

NOTE FOR CHART C:

LENGTH OF RIGHT-TURN LANE BASED ON THE AVERAGE NUMBER OF VEHICLES THAT WOULD STORE PER CYCLE, FOR V_2 SHOWN.

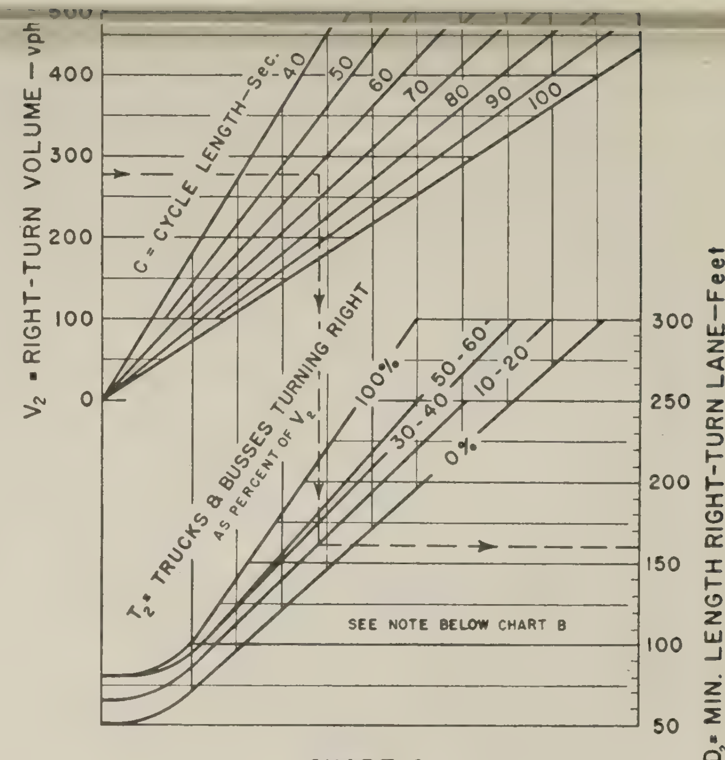


CHART C

DESIGN CAPACITY OF ONE APPROACH:—

(1) OBTAIN K_2 FROM CHART A OR B.

(2) OBTAIN DESIGN CAPACITY OF COMBINED THROUGH AND LEFT-TURN MOVEMENT (M_2) FROM CHART 2 OR 3 USING:

W/2 = APPROACH WIDTH EXCLUSIVE OF RIGHT-TURN LANE; AND

R = 0%.

(3) CALCULATE $V_2 = \frac{M_2 \times R}{100 - R}$

(4) WHEN $V_2 < K_2$: $K = M_2 + V_2$

(5) WHEN $V_2 > K_2$: FIND $M_2' = \frac{K_2(100-R)}{R}$ AND $K = M_2' + K_2$

(6) OBTAIN D_2 FROM CHART C FOR V_2 OR K_2, WHICHEVER GOVERNS.

NOTE: POSSIBLE CAPACITY OF RIGHT-TURN LANE = $1.2K_2$.

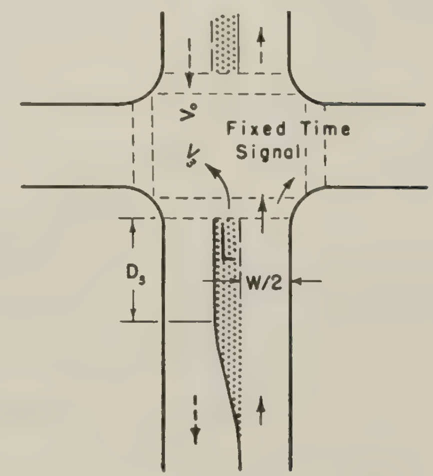
DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

TWO-WAY STREET — WITH RIGHT-TURN LANE

NO SEPARATE SIGNAL INDICATION FOR TURNING MOVEMENT

CHART 7

TWO-WAY STREET
WITH LEFT-TURN LANE
NO SEPARATE SIGNAL INDICATION FOR TURNING MOVEMENT



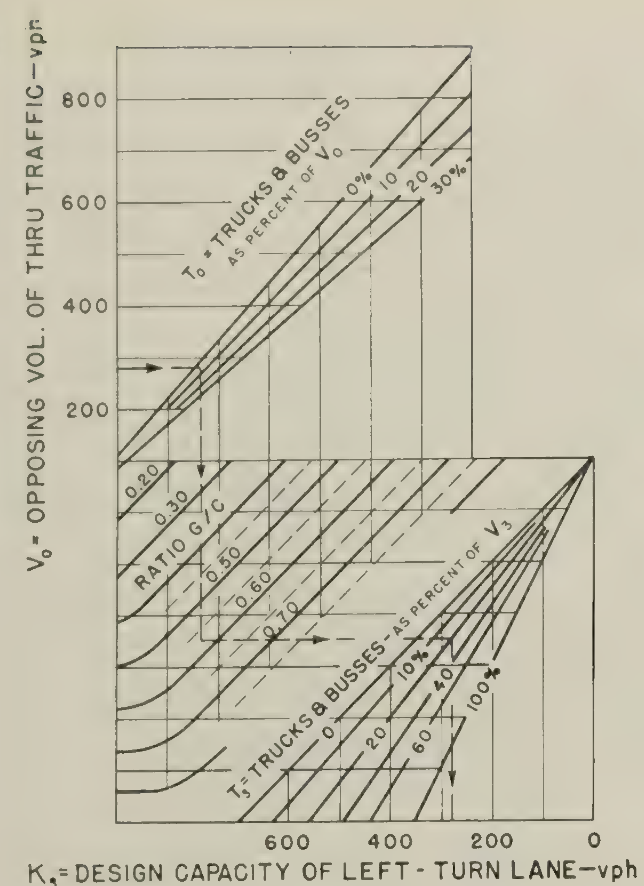


CHART A

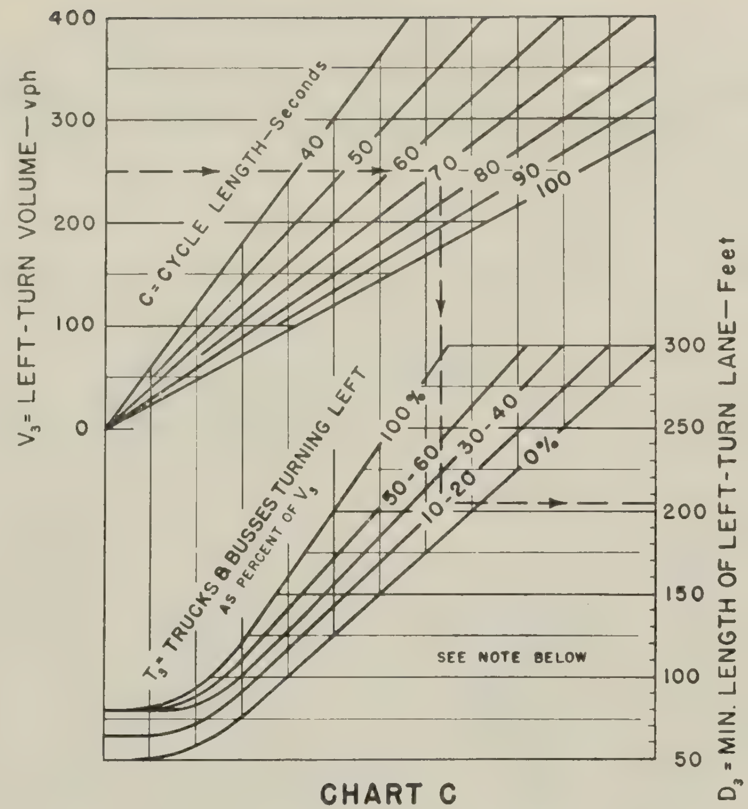


CHART C

NOTE FOR CHART C:
LENGTH OF LEFT-TURN LANE BASED ON 1.5 TIMES THE AVERAGE NUMBER OF VEHICLES THAT WOULD STORE PER CYCLE, FOR V_3 SHOWN.

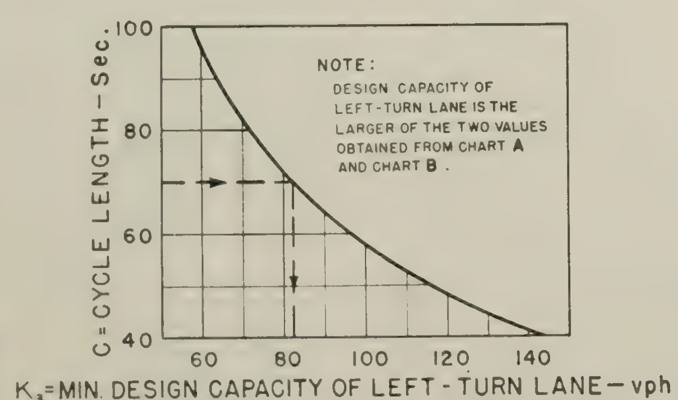


CHART B

DESIGN CAPACITY OF ONE APPROACH:—

(1) OBTAIN K_3 FROM CHART A OR B

(2) OBTAIN DESIGN CAPACITY OF COMBINED THROUGH AND RIGHT-TURN MOVEMENT (M_3) FROM CHART 2, 3, 4, OR 6, USING:

W/2 = APPROACH WIDTH EXCLUSIVE OF LEFT-TURN LANE; AND

L = 0%

(3) CALCULATE $V_3 = \frac{M_3 \times L}{100-L}$

(4) WHEN $V_3 < K_3$: $K = M_3 + V_3$

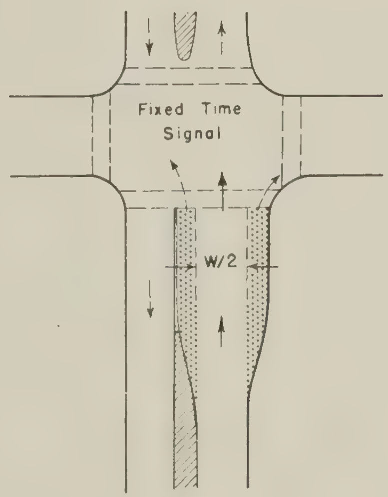
(5) WHEN $V_3 > K_3$: FIND $M_3' = \frac{K_3(100-L)}{L}$ AND $K = M_3' + K_3$

(6) OBTAIN D_3 FROM CHART C FOR V_3 OR K_3, WHICHEVER GOVERNS

NOTE: POSSIBLE CAPACITY OF LEFT-TURN LANE = $1.2K_3$

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
TWO-WAY STREET — WITH LEFT-TURN LANE
NO SEPARATE SIGNAL INDICATION FOR TURNING MOVEMENT

TWO-WAY STREET
WITH LEFT- AND RIGHT-TURN LANES
NO SEPARATE SIGNAL INDICATION
FOR TURNING MOVEMENTS



DESIGN CAPACITY OF ONE APPROACH:–

(1) OBTAIN K_2 FROM CHART 7 AND K_3 FROM CHART 8

(2) OBTAIN DESIGN CAPACITY OF THROUGH MOVEMENT (M_1), FROM CHART 2 OR 3, USING:

W/2 = APPROACH WIDTH EXCLUSIVE OF TURNING LANES, R = 0 %; AND L = 0 %

(3) CALCULATE $V_2 = \frac{M_1 \times R}{100-R-L}$ AND $V_3 = \frac{M_1 \times L}{100-R-L}$

(4) WHEN $V_2 < K_2$ AND $V_3 < K_3$: $K = M_1 + V_2 + V_3$

(5) WHEN $V_2 > K_2$ AND/OR $V_3 > K_3$, CALCULATE M_1' ON BASIS OF K_2 OR K_3, WHICHEVER GOVERNS; IF K_3 GOVERNS, $M_1' = \frac{K_3(100-R-L)}{L}$, AND $V_2' = \frac{M_1' R}{100-R-L}$, AND $K = M_1' + V_2' + K_3$

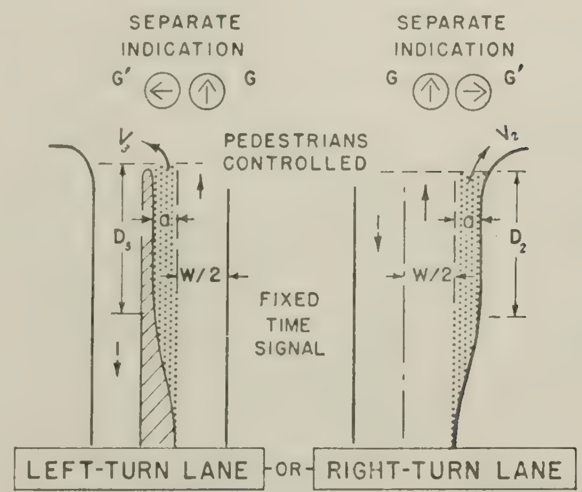
(6) OBTAIN D_2 AND D_3 FROM CHARTS 7 AND 8.

NOTE: FOR POSSIBLE CAPACITY OF RIGHT- OR LEFT-TURN LANE MULTIPLY BY 1.2

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
TWO-WAY STREET — WITH LEFT- AND RIGHT-TURN LANES
NO SEPARATE SIGNAL INDICATION FOR TURNING MOVEMENTS

CHART 9

TWO-WAY STREET
WITH RIGHT- OR LEFT-TURN LANE
SEPARATE SIGNAL INDICATION FOR RIGHT- OR LEFT-TURN MOVEMENT



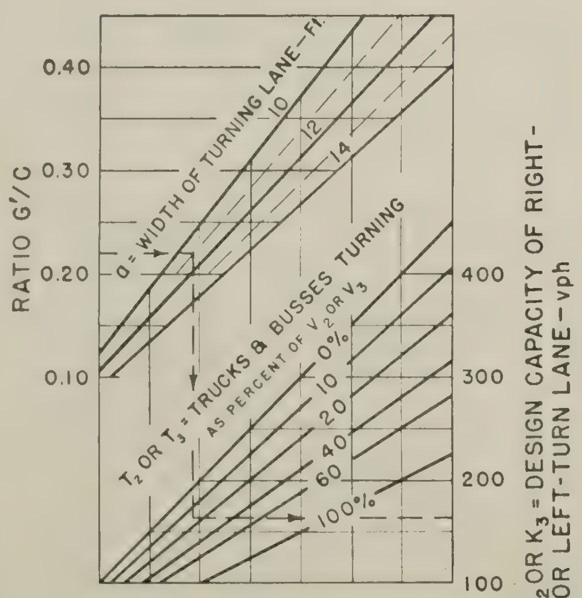


CHART A

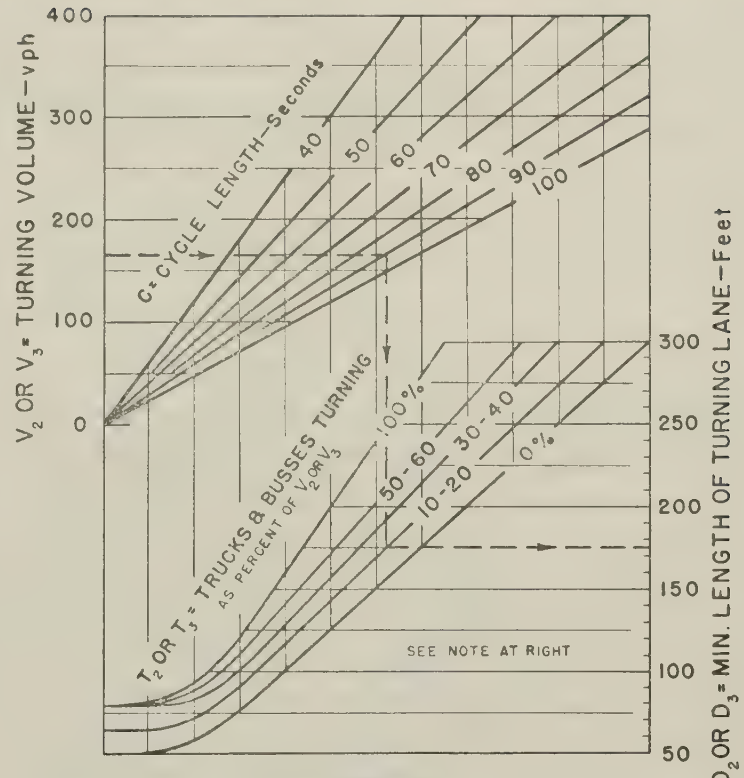


CHART B

NOTE FOR CHART B:
LENGTH OF RIGHT- OR LEFT-TURN LANE BASED ON 1.5 TIMES THE AVERAGE NUMBER OF VEHICLES THAT WOULD STORE PER CYCLE, FOR V_2 OR V_3 SHOWN.

DESIGN CAPACITY OF ONE APPROACH:

WITH LEFT-TURN LANE

(1) OBTAIN K_3 FROM CHART A.

(2) OBTAIN DESIGN CAPACITY OF COMBINED THROUGH AND RIGHT-TURN MOVEMENT (M_3) FROM CHART 2, 3, 4, OR 6, USING:

W/2 = APPROACH WIDTH EXCLUSIVE OF LEFT-TURN LANE; AND L = 0 %.

(3) CALCULATE $V_3 = \frac{M_3 \times L}{100-L}$

(4) WHEN $V_3 < K_3$: $K = M_3 + V_3$

(5) WHEN $V_3 > K_3$: FIND $M_3' = \frac{K_3(100-L)}{L}$ AND $K = M_3' + K_3$

(6) OBTAIN D_3 FROM CHART B FOR V_3 OR K_3, WHICHEVER GOVERNS.

NOTE: POSSIBLE CAPACITY OF LEFT-TURN LANE = $1.2 K_3$

WITH RIGHT-TURN LANE

(1) OBTAIN K_2 FROM CHART A.

(2) OBTAIN DESIGN CAPACITY OF COMBINED THROUGH AND LEFT-TURN MOVEMENT (M_2) FROM CHART 2 OR 3, USING:

W/2 = APPROACH WIDTH EXCLUSIVE OF RIGHT-TURN LANE; AND R = 0 %.

(3) CALCULATE $V_2 = \frac{M_2 \times R}{100-R}$

(4) WHEN $V_2 < K_2$: $K = M_2 + V_2$

(5) WHEN $V_2 > K_2$: FIND $M_2' = \frac{K_2(100-R)}{R}$ AND $K = M_2' + K_2$

(6) OBTAIN D_2 FROM CHART B FOR V_2 OR K_2, WHICHEVER GOVERNS.

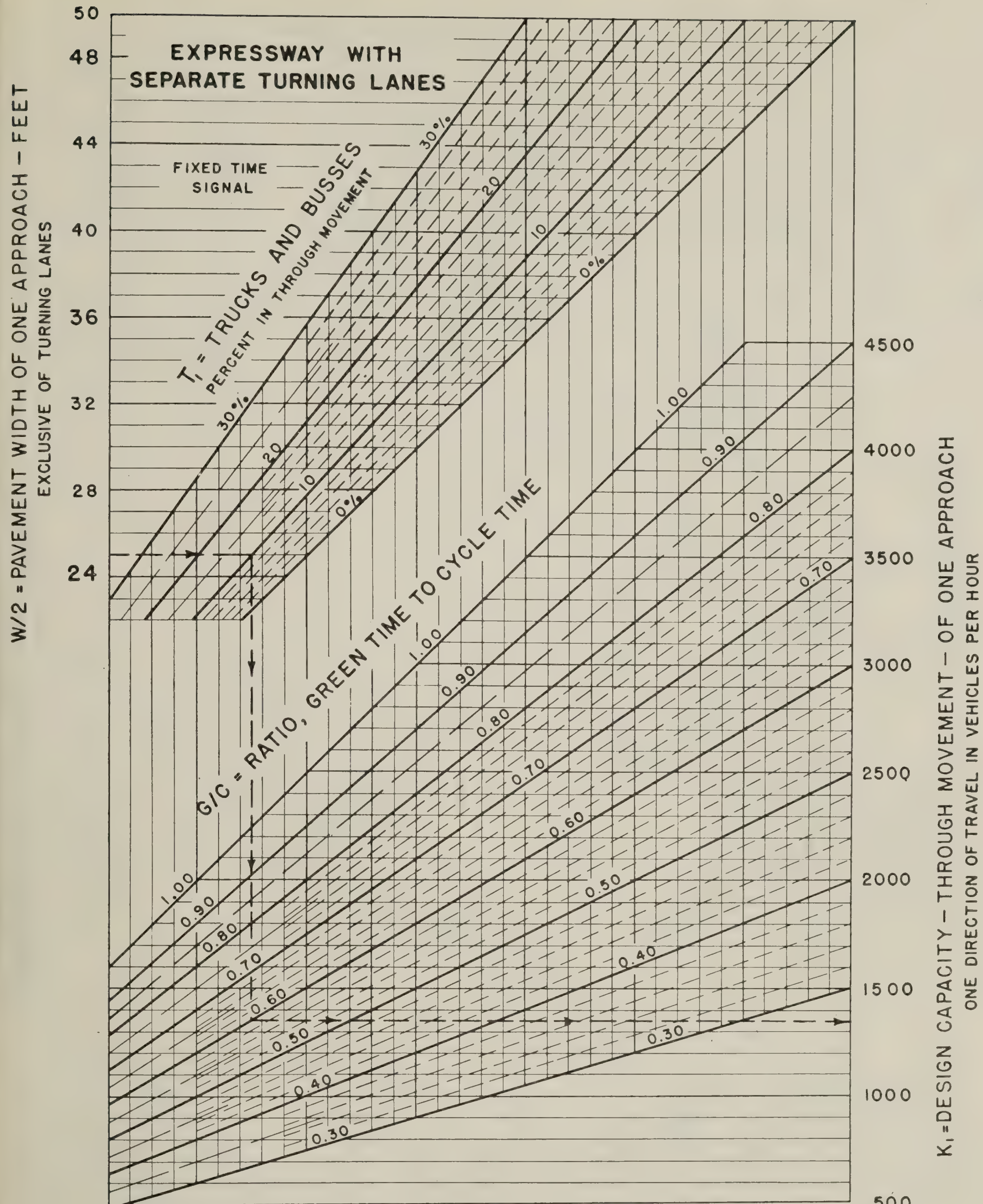
NOTE: POSSIBLE CAPACITY OF RIGHT-TURN LANE = $1.2 K_2$

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

TWO-WAY STREET — WITH RIGHT- OR LEFT-TURN LANE

SEPARATE SIGNAL INDICATION FOR TURNING MOVEMENT

CHART 10



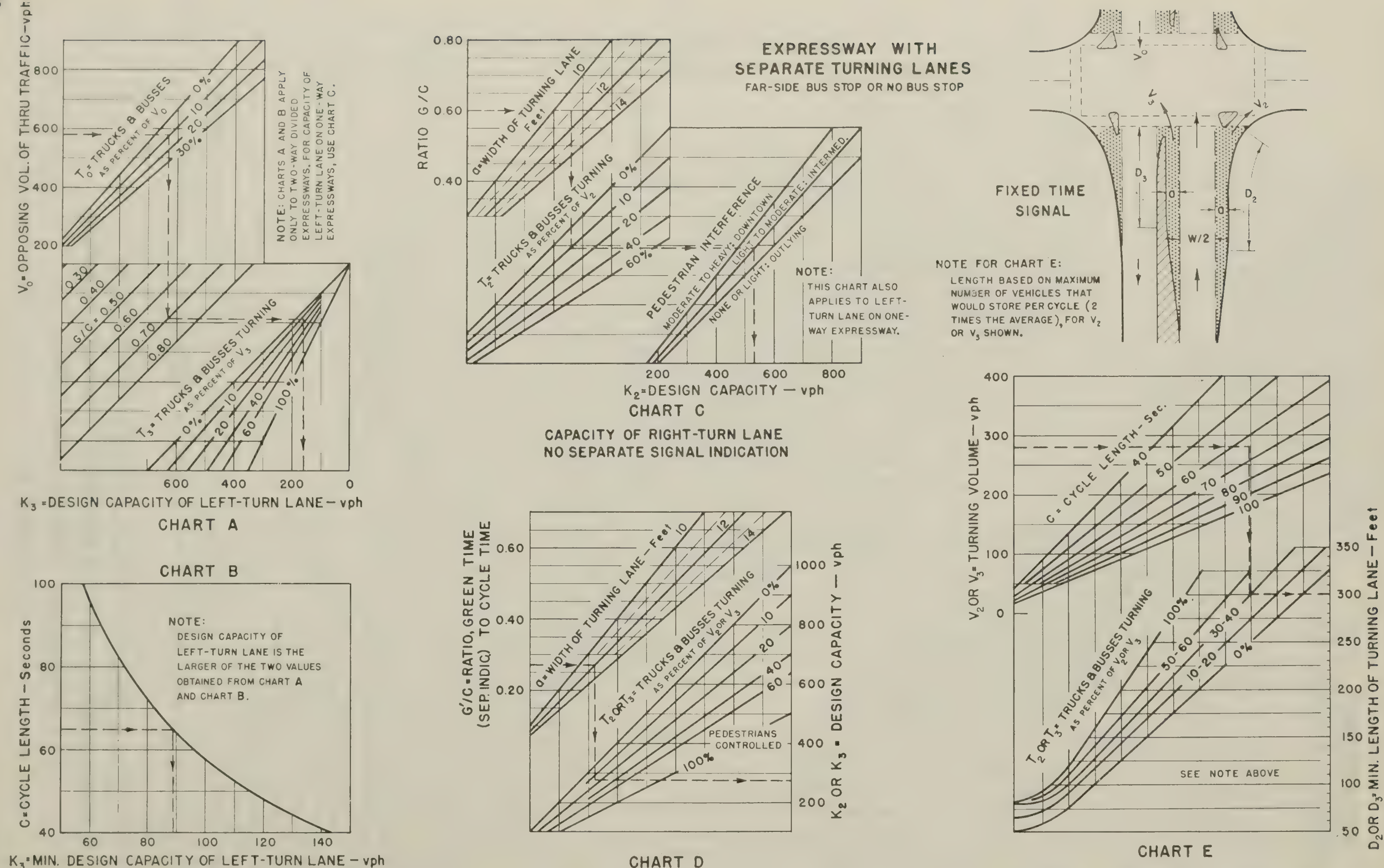
NOTE:– For capacity of separate turning lanes and sketch of intersection layout, see chart 12.

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

EXPRESSWAYS WITH SEPARATE TURNING LANES

CAPACITY OF THROUGH LANES ONLY

CHART 11



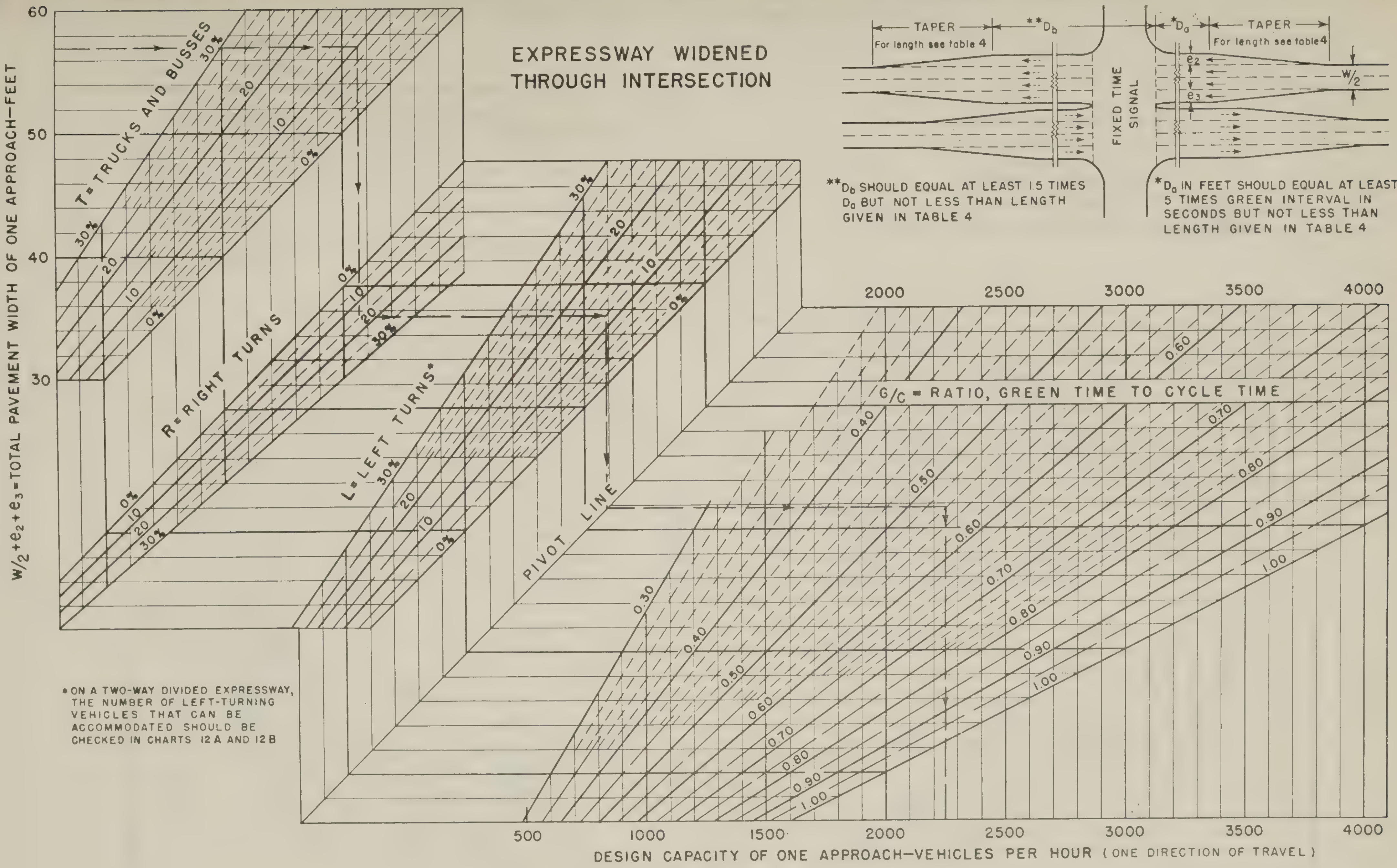
CAPACITY OF RIGHT-TURN LANE
NO SEPARATE SIGNAL INDICATION

CHARTS A & B: CAPACITY OF LEFT-TURN LANE,
NO SEPARATE SIGNAL INDICATION

CAPACITY OF RIGHT- OR LEFT-TURN LANE
WITH SEPARATE SIGNAL INDICATION

LENGTH OF RIGHT- OR LEFT-TURN LANE
WITH OR WITHOUT SEPARATE SIGNAL INDICATION

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS
EXPRESSWAYS WITH SEPARATE TURNING LANES
CAPACITY OF SEPARATE TURNING LANES ONLY
CHART 12

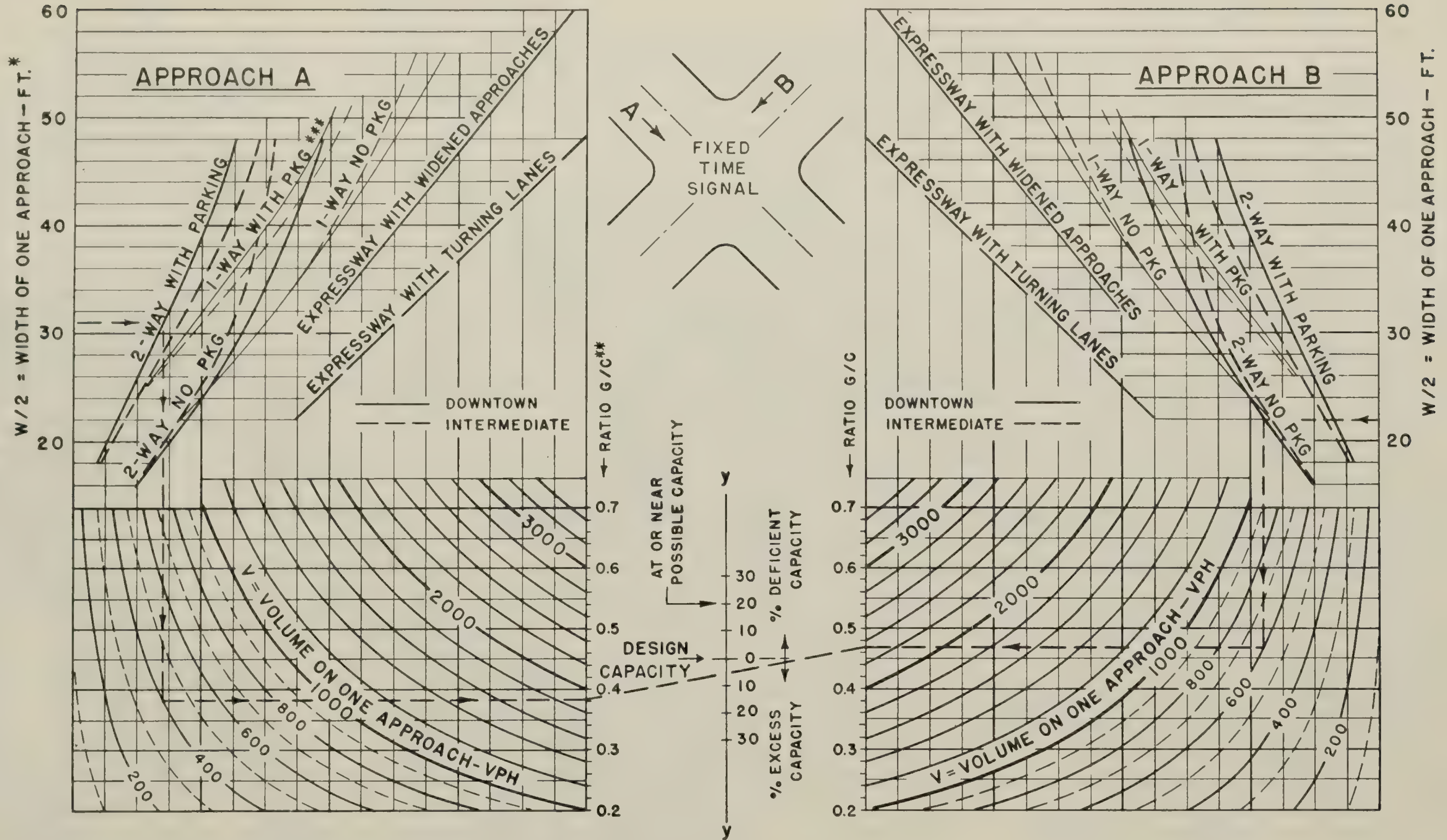


DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

EXPRESSWAY WIDENED THROUGH INTERSECTION

CHART 13

OVER-ALL INTERSECTION CAPACITY — AVERAGE CONDITIONS



* — FOR TWO-WAY STREET —
W/2 IS WIDTH OF ONE APPR., USUALLY 1/2 NORMAL CURB-TO-CURB WIDTH.
FOR ONE-WAY STREET —
W/2 IS WIDTH OF STREET, USUALLY NORMAL CURB-TO-CURB WIDTH.
FOR EXPRESSWAY WITH TURNING LANES —
W/2 IS NORMAL WIDTH OF TRAVELED WAY EXCLUSIVE OF TURNING LANES.
FOR EXPRESSWAY WITH WIDENED APPROACHES —
W/2 IS THE FULL WIDTH OF WIDENED APPROACH, INCLUDING THE ADDED LANES (AND CORRESPONDS TO $W/2+e_2+e_3$ IN CHART 13).

** — PROPORTION OF GREEN TIME REQUIRED ON THE ONE APPROACH FOR OPERATION AT DESIGN CAPACITY.

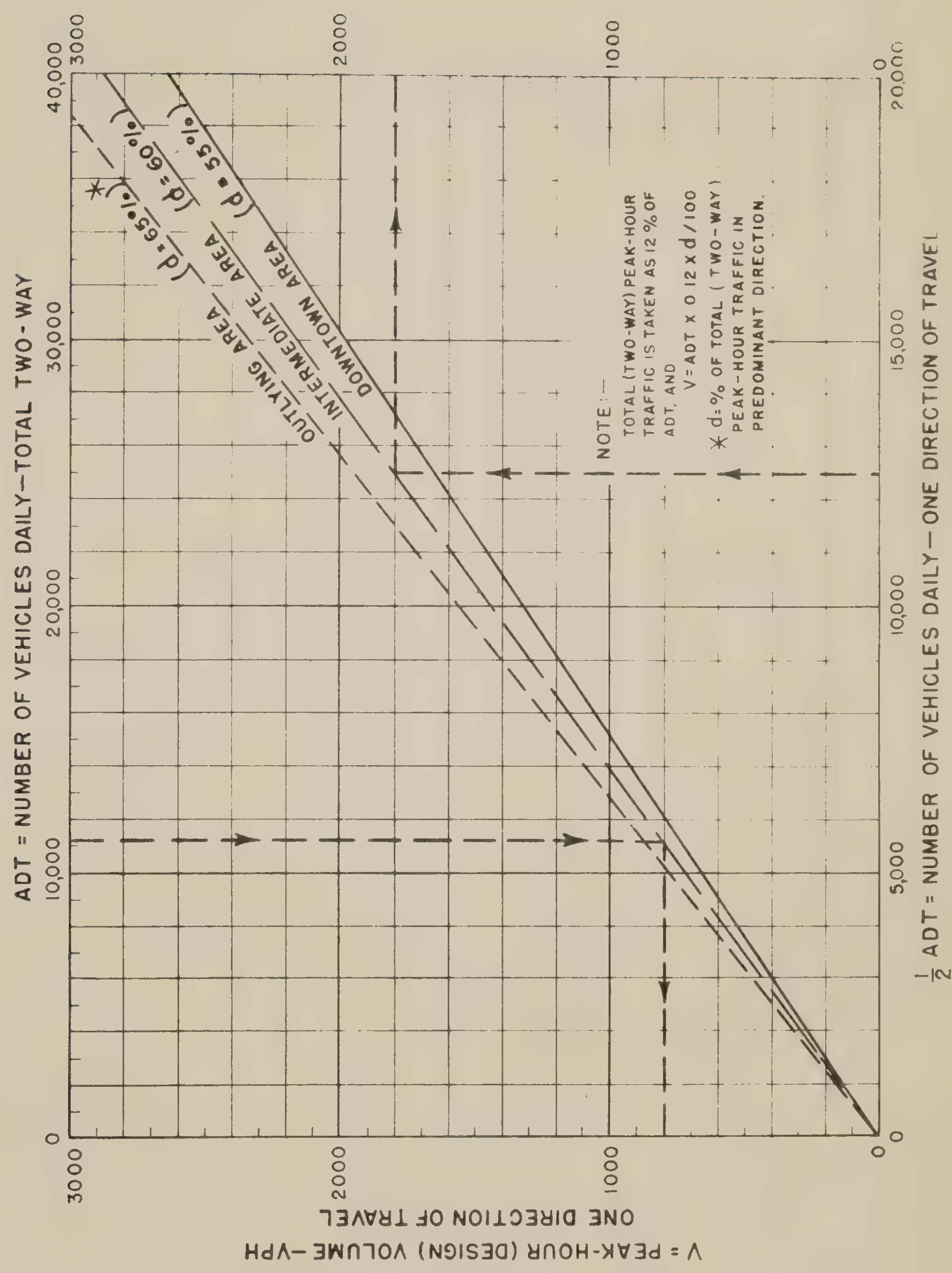
*** — PARKING ON ONE SIDE ONLY.

AVERAGE CONDITIONS — EACH APPROACH:

TRUCKS AND BUSSES = 10%
TURNING MOVEMENTS —
STREETS = 20%
EXPRESSWAYS = 15%
AMBER = 10% OF CYCLE

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

OVER-ALL INTERSECTION CAPACITY — AVERAGE CONDITIONS



RELATION BETWEEN HOURLY AND DAILY TRAFFIC

CHART 15

U. S. GOVERNMENT PRINTING OFFICE: 1951—911329

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

PUBLICATIONS of the Bureau of Public Roads

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

ANNUAL REPORTS

(See also adjacent column)

Reports of the Chief of the Bureau of Public Roads:

1937, 10 cents. 1938, 10 cents. 1939, 10 cents.

Work of the Public Roads Administration:

1940, 10 cents. 1941, 15 cents. 1942, 10 cents. 1946, 20 cents. 1947, 20 cents. 1948, 20 cents. 1949, 25 cents.

Annual Report, Bureau of Public Roads, 1950, 25 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

UNIFORM VEHICLE CODE

Act I.—Uniform Motor-Vehicle Administration, Registration, Certificate of Title, and Antitheft Act. 10 cents.

Act II.—Uniform Motor-Vehicle Operators' and Chauffeurs' License Act. 10 cents.

Act III.—Uniform Motor-Vehicle Civil Liability Act. 10 cents.

Act IV.—Uniform Motor-Vehicle Safety Responsibility Act. 10 cents.

Act V.—Uniform Act Regulating Traffic on Highways. 20 cents.

Model Traffic Ordinance. 15 cents.

MISCELLANEOUS PUBLICATIONS

Bibliography of Highway Planning Reports. 30 cents.

Construction of Private Driveways (No. 272MP). 10 cents.

Economic and Statistical Analysis of Highway Construction Expenditures. 15 cents.

Electrical Equipment on Movable Bridges (No. 265T). 40 cents.

Federal Legislation and Regulations Relating to Highway Construction. 40 cents.

Financing of Highways by Counties and Local Rural Governments, 1931–41. 45 cents.

Guides to Traffic Safety. 10 cents.

Highway Accidents. 10 cents.

Highway Bond Calculations. 10 cents.

Highway Bridge Location (No. 1486D). 15 cents.

Highway Capacity Manual. 65 cents.

Highway Needs of the National Defense (House Document No. 249). 50 cents.

Highway Practice in the United States of America. 50 cents.

Highway Statistics, 1945. 35 cents.

Highway Statistics, 1946. 50 cents.

Highway Statistics, 1947. 45 cents.

Highway Statistics, 1948. 65 cents.

Highway Statistics, Summary to 1945. 40 cents.

Highways of History. 25 cents.

Identification of Rock Types. 10 cents.

Interregional Highways (House Document No. 379). 75 cents.

Legal Aspects of Controlling Highway Access. 15 cents.

Manual on Uniform Traffic Control Devices for Streets and Highways. 50 cents.

Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft. $1.75.

Public Control of Highway Access and Roadside Development. 35 cents.

Public Land Acquisition for Highway Purposes. 10 cents.

Roadside Improvement (No. 191MP). 10 cents.

Specifications for Construction of Roads and Bridges in National Forests and National Parks (FP–41). $1.50.

Taxation of Motor Vehicles in 1932. 35 cents.

The Local Rural Road Problem. 20 cents.

Tire Wear and Tire Failures on Various Road Surfaces. 10 cents.

Transition Curves for Highways. $1.25.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

ANNUAL REPORTS

(See also adjacent column)

Public Roads Administration Annual Reports:

1943. 1944. 1945.

MISCELLANEOUS PUBLICATIONS

Bibliography on Automobile Parking in the United States.

Bibliography on Highway Lighting.

Bibliography on Highway Safety.

Bibliography on Land Acquisition for Public Roads.

Bibliography on Roadside Control.

Express Highways in the United States: a Bibliography.

Indexes to PUBLIC ROADS, volumes 17–19, 22, and 23.

Road Work on Farm Outlets Needs Skill and Right Equipment.

STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF DECEMBER 31, 1950

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM: PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$19,494	$11,001	$5,693	214.6	$5,288	$2,473	105.1	$13,298	$6,387	338.5	$29,587	$14,553	658.2
Arizona	5,181	1,246	892	30.1	356	246	10.9	6,738	4,810	112.2	8,340	5,950	153.2
Arkansas	7,401	8,421	4,662	222.2	2,821	1,579	52.0	16,305	8,011	422.6	27,547	14,252	696.8
California	12,688	44,480	16,724	233.6	2,588	1,343	25.0	49,344	23,963	268.7	96,412	42,030	527.3
Colorado	7,145	2,136	1,148	60.2	2,548	1,389	54.9	10,339	5,729	230.1	15,023	8,266	345.2
Connecticut	4,533	7,240	3,760	21.3	3,669	1,668	2.9	5,645	3,108	9.8	16,554	8,536	34.0
Delaware	2,212	998	600	22.3	1,019	508	5.0	5,921	2,858	35.1	7,938	3,966	62.4
Florida	8,299	12,367	6,400	232.1	10,428	5,074	242.7	12,898	6,349	279.8	35,693	17,823	754.6
Georgia	9,380	13,998	7,177	272.2	9,462	3,857	98.6	31,137	15,391	721.5	54,597	26,425	1,092.3
Idaho	7,475	7,032	4,435	236.7	2,477	1,534	100.7	5,645	2,896	125.0	15,154	8,865	462.4
Illinois	34,462	37,275	20,450	314.6	15,829	8,087	113.6	46,738	23,027	325.2	99,842	51,564	753.4
Indiana	14,960	32,447	16,740	158.4	6,932	3,346	35.5	16,050	8,291	88.7	55,429	28,377	282.6
Iowa	6,947	14,108	6,150	360.0	4,494	2,196	110.5	11,754	5,906	314.1	30,356	14,252	784.6
Kansas	10,942	10,217	4,259	921.9	1,976	991	271.9	10,523	5,264	517.6	22,716	10,514	1,711.4
Kentucky	8,456	11,082	5,351	96.8	4,826	2,419	76.5	16,133	7,954	282.4	32,041	15,724	455.7
Louisiana	8,722	15,339	7,251	112.3	6,942	3,228	56.7	20,379	10,782	222.7	42,660	21,261	391.7
Maine	4,311	5,325	2,863	65.6	1,784	898	10.3	6,546	3,480	69.8	13,655	7,241	145.7
Maryland	5,323	4,630	2,293	21.9	4,393	1,760	16.3	10,586	4,823	36.2	19,609	8,876	74.4
Massachusetts	9,289	3,150	776	.7	4,921	2,259	1.6	64,394	31,946	64.0	72,465	34,981	66.3
Michigan	15,102	12,510	6,441	387.6	10,609	5,626	169.5	38,337	15,492	279.5	61,456	27,559	836.6
Minnesota	11,434	7,378	4,379	770.5	711	339	72.7	18,593	10,193	361.3	26,682	14,911	1,204.5
Mississippi	10,107	14,241	7,510	498.3	2,725	1,302	75.6	8,141	4,174	258.4	25,107	12,986	832.3
Missouri	14,534	30,578	16,697	880.1	5,806	2,398	132.8	27,852	13,775	377.9	64,236	33,070	1,390.8
Montana	10,218	13,150	6,701	421.2	4,516	2,650	88.2	9,677	5,803	208.9	27,343	15,154	718.3
Nebraska	10,859	14,160	7,445	490.9	5,287	2,583	111.2	9,674	5,135	274.3	29,121	15,163	876.4
Nevada	5,566	2,557	2,112	38.9	972	809	59.7	3,710	3,055	125.4	7,239	5,976	224.0
New Hampshire	3,229	3,106	1,730	26.2	477	229	4.6	3,734	1,859	30.9	7,317	3,818	61.7
New Jersey	9,059	2,672	1,336	8.8	4,135	1,887	5.5	16,790	7,843	19.2	23,597	11.066	33.5
New Mexico	5,950	2,287	1,524	76.5	4,041	2,581	119.4	7,320	4,764	168.5	13,648	8,869	364.4
New York	47,090	61,865	31,534	176.7	18,877	8,427	39.0	106,574	49,859	198.4	187,316	89,820	414.1
North Carolina	9,065	16,455	7,930	417.6	6,282	2,994	99.5	22,574	10,759	519.9	45,311	21,683	1,037.0
North Dakota	6,636	7,852	4,050	1,208.1	2,742	1,315	254.3	5,128	2,546	424.2	15,722	7,911	1,886.6
Ohio	16,490	22,425	10,548	266.7	26,120	14,724	194.4	61,688	29,865	245.8	110,233	55,137	706.9
Oklahoma	9,960	7,341	4,384	68.8	10,012	5,467	122.8	19,202	9,094	421.7	36,555	18,945	613.3
Oregon	6,207	2,111	921	18.2	3,593	1,891	63.8	9,639	5,573	137.6	15,343	8,385	219.6
Pennsylvania	22,020	6,325	3,073	13.4	17,080	8,895	31.2	74,643	36,858	197.2	98,950	48,826	241.8
Rhode Island	1,956	6,743	3,371	50.9	520	260	1.4	13,224	6,710	10.4	20,487	10,341	62.7
South Carolina	6,270	9,028	4,652	212.3	2,171	1,068	73.0	7,625	4,011	196.9	18,824	9,731	482.2
South Dakota	5,802	6,903	3,911	630.1	2,153	1,251	160.0	8,534	5,265	619.0	17,590	10,427	1,409.1
Tennessee	9,203	10,889	5,259	200.2	7,054	3,419	138.0	18,281	8,260	318.2	36,224	16,938	656.4
Texas	19,812	4,491	2,295	83.9	16,453	8,466	247.1	43,279	20,110	884.2	64,223	30,871	1,215.2
Utah	4,905	3,789	2,773	82.2	763	567	25.7	4,508	3,268	140.4	9,060	6,608	248.3
Vermont	2,368	2,211	1,227	31.7	601	304	9.0	4,460	2,062	26.8	7,272	3,593	67.5
Virginia	10,203	20,951	10,374	440.2	6,289	3,109	175.5	14,182	6,927	220.4	41,422	20,410	836.1
Washington	6,864	7,195	2,625	68.5	1,560	732	22.0	21,741	10,452	141.4	30,496	13,809	231.9
West Virginia	5,131	15,088	6,174	112.4	2,795	1,406	39.6	9,444	4,775	96.7	27,327	12,355	248.7
Wisconsin	16,031	16,199	8,806	375.4	2,757	1,282	68.9	13,191	6,463	319.2	32,147	16,551	763.5
Wyoming	3,761	1,146	768	15.3	1,308	854	11.3	6,188	3,812	169.8	8,642	5,434	196.4
Hawaii	2,337	8,178	3,466	22.4	3,640	1,568	12.2	3,637	1,759	16.5	15,455	6,813	51.1
District of Columbia	3,904	4,040	2,020	4.1	703	564	.9	1,068	534	.9	5,811	3,118	5.9
Puerto Rico	3,693	13,157	6,023	66.2	755	338	2.7	9,354	4,035	37.1	23,266	10,396	106.0
TOTAL	502,986	599,513	299,883	11,761.8	267,162	134,182	4,022.2	982,365	486,065	11,911.0	1,849,040	920,130	27,695.0

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