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INTERCHANGE CAPACITY ANALYSIS MODEL

By

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ABSTRACT

In this day and age of the super highway one problem exists that is all too familiar to all of us who have driven in "rush-hour" traffic, the traffic jam; better known to the highway designer as the over-capacity condition. The over-capacity condition develops when the amount of traffic desiring to use a specific geometric element of the highway is greater than the amount of traffic that particular element is designed to carry. The origin of every traffic congestion area is an interchange. It is the interchange with its multiple vehicular interactions that is burdened with the excessive desire of vehicular movements responsible for the massive congestion that is commonplace on our freeways today.

The area of interchange design is extremely complicated, yet at the same time, is extremely critical in the successful design of a highway interchange sequence. It is so critical in fact that improper design of only one geometric element of one interchange may create a disaster area for miles on some freeway. Therefore there is significant need for an effective, efficient, yet fool-proof method of interchange configuration evaluation.

The linear programming model provides the highway designer with such a mathematical tool for the evaluation of the characteristics of an interchange subject to basic configuration,

physical features, and traffic patterns. With this tool, the designer can more effectively consider the problems of vehicular interactions and peak-period congestion within the framework of an interchange design sequence.

The formulation of the linear programming model is a straightforward maximization of the traffic entering the interchange, where the total number of movements entering the interchange is a function of the number of approaches. That function is $x = n(n-1)$ where x is the maximum number of possible movements and n is the number of approaches. The objective function describing the traffic entering the interchange is subject to both the geometric characteristics of the interchange and the vehicular distribution through the interchange. The solution of the linear programming formulation identifies the critical element or elements of the interchange so that the designer can direct his attention to the needed areas of improvement and can modify these elements to increase their capacities.

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INTRODUCTION

One of the problems faced by the highway designer is the analysis of interchanges for capacity considerations. The linear programming model provides the highway designer with an effective mathematical tool for the evaluation of the characteristics of an interchange subject to basic configuration, physical features, and traffic patterns. With this ability, the designer can more effectively consider the problems of vehicular interactions and peak-period congestion within the framework of an interchange design sequence.

A linear programming model provides an effective means of determining the capacity of any type of interchange. The capacity is defined as the maximum volume capable of entering the interchange without causing the capacity of any geometric element of the interchange to be exceeded.

A most difficult task ofthe highway designer is the evaluation of proposed highway interchange configurations. Considering the cost of highway construction today, it is not an exageration to say that a million dollar mistake can be made in interchange configuration selection. Burdened with this responsibility, the highway designer requires the most powerful tool available to assist him in his decision making process. This interchange capacity linear programming analysis model is just such a tool, providing optimal maximization solutions.

The purpose of this paper is to document the formulation of the highway interchange as a linear programming model and to illustrate its usefullness to the Colorado State Highway Department.

GENERAL APPROACH

A linear programming model provides a rather effective means of determining the capacity of any type of interchange, regardless of the complexity of the geometric configuration. The capacity is defined as the maximum volume capable of entering the interchange without causing the capacity of any geometric element of the interchange to be exceeded. Because the capacity is the maximum number of vehicles that can use the interchange, the objective function of the model is to be maximized subject to the geometric characteristics of the interchange and the vehicular distribution through the interchange.

DEVELOPMENT OF THE OBJECTIVE FUNCTION

To maximize the traffic entering the interchange, each of the entering vehicular movements that may occur at an interchange must be considered, northbound to eastbound for example. The total number of vehicular movements that may occur at an interchange is a function of the number of approaches. That function is

$$x = n(n-1)$$

where x is the maximum number of possible movements and n is the number of approaches. Therefore, for a four-leg interchange, with all movements permitted, there are twelve possible movements. Thus, the variables for the objective function represent the volume of each of the twelve movements approaching the interchange. Each possible movement must be explicitly defined. Because the volume entering the interchange is to be maximized, the objective function for a four-leg interchange capacity problem is

$$\text{Maximize} \quad W_1V_1 + W_2V_2 + W_3V_3 + W_4V_4 + W_5V_5 + W_6V_6 + W_7V_7 + W_8V_8 + W_9V_9 + W_{10}V_{10} + W_{11}V_{11} + W_{12}V_{12}$$

or

$$\text{Maximize} \quad \sum_{i=1}^{12} W_iV_i$$

Because each variable in the objective function represents an individual movement, the weight value associated with each variable is one. Hence, the resulting objective function is

$$\text{Maximize} \quad V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7 + V_8 + V_9 + V_{10} + V_{11} + V_{12}$$

or

$$\text{Maximize} \quad \sum_{i=1}^{12} V_i$$

To determine the maximum volume capable of entering the interchange requires that this function be maximized subject to various geometric and vehicular distribution constraints.

DEVELOPMENT OF THE CONSTRAINTS

There are two types of constraints that must be met. The first set of constraints relates to the capacity of each of the interchange elements. Each of these constraints is related to a particular geometric element of the interchange and states that the volume using the element must not exceed the capacity of the geometric element. The specific values of the capacity constraints actually define the geometric characteristics of the interchange to be analyzed. Capacity of each element is determined by type of facility, number of lanes, signalization if any, level of service, lane width, restricted lateral clearance, percentage of trucks and terrain. The effect of each of these factors on capacity will be analyzed in detail later.

The capacities of the interchange elements are determined by either the vehicular movements or the particular geometric elements. Each geometric element may readily be assigned a capacity through consideration of the specific geometric characteristics of that element. It must then follow that the traffic using that element, whether it be a single movement on a ramp or the sum of three vehicular movements on the main freeway line, be limited by its capacity.

The second set of constraints is developed to define the distribution of the movements through the interchange.

This set of constraints ensures that the distribution of traffic among the various movements entering the interchange will be the appropriate distribution. To develop these constraints, accurate count data must be available. The procedure is to determine the relationship between the volume of one movement and all others. In other words, we are saying

$$V_i = P_i V_1$$

where P_i equals the ratio V_i^*/V_1^*, where V_i^* and V_1^* are the measured volumes as determined from the count data.

PERIOD OF ANALYSIS

The analysis may be conducted on a 24-hour or average daily traffic basis. However, a peak-hour analysis must be made if analyzing an interchange for design purposes. The reasons for this are that all design criteria are based on the design hour volume which occurs during a peak period, and that the afternoon peak-period traffic patterns generally differ from the morning peak patterns. The design hour volume mentioned above is defined as the 30th highest hourly volume counted during the year. Since it is impractical to design for all possible volume conditions, highway designers have agreed to the 30th highest hour as a practical volume condition limit. On freeways, this 30th highest hour or design hour occurs during a peak period. This peak may be a morning or afternoon peak as the difference in daily peak periods may be drastic. Consider the freeway leading from the subburbs to the downtown area. In the morning the vast majority of traffic is traveling toward the business center, and in the opposite direction in the afternoon. Because of this variation of traffic patterns, each peak period, morning and afternoon, must be evaluated for the interchange of interest.

ASSIGNMENT OF CAPACITY VALUES

With the objective function now defined and the constraint equations developed, only the assignment of specific capacity values to the physical constraint equations remains before the linear programming problem is solved. Many factors have an effect on the capacity of a geometric element. Those which are significant are level of service, type of facility, number of lanes, signalization if any, lane width, restricted lateral clearance, percentage of trucks and terrain.

Level of service is a term used to describe traffic flow conditions. The six possible conditions are represented by alphabetical designations, A through F. Level of service A is the free flow condition. Levels B and C describe the stable flow condition, B being the upper speed range and C the lower speed range. Level of service D is described as approaching unstable flow. Service level E, also defined as capacity, represents the unstable flow condition. The volumes associated with level of service E are the maximum possible under uninterrupted flow conditions and therefore represent the capacity volumes. Level of service F describes the forced flow condition. No traffic volumes are associated with level F because traffic cannot move for indefinite periods of time under this condition.

The volumes then that will be used in assignment of capacity values are those pertaining to level of service E, the capacity service level. These volumes are defined by the 1965 Highway Capacity Manual as the following hourly capacities

FACILITY	CAPACITY
Freeway	2000 vehicles per lane per hour
Ramp	1500 vehicles per lane per hour
Arterial street	1500 vehicles per lane per hour of green time

So then to assign specific capacity values for a particular geometric element, first determine the type of facility for the given element and multiply the capacity for that facility times the number of lanes of that element. This initial hourly capacity, computed as CL, C being capacity per lane and L being the number of lanes, will then be modified to reflect the effect of the other aforementioned factors.

As may have been noticed in the designation of capacity of an arterial street, signalization plays an important role in the determination of capacity for the intersecting streets. For streets having a traffic signal close enough to the selected interchange to influence the traffic flow, the hourly capacity is reduced by the percentage of time lost to the red cycle. Thus, for a facility controlled by a signal allowing the green cycle eighty per cent of the time, the factor G, for green time percentage, is equal to 0.80. The introduction of the signalization modifier into the capacity equation now yields the equation

$$\text{Capacity} = CLG$$

where G represents the green time percentage.

The effects of lane width and restricted lateral clearance on capacity are combined into one factor. The Highway Research Board has determined that these two factors are interdependent. The combined effect of lane width and restricted lateral clearance is expressed as the adjustment factor, W. This factor is determined using Table I, taken from the Highway Capacity Manual, Special Report 87, page 256, 1965.

Now with the introduction of W into the capacity equation we have

$$\text{Capacity} = CLGW$$

where W represents the adjustment factor for the effect of lane width and restricted lateral clearance.

TABLE I

COMBINED EFFECT OF LANE WIDTH AND RESTRICTED LATERAL CLEARANCE ON CAPACITY AND SERVICE VOLUMES OF DIVIDED FREEWAYS AND EXPRESSWAYS WITH UNINTERRUPTED FLOW

Distance From Traffic Lane Edge to Obstruction (FT)	Adjustment Factor, W, for Lane Width and Restricted Lateral Clearance			
	12-FT Lanes	11-FT Lanes	10-FT Lanes	9-FT Lanes
	(a) 4-Lane Divided Freeway, One Direction of Travel			
6	1.00	0.97	0.91	0.81
4	0.99	0.96	0.90	0.80
2	0.97	0.94	0.88	0.79
0	0.90	0.87	0.82	0.73
	(b) 6- and 8-Lane Divided Freeway, One Direction of Travel			
6	1.00	0.96	0.89	0.78
4	0.99	0.95	0.88	0.77
2	0.97	0.93	0.87	0.76
0	0.94	0.91	0.85	0.74

The final modification factor considered is T, the adjustment factor for the combined effect of terrain and percentage of trucks. Again the Highway Research Board has determined that these two factors are interdependent. This factor T is determined using Table II, again taken from the Highway Capacity Manual, Special Report 87, page 257, 1965.

TABLE II

AVERAGE GENERALIZED ADJUSTMENT FACTORS FOR TRUCKS ON FREEWAYS AND EXPRESSWAYS, OVER EXTENDED SECTION LENGTHS

	Factor T		
Percentage of Trucks	Level Terrain	Rolling Terrain	Mountainous Terrain
1	0.99	0.97	0.93
2	0.98	0.94	0.88
3	0.97	0.92	0.83
4	0.96	0.89	0.78
5	0.95	0.87	0.74
6	0.94	0.85	0.70
7	0.93	0.83	0.67
8	0.93	0.81	0.64
9	0.92	0.79	0.61
10	0.91	0.77	0.59
12	0.89	0.74	0.54
14	0.88	0.70	0.51
16	0.86	0.68	0.47
18	0.85	0.65	0.44
20	0.83	0.63	0.42

Introducing T into the capacity equation yields

$$\text{Capacity} = CLGWT$$

Now, to recap the capacity equation, the hourly capacity for a particular geometric element of a highway interchange is computed by evaluating the product of C, the capacity per lane of that particular type of facility, L, the number of lanes, G, the green time percentage, W, the adjustment factor for the effect of lane width and restricted lateral clearance, and T, the adjustment factor for the effect of terrain and percentage of trucks.

SOLUTION OF THE MODEL

With the assignment of capacity values to the physical constraint equations, the linear programming model for the interchange is now complete. The solution of the linear programming model is obtained using the simplex procedure. For problems of the size produced in modeling highway interchanges, any good computer program designed for the simplex procedure may be used to determine the problem solution.

INTERPRETATION OF RESULTS

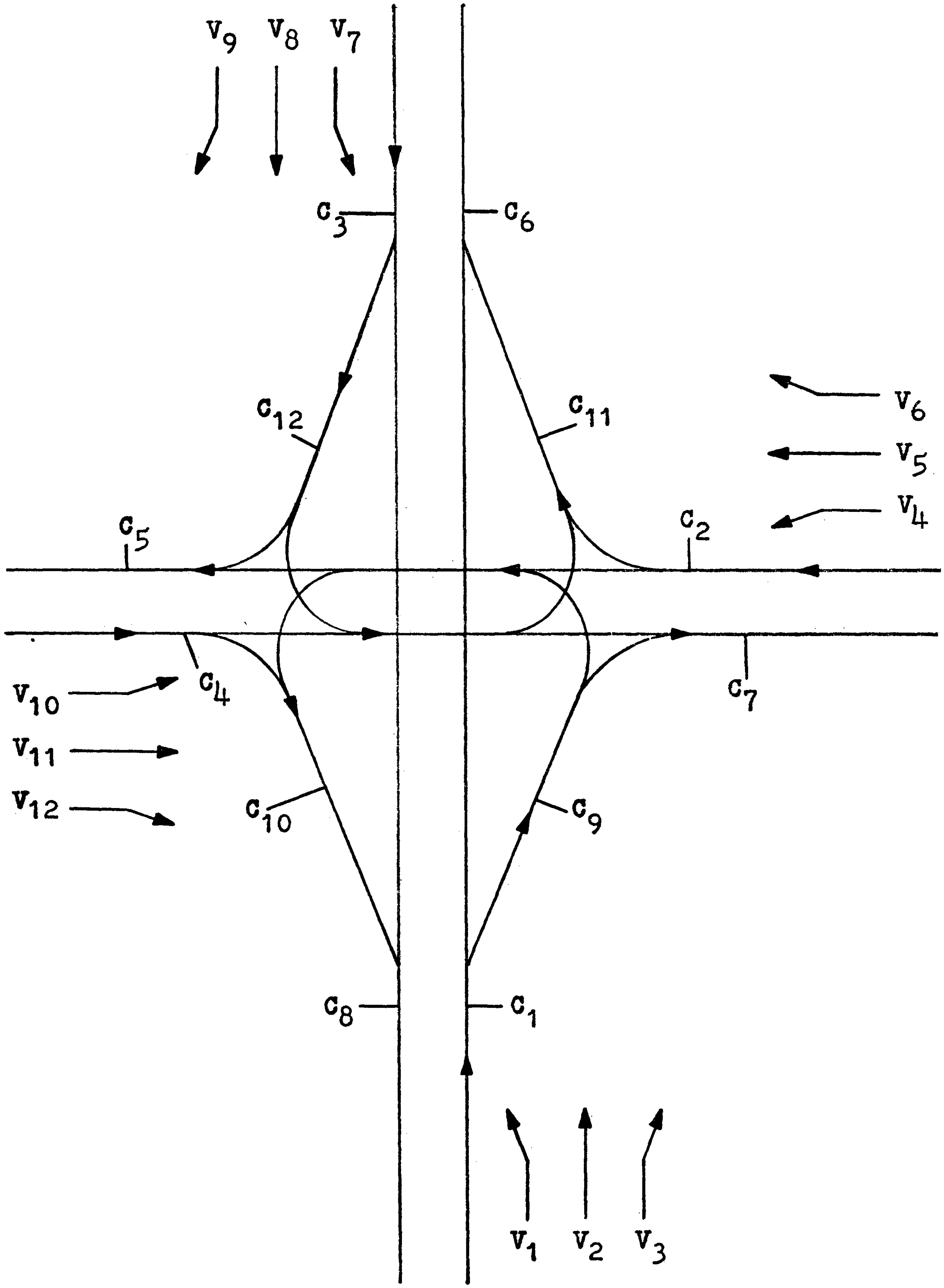
The purpose of the physical and interrelationship constraints is to define the area of possible solutions that will maximize the objective function. At least one of the physical constraints will be the critical constraint, and in the optimal solution that constraint becomes an equality. It is possible for two or three physical constraints to become critical simultaneously. The solution will indicate the value of the objective function, the values of each of the vehicular movements, the critical physical constraint or constraints and the unused capacity of the physical constraints that are not critical.

The value of the objective function is interpreted as the maximum total volume that may be accommodated by the interchange configuration before congestion begins to develop. The critical element, that element on which the volume equals the elements capacity, is also identified. This is interpreted as the element at which congestion will first develop and is, therefore, the segment that limits the overall capacity of the interchange. By identifying the critical element or elements, the designer can direct his attention to the needed areas of improvement and can modify these elements to increase their capacities. Thus, the linear programming model can aid the designer in developing new interchange configurations that provide higher capacities than the one currently under analysis.

FORMULATION OF TYPICAL MODELS

There are two major classifications of highway interchanges, the diamond and the cloverleaf. Practically all interchanges can be classified as belonging to one of these two groups. The formulation of the interchange capacity model follows for the typical diamond and cloverleaf interchanges.

DIAMOND INTERCHANGE



FORMULATION OF THE DIAMOND INTERCHANGE

Maximize $V_1+V_2+V_3+V_4+V_5+V_6+V_7+V_8+V_9+V_{10}+V_{11}+V_{12}$

Subject To

$$
\begin{aligned}
V_1+V_2+V_3 &\leq C_1 \\
V_4+V_5+V_6 &\leq C_2 \\
V_7+V_8+V_9 &\leq C_3 \\
V_{10}+V_{11}+V_{12} &\leq C_4 \\
V_1+V_5+V_9 &\leq C_5 \\
V_2+V_6+V_{10} &\leq C_6 \\
V_3+V_7+V_{11} &\leq C_7 \\
V_4+V_8+V_{12} &\leq C_8 \\
V_1+V_3 &\leq C_9 \\
V_4+V_{12} &\leq C_{10} \\
V_6+V_{10} &\leq C_{11} \\
V_7+V_9 &\leq C_{12} \\
P_2V_1-V_2 &= C_{13} = 0 \\
P_3V_1-V_3 &= C_{14} = 0 \\
P_4V_1-V_4 &= C_{15} = 0 \\
P_5V_1-V_5 &= C_{16} = 0 \\
P_6V_1-V_6 &= C_{17} = 0 \\
P_7V_1-V_7 &= C_{18} = 0 \\
P_8V_1-V_8 &= C_{19} = 0 \\
P_9V_1-V_9 &= C_{20} = 0 \\
P_{10}V_1-V_{10} &= C_{21} = 0 \\
P_{11}V_1-V_{11} &= C_{22} = 0 \\
P_{12}V_1-V_{12} &= C_{23} = 0
\end{aligned}
$$

The P_i's shown in the last eleven constraints are defined as V_i^*/V_1^*, the ratio of the counted volumes.

Closer inspection of the constraints reveals that a consolidation can be made upon substituting for $V_i = P_i V_1$ from the last eleven constraints into the first twelve constraints. This substitution yields

$$V_1(1 + P_2 + P_3) \leq C_1$$
$$V_1(P_4 + P_5 + P_6) \leq C_2$$
$$V_1(P_7 + P_8 + P_9) \leq C_3$$
$$V_1(P_{10} + P_{11} + P_{12}) \leq C_4$$
$$V_1(1 + P_5 + P_9) \leq C_5$$
$$V_1(P_2 + P_6 + P_{10}) \leq C_6$$
$$V_1(P_3 + P_7 + P_{11}) \leq C_7$$
$$V_1(P_4 + P_8 + P_{12}) \leq C_8$$
$$V_1(1 + P_3) \leq C_9$$
$$V_1(P_4 + P_{12}) \leq C_{10}$$
$$V_1(P_6 + P_{10}) \leq C_{11}$$
$$V_1(P_7 + P_9) \leq C_{12}$$

going one step further results in

$$V_1 \leq \frac{C_1}{1 + P_2 + P_3}$$

$$V_1 \leq \frac{C_2}{P_4 + P_5 + P_6}$$

$$V_1 \leq \frac{C_3}{P_7 + P_8 + P_9}$$

$$V_1 \leq \frac{C_4}{P_{10} + P_{11} + P_{12}}$$

$$V_1 \leq \frac{C_5}{1 + P_5 + P_9}$$

$$V_1 \leq \frac{C_6}{P_2 + P_6 + P_{10}}$$

$$V_1 \leq \frac{C_7}{P_3 + P_7 + P_{11}}$$

$$V_1 \leq \frac{C_8}{P_4 + P_8 + P_{12}}$$

$$V_1 \leq \frac{C_9}{1 + P_3}$$

$$V_1 \leq \frac{C_{10}}{P_4 + P_{12}}$$

$$V_1 \leq \frac{C_{11}}{P_6 + P_{10}}$$

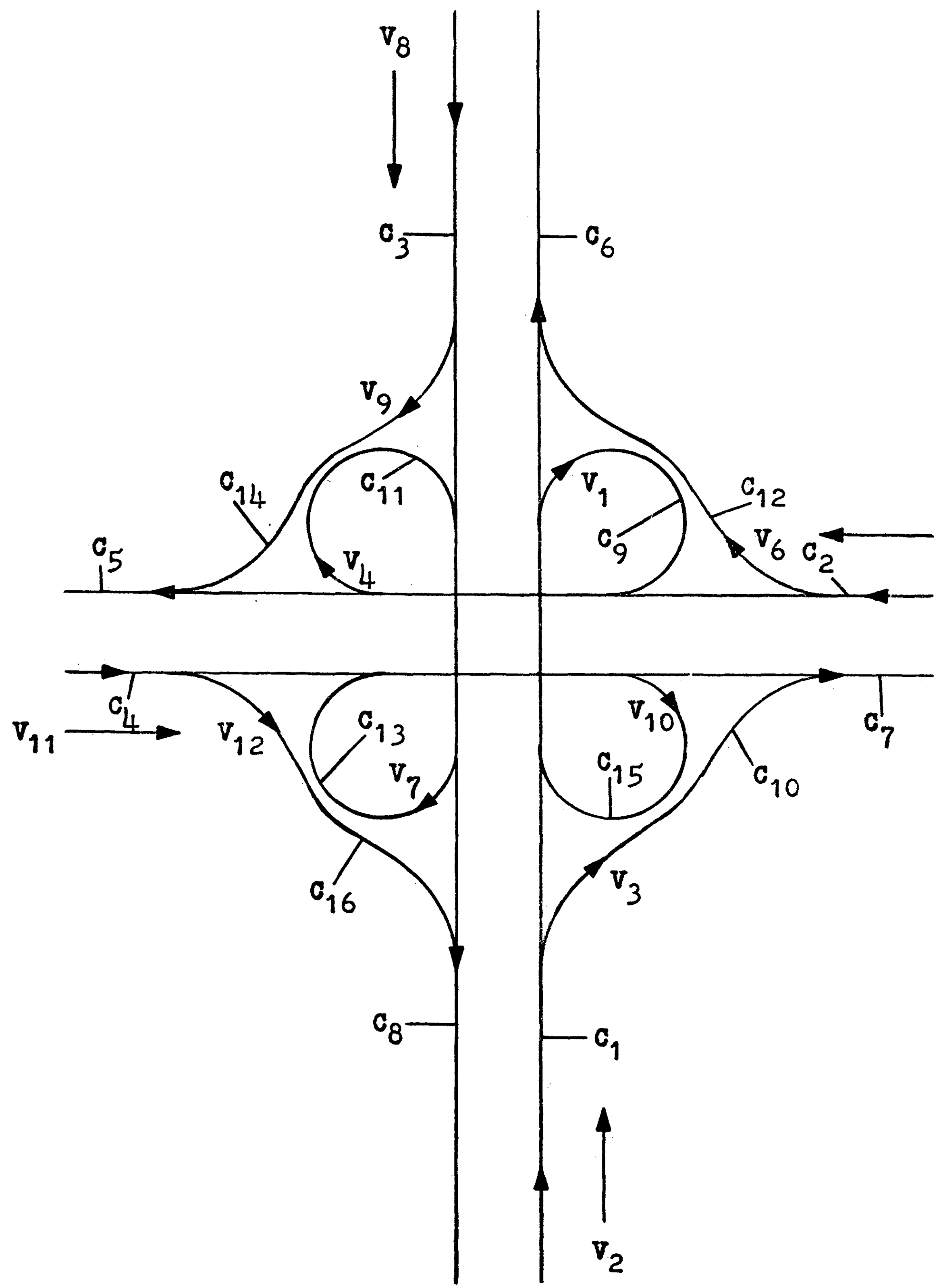
$$V_1 \leq \frac{C_{12}}{P_7 + P_9}$$

Hence, with all C_i's and P_i's being known values, the linear programming model is no longer necessary.

Completion of the analysis is now a simple matter. Examine the remaining twelve inequalities on V_1. The one which is most restrictive is the one of interest. Here the value of V_1 is determined, the C_i of this constraint defines the critical element, the values of all other movements can be determined from V_1, and the maximum possible entering volume can be found.

Therefore, the formulation of the highway interchange as a linear programming model has resulted in a significant simplification of interchange analysis.

CLOVERLEAF INTERCHANGE



FORMULATION OF THE CLOVERLEAF INTERCHANGE

Maximize $V_1+V_2+V_3+V_4+V_5+V_6+V_7+V_8+V_9+V_{10}+V_{11}+V_{12}$

Subject To

$$
\begin{aligned}
V_1+V_2+V_3 &\le C_1 \\
V_4+V_5+V_6 &\le C_2 \\
V_7+V_8+V_9 &\le C_3 \\
V_{10}+V_{11}+V_{12} &\le C_4 \\
V_1+V_5+V_9 &\le C_5 \\
V_2+V_6+V_{10} &\le C_6 \\
V_3+V_7+V_{11} &\le C_7 \\
V_4+V_8+V_{12} &\le C_8 \\
V_1 &\le C_9 \\
V_3 &\le C_{10} \\
V_4 &\le C_{11} \\
V_6 &\le C_{12} \\
V_7 &\le C_{13} \\
V_9 &\le C_{14} \\
V_{10} &\le C_{15} \\
V_{12} &\le C_{16} \\
P_2V_1-V_2 &= C_{17} = 0 \\
P_3V_1-V_3 &= C_{18} = 0 \\
P_4V_1-V_4 &= C_{19} = 0 \\
P_5V_1-V_5 &= C_{20} = 0 \\
P_6V_1-V_6 &= C_{21} = 0 \\
P_7V_1-V_7 &= C_{22} = 0 \\
P_8V_1-V_8 &= C_{23} = 0 \\
P_9V_1-V_9 &= C_{24} = 0 \\
P_{10}V_1-V_{10} &= C_{25} = 0 \\
P_{11}V_1-V_{11} &= C_{26} = 0 \\
P_{12}V_1-V_{12} &= C_{27} = 0
\end{aligned}
$$

The P_i's shown in the last eleven constraints are defined as V_i^*/V_1^*, the ratio of the counted volumes.

The constraints in this formulation can be handled in the same manner as was done for the diamond interchange formulation. The results are

$$V_1 \leq \frac{C_1}{1 + P_2 + P_3}$$

$$V_1 \leq \frac{C_2}{P_4 + P_5 + P_6}$$

$$V_1 \leq \frac{C_3}{P_7 + P_8 + P_9}$$

$$V_1 \leq \frac{C_4}{P_{10} + P_{11} + P_{12}}$$

$$V_1 \leq \frac{C_5}{1 + P_5 + P_9}$$

$$V_1 \leq \frac{C_6}{P_2 + P_6 + P_{10}}$$

$$V_1 \leq \frac{C_7}{P_3 + P_7 + P_{11}}$$

$$V_1 \leq \frac{C_8}{P_4 + P_8 + P_{12}}$$

$$V_1 \leq C_9$$

$$V_1 \leq \frac{C_{10}}{P_3}$$

$$V_1 \leq \frac{C_{11}}{P_4}$$

$$V_1 \leq \frac{C_{12}}{P_6}$$

$$V_1 \leq \frac{C_{13}}{P_7}$$

$$V_1 \leq \frac{C_{14}}{P_9}$$

$$V_1 \leq \frac{C_{15}}{P_{10}}$$

$$V_1 \leq \frac{C_{16}}{P_{12}}$$

and the final analysis proceeds as before.

NUMERICAL EXAMPLE

An interchange capacity analysis numerical example is presented here for the Interstate 25 - Speer Boulevard interchange. The analysis of this cloverleaf interchange is based on traffic volume counts taken March 14, 1974.

Assignment of capacities:

Freeway: 4 lanes one direction, no signalization, no lateral clearance effect, 12% trucks, level terrain

Capacity = CLGWT = (2000)(4)(1)(1)(0.89)
= 7120

Arterial: 3 lanes one direction, no signalization, no lateral clearance effect, 8% trucks, level terrain

Capacity = CLGWT = (1500)(3)(1)(1)(0.93)
= 4185

Ramps: 1 lane, no signalization, no lateral clearance effect, 12% trucks, level terrain

Capacity = CLGWT = (1500)(1)(1)(1)(0.89)
= 1335

So that: $C_1 = C_3 = C_6 = C_8 = 7120$

$C_2 = C_4 = C_5 = C_7 = 4185$

$C_9 = C_{10} = C_{11} = C_{12} = 1335$

$C_{13} = C_{14} = C_{15} = C_{16} = 1335$

Volume Count Data:

	Morning Peak	P_i	Afternoon Peak	P_i
V_1	180		371	
V_2	4355	24.2	4500	12.1
V_3	48	0.3	64	0.2
V_4	50	0.3	155	0.4
V_5	453	2.5	1467	4.0
V_6	430	2.4	1161	3.1
V_7	866	4.8	645	1.7
V_8	4512	25.1	4370	11.8
V_9	215	1.2	142	0.4
V_{10}	201	1.1	233	0.6
V_{11}	1531	8.5	725	2.0
V_{12}	630	3.5	303	0.8
Total	13471		14136	

Substitution of the known C and P values into the final sixteen inequalities on V_1 result in the following ratios and restrictive values for the given C_i's.

	Morning Peak	V_1	Afternoon Peak	V_1
c_1	7120/25.5	279	7120/12.4	574
c_2	4185/5.2	804	4185/7.5	558
c_3	7120/31.1	229*	7120/13.9	512
c_4	4185/13.1	319	4185/3.4	1230
c_5	4185/4.7	889	4185/5.4	774
c_6	7120/27.7	257	7120/15.8	450
c_7	4185/13.6	308	4185/3.9	1071
c_8	7120/28.9	246	7120/13.0	548
c_9	1335	1335	1335	1335
c_{10}	1335/0.3	4450	1335/0.2	6680
c_{11}	1335/0.3	4450	1335/0.4	3339
c_{12}	1335/2.4	556	1335/3.1	431*
c_{13}	1335/4.8	278	1335/1.7	785
c_{14}	1335/1.2	1112	1335/0.4	3339
c_{15}	1335/1.1	1213	1335/0.6	2226
c_{16}	1335/3.5	381	1335/0.8	1669

The most restrictive inequalities have been designated, (*), and hence the critical element has been determined.

Results of the analysis are:

Morning Peak	Afternoon Peak
V_1 = 229	V_1 = 431
C_3 is the critical element	C_{12} is the critical element
V_2 = 5540	V_2 = 5211
V_3 = 69	V_3 = 86
V_4 = 69	V_4 = 172
V_5 = 572	V_5 = 1723
V_6 = 549	V_6 = 1335
V_7 = 1099	V_7 = 732
V_8 = 5746	V_8 = 5082
V_9 = 275	V_9 = 172
V_{10} = 252	V_{10} = 258
V_{11} = 1946	V_{11} = 861
V_{12} = 801	V_{12} = 345
Interchange capacity:	Interchange capacity:
17147	16408

COMPARISON TO THE COLORADO STATE HIGHWAY DEPARTMENT METHOD OF INTERCHANGE CAPACITY ANALYSIS

The Colorado State Highway Department method of interchange capacity analysis is lacking in that it does not consider traffic movement interactions to the extent possible using the linear programming model method. However, it is similar to this interchange capacity analysis model in several aspects.

First, the capacity of each individual geometric element is analyzed. This capacity is determined in the same manner as described in this paper, arrived at using the equation

$$\text{Capacity} = CLGWT.$$

Again, this equation is derived from determinations made by the Highway Research Board and specified in the Highway Capacity Manual, Special Report 87, 1965.

Secondly, the distribution of the traffic movements through the interchange is analyzed using accurate count data. This analysis is performed for the peak-period traffic patterns only because all analysis and decisions concerning interchange configurations are based on the design hour volumes. Also, the traffic patterns for both the morning and afternoon peak-periods are evaluated to ensure adequate interchange design.

The actual procedure is as follows:

1) Determine hourly capacity of each individual geometric element.
2) Using count distribution data, determine which element is nearest to capacity using the ratio of volume/capacity.
3) Determine the per cent increase necessary to raise the element having the largest volume/capacity ratio to the capacity figure.
4) Increase volumes on all geometric elements by this same factor.
5) Determine the capacity of the interchange by totaling all volumes entering the interchange.

The formulation of the highway interchange as a linear program and subsequent simplification of the problem to evaluation of capacity related ratios is of particular value to the highway designer. In comparative analysis, the evaluation procedure presented in this paper has shown the present procedure to be satisfactory in selecting the critical element. It is noted that both procedures are consistent in the examination of volume-capacity related values. The method presented here is noteworthy in that (1) It has confirmed that past interchange evaluations have been effectively conducted. (2) It does provide the highway designer with the optimum value of traffic entering the interchange through complete consideration of traffic interactions. and (3) Most importantly, it provides the highway designer with a quicker, simpler and therefore more efficient method of interchange configuration analysis. Hence, this model provides the highway designer with a more effective mathematical tool for the evaluation of the operational characteristics of an interchange subject to basic configuration, physical features, and traffic patterns.

With this ability, the designer can more effectively consider the problems of vehicular interactions and peak-period congestion within the framework of an interchange design sequence.

APPENDIX

A BASIC Program for Solving Interchange Capacity Analysis Problems.

The results given by this program are:

1. The individual volumes at capacity.
2. The capacity of the interchange.
3. The element or elements which first reach capacity.
4. The available volume remaining on each element at capacity.

The program has the capability of analyzing both diamond and cloverleaf interchanges. The procedure for using this program is:

1. The user enters the interchange type to be analyzed, diamond or cloverleaf.
2. The program defines the capacities and volumes for the user.
3. The user enters the capacities.
4. The user enters the volumes.

Two example solutions follow, the first for a diamond interchange and the second for a cloverleaf interchange. The BASIC program for solving interchange capacity analysis problems follows the examples.

Example 1

```
THIS PROGRAM ANALYZES THE TYPICAL DIAMOND AND CLOVERLEAF
INTERCHANGES FOR CAPACITY CONSIDERATIONS.
WHAT TYPE INTERCHANGE IS TO BE ANALYZED?
DIAMOND = 1     CLOVERLEAF = 2

? 1

FOR THE DIAMOND INTERCHANGE THE CAPACITIES ARE DEFINED AS:

C(1)  NORTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE
C(2)  WESTBOUND TRAFFIC EAST OF THE INTERCHANGE
C(3)  SOUTHBOUND TRAFFIC NORTH OF THE INTERCHANGE
C(4)  EASTBOUND TRAFFIC WEST OF THE INTERCHANGE
C(5)  WESTBOUND TRAFFIC WEST OF THE INTERCHANGE
C(6)  NORTHBOUND TRAFFIC NORTH OF THE INTERCHANGE
C(7)  EASTBOUND TRAFFIC EAST OF THE INTERCHANGE
C(8)  SOUTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE
C(9)  OFF RAMP FROM NORTHBOUND TRAFFIC
C(10) ON RAMP TO SOUTHBOUND TRAFFIC
C(11) ON RAMP TO NORTHBOUND TRAFFIC
C(12) OFF RAMP FROM SOUTHBOUND TRAFFIC

AND THE TRAFFIC VOLUMES ARE DEFINED AS:

V(1)  NORTHBOUND TO WESTBOUND MOVEMENT
V(2)  NORTHBOUND THROUGH TRAFFIC
V(3)  NORTHBOUND TO EASTBOUND MOVEMENT
V(4)  WESTBOUND TO SOUTHBOUND MOVEMENT
V(5)  WESTBOUND THROUGH TRAFFIC
V(6)  WESTBOUND TO NORTHBOUND MOVEMENT
V(7)  SOUTHBOUND TO EASTBOUND MOVEMENT
V(8)  SOUTHBOUND THROUGH TRAFFIC
V(9)  SOUTHBOUND TO WESTBOUND MOVEMENT
V(10) EASTBOUND TO NORTHBOUND MOVEMENT
V(11) EASTBOUND THROUGH TRAFFIC
V(12) EASTBOUND TO SOUTHBOUND MOVEMENT


INPUT THE CAPACITIES IN ORDER, 1 TO 12

? 7120,4185,7120,4185,4185,7120,4185,7120,1335,1335,1335,1335

INPUT THE VOLUMES IN ORDER, 1 TO 12

? 371,4500,64,155,1467,1161,645,4370,142,233,725,303
```

```
THE INDIVIDUAL VOLUMES AT CAPACITY ARE:

V( 1     ) =  355.298 VEHICLES
V( 2     ) =  4309.54 VEHICLES
V( 3     ) =  61.2912 VEHICLES
V( 4     ) =  148.44  VEHICLES
V( 5     ) =  1404.91 VEHICLES
V( 6     ) =  1111.86 VEHICLES
V( 7     ) =  617.701 VEHICLES
V( 8     ) =  4185.04 VEHICLES
V( 9     ) =  135.99  VEHICLES
V( 10    ) =  223.138 VEHICLES
V( 11    ) =  694.315 VEHICLES
V( 12    ) =  290.176 VEHICLES

THE CAPACITY OF THE INTERCHANGE IS 13537.7 VEHICLES

THE ELEMENT LIMITED BY C( 11    ) HAS REACHED CAPACITY

THE AVAILABLE VOLUME REMAINING ON EACH ELEMENT AT CAPACITY IS:

FOR THE ELEMENT LIMITED BY C( 1     ) -  2393.87 VEHICLES
FOR THE ELEMENT LIMITED BY C( 2     ) -  1519.79 VEHICLES
FOR THE ELEMENT LIMITED BY C( 3     ) -  2181.27 VEHICLES
FOR THE ELEMENT LIMITED BY C( 4     ) -  2977.37 VEHICLES
FOR THE ELEMENT LIMITED BY C( 5     ) -  2288.8  VEHICLES
FOR THE ELEMENT LIMITED BY C( 6     ) -  1475.46 VEHICLES
FOR THE ELEMENT LIMITED BY C( 7     ) -  2811.69 VEHICLES
FOR THE ELEMENT LIMITED BY C( 8     ) -  2496.34 VEHICLES
FOR THE ELEMENT LIMITED BY C( 9     ) -  918.411 VEHICLES
FOR THE ELEMENT LIMITED BY C( 10    ) -  896.385 VEHICLES
FOR THE ELEMENT LIMITED BY C( 11    ) -  7.27596E-12  VEHICLES
FOR THE ELEMENT LIMITED BY C( 12    ) -  581.309 VEHICLES
```

Example 2

```
THIS PROGRAM ANALYZES THE TYPICAL DIAMOND AND CLOVERLEAF
INTERCHANGES FOR CAPACITY CONSIDERATIONS.
WHAT TYPE INTERCHANGE IS TO BE ANALYZED?
DIAMOND = 1    CLOVERLEAF = 2

? 2

FOR THE CLOVERLEAF INTERCHANGE THE CAPACITIES ARE DEFINED AS:

C(1)  NORTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE
C(2)  WESTBOUND TRAFFIC EAST OF THE INTERCHANGE
C(3)  SOUTHBOUND TRAFFIC NORTH OF THE INTERCHANGE
C(4)  EASTBOUND TRAFFIC WEST OF THE INTERCHANGE
C(5)  WESTBOUND TRAFFIC WEST OF THE INTERCHANGE
C(6)  NORTHBOUND TRAFFIC NORTH OF THE INTERCHANGE
C(7)  EASTBOUND TRAFFIC EAST OF THE INTERCHANGE
C(8)  SOUTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE
C(9)  NORTHBOUND TO WESTBOUND RAMP
C(10) NORTHBOUND TO EASTBOUND RAMP
C(11) WESTBOUND TO NORTHBOUND RAMP
C(12) WESTBOUND TO NORTHBOUND RAMP
C(13) SOUTHBOUND TO EASTBOUND RAMP
C(14) SOUTHBOUND TO WESTBOUND RAMP
C(15) EASTBOUND TO NORTHBOUND RAMP
C(16) EASTBOUND TO SOUTHBOUND RAMP

AND THE TRAFFIC VOLUMES ARE DEFINED AS:

V(1)  NORTHBOUND TO WESTBOUND MOVEMENT
V(2)  NORTHBOUND THROUGH TRAFFIC
V(3)  NORTHBOUND TO EASTBOUND MOVEMENT
V(4)  WESTBOUND TO SOUTHBOUND MOVEMENT
V(5)  WESTBOUND THROUGH TRAFFIC
V(6)  WESTBOUND TO NORTHBOUND MOVEMENT
V(7)  SOUTHBOUND TO EASTBOUND MOVEMENT
V(8)  SOUTHBOUND THROUGH TRAFFIC
V(9)  SOUTHBOUND TO WESTBOUND MOVEMENT
V(10) EASTBOUND TO NORTHBOUND MOVEMENT
V(11) EASTBOUND THROUGH TRAFFIC
V(12) EASTBOUND TO SOUTHBOUND MOVEMENT


INPUT THE FIRST EIGHT CAPACITIES IN ORDER, 1 TO 8

? 7120,4185,7120,4185,4185,7120,4185,7120

INPUT THE REMAINING EIGHT CAPACITIES IN ORDER, 9 TO 16

? 1335,1335,1335,1335,1335,1335,1335,1335

INPUT THE VOLUMES IN ORDER, 1 TO 12
? 371,4500,64,155,1467,1161,645,4370,142,233,725,303
```

```
THE INDIVIDUAL VOLUMES AT CAPACITY ARE:

V( 1    ) =  426.602 VEHICLES
V( 2    ) =  5174.42 VEHICLES
V( 3    ) =  73.5917 VEHICLES
V( 4    ) =  178.23  VEHICLES
V( 5    ) =  1686.86 VEHICLES
V( 6    ) =  1335.   VEHICLES
V( 7    ) =  741.667 VEHICLES
V( 8    ) =  5024.94 VEHICLES
V( 9    ) =  163.282 VEHICLES
V( 10   ) =  267.92  VEHICLES
V( 11   ) =  833.656 VEHICLES
V( 12   ) =  348.411 VEHICLES

THE CAPACITY OF THE INTERCHANGE IS  16254.6 VEHICLES


THE ELEMENT LIMITED BY C( 12   ) HAS REACHED CAPACITY


THE AVAILABLE VOLUME REMAINING ON EACH ELEMENT AT CAPACITY IS:

FOR THE ELEMENT LIMITED BY C( 1    ) -  1445.39 VEHICLES
FOR THE ELEMENT LIMITED BY C( 2    ) -  984.91  VEHICLES
FOR THE ELEMENT LIMITED BY C( 3    ) -  1190.12 VEHICLES
FOR THE ELEMENT LIMITED BY C( 4    ) -  2735.01 VEHICLES
FOR THE ELEMENT LIMITED BY C( 5    ) -  1908.26 VEHICLES
FOR THE ELEMENT LIMITED BY C( 6    ) -  342.661 VEHICLES
FOR THE ELEMENT LIMITED BY C( 7    ) -  2536.09 VEHICLES
FOR THE ELEMENT LIMITED BY C( 8    ) -  1568.42 VEHICLES
FOR THE ELEMENT LIMITED BY C( 9    ) -  908.398 VEHICLES
FOR THE ELEMENT LIMITED BY C( 10   ) -  1261.41 VEHICLES
FOR THE ELEMENT LIMITED BY C( 11   ) -  1156.77 VEHICLES
FOR THE ELEMENT LIMITED BY C( 12   ) -  7.27596E-12  VEHICLES
FOR THE ELEMENT LIMITED BY C( 13   ) -  593.333 VEHICLES
FOR THE ELEMENT LIMITED BY C( 14   ) -  1171.72 VEHICLES
FOR THE ELEMENT LIMITED BY C( 15   ) -  1067.08 VEHICLES
FOR THE ELEMENT LIMITED BY C( 16   ) -  986.589 VEHICLES
```

BASIC Program for Solving Interchange Capacity Analysis Problems

```
002 PRINT "THIS PROGRAM ANALYZES THE TYPICAL DIAMOND AND CLOVERLEAF
004 PRINT "INTERCHANGES FOR CAPACITY CONSIDERATIONS.
006 PRINT "WHAT TYPE INTERCHANGE IS TO BE ANALYZED?
008 PRINT "DIAMOND = 1     CLOVERLEAF = 2'
009 PRINT
010 INPUT M
011 PRINT
012 IF M = 2 THEN 900
014 PRINT 'FOR THE DIAMOND INTERCHANGE THE CAPACITIES ARE DEFINED AS:
015 PRINT
016 PRINT 'C(1)  NORTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE'
018 PRINT 'C(2)  WESTBOUND TRAFFIC EAST OF THE INTERCHANGE'
020 PRINT 'C(3)  SOUTHBOUND TRAFFIC NORTH OF THE INTERCHANGE'
022 PRINT 'C(4)  EASTBOUND TRAFFIC WEST OF THE INTERCHANGE'
24 PRINT "C(5)  WESTBOUND TRAFFIC WEST OF THE INTERCHANGE'
026 PRINT "C(6)  NORTHBOUND TRAFFIC NORTH OF THE INTERCHANGE'
028 PRINT 'C(7)  EASTBOUND TRAFFIC EAST OF THE INTERCHANGE'
030 PRINT "C(8)  SOUTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE'
032 PRINT "C(9)  OFF RAMP FROM NORTHBOUND TRAFFIC"
034 PRINT 'C(10) ON RAMP TO SOUTHBOUND TRAFFIC'
036 PRINT 'C(11) ON RAMP TO NORTHBOUND TRAFFIC'
038 PRINT "C(12) OFF RAMP FROM SOUTHBOUND TRAFFIC'
039 PRINT
040 PRINT 'AND THE TRAFFIC VOLUMES ARE DEFINED AS:
041 PRINT
042 PRINT 'V(1)  NORTHBOUND TO WESTBOUND MOVEMENT"
044 PRINT "V(2)  NORTHBOUND THROUGH TRAFFIC'
046 PRINT "V(3)  NORTHBOUND TO EASTBOUND MOVEMENT'
048 PRINT "V(4)  WESTBOUND TO SOUTHBOUND MOVEMENT"
050 PRINT "V(5)  WESTBOUND THROUGH TRAFFIC'
052 PRINT "V(6)  WESTBOUND TO NORTHBOUND MOVEMENT'
054 PRINT "V(7)  SOUTHBOUND TO EASTBOUND MOVEMENT"
056 PRINT "V(8)  SOUTHBOUND THROUGH TRAFFIC'
058 PRINT "V(9)  SOUTHBOUND TO WESTBOUND MOVEMENT"
060 PRINT "V(10) EASTBOUND TO NORTHBOUND MOVEMENT"
062 PRINT "V(11) EASTBOUND THROUGH TRAFFIC'
064 PRINT "V(12) EASTBOUND TO SOUTHBOUND MOVEMENT"
068 PRINT
070 PRINT
072 PRINT "INPUT THE CAPACITIES IN ORDER, 1 TO 12"
073 PRINT
090 DIM C(16), P(12), R(16), V(12), Z(16)
100 INPUT C(1),C(2),C(3),C(4),C(5),C(6),C(7),C(8),C(9),C(10),C(11),C(12)
101 PRINT
105 PRINT "INPUT THE VOLUMES IN ORDER, 1 TO 12"
106 PRINT
110 INPUT V(1),V(2),V(3),V(4),V(5),V(6),V(7),V(8),V(9),V(10),V(11),V(12)
111 PRINT
```

```
120 FOR I = 2 TO 12
122 P(I) = V(I)/V(1)
124 NEXT I
130 R(1) = C(1)/(1+P(2)+P(3))
140 R(2) = C(2)/(P(4)+P(5)+P(6))
150 R(3) = C(3)/(P(7)+P(8)+P(9))
160 R(4) = C(4)/(P(10)+P(11)+P(12))
170 R(5) = C(5)/(1+P(5)+P(9))
180 R(6) = C(6)/(P(2)+P(6)+P(10))
190 R(7) = C(7)/(P(3)+P(7)+P(11))
200 R(8) = C(8)/(P(4)+P(8)+P(12))
210 R(9) = C(9)/(1+P(3))
220 R(10)=C(10)/(P(4)+P(12))
230 R(11)=C(11)/(P(6)+P(10))
240 R(12)=C(12)/(P(7)+P(9))
250 FOR I=1 TO 11
260 FOR J=I+1 TO 12
270 IF R(I)-R(J) < 0 THEN 310
280 T = R(I)
290 R(I) = R(J)
300 R(J) = T
310 NEXT J
320 NEXT I
321 V(1) = R(1)
322 FOR I = 2 TO 12
23 V(I) = V(1)*P(I)
324 NEXT I
325 FOR I = 1 TO 12
326 V = V + V(I)
327 NEXT I
330 PRINT
340 PRINT
350 PRINT "THE INDIVIDUAL VOLUMES AT CAPACITY ARE:
355 PRINT
356 PRINT
360 FOR I = 1 TO 12
370 PRINT "V("I") = "V(I)"VEHICLES"
380 NEXT I
385 PRINT
390 PRINT "THE CAPACITY OF THE INTERCHANGE IS"V"VEHICLES"
395 PRINT
396 PRINT
400 Z(1) = C(1)-(V(1)+V(2)+V(3))
410 Z(2) = C(2)-(V(4)+V(5)+V(6))
420 Z(3) = C(3)-(V(7)+V(8)+V(9))
430 Z(4) = C(4)-(V(10)+V(11)+V(12))
440 Z(5) = C(5)-(V(1)+V(5)+V(9))
450 Z(6) = C(6)-(V(2)+V(6)+V(10))
460 Z(7) = C(7)-(V(3)+V(7)+V(11))
470 Z(8) = C(8)-(V(4)+V(8)+V(12))
480 Z(9) = C(9)-(V(1)+V(3))
```

```
490 Z(10)=C(10)-(V(4)+V(12))
500 Z(11)=C(11)-(V(6)+V(10))
510 Z(12)=C(12)-(V(7)+V(9))
511 FOR I = 1 TO 12
512 IF Z(I) < 1 THEN 515
513 NEXT I
514 GO TO 517
515 PRINT 'THE ELEMENT LIMITED BY C('I') HAS REACHED CAPACITY'
516 GO TO 513
517 PRINT
518 PRINT 'THE AVAILABLE VOLUME REMAINING ON EACH ELEMENT AT CAPACITY IS:
519 PRINT
520 FOR I = 1 TO 12
530 PRINT "FOR THE ELEMENT LIMITED BY C("I") - 'Z(I)'VEHICLES'
540 NEXT I
545 PRINT
550 GO TO 2000
900 PRINT 'FOR THE CLOVERLEAF INTERCHANGE THE CAPACITIES ARE DEFINED AS:
901 PRINT
902 PRINT 'C(1)  NORTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE'
904 PRINT 'C(2)  WESTBOUND TRAFFIC EAST OF THE INTERCHANGE"
906 PRINT 'C(3)  SOUTHBOUND TRAFFIC NORTH OF THE INTERCHANGE'
908 PRINT 'C(4)  EASTBOUND TRAFFIC WEST OF THE INTERCHANGE'
10 PRINT 'C(5)  WESTBOUND TRAFFIC WEST OF THE INTERCHANGE'
912 PRINT "C(6)  NORTHBOUND TRAFFIC NORTH OF THE INTERCHANGE'
914 PRINT "C(7)  EASTBOUND TRAFFIC EAST OF THE INTERCHANGE"
916 PRINT 'C(8)  SOUTHBOUND TRAFFIC SOUTH OF THE INTERCHANGE'
918 PRINT 'C(9)  NORTHBOUND TO WESTBOUND RAMP"
920 PRINT 'C(10) NORTHBOUND TO EASTBOUND RAMP'
922 PRINT 'C(11) WESTBOUND TO NORTHBOUND RAMP'
924 PRINT 'C(12) WESTBOUND TO NORTHBOUND RAMP'
926 PRINT 'C(13) SOUTHBOUND TO EASTBOUND RAMP'
928 PRINT 'C(14) SOUTHBOUND TO WESTBOUND RAMP'
930 PRINT 'C(15) EASTBOUND TO NORTHBOUND RAMP'
932 PRINT 'C(16) EASTBOUND TO SOUTHBOUND RAMP'
934 PRINT
936 PRINT 'AND THE TRAFFIC VOLUMES ARE DEFINED AS:"
938 PRINT
940 PRINT 'V(1)  NORTHBOUND TO WESTBOUND MOVEMENT'
942 PRINT 'V(2)  NORTHBOUND THROUGH TRAFFIC'
944 PRINT 'V(3)  NORTHBOUND TO EASTBOUND MOVEMENT'
946 PRINT 'V(4)  WESTBOUND TO SOUTHBOUND MOVEMENT'
948 PRINT 'V(5)  WESTBOUND THROUGH TRAFFIC'
950 PRINT 'V(6)  WESTBOUND TO NORTHBOUND MOVEMENT'
952 PRINT 'V(7)  SOUTHBOUND TO EASTBOUND MOVEMENT'
954 PRINT 'V(8)  SOUTHBOUND THROUGH TRAFFIC'
956 PRINT "V(9)  SOUTHBOUND TO WESTBOUND MOVEMENT"
958 PRINT "V(10) EASTBOUND TO NORTHBOUND MOVEMENT"
960 PRINT 'V(11) EASTBOUND THROUGH TRAFFIC'
962 PRINT 'V(12) EASTBOUND TO SOUTHBOUND MOVEMENT"
```

```
968 PRINT
970 PRINT
990 PRINT 'INPUT THE FIRST EIGHT CAPACITIES IN ORDER, 1 TO 8'
995 PRINT
1000 INPUT C(1),C(2),C(3),C(4),C(5),C(6),C(7),C(8)
1002 PRINT
1005PRINT  'INPUT THE REMAINING EIGHT CAPACITIES IN ORDER, 9 TO 16'
1008 PRINT
1010 INPUT C(9),C(10),C(11),C(12),C(13),C(14),C(15),C(16)
1012 PRINT
1015 PRINT 'INPUT THE VOLUMES IN ORDER, 1 TO 12"
1020 INPUT V(1),V(2),V(3),V(4),V(5),V(6),V(7),V(8),V(9),V(10),V(11),V(12)
1022 PRINT
1030 FOR I = 1 TO 12
1032 P(I) = V(I)/V(1)
1034 NEXT I
1040 R(1) = C(1)/(1+P(2)+P(3))
1050 R(2) = C(2)/(P(4)+P(5)+P(6))
1060 R(3) = C(3)/(P(7)+P(8)+P(9))
1070 R(4) = C(4)/(P(10)+P(11)+P(12))
1080 R(5) = C(5)/(1+P(5)+P(9))
1090 R(6) = C(6)/(P(2)+P(6)+P(10))
1100 R(7) = C(7)/(P(3)+P(7)+P(11))
1110 R(8) = C(8)/(P(4)+P(8)+P(12))
1120 R(9) = C(9)
1130 R(10)=C(10)/P(3)
1140 R(11)=C(11)/P(4)
1150 R(12)=C(12)/P(6)
1160 R(13)=C(13)/P(7)
1170 R(14)=C(14)/P(9)
1180 R(15)=C(15)/P(10)
1190 R(16)=C(16)/P(12)
1200 FOR I=1 TO 15
1210 FOR J=I+1 TO 16
1220 IF R(I)-R(J) < 0 THEN 1260
1230 T = R(I)
1240 R(I) = R(J)
1250 R(J) = T
1260 NEXT J
1270 NEXT I
1280 V(1) = R(1)
1290 FOR I = 2 TO 12
1300 V(I) = V(1)*P(I)
1310 NEXT I
1320 FOR I = 1 TO 12
1330 V = V + V(I)
1340 NEXT I
```

```
1350 PRINT
1360 PRINT
1370 PRINT 'THE INDIVIDUAL VOLUMES AT CAPACITY ARE:"
1375 PRINT
1376 PRINT
1380 FOR I = 1 TO 12
1390 PRINT 'V("I") = 'V(I) 'VEHICLES'
1400 NEXT I
1405 PRINT
1410 PRINT 'THE CAPACITY OF THE INTERCHANGE IS 'V"VEHICLES'
1412 PRINT
1414 PRINT
1420 Z(1) = C(1)-(V(1)+V(2)+V(3))
1430 Z(2) = C(2)-(V(4)+V(5)+V(6))
1440 Z(3) = C(3)-(V(7)+V(8)+V(9))
1450 Z(4) = C(4)-(V(10)+V(11)+V(12))
1460 Z(5) = C(5)-(V(1)+V(5)+V(9))
1470 Z(6) = C(6)-(V(2)+V(6)+V(10))
1480 Z(7) = C(7)-(V(3)+V(7)+V(11))
1490 Z(8) = C(8)-(V(4)+V(8)+V(12))
1500 Z(9) = C(9)-V(1)
1510 Z(10)=C(10)-V(3)
1520 Z(11)=C(11)-V(4)
1530 Z(12)=C(12)-V(6)
1540 Z(13)=C(13)-V(7)
1550 Z(14)=C(14)-V(9)
1560 Z(15)=C(15)-V(10)
1570 Z(16)=C(16)-V(12)
1580 FOR I = 1 TO 16
1590 IF Z(I) < 1 THEN 1620
1600 NEXT I
1610 GO TO 1650
1620 PRINT 'THE ELEMENT LIMITED BY C("I") HAS REACHED CAPACITY"
1622 PRINT
1624 PRINT
1630 GO TO 1600
1640 PRINT
1650 PRINT 'THE AVAILABLE VOLUME REMAINING ON EACH ELEMENT AT CAPACITY IS:
1660 PRINT
1670 FOR I = 1 TO 16
1680 PRINT 'FOR THE ELEMENT LIMITED BY C("I") - 'Z(I) 'VEHICLES'
1690 NEXT I
2000 END
```

LITERATURE CITED

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

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