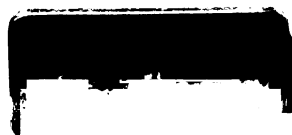
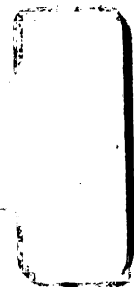
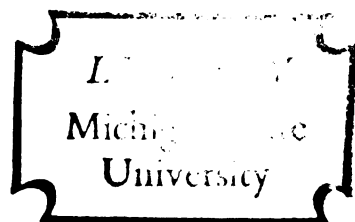


ANALYSIS OF A DUAL-DUAL FREEWAY

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
BERNARD DONALD ALKIRE
1969

THESIS



ABSTRACT

ANALYSIS OF A DUAL-DUAL FREEWAY

by Bernard Donald Alkire

A capacity and level of service analysis is performed on a portion of a dual-dual freeway. This is done to determine if the design of a dual-dual freeway will satisfy requirements for a high volume corridor with fewer than four lanes of traffic on any roadway, and a level of service for each roadway of at least D.

A procedure for the analysis of each of the elements of the dual-dual freeway is developed and is used for obtaining spot volumes at critical locations on the freeway. These volumes are then compared to known standards to obtain the level of service for each section. The elements analyzed in this fashion are: the freeway; weaving areas; two-lane entrance and exit ramps; one-lane ramps; and left-hand entrance and exit ramps.

The results indicate the dual-dual freeway is a good method for moving high volumes of traffic and

still maintain only four lanes per roadway. Of all the elements analyzed, the design of the two-lane ramps at major interchanges is the most critical. The use of parallel acceleration or deceleration lanes is analyzed in view of overcoming problems in these areas.

ANALYSIS OF A DUAL-DUAL FREEWAY

By

Bernard Donald Alkire

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Civil Engineering

1969

155710
6-6-69

ACKNOWLEDGEMENTS

I would like to extend special thanks to Dr. Gail Blomquist, my advisor, for his suggestions and assistance in the completion of this thesis.

To the Michigan Department of State Highways for the use of their base maps and traffic assignment figures; and to Mr. Ernest Morey my squad leader at the Michigan State Highway Department.

Particular thanks to my wife Patricia for her help and understanding during the preparation of this thesis.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS.	ii
LIST OF TABLES.	vi
LIST OF FIGURES	viii
LIST OF APPENDICES.	ix
CHAPTER	
I. PROBLEM AND DEFINITION OF TERMS USED. . . .	1
The Problem	1
Statement of the Problem.	1
Justification of the Dual-Dual Freeway.	2
Definition of Terms Used.	3
Level of Service.	3
Capacity.	4
Lane Designations	4
Organization of Remainder of the Thesis	5
II. GENERAL DESIGN CHARACTERISTICS.	6
Geometric Standards	7
Traffic Standards	9

Table of Contents.--Cont.

CHAPTER	Page
Safety Standards.	9
Factors Affecting Level of Service. . . .	11
Roadway Factors	11
Shoulders	11
Lateral Clearance	12
Alignment	12
Grades.	13
Traffic Factors	13
Trucks.	13
Peak-hour Factor.	14
Method of Numerical Analysis.	15
III. ANALYSIS AND RESULTS OF THE DESIGN ELEMENTS	17
Freeway Lanes	17
Analysis.	17
Results	23
Weaving Section	26
Analysis.	26
Results	29
Two-Lane Entrance and Exit Ramps.	30
Analysis.	30
Two-Lane Exit Ramps	30
Two-Lane Entrance Ramps	35

Table of Contents.--Cont.

CHAPTER	Page
Results	37
Two-Lane Exit Ramps	38
Two-Lane Entrance Ramps	39
Single-Lane Ramps	40
Analysis.	40
Results	44
Left-Hand Entrance and Exit Ramps	45
Analysis.	47
Results	49
IV. CONCLUSIONS AND RECOMMENDATIONS	50
Conclusions	50
Recommendations	53
BIBLIOGRAPHY.	55
APPENDIX.	59

LIST OF TABLES

Table	Page
I. LEVEL OF SERVICE FOR UNINTERRUPTED FLOW SERVICE VOLUME/CAPACITY (PHF 0.91)	66
II. LANE DISTRIBUTION LANE 1 (NO RAMP MOVEMENT WITHIN 4000 FEET)	67
III. PERCENTAGE OF RAMP TRAFFIC IN LANE 1. . . .	68
IV. PERCENTAGE OF EXIT TRAFFIC UPSTREAM OF RAMP WITH AUXILIARY LANE.	69
V. PERCENTAGE OF ENTRANCE TRAFFIC DOWNSTREAM OF RAMP WITH AUXILIARY LANE	70
VI. ANALYSIS OF FREEWAY SECTION	72
VII. ANALYSIS OF WEAVING AREAS	73
VIII. VOLUME DISTRIBUTION RAMP 2 TWO-LANE EXIT RAMP SPOT VOLUME.	74
IX. VOLUME DISTRIBUTION RAMP 5 TWO-LANE ENTRANCE SPOT VOLUME.	75
X. VOLUME DISTRIBUTION RAMP 17 TWO-LANE ENTRANCE RAMP SPOT VOLUME	76
XI. VOLUME DISTRIBUTION RAMP 20 TWO-LANE EXIT RAMP SPOT VOLUME.	77
XII. VOLUME DISTRIBUTION RAMP 23 TWO-LANE EXIT RAMP SPOT VOLUME.	78

List of Tables.--Cont.

Table	Page
XIII. VOLUME DISTRIBUTION RAMP 25 TWO-LANE ENTRANCE RAMP SPOT VOLUME	79
XIV. VOLUME DISTRIBUTION RAMP 27 TWO-LANE ENTRANCE RAMP SPOT VOLUME	80
XV. VOLUME DISTRIBUTION RAMP 28 TWO-LANE EXIT RAMP SPOT VOLUME.	81
XVI. VOLUME DISTRIBUTION RAMP 7 ONE-LANE EXIT RAMP SPOT VOLUME.	82
XVII. VOLUME DISTRIBUTION RAMPS 8 & 9 ONE-LANE ENTRANCE RAMP SPOT VOLUME	83
XVIII. VOLUME DISTRIBUTION RAMP 12 ONE-LANE ENTRANCE RAMP SPOT VOLUME	84
XIX. VOLUME DISTRIBUTION RAMPS 13 & 14 ONE-LANE EXIT RAMPS SPOT VOLUME.	85
XX. VOLUME DISTRIBUTION RAMPS 3 & 4 ONE-LANE LEFT-HAND ENTRANCE AND EXIT RAMP SPOT VOLUMES	86
XXI. VOLUME DISTRIBUTION RAMPS 18 & 19 ONE-LANE LEFT-HAND ENTRANCE AND EXIT RAMPS SPOT VOLUMES	87

LIST OF FIGURES

Figure	Page
1. Dual-Dual Freeway Plan	60
2. Typical Half Section Dual-Dual Freeway . . .	61
3. Typical Section Intersecting Freeway	62
4. Traffic Assignment Plan.	63
5. Treatment of Inner Roadway at Section 7-8 & 12-13.	64

LIST OF APPENDICES

Appendix	Page
A. GENERAL PLAN OF DUAL-DUAL FREEWAY AND TYPICAL CROSS SECTION.	59
B. VOLUME DISTRIBUTION TABLES	65
C. VOLUME DISTRIBUTION RESULTS.	71

CHAPTER I

PROBLEM AND DEFINITION OF TERMS USED

It is a well-known fact that urban freeway travel has increased to a point where the rush hour traffic jam has become a permanent part of urban life. This condition has produced a public awareness of the inadequacy of our freeway systems and a clamor for additional freeways. It is the function of the highway engineer to design these new facilities and to provide safety, economy, and convenience for the freeway user. This thesis presents an analysis of one of the recent innovations in highway design that is being used to realize these goals.

The Problem

Statement of the Problem

As the need for more freeways increased, it became apparent that it would be necessary to design a freeway that would provide: (1) high volumes of traffic

without having a roadway with more than four lanes of traffic in one direction, (2) separate roadways with minimal friction for high speed through traffic, (3) latest in safety features, and (4) a level of service of at least D for the various elements that make up the freeway.

Justification of the Dual-Dual Freeway

A dual-dual freeway, as the name indicates, has two positively divided roadways for each direction. This type of freeway is designed to reduce hazardous maneuvers associated with very wide paved areas. It has been shown that the maximum number of lanes that can be safely utilized in one roadway is four [1]. Above this number, the increased weaving which takes place within a freeway section will reduce the capacity and increase the accident rate.

Further justification for the selection of the dual-dual freeway is the fact that this type of freeway will provide two types of service on one right of way. First, the outer roadways of the freeway provide access

and egress to interchanges and carry the majority of short trip drivers. These outer roadways are characterized by high traffic volumes and a large number of weaving movements. As a result of the weaving and the short trip nature of the driving it should be expected that the speeds and capacity on the outer roadways will be somewhat below that of the inner roadways. In contrast to this, the inner roadways provide high speed and noninterrupted flow with a minimum of friction from weaving. Since there is only one point of exit and entrance into the inner roadways, it is expected that the inner roadway should provide the express route that is needed to get the long distance commuter from the central business district to his home with the least possible interruption.

Definition of Terms Used

Level of Service

Level of service is a term which broadly interpreted denotes any one of an infinite number of differing combinations of operating conditions that may occur on a given road. In practice, selected levels are defined in

terms of particular limiting values, such as speed, volume per lane, weaving volumes, diverge volumes, and merge volumes [2].

Level of Service is indicated by letter A, B, C, D, E, or F.

Capacity

Capacity is the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway during a given period of time under prevailing roadway and traffic conditions [2].

Lane Designations

In the analysis of a section of freeway it is necessary to designate, by number, each lane on the freeway and two-lane ramps. For this thesis the lanes of the freeway are numbered right to left in the direction of traffic. Thus, for a six lane freeway the lanes for either direction are 1 for the right-hand lane, 2 for the middle lane, and 3 for the lane adjacent to the median. On a two-lane ramp the lane on the right is designated lane B and the left lane is lane A.

Organization of Remainder of the Thesis

In order to analyze the different elements of the freeway the remainder of the thesis is divided into two parts. The first part is a general discussion of the factors affecting level of service and how they affect the design of the dual-dual section of freeway. The second part of the analysis is quantitative in nature and will be concerned with the actual volume that can be carried by a section of the freeway and the level of service for that section. In the second part of the analysis the critical sections of the freeway are isolated into four groups of similar characteristics: (1) the freeway sections; (2) the right-hand entrances and exits (including both one- and two-lane ramps); (3) the left-hand entrances and exits; and (4) the weaving areas. Each of these groups has a different method of numerical analysis and is treated separately.

In order to locate the critical sections, Figure 1, Appendix A, may be used. In this figure each section of freeway and ramp is given a number or letter designation. Discussion of the critical sections are identified by use of the number or letter only in the remainder of the thesis.

CHAPTER II

GENERAL DESIGN CHARACTERISTICS

The proposed facility is being designed for a highly urbanized area with a metropolitan population of approximately three million people. The need for the freeway has been established by an origin-destination study made for the purpose of planning the metropolitan freeway system. Corridor locations and traffic assignments were made as part of this study.

The freeway is generally of the depressed type and is at grade only for the portions necessary to design the interchanges. The types of interchanges have been determined and, for the section being analyzed, a four level directional interchange (Maltese Cross) has been selected. A major existing freeway intersects the proposed facility and must be integrated into the design of the interchange. Alterations to the existing freeway must be kept to a minimum and should not interfere with traffic on this route. Thus, the low levels of service

provided on the intersecting freeway are a result of the existing conditions and are not subject to improvements.

Geometric Standards

The design standards for the freeway and interchange sections generally conform to the standards set forth in A Policy on Geometric Design of Rural Highways [3].

The main items are as follows:

A. Design speed.

1. Freeway--60 mph.
2. Ramps and turning roadways--35 mph.

B. Gradient.

1. Freeways--equal to or less than 3 per cent.
2. Ramps and turning roadways--less than 5 per cent desirable for positive grades--6 per cent maximum.

C. Traffic lane width.

1. Freeway--12 feet.
2. Ramps and turning roadways--12.5 feet, with additional width provided on curves of short radius as provided for in the Policy on Geometric Design of Rural Highways [3].

D. Horizontal curvature.

1. Freeway--3 degrees or less.
2. Ramps and turning roadways--as per Policy on Geometric Design of Rural Highways [3].

E. Shoulders.

1. Continuous full width refuge shoulders provided at both right and left side of four lane freeways and at the right side of freeways with less than four lanes, including the turning roadway and ramps.

F. Median width.

1. Minimum 26 feet between opposing roadways with positive median barrier and 26 feet between inner and outer roadways in the dual-dual section. The intersecting freeway has 12 foot medians with a positive median barrier.

G. Length of acceleration and deceleration lanes and lane drops are Michigan standards and are considered adequate [4].

A typical section of the dual-dual freeway and the intersecting freeway are included in the Appendix A as Figures 2 and 3.

Traffic Standards

In addition to the geometric standards it is necessary to establish standards for evaluating the ability of the section to carry the assigned traffic. The standards for this category are as follows:

- A. Level of service D--this is the lowest level of stable flow with traffic approaching instability. At this level of service, drivers have little freedom to maneuver and comfort and convenience are low. Under ideal conditions an average of 1,800 passenger cars per lane per hour can be carried in any section [2]. This is the level of service that is considered to be the minimum design standard for the freeway sections.
- B. Percentage of trucks--5 per cent on all roadways except the inner dual roadways for which 3 per cent is used for design and analysis.
- C. Average daily traffic and design hourly volume--this information has been provided by the Michigan Department of State Highways [5]. (See Figure 4, Appendix A.)

Safety Standards

Early in 1968, a report entitled, Highway Design and Operational Practices Related to Highway Safety [6], was made available to designers of highway facilities.

This report made recommendations on practices that should be followed if maximum driver safety is to be assured. Many of the recommendations of this report are incorporated into the design of the dual-dual freeway. Particular attention is focused on the design of the median barriers. The safety report notes that a concrete barrier with a curved face is very effective on roadways with narrow medians. Since the cross section of the dual-dual freeway shows that the medians are only 26 feet, it was decided to adopt this type of barrier. Other design features used to improve the safety of the freeway section are increased distance to fixed objects adjacent to the freeway and provisions for flatter side slopes in areas of embankment and cuts. The objective of these design improvements is to reduce the number of objects being struck by vehicles leaving the freeway out of control.

In the design of the dual-dual section of freeway, 30 feet is considered to be the minimum distance to any fixed object except the median barrier or a retaining wall, in which 14 feet is used as the minimum side clearance.

Factors Affecting Level of Service

Prior to making the numerical analysis of the design some of the factors that affect the value of capacity and level of service should be considered. These factors are divided into two general groups, the roadway and traffic factors. The roadway factors are those physical items of design that could be restrictive to the flow of traffic if adequate design standards are not maintained. The traffic factors are the same in the sense that they may be restrictive to the flow of traffic, though these factors are determined by the composition of the traffic and the habits of the driver. Both types of factors, if inadequate, tend to reduce the capacity of the roadway by introducing conditions that are not considered to be normal as far as calculation of capacity is concerned.

Roadway Factors

Shoulders.--As stated in the section on design standards, continuous full width refuge shoulders are to be provided on both sides of the four lane roadways and

on the right side of roadways of less than four lanes. Turning roadways and ramps will also have a full width right shoulder and a left shoulder of at least six feet. Bridge sections have the right shoulder carried through and the left shoulders as recommended in the Policy on Arterial Highways in Urban Areas [7]. In no case is insufficient shoulder width a problem in the analysis of the interchange and no capacity adjustments are required for this factor.

Lateral Clearance.--As a result of the major reappraisal of safety standards in the design of expressways brought forth with the issuance of the Yellow Book [6], the lateral clearance is set at a 14 foot minimum for retaining walls and bridge parapets; and 30 feet for piers and columns in the outside shoulders. The inner roadways have half of the 26 foot medians as side clearance. While there may be some doubts as to the sufficiency of the side clearance from the point of safety, it is unlikely that the clearance will affect the capacity.

Alignment.--Considering that the alignment elements (vertical and horizontal curves) are controlled by the design speed of 60 miles per hour, there will be no

adjustment necessary to compensate for inadequate alignment.

Grades.--One of the factors that has very large influence on the capacity of any section is the grade of that section. On a long grade the right-hand lane will be occupied almost exclusively by slow moving vehicles which will reduce the number of freeway lanes available for other vehicles. In order to carry the same capacity as on a level section it is necessary to add a lane to the freeway. It is assumed that freeway grades of less than 2 per cent and one half mile length will have little effect on capacity [2]. As the previous statement suggests, the level of service on any given section of grade is a function of the number of slow vehicles, the rate of grade, and the length of the grade. A discussion of the effect of grades will be included in the analysis of the section that is being affected by grade.

Traffic Factors

Trucks.--It is apparent from the discussion on grades that the percentage of trucks on a roadway affect the capacity of the roadway. Trucks, by their physical

dimensions are equivalent to two or more passenger cars. However, the main affect on capacity is not caused by truck size, but rather by truck performance characteristics [8]. It may be observed from the performance characteristics that as length and steepness of grade increase, speed is reduced and platooning becomes more pronounced. In the extreme case where trucks cause a substantial reduction in speed, passenger cars avoid the right-hand lane altogether; and an additional lane is required to retain the original level of service. In the analysis of the dual-dual freeway an overall factor of 0.95 is used to adjust for the 5 per cent trucks that are expected on the freeway. This factor will apply to the outer roadways of the dual-dual freeway, all turning roadways, and ramps. At this point it should be mentioned that it is standard procedure for all volumes used in this analysis be in terms of mixed traffic rather than the more artificial term of equivalent passenger-car volumes.

Peak-hour factor.--Variations in the demand throughout any given hour may produce rates of flow for short periods which substantially exceed the average rate. To compensate for this possibility a peak-hour factor is

used to modify the design volumes for level of service C and D. This modification is called the peak-hour factor and is related to the population of the metropolitan area for which it is used [9]. For the evaluation of the design being carried out in this paper, a peak-hour factor of 0.91 is used for all roadways.

Method of Numerical Analysis

The procedure used in the analysis of the design will follow that recommended by the Highway Capacity Manual [2]. However, there are numerous occasions that arise that do not fit the criteria used in that manual. In these cases, research literature is used to supplement the manual's methods of analysis. The steps in the numerical analysis are as follows:

- A. Subdivide the roadway under consideration into sections having reasonably uniform conditions.
- B. Analyze all freeway sections for capacity.
- C. Isolate and identify all critical sections (entrance and exit ramps, weaving areas, etc.).

- D. Group all critical sections into the following categories:
 - 1. Freeways
 - 2. Turning roadways
 - 3. Right-hand entrance and exits
 - 4. Two-lane entrance and exit ramps
 - 5. Left-hand entrances and exits
 - 6. Weaving areas
- E. Make the numerical analysis of each of the categories and determine the level of service.
- F. Make recommendations and conclusions.

CHAPTER III
ANALYSIS AND RESULTS OF THE
DESIGN ELEMENTS

Freeway Lanes

Analysis

Analyzing the freeway lane capacity within the interchange area is a major part of the numerical analysis for level of service. Generally, it is standard practice to determine the level of service only at critical locations on the freeway. However, in order to obtain a balanced design, it is necessary to evaluate the level of service at all changes of traffic flow conditions. The Highway Capacity Manual states that the variations in level of service between adjacent sections should not be more than one level of service if a reasonable balance of design is to be obtained [2]. This is one of the conditions that should be met as the analysis proceeds and is

a major consideration in the recommendation for improvement.

As noted in Chapter II, where the factors affecting level of service were discussed, one adjustment factor for capacity that can be expected on a high volume freeway is the adjustment factor for long grades. In the design of the dual-dual freeway all grades are less than 3 per cent and as stated in a study by Newman and Moskowitz, "Grades between 2 and 3 per cent will form queues but will move fast enough to maintain high rates of flow" [9]. Thus, the capacity on the west bound roadways should not be reduced. On the east bound roadways there is a 3 per cent downgrade, but again no correction is applied because flat and intermediate downgrades are considered to be the same as level [2].

The only other factor that might reduce the capacity of the freeways is the presence of trucks on the roadways. In the Traffic Standards section of this thesis it is stated that traffic will include 5 per cent trucks on the outer roadways and 3 per cent on the inner roadways. Therefore, an appropriate factor is used for adjusting the capacity values used in determining the level of service for all sections.

Also included in this section is a determination of freeway lane capacity for the intersecting freeway. The intersecting freeway is an existing facility with standards lower than the dual-dual freeway. The level of service that has to be accepted for this roadway is level E. It is anticipated that a possible source of congestion on this roadway will be the areas adjacent and downstream from the two-lane entrance ramps. A detailed discussion of the design of ramps is included in the section covering the two-lane entrance and two-lane exit ramps.

The method of computing the level of service for the freeway sections was adopted from the Highway Capacity Manual [2], but is modified to suit the data available. As is the case with many engineering problems a trial and error solution is required. To make the process as functional as possible, the following procedure is used for all freeway sections:

- A. List all known factors; such as, demand volume, number of lanes, alignment conditions, lateral restrictions, and percentage of trucks.
- B. Calculate or find the necessary correction factors. T_L , the truck correction factor, is calculated using an assumed level of service.

- C. Solve the equation $SV = 2000 \cdot N \cdot V/C \cdot W \cdot T_L$ for V/C ratio [2]. In this equation SV equals the demand volume; N equals number of lanes; W equals the truck factor at the assumed level of service; and V/C = Volume Capacity ratio.
- D. Convert the V/C ratio into basic V/C. Basic $V/C = V/C \div PHF$. If the results of C above are in the range of values for level of service A and B, then Basic $V/C = V/C$.
- E. From Appendix B, Table I, determine the level of service by comparing the calculated V/C ratio x PHF to the table of limiting values of V/C ratio x PHF. (For level of service A and B the peak hour factor is neglected.)
- F. If the assumed level of service is correct, accept the level of service as determined, if not, assume a new level of service and recompute.

The results of the freeway capacity check indicate several features about the design that might not be apparent if the capacity determination were made only at critical locations. As stated previously, one of the major reasons for determining the level of service is to observe the balance of the design. Table VI, Appendix C, illustrates the fact that generally the balance for the outer roadways is good, but the inner roadways are out of balance at the interchange. One of the criteria for balanced design is the requirement that the level of service between adjacent sections should not vary more than one

level of service. This principle is violated in three locations on the inner roadways, twice on the eastbound inner roadway, and once on the westbound inner roadway. In the outer roadways there are two different levels of service on the entire roadway and on the eastbound roadway level B is maintained for four out of five of the sections.

The balance is not as good for the inner roadway because the level of service is greatly affected by the ramps that allow traffic to exit from or enter the inner roadways. From Table VI, Appendix C it is possible to interpret the results of crossing over from inner to outer roadway. For section 6A-7 of the dual-dual freeway the level of service remains constant at level D. However, as traffic exits from the inner roadway to the outer roadway the volume of traffic remaining on the inner roadway is reduced and the level of service for the inner roadway raises to level B (Section 7-8). Further downstream two entrance ramps add traffic to the inner roadway and the level of service drops to level C (Section 8-9) at the first ramp and to level E (Section 9-10) at the second ramp. The level of service E is carried through the

remaining portion of the inner roadway until it ends 10,000 feet downstream.

From the above discussion it is apparent that the design of the two sections on the inner roadways must be altered to meet the requirements of balanced design. The alterations should be: (1) the level of service for Section 7-8 should be lowered to level C, and (2) the level of service for Section 9-10 should be raised to level D. If this is done all sections on the inner roadway will be level of service C or D; with the majority of the inner roadways at a level D.

The westbound inner roadway has a similar problem at Section 12-13, except in this case the level of service is raised from level D to level C where an exit ramp removes traffic from the inner roadway. In this section the level of service should be lowered to level D to eliminate the unbalance.

The intersecting freeway is a much more complicated problem as far as obtaining balance design because of the impossibility of altering the existing facilities. The level of service E for Sections 22-23, 24-25, 25-27, and 28-29 can not be improved without adding lanes or

metering the flow. The only possibility for obtaining a more balanced design in this area is to lower the level of service on Sections 23-24 and 27-28.

The other major design criteria is a level of service of at least level D for all roadways. It has been shown that two sections on the inner roadways, and four sections on the intersecting freeway do not meet this standard. It has already been stated that due to existing conditions it is doubtful if the level of service on the intersecting freeway can be raised. However, the level of service for the two sections with level of service E on the dual-dual freeway can be improved.

Results

The previous sections discussed the shortcomings of the freeway concerning design balance and level of service. Recommendations will now be considered to relieve the problems that have been encountered. In order to obtain a balanced design the level of service for Section 7-8 should be lowered from B to C. This may be done by increasing the through traffic on the inner roadway or by decreasing the number of lanes. Since the traffic

volumes are predetermined, and can not be changed, the only solution would be to decrease the number of through lanes. Due to possible future operational requirements it is necessary to carry the three lanes across the bridge and to the next ramp.

An alternative to building only two lanes would be to construct three lanes and then paint out the extra lane between the exit and entrance ramps as shown in Appendix A, Figure 5. This should have the same affect as having only two lanes, but the third lane will still be available if operational difficulties are experienced. The same solution is also recommended for use on the westbound inner roadways at Section 12-13, even though it is operating at a high level C.

The other problem with the dual-dual freeway is the fact that Sections 14-15 and 9-10 are operating at level of service E instead of the desired level D. Possible solutions are adding a lane or decreasing the volume capacity ratio. Since physical factors control the width of the right of way available increasing the number of lanes is impractical. Thus, decreasing the volume capacity ratio is the only method of raising the

level of service under these circumstances. By inspection, the volume capacity ratio can be decreased by decreasing the demand volume, or by increasing the capacity. As mentioned previously the demand volumes are fixed and can not be adjusted; therefore, the only approach left is to increase the capacity. Inspection of the formula for determining the volume capacity ratio [2] indicates that the capacity is equal to $2000 \cdot N \cdot W \cdot T_L$. In this equation N equals a constant (3); W equals a constant (1.00), and T_L equals (.95). The only way of increasing capacity would be to increase the adjustment factor for trucks to unity. This would be possible only if the percentage of trucks on the inner roadway is reduced to zero. Therefore, it is recommended that truck traffic be prohibited on the inner roadways. If this is done the level of service for Sections 9-10 and 14-15 will be raised to level D.

For the intersecting freeway the solution to the problem of design balance is the same as for the dual-dual freeway. That is, reduce the number of lanes beyond the nose of the exit ramp as shown in Appendix A, Figure 5. It is particularly important to retain the three lane width in this area because this freeway is carrying such

high volumes of traffic. An error in assignment could have disastrous results if a restriction is built into the freeway. The level of service E for the sections will have to be accepted without improvement since the existing situation makes it impossible to either increase the number of lanes or decrease the demand volume.

Weaving Section

Analysis

Within the interchange being analyzed there are sections for which maximum service volume is determined by the sections ability to allow vehicles to successively merge and diverge. This maneuver is called weaving and is another of the operational characteristics that can determine the level of service along a freeway.

The basic situation involving weaving is where two vehicles on separate roadways enter, cross paths, and exit on separate roadways. As this movement is being accomplished there is a time and place where both vehicles occupy the same lane. This restricts the maximum volume

that can weave at any given section to the maximum capacity of a single lane [2]. Therefore, it is apparent that in order to accommodate any large amount of weaving, additional lanes will have to be added to the freeway section.

In addition to width of weaving section another variable that can increase the amount of weaving a section can accommodate is the length of the weaving sections. This fact can be deduced by observing the operation of a weaving section at high volumes. For example, with low traffic volumes a vehicle may almost always enter the weaving area, find a gap, and complete the maneuver without conflict. This requires a weaving distance only as great as is required to change lanes (normally 600 feet at freeway speeds) [9]. However, as the volumes increase the driver approaching the weaving section may find there are no gaps in the lanes to weave into and he must adjust his speed and wait for a gap in the traffic. While the driver is waiting for a gap to develop the vehicle continues in its original lane increasing the length of weaving section required. There is a volume at which it is no longer desirable to increase the length of weaving

section and a condition of stop and wait for a gap develops. This volume will ordinarily occur when the section is operating at capacity and is in the realm of unstable flow.

In developing a method of analysis for a weaving section it is necessary to first identify the sections that will be analyzed for weaving. It should be noted that the basic factor that identifies a weaving section is vehicles entering a common roadway from two or more entrance flows, and afterwards splitting into two or more exit flows. Sections 3-4, 5-6, 18-19, and 20-21 meet this requirement and are analyzed as weaving sections. The same sections are also analyzed as exit and entrance ramps with an auxiliary lane. The actual level of service for the section will be the lowest level of service obtained from the two analyses.

The analysis of a weaving section can be completed in a straightforward manner once the sections have been identified. The method to be used will proceed as follows:

- A. Assume a level of service and relate this to the quality of flow desired. (Table III, Highway Capacity Manual.) [2].

- B. Using the weaving volume and the quality of flow as determined above, enter Figure 7.4, Highway Capacity Manual and determine the length of weaving sections required for this volume [2].
- C. Determine the number of lanes required for the demand volume of the section. The equation

$$N = \frac{V(k-1)Vw_2}{SV}$$

will determine the number of lanes required [2]. In this equation N equals number of lanes; k equals weaving influence factor (use $k = 3.0$ for sections where operations are represented by curve III, IV, and V), Vw_2 equals minor weaving volume and SV equals maximum lane service volume. Table 7.1, Highway Capacity Manual, can be used to determine maximum lane service volume for a given quality of flow [2].

- D. From the results of B and C above, it is possible to determine the sufficiency of the number of lanes and the length of weaving sections for the given quality of flow.

Results

Table VII, Appendix C is a tabulation of results for the weaving areas within the study sections. The results indicate that all weaving areas have an adequate number of lanes. The length of weaving area required in all cases is between quality of flow III and IV which provides a level of service D.

In order to improve the level of service for any of the weaving sections it is necessary to increase the

length of the sections. Since physical characteristics are such that it is impractical to lengthen the weaving sections level of service D is acceptable.

Two-Lane Entrance and Exit Ramps

Analysis

Generally, in the design of interchange ramps and turning roadways it is desirable to have only one-lane exit and entrance ramps. However, in the case of an interchange involving two freeways turning volumes in excess of one-lane capacities are frequent and it may be necessary to provide two-lane entrance and exit ramps. Procedures for analyzing two-lane ramps are not well-defined and it is necessary to develop a method of analysis using known information concerning the lateral placement of traffic in the vicinity of a ramp.

Two-lane exit ramps.--In analyzing two-lane exit ramps, one basic fact emerges, a long parallel deceleration lane is required if smooth flow is to be maintained [9]. With high ramp volumes it is impossible for lane 1

to carry all freeway traffic destined for the exit ramp. A certain number of ramp bound vehicles must travel in lane 2 of the freeway. This requires vehicles to weave across lane 1 through traffic to get to ramp lane A. Safety considerations require the elimination of this type of driving hazard.

The parallel deceleration is a feature that can be easily incorporated into the design of the road to eliminate this condition. This additional lane allows vehicles bound for ramp lanes B and A to move laterally to a position where they are not required to weave through the freeway traffic. Assuming that all ramp bound traffic is in either freeway lane 1 or 2 upstream from the exit it can be seen that the parallel lane must be at least 600 feet long, or the distance required for lane 2 vehicles to weave to lane 1 and lane 1 vehicles to weave to the parallel deceleration lane. In order to provide a margin of safety 800 feet is considered to be the minimum length for such a lane if lane A is to carry any amount of traffic [2].

As in the problem with single-lane exit ramps it is necessary to check the volume of traffic in each lane

at certain sections upstream of the exit. In the case of the two lane exits for the dual-dual section of freeway it is necessary to find the lane 1 and auxiliary lane volumes at the selected sections and check these volumes against the allowable diverge volumes set forth in the Highway Capacity Manual [2].

In order to determine the spot volumes for any lane at any given section on the freeway it is necessary to account for the traffic that is passing that section. The traffic could be made up of three types of vehicles: vehicles entering from a ramp upstream, vehicles that desire to exit at a ramp downstream, and vehicles which have not been involved in a ramp movement within 4000 feet. Tables II, III, IV, and V, Appendix B, showing lane distribution for ramp and thru traffic have been prepared and will be used as an aid in evaluation of the spot volumes.

The use of these tables require three assumptions:

- (1) Distribution is under pressure of high volume in lane 1;
- (2) For all two-lane ramps lane B carries 1800 VPH and lane A carries the remainder of the assigned traffic, and;
- (3) Spot volumes will be checked at 500 foot intervals and

the measurement of the areas of influence can be rounded to the nearest 500 feet interval.

In the analysis of two-lane exit ramps it is necessary to treat two different types: an exit with an auxiliary lane provided and one without auxiliary lane. On the dual-dual section of freeway the two-lane exits have auxiliary lanes and the analysis for these exits are different than for the exits without auxiliary lanes.

For the two-lane exit ramps with auxiliary lanes the spot volume for any lane at any section is the sum of the entrance, exit, and through traffic in that particular lane. To obtain the spot volumes for the effect of the adjacent entrance ramp, Table V, Appendix B is used. For example, in a freeway section with a 4000 foot auxiliary lane, 1000 feet downstream from the entrance nose Table V shows 56 percent of the entrance ramp volume remaining in the auxiliary lane. The entrance ramp traffic in lane 1 at the same point downstream is also obtained from Table V and is the sum of the ramp traffic that moved to lane 1 and not to lane 2, and the percentage of ramp traffic that has moved from the auxiliary lane to lane 1 in the preceeding 500 feet.

After determining the effect of the adjacent entrance ramp on the required sections, the next step is to find the exit ramp volume at the same section. In determining the lane 1 distribution of the exit ramp volume at any point upstream of the nose, Table IV, Appendix B is used. Since this is a two-lane exit, it is necessary to distribute the volumes for both lane A and B separately and then combine these volumes for the total exit bound traffic at the section. A special case of a two-lane exit ramp is one that has a parallel deceleration lane in addition to the auxiliary lane. In this case the parallel deceleration lane is treated as if it were an auxiliary lane and the auxiliary lane were lane 1. Thus at a point 1000 feet upstream from the exit nose, 93 per cent of all the lane B traffic is in the auxiliary lane and 7 per cent is in lane 1. In the next 500 feet 0.80 of the 93 per cent will move to the parallel deceleration lane and in the 500 feet prior to the nose the remaining 0.20 of the 93 per cent and the 7 per cent that was in lane 1 will move to the parallel deceleration lane. Lane A traffic would be distributed in a similar manner.

The other type of two-lane exit ramp that is encountered in this analysis is a two-lane exit without an auxiliary lane. In addition to there being no auxiliary lane the traffic distribution problems are further simplified by the fact that there is no entrance ramp traffic to account for at the check sections.

To determine the spot volumes at any 500 feet sections is a matter of determining the through traffic and the exit bound traffic at the check point. For this type of exit several assumptions are made in addition to the ones already set forth: (1) Lane 1 is carrying only traffic bound for ramp lane B; and (2) Lane B traffic is in lane 1 or 2 and lane A traffic is in lane 2 or 3. If these assumptions are made the volumes can be determined directly from Table III, Appendix B.

Two-Lane Entrance Ramps.--The two-lane entrance ramp is similar to the two-lane exit ramp with some of the same assumptions required to obtain the spot volumes at a section downstream from the nose of the entrance ramp. As was the case for the two-lane exit ramps it is assumed that: (1) lane 1 has high volumes of flow; (2) ramp lane B is assigned 1800 VPH and ramp lane A is

assigned the remainder; and (3) the length of the section can be rounded to the nearest 500 feet without error.

The spot volume per freeway lane in the case of the dual-dual freeway ramps is made up of the volume of traffic originating at an adjacent entrance ramp; the volume of traffic in the lane destined for an exit ramp; and the through volume in the lane. For example, dual-dual freeway section 5-6 is adjacent to a two-lane entrance ramp and the spot volumes would be determined as follows: Entrance ramp lane B vehicles would be distributed to lane 1 as indicated in Table V, Appendix B and in the same manner would be distributed again out of lane 1 into lane 2. Entrance ramp lane A is a direct entry into lane 1 and would also be distributed to lane 2 using Table V. Thus any point in lane 1 has three entrance ramp volume segments: Lane B traffic that has previously entered lane 1 and has not moved to lane 2; Lane B traffic that has moved into lane 1 in the preceding 500 feet; and lane A traffic that has not left lane 1. These three segments give the spot volume at any point due to the entrance ramp traffic. The remainder of the spot volume at any section is due to exit ramp traffic.

In order to obtain the spot volumes for the different sections it is assumed that 100 per cent of the ramp bound traffic is at the nose of the entrance ramp and as this traffic moves downstream it is assumed that the traffic moves to lane 1 and then to the auxiliary lane as if two auxiliary lanes were provided.

The other two-lane entrance ramps are on the intersecting freeway and do not have an auxiliary lane. Instead lane A traffic is assumed to enter directly into lane 1, then move to lane 2 and lane 3 as indicated in Table III, Appendix B. Lane B traffic is distributed using the same table; however, it is assumed that the lane B traffic will move only to lane 1 or 2. A controlling factor for lane 1 traffic is the fact that the percentage of traffic in the right lane cannot be less than the percentage indicated in Table II, Appendix B.

Results

Tabulated in Appendix C, Table VIII through XV is a volume distribution sheet for each two-lane entrance and exit ramp within the study area. On these sheets

are the spot volumes for each lane. The spot volumes, as shown on the sheet, are made up of the traffic volumes contributed by the entrance ramp, exit ramp, and through traffic and are calculated using the methods previously described. By inspection of the volume distribution sheet it is possible to pick out the section and lanes that have volumes in excess of those allowed for the desired level of service. In a prior section of this thesis it was stated that the desirable level of service was D. At this level 1800 VPH would be the maximum volume per lane at any given time. If this volume is exceeded, either a lesser level of service must be accepted or the physical layout of the ramp would have to be altered.

Two-Lane Exit Ramps.--Volume distribution Table VIII, Appendix C, indicates that ramp 2 on the dual-dual freeway has a volume of 2210 VPH in the auxiliary lane, 1000 feet upstream from the ramp nose. This point coincides with the beginning of the parallel deceleration lane and indicates an insufficient length of parallel deceleration lane. An additional 500 to 1000 feet of lane is recommended in order to allow more ramp-bound vehicles to move out of lane 1 to the parallel

deceleration line. Ramp 20, the other two-lane exit on the dual-dual freeway, does not have a spot volume in excess of 1800 VPH and is considered to be adequate.

On the intersecting freeway the spot volumes indicate a different situation from the two-lane exit ramps on the dual-dual freeway. In this case assigned traffic volumes are so high that it is impossible to reduce the spot volumes in lanes 2 and 3 below 1800 VPH without reducing the total volume of traffic by metering or by increasing the number of lanes.

Two-Lane Entrance Ramps.--Of the four two-lane entrance ramps, all have spot volumes in excess of 1800 VPH in at least one lane. On the dual-dual section of freeway, Table IX, Appendix C, ramp 5 has a spot volume of 2170 500 feet downstream from the nose. Table X, Appendix C, has a maximum spot volume of 2060 VPH in the auxiliary lane 500 feet downstream from the nose. These spot volumes indicate that the 500 feet prior to the nose of a ramp is the area in which maximum congestion occurs. The easiest way to eliminate this congestion is to increase the number of vehicles that use lane A and thus decrease the number of vehicles making multiple weaves.

Since it is the nature of drivers to prefer lane B of the ramp, special design details have to be made to encourage drivers to use lane A of the ramp. By aligning the ramp in such a fashion that direct entry into the freeway can be made from lane A, traffic will choose the path of least resistance and move to the left decreasing the multiple weaving downstream from the ramp nose.

On the intersecting freeway Tables XIII and XIV, Appendix C, show a spot volume in excess of 1800 VPH. This is to be expected considering the high volume of assigned traffic for this road. It appears that there is no way short of metering or adding lanes that can be recommended to increase the level of service D.

Single-Lane Ramps

Analysis

The single-lane ramp is another segment of design that should be investigated to determine its effect on capacity and level of service. Ramp capacity is generally determined by the design limitation at one of the

following locations: the entrance or exit point at the freeway, the ramp proper, or the terminus of the ramp with the surface street system. In most cases it is the merge or diverge volumes at the freeway that will control the capacity of the freeway. As for the ramp proper, it is assumed that the maximum design volume will be 1800 VPH. Figure 4, Appendix A indicates the maximum assigned volume for any one-lane ramp in the dual-dual section of freeway is 1410 VPH; therefore, ramp proper will not be the limiting location for capacity analysis. The other location that may determine the maximum service volume is the terminus of the ramp with the surface street. In the section being analyzed the ramps do not terminate on surface streets but at another merge or diverge, and would be analyzed as normal ramp merge or diverge areas.

Several procedures have been developed for determining the merge or diverge volume for one-lane ramps. However, regardless of the procedure used, the information required is the same. As is the case with the two-lane ramps, the volume of traffic at any point on the freeway adjacent to the ramp is the sum of three possible traffic elements. These traffic elements are as follows:

- A. Traffic in the lane being evaluated that is destined for an exit ramp.
- B. Traffic that originates at an entrance ramp.
- C. Traffic that is in the lane, but has not been involved in a ramp movement within 4000 feet, and is considered to be through traffic.

Evaluation of each of these elements will be carried out by the same method used for the two-lane ramps. Spot volumes are determined at selected points adjacent to the ramp and the merge and diverge volumes and these volumes are checked against those in the Highway Capacity Manual [2]. As is the case for two-lane ramps, Tables II and III, Appendix B, are used in the determination of spot volumes. Table II is used to determine lane 1 through volume. Table III is used to determine lane 1 volume upstream and downstream of the off-ramp nose.

A special case that arises in the analysis of the single-lane ramps in the dual-dual freeway is two off-ramps or two on-ramps located adjacent to each other. In this situation it is necessary to add another element

to the group that makes up the traffic for any one point. This additional element is the effect of the adjacent ramp on the spot volume being checked. For example, Figure 1, Appendix A shows ramps 8 and 9 of the dual-dual freeway sections are adjacent entrance ramps. To evaluate the spot volume in lane 1, 500 feet downstream of the nose of ramp 9 it is necessary to find:

- A. The through volume, using Table II, Appendix B.
- B. The number of vehicles from ramp 8 that are in lane 1 at the check point. Use Table III, Appendix B.
- C. The number of vehicles from ramp 9 that are in lane 1 at the check point. Use Table III, Appendix B.

Thus, total volume in lane 1 at a point 500 feet downstream from ramp 9's nose equals $180 + 270 + 950 = 1400$ VPH. This example illustrates the procedure that will be used on all of the one-lane exit ramps in this study section. An assumption that is made when using Tables II and III is that the percentage of traffic should yield

volumes near 1800 VPH. However, if the volume in the right lane is considerably less than 1800 VPH, then the section is obviously satisfactory and the actual distribution is of no significance.

In a situation such as is encountered in the analysis of the one-lane ramps for the dual-dual section the most critical section that is encountered is a point either 500 feet upstream of the off-ramps or 500 feet downstream of the on-ramps. This is the case only when there is no traffic that is weaving through the ramp bound traffic as for adjacent on-off or off-on ramp combinations.

Results

Appendix C, Tables XVI, XVII, XVIII, and XIX are tabulations of the spot volumes for the one-lane ramps on the dual-dual section of freeway. It is noted that the maximum lane 1 spot volumes for ramps 7, 8, 9, 12, and 13 are well below the maximum allowable value of 1800 VPH for level of service D. These ramps are thus considered to be of adequate design and there are no recommendations to improve their operation.

For ramp 14, it is noted that the maximum spot volume in lane 1 is 1880 VPH. This is slightly greater than the allowable maximum of 1800 VPH for level of service D. To improve service level at this ramp it is recommended that the nose of ramp 14 be moved 500 feet to the east to reduce the maximum spot volume of 1720 VPH. This value is within the allowable volume for level of service D and will insure smooth operating conditions on the inner roadway.

Left-Hand Entrance and Exit Ramps

In the design of the interchange under consideration there are two-left hand exits and two-left hand entrance ramps. These ramps allow outer roadway traffic to move to the inner roadways and inner roadway traffic to move to the outer roadways. It is anticipated that these ramps will be carrying high speed traffic and should be designed to cause as little disturbance as possible. Studies indicate that speed in all lanes adjacent to the left-hand entrance ramps are higher than

the comparable right-hand entrance ramps [11]. This operational characteristic must be kept in mind in the design of the ramps and can be used to aid the flow through these areas. In general, there has been a reluctance in the past for most highway agencies to use, or recommend, the design of the left-hand ramps. Thus, the amount of data that is available is limited [12].

In the design of the left entrance or exit ramps there are major problems that must be considered if the design is to be adequate. Following are some of the major problems encountered:

- A. Because of a tendency of drivers to use the left lane of the freeway more than the other lanes, any disruption in the left lane will effect the volume of the other lanes as well [9].
- B. Entrance vehicles must merge into the high speed and high volume lane. This increases the possibility of an accident on the freeway [11].
- C. There is an increase of weaving and hazardous maneuvers in an area adjacent to left-hand ramps [11].

- D. Trucks generally are positioned in the right-hand lane and the weaving required to enter the left-hand exit ramp will result in serious disruptions for conditions of high truck volume.
- E. Accident frequency appears to be greater in the area adjacent to a left-hand exit and entrance ramps [13,14].

The above mentioned items should be considered if the design of the left-hand exits and entrances are not to cause operational problems. Once these items have contributed their part to the design, a method must be presented that will permit a quantitative and qualitative analysis of the selected design.

Analysis

In establishing a method to determine merge, diverge, and weaving volumes, the approach is basically the same as for a right-hand ramp. The difference is through traffic will be in the left-lane instead of the right. As with any ramp the elements that are required

to make the analysis are the through traffic volumes, the on-ramp traffic volume, and off-ramp traffic volumes.

In the situation presented, the combination of traffic volumes for an entrance-exit combination with auxiliary lane will apply. As stated in the Highway Capacity Manual [2], some point between the ramp there will be a critical section which will have the maximum number of vehicles per lane merging, diverging, or weaving as the case may be [2].

To find the locations of these critical sections Tables IV and V, Appendix B are used. These tables make it possible to determine the percentage of vehicles from the on-ramp, or the vehicles destined for the off-ramp, that are occupying a particular lane at some given position between the two noses. For example, at a point 500 feet downstream from the entrance ramp nose, 65 per cent of the entrance ramp volume will be in the left lane of the freeway, and at a point 1000 feet upstream from the off-ramp nose, 30 per cent of the off-ramp vehicles are in the left-hand freeway lane. Tables XX and XXI, Appendix C demonstrate a complete breakdown by lane of all traffic within the section under study. By observation

of the lane volumes the critical locations can be readily identified.

Results

For freeway section 3-4 maximum lane values are as follows: (1) merge volume--1330 VPH, (2) diverge volume--1130 VPH, and (3) weaving volume--1510 VPH. In this case weaving volume is the greatest. When this value is compared to the values in Table 8.1 in the Highway Capacity Manual [2], a level of service D is obtained for the section.

Likewise for freeway section 18-19 the maximum values for merge, diverge and weaving volumes are 1220 VPH, 1360 VPH, and 1340 VPH respectfully. In this section the diverge value is the greatest and Table 8.1 gives a level of service C [2].

With the levels of service obtained from the analysis of these sections it is apparent that an adequate level of service is maintained and no improvements are recommended.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Increasing demand for freeways has led to the development of a new method of freeway design that allows high volumes of traffic on a single right of way and, yet, limits the number of lanes in any direction to four. This thesis has been concerned with the capacity and level of service analysis of such a freeway, a dual-dual freeway. An attempt was made to isolate the various elements of the dual-dual freeway and to analyze each of these elements for capacity and level of service. The desired results of the design were a level of service D for all dual-dual freeway elements, and a balanced design.

From the analysis of the dual-dual freeway the following elements of the design need improvement if a balanced design with a level of service D is to be achieved.

A. Dual-dual freeway

1. Sections 7-8 and 12-13 have a level of service that is too high to achieve a balanced design for the overall freeway. This is a result of the movement of a large volume of traffic from the inner roadway to the outer roadway.
2. Sections 14-15 and 9-10 have too low a level of service to meet the requirement set forth in Chapter II.
3. The intersecting freeway, an existing facility, has a level of service E and is not subject to improvement.

B. Weaving areas

1. The weaving areas as defined in Chapter III, have a sufficient number of lanes, and are of sufficient length to maintain a level of service D. However, the quality of flow could be increased by increasing the length of the weaving area.

C. Two-lane exit ramps

1. Ramp 2 on the eastbound outer roadway has a spot volume in excess of 1800 VPH. This could result in a complete breakdown of flow at this ramp and steps should be taken to remedy this situation.
2. The two-lane exits on the intersecting freeway are in areas that have spot volumes greatly in excess of 1800 VPH. However, it is impossible to improve the situation without undertaking major revisions on the freeway itself.

D. Two-lane entrance ramps

1. Ramp 5 and ramp 17 have spot volumes 500 feet downstream from the nose in excess of 1800 VPH.

2. As was the case for the two-lane exit ramp there is too much assigned traffic to obtain a level of service D on the intersecting freeway downstream from entrance ramps.
- E. Single-lane ramps--Ramp 14 has a spot volume greater than 1800 VPH due to the effect of the adjacent ramp. This should be improved if a smooth flow of traffic is to be maintained.
- F. Left-hand entrance and exit ramps--The limiting factor for these ramps is the length of weaving areas between the exit and the entrance ramps. As noted in Chapter III this is adequate for level of service D. Therefore, it is assumed that these ramps function in an efficient manner.

Over all the analysis of the dual-dual freeway section and its various elements point out the fact that a dual-dual freeway can be effectively used to obtain high volumes of traffic within a limited right of way. If the standards set forth in Chapter II are followed, a level of service D may be easily obtained. The only problem with this type of design is providing for the high turning volumes at a major interchange. However, if adequate parallel acceleration and deceleration lanes are maintained this problem can be eliminated.

Recommendations

As noted in the conclusion, various sections of the dual-dual freeway are not up to the standards that were originally set forth. In order to eliminate these sub-standard sections the following recommendations are suggested:

A. Dual-dual freeway

1. In order to provide a balanced design section 7-8 and 12-13 should have the number of lanes for traffic reduced from three to two. Since other circumstances require the construction of three lanes, it may be possible to achieve the same effect by painting out one lane. Figure 5, Appendix A is a sketch of such a solution.
2. Section 14-15 and 9-10 need increased capacity to raise the level of service for these sections from E to D. By prohibiting truck traffic on the inner roadways this result can be achieved.

B. Two-lane exit and entrance ramps

1. Ramps 2, 5, and 17 have spot volumes in excess of 1800 VPH. In all three cases this can be prevented by increasing the length of the parallel deceleration and acceleration lane to 1500 feet.

C. Single-lane ramps

1. Ramp 14 should be moved 500 feet to the east in order to lessen the effect of the adjacent ramp. This will reduce all spot volumes to less than 1800 VPH.

The recommendations noted above are all specific points required to improve a certain section in the freeway design. A more general recommendation for this type of facility is to provide adequate space to construct the interchanges along the dual-dual freeway. It is at the interchanges that weaving, diverging, and merging takes place with the greatest frequency and these maneuvers require space.

One other general recommendation that will help this type of facility function in the best possible manner would be the exclusion of truck traffic from the inner roadways. If this is done the high speed inner roadways are certain to develop less friction and a higher capacity.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Institute of Traffic Engineers. Capacities and Limitations of Urban Transportations Modes. Washington: Institute of Traffic Engineers, 1965.
2. Highway Research Board. Highway Capacity Manual. Washington: Highway Research Board, 1965.
3. American Association of State Highway Officials. A Policy on Geometric Design of Rural Highways. Washington: American Assoc. of State Highway Officials, 1964.
4. Michigan Department of State Highways. Road Standard Plans and Standard Guides. Lansing: Michigan Department of State Highways, 1964.
5. Michigan Department of State Highways. I-96 Freeway Planning and Route Location Study: City of Detroit. Vol. I. Lansing: Michigan Department of State Highways, 1964.
6. American Association of State Highway Officials. Highway Design and Operational Practices Related to Highway Safety. Washington: American Association of State Highway Officials, 1967.
7. American Association of State Highway Officials. A Policy on Arterial Highways in Urban Areas. Washington: American Association of State Highway Officials, 1957.
8. Newman, L. and Moskowitz, K. "Effects of Grade on Service Volume," Highway Research Record, 99: 224-243, 1965.
9. Newman, L. and Moskowitz, K. Notes on Freeway Capacity. Traffic Bulletin 4. Sacramento: State of California, Division of Highways, 1962.

10. Hess, J. W. "Capacities and Characteristics of Ramp-Freeway Connections," Highway Research Record, 27:69-115, 1963.
11. Worrall, R. D. and others. "Study of Operational Characteristics of Left Hand Entrance and Exit Ramps on Urban Freeways," Highway Research Record, 99:244-274, 1965.
12. Greenshields, B. D. "A Study of Traffic Capacity," Proceedings of Highway Research Board. Bulletin 14:448-474, 1934.
13. Fisher, R. L. "Accident and Operating Experience at Interchanges," Highway Research Bulletin, 235:125-138, 1959.
14. Michigan Department of State Highways. A Comparison of Left Hand Entrances and Exits with Right Hand Entrances and Exits on a Divided Limited Access Highway. Lansing: Traffic Division, Michigan Department of State Highways, 1958.
15. Berry, D. J. and others. "A Study of Left Hand Exit Ramps on Freeways," Highway Research Record, 21:1-16, 1963.
16. Hess, J. W. "Ramp Freeway Terminal Operation as Related to Freeway Lane Volume Distribution and Adjacent Ramp Influence," Highway Research Record, 99:81-116, 1965.
17. Normann, O. K. "Operation of Weaving Areas," Highway Research Bulletin, 167:38-41, 1957.
18. Malo, A. F.; Mika, H. S.; and Walbridge, V. P. "Traffic Behavior on an Urban Expressway," Highway Research Bulletin, 235:19-37, 1960.
19. Keese, C. J.; Pinnell, C.; and McCasland, W. R. "A Study of Freeway Traffic Operations," Highway Research Bulletin, 235:73, 1960.

20. Drew, D. R. and Keese, C. J. "Freeway Level of Service as Influenced by Volume and Capacity Characteristics," Highway Research Record, 99: 1-49, 1965.
21. Furutome, Ichiro and Moskowitz, Karl. "Traffic Behavior and Off Ramp Design," Highway Research Record, 21:17-31, 1963.
22. Wattleworth, J. A. and others. "Operational Effects of Some Entrance Ramp Geometrics on Freeway Merging," Highway Research Record, 202:79-113, 1966.
23. Tipton, William E. "An Investigation of Factors Affecting the Design Location of Freeway Ramps," Highway Research Record, 152:1-36, 1967.
24. Alexander, Christopher and Manheim, M. L. "The Design of Highway Interchanges: An Example of a General Method for Analyzing Engineer Design Problems," Highway Research Record, 83:48-75, 1965.
25. May, A. D. and Wagner, F. A. A Summary of Quality and Fundamental Characteristics of Traffic Flow. Lansing: Michigan State University, 1960.
26. Legarra, John. "Progress in Freeway Capacity Studies," American Highways, 38:11, 21-23, July, 1958.
27. Johnson, Roger T. "Freeway Fatal Accidents 1961 and 1962," Highway Research Record, 99:117-156, 1965.

APPENDIX A
GENERAL PLAN OF DUAL-DUAL FREEWAY
AND
TYPICAL CROSS SECTIONS

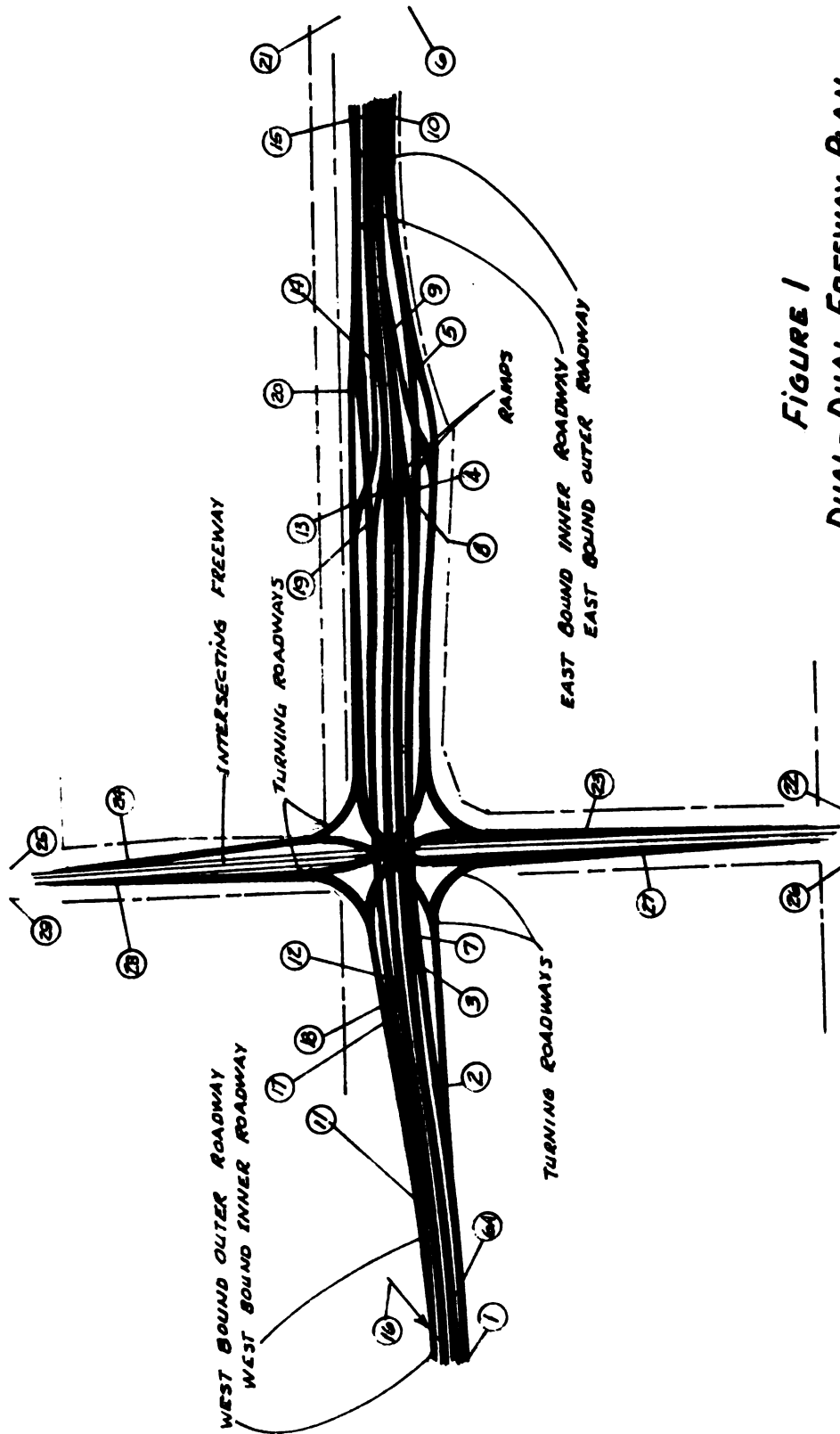


FIGURE 1
DUAL-DUAL FREEWAY PLAN

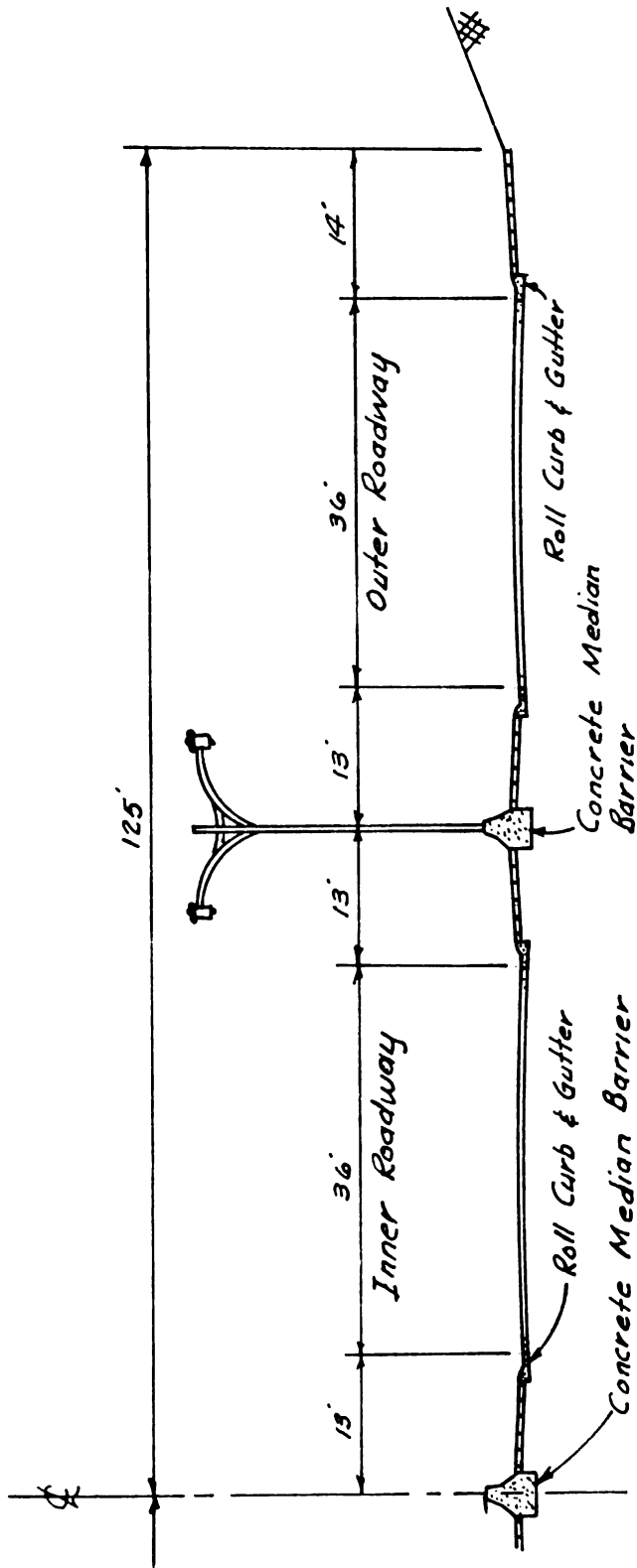
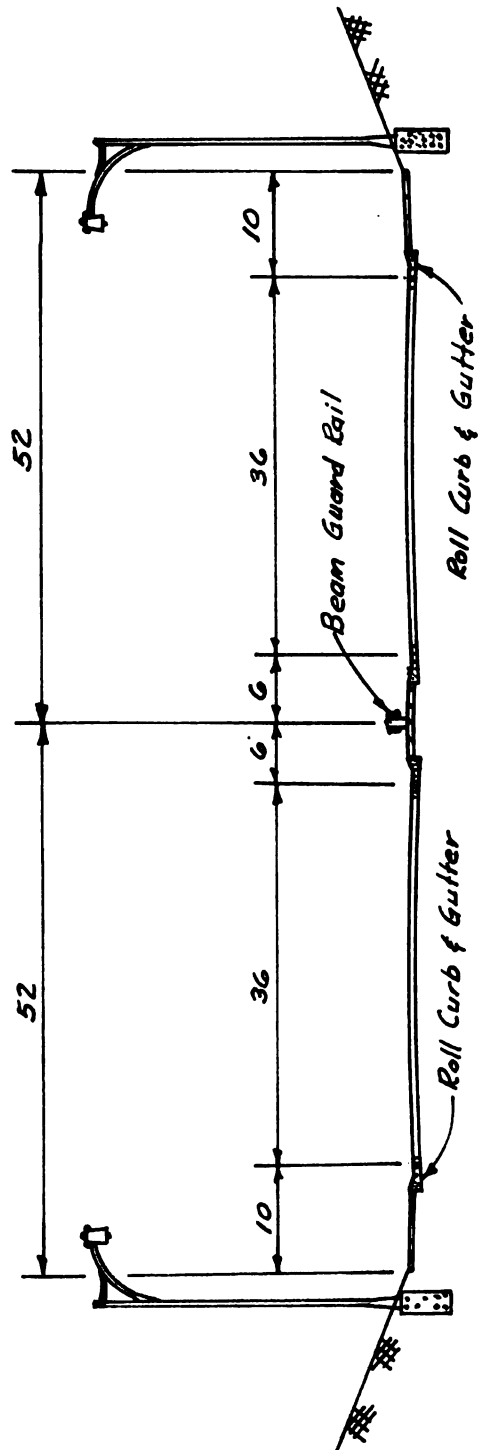


FIGURE 2
TYPICAL HALF SECTION
DUAL- DUAL FREEWAY

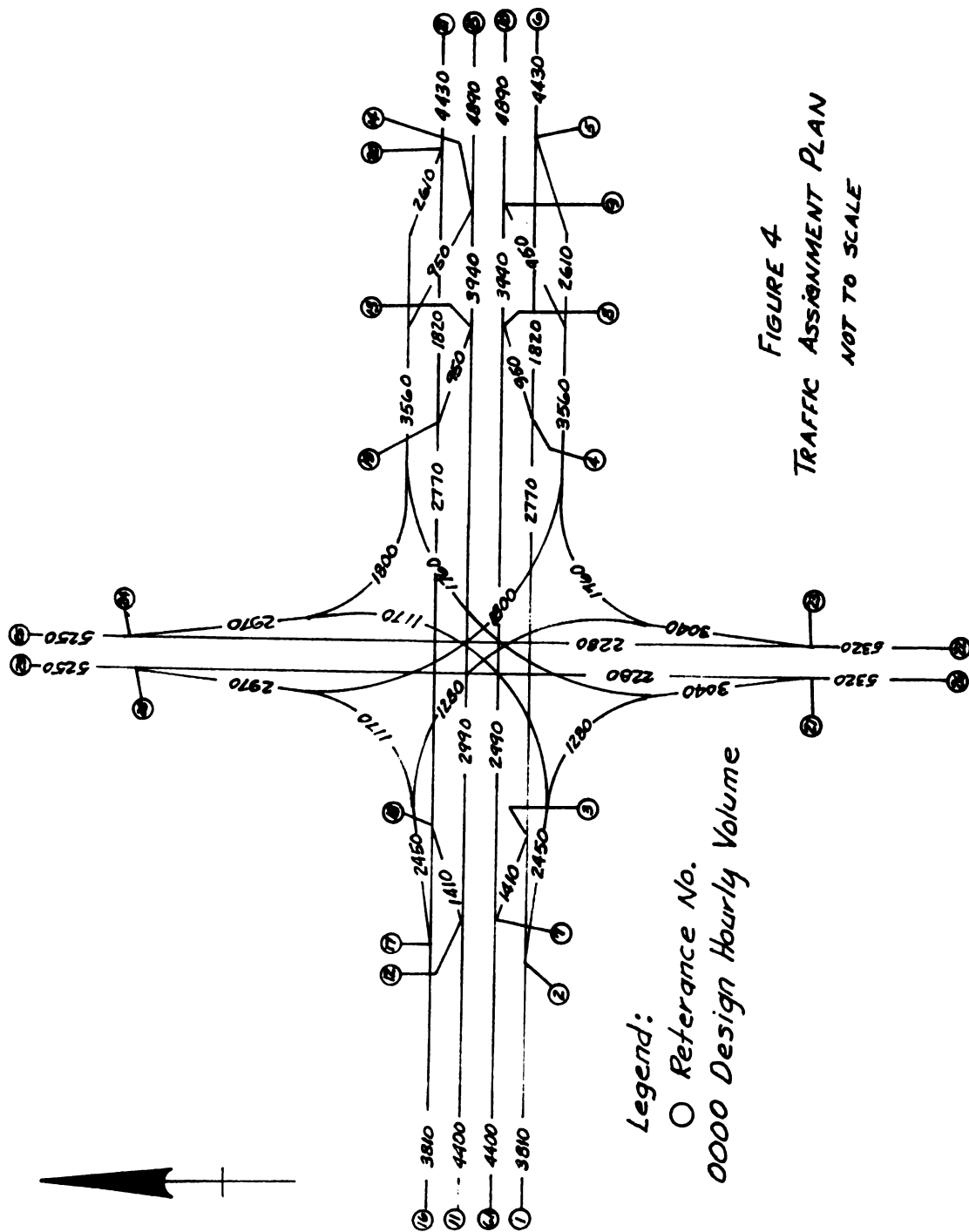
NOTE :

1. All freeway slopes to be $2\frac{1}{2}:1$
2. Outer roadway varies 24 to 48 feet.



NOTE:
All freeway slopes to be $2\frac{1}{2}:1$
normally, but not steeper than 2:1

FIGURE 3
TYPICAL SECTION
INTERSECTING FREEWAY
NO SCALE



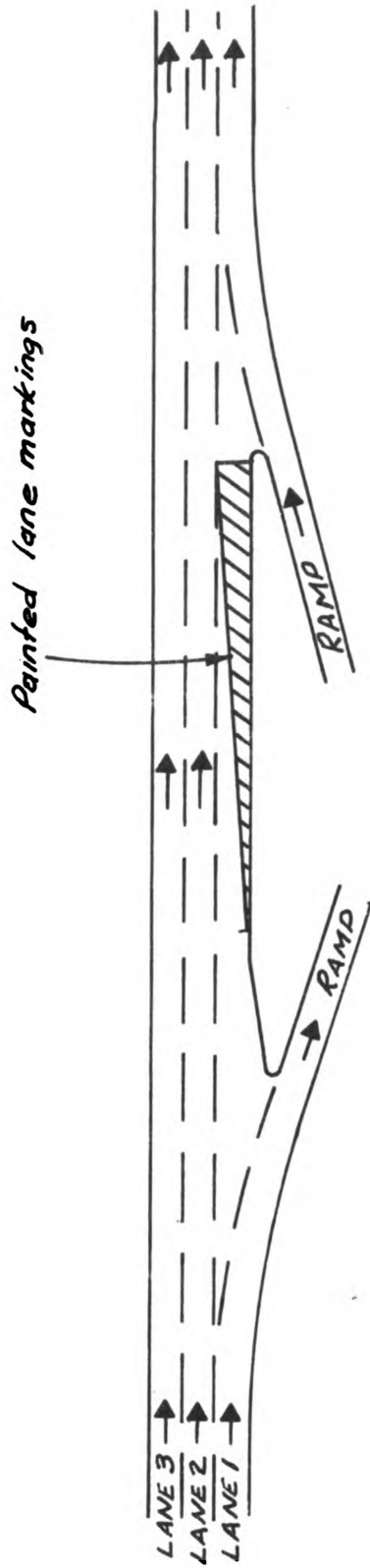


FIGURE 5
TREATMENT OF INNER ROADWAY
AT SECTION 7-8 & 12-13
NOT TO SCALE

APPENDIX B

VOLUME DISTRIBUTION TABLES

TABLE I
LEVEL OF SERVICE FOR UNINTERRUPTED FLOW^a
SERVICE VOLUME/CAPACITY (PHF 0.91)

BASIC LIMITING VALUE FOR:							
Level of Service	4 Lane Freeway (2 Lanes/Direction)		6 Lane Freeway (3 Lanes/Direction)		8 Lane Freeway (4 Lanes/Direction)		
	V/C Ratio	Demand Volume	V/C Ratio	Demand Volume	V/C Ratio	Demand Volume	
A - Freeflow	$\leq .35$	≤ 1400	≤ 0.40	≤ 2400	≤ 0.43	≤ 3400	
B - Stable Flow	$\leq .50$	≤ 2000	≤ 0.58	≤ 3500	≤ 0.63	≤ 5000	
C - Stable Flow	$\leq .75 \times \text{PHF}$	≤ 2750	$\leq .80 \times \text{PHF}$	≤ 4350	$\leq 0.83 \times \text{PHF}$	≤ 6000	
D - Stable Flow	$\leq .90 \times \text{PHF}$	≤ 3300	$\leq .90 \times \text{PHF}$	≤ 4900	$\leq .90 \times \text{PHF}$	≤ 6600	
E - Unstable Flow	≤ 1.00	≤ 4000	≤ 1.00	≤ 6000	≤ 1.00	≤ 8000	
F - Forced Flow	UNDETERMINED						

^a Highway Research Board. Highway Capacity Manual. Report 87 (Washington: Government Printing Office, 1965), pp. 252-253.

TABLE II
 LANE DISTRIBUTION LANE 1
 (NO RAMP MOVEMENT WITHIN 4000 FEET)^a

Thru Volume VPH	Percent of traffic in Lane 1 Roadway (One Direction)		
	2 Lanes	3 Lanes	4 Lanes
< 1500	20		
1500-2000	25		
2000-2500	30		
2500-3000	35		
3000-3500	40	6	
3500-4000		10	
4000-4500		14	8
4500-5000		18	9
5000-5500			9
5500-6000			10
6000-6500			10

^a Karl Moskowitz and Leonard Newman, Notes on Freeway Capacity, Traffic Bulletin No. 4 (Sacramento: State of California Department of State Highway, 1962) Figure 1.

TABLE III
PERCENTAGE OF RAMP TRAFFIC IN LANE 1^a

ENTRANCE RAMP		EXIT RAMP	
Dist. Downstream From Ramp Nose	Per cent of Ramp Traffic in Lane 1	Dist. Upstream From Ramp Nose	Per cent of Ramp Traffic in Lane 1
0	0	0	0
500	100	500	100
1000	60	1000	93
1500	32	1500	79
2000	18	2000	63
2500	14	2500	46
3000	12	3000	29
3500	11	3500	16
4000	10	4000	11

^aKarl Moskowitz and Leonard Newman, ibid., Figure 3.

TABLE IV
PERCENTAGE OF EXIT TRAFFIC UPSTREAM OF RAMP WITH AUXILIARY LANE^a

Length of Auxiliary Lane (ft.)	Distance Upstream from Ramp Nose									
	0'	500'	1000'	1500'	2000'	2500'	3000'	3500'	4000'	
	Aux. Lane Lane 1	Aux. Lane Lane 1	Aux. Lane Lane 1	Aux. Lane Lane 1	Aux. Lane Lane 1	Aux. Lane Lane 1	Aux. Lane Lane 1	Aux. Lane Lane 1	Aux. Lane Lane 1	
1000'	100	0 74 26	0 93							
1500'	100	0 87 13	63 30	0 79						
2000'	100	0 89 11	73 20	50 29	0 63					
2500'	100	0 89 11	75 18	58 21	37 26	0 46				
3000'	100	0 89 11	75 18	59 20	41 22	23 23	0 29			
3500'	100	0 89 11	75 18	59 20	42 21	26 20	13 16	0 16		
4000'	100	0 89 11	75 18	59 20	42 21	26 20	15 14	9 7	0 11	

^aKarl Moskowitz and Leonard Newman, *ibid.*, Figures 3 and 4.

TABLE V

PERCENTAGE OF ENTRANCE TRAFFIC DOWNSTREAM OF RAMP WITH AUXILIARY LANE^a

Length of Auxiliary Lane (ft.)	Distance Downstream from Ramp Nose									
	0'	500'	1000'	1500'	2000'	2500'	3000'	3500'	4000'	
	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1	Aux. Lane 1
1000	100	0	20	80	0	68				
1500	100	0	35	65	7	67	0	43		
2000	100	0	50	50	14	66	3	48	0	30
2500	100	0	62	38	23	62	9	49	3	33
3000	100	0	75	25	32	58	14	50	10	36
3500	100	0	80	20	44	48	25	47	16	36
4000	100	0	85	15	56	38	35	43	22	38

^aKarl Moskowitz and Leonard Newman, *ibid.*, Figure 3.

APPENDIX C

VOLUME DISTRIBUTION RESULTS

TABLE VI
ANALYSIS OF FREEWAY SECTIONS

IDENTIFICATION		PREVAILING CONDITIONS				VOLUME & CAPACITY DATA		
Road	Section	Grade Percent	Section Length Feet	Grade Length Miles	Base Vol. = 2000 NWT C VPH	Design Vol. VPH	$\frac{\text{Volume}}{\text{Capacity}} = \frac{V}{C}$	Basic V/C Ratio = (V/C)/(PHF) Level of Service
Dual-Dual Freeway								
E.B. Outer	1-2	+1.30	3,970	.63	5700	3810	0.67	.74 C
E.B. Outer	2-3	+1.30	880	.63	3800	1360	0.36	.36 B
E.B. Outer	3-4	-1.90	1,290	.40	5700	2770	0.49	.49 B
E.B. Outer	4-5	-1.90	1,070	.40	3800	1820	0.48	.48 B
E.B. Outer	5-6	+0.90	2,230	.60	7600	4430	0.58	.58 B
E.B. Inner	6A-7	+1.30	10,000	.63	5800	4400	0.76	.84 D
E.B. Inner	7-8	-1.70	2,050	.36	5800	2990	0.52	.52 B
E.B. Inner	8-9	+0.66	860	.64	5800	3940	0.68	.75 C
E.B. Inner	9-10	+0.66	13,000	.64	5800	4890	0.84	.92 E
W.B. Inner	11-12	-1.30	9,700	.63	5800	4400	0.76	.83 D
W.B. Inner	12-13	+1.70	2,030	.36	5500	2990	0.54	.59 C
W.B. Inner	13-14	-0.66	960	.64	5800	3940	0.68	.75 C
W.B. Inner	14-15	-0.66	13,200	.64	5800	4890	0.84	.92 E
W.B. Outer	16-17	-1.30	3,950	.63	5700	3810	0.67	.74 C
W.B. Outer	17-18	-1.30	410	.63	3800	1360	0.36	.36 B
W.B. Outer	18-19	+1.90	1,390	.40	4980	2770	0.56	.62 C
W.B. Outer	19-20	+1.90	1,430	.40	3320	1820	0.55	.60 C
W.B. Outer	20-21	-0.90	2,100	.63	7600	4430	0.58	.58 B
Intersecting Freeway								
North Bd.	22-23	+1.30	2,240	.40	5700	5320	0.93	>1.00 E
North Bd.	23-24	-3.00	2,560	.13	3800	2280	0.60	.66 C
North Bd.	24-25	+1.21	2,320	.37	5700	5250	0.92	>1.00 E
South Bd.	26-27	-1.30	1,780	.40	5700	5320	0.93	>1.00 E
South Bd.	27-28	+3.00	2,900	.13	3800	2280	0.60	.66 C
South Bd.	28-29	-1.21	2,520	.37	5700	5250	0.92	>1.00 E

TABLE VII

ANALYSIS OF WEAVING AREAS

Weaving Section	Design Hour Volume			Length of Weaving Section [2]*			Weave Factor (k) [2]**	Adjusted Segment Volume	Lane Service Volume[2]*	Lanes Required	Lanes Provided
	Segment V	Weave $Vw_1 + Vw_2$	Minor Weave Vw_2	Curve III	Curve IV	Recommended					
WESTBOUND											
Westbound Outer Section 20-21	4430	3820	880	3000	1600	2300	3	6190	1660	3.7	4
WB - NB & SB											
Turning Roadway Section V U	3560	1910	550	1400	600	800	3	4660	1640	2.8	3
INNER ROADWAY											
to Outer Roadway Section 18-19	2770	2360	950	1900	900	1400	3	4670	1660	2.8	3
EASTBOUND											
Inner Roadway to Outer Roadway Section 3-4	2770	2360	950	1900	900	1400	3	4670	1660	2.8	3
NB & SB - EB											
Turning Roadway Sect. G-H	3560	1650	400	1000	400	600	3	4360	1660	2.7	3
EASTBOUND OUTER											
Section 5-6	4430	3280	880	3000	1600	2300	3	6190	1660	3.7	4

*[2] Fig. 7.4, p. 166, Highway Capacity Manual, 1965.**[2] Table 7.1, p. 170, Highway Capacity Manual, 1965 (1750 PCPH adjusted for trucks).

TABLE VIII
VOLUME DISTRIBUTION RAMP 2
TWO-LANE EXIT RAMP SPOT VOLUME

Dist. Upstream	LANE 1				AUXILIARY LANE		
	Entr. Ramp	Exit Ramp	Thru	Total	Entr. Ramp	Exit Ramp	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH
4000	0	560	600	1160	800	0	800
3500	120	440	600	1160	680	450	1130
3000	300	460	600	1360	450	790	1240
2500	340	470	600	1410	280	1160	1440
2000	300	440	600	1340	180	1530	1710
1500	240	310	600	1150	110	1880	1990
1000	220	240	600	1060	40	2170	2210
500	170	70	600	840	20	1050	1070
0	140	0	600	740	0	650	650

ENTRANCE RAMP VOLUME = 800 VPH

EXIT RAMP VOLUME = 2450 VPH

FREEWAY VOLUME = 3810 VPH

TABLE IX
VOLUME DISTRIBUTION RAMP 5
TWO-LANE ENTRANCE SPOT VOLUME

Dist. Downstream	LANE 1			AUXILIARY LANE		
	Entr. Ramp	Exit Ramp	Total	Entr. Ramp	Exit Ramp	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH
0	810	0	810	1800	0	1800
500	1300	870	2170	900	0	900
1000	1210	350	1560	260	700	960
1500	630	110	740	50	980	1030
2000	300	0	300	0	1090	1090

ENTRANCE RAMP VOLUME = 2610 VPH

EXIT RAMP VOLUME = 1090 VPH

FREEWAY VOLUME = 4430 VPH

TABLE X
VOLUME DISTRIBUTION RAMP 17
TWO-LANE ENTRANCE RAMP SPOT VOLUME

Dist. Upstream	LANE 1				AUXILIARY LANE		
	Entr. Ramp	Exit Ramp	Thru	Total	Entr. Ramp	Exit Ramp	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH
0	0	90	200	290	650	0	650
500	100	60	200	360	1990	70	2060
1000	230	110	200	540	1580	120	1700
1500	580	160	200	940	1150	210	1360
2000	960	170	200	1330	530	340	870
2500	810	160	200	1170	260	470	730
3000	620	140	200	960	150	600	750
3500	440	90	200	730	70	710	730
4000	360	0	200	560	0	800	800

ENTRANCE RAMP VOLUME = 2450 VPH

EXIT RAMP VOLUME = 800 VPH

FREEWAY VOLUME = 3810 VPH

TABLE XI
VOLUME DISTRIBUTION RAMP 20
TWO-LANE EXIT RAMP SPOT VOLUME

Dist. Downstream	LANE 1			AUXILIARY LANE		
	Entr. Ramp	Exit Ramp	Total	Entr. Ramp	Exit Ramp	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH
0	180	810	990	0	1800	1800
500	370	890	1260	60	1660	1720
1000	660	950	1610	150	1370	1520
1500	540	960	1500	540	890	1430
2000	0	1110	1110	1090	0	1090

ENTRANCE RAMP VOLUME = 1090 VPH

EXIT RAMP VOLUME = 2610 VPH

FREEWAY VOLUME = 4430 VPH

TABLE XII

VOLUME DISTRIBUTION RAMP 23 TWO-LANE EXIT RAMP SPOT VOLUME

Dist. Upstream	LANE 3				LANE 2				LANE 1			
	Lane A		Lane B		Lane A		Lane B		Lane A		Lane B	
	VPH	VPH	Thru	Total	VPH	VPH	Thru	Total	VPH	VPH	Thru	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
0	0	0	0	1590	1590	0	0	690	690	0	1800	1800
500	0	0	0	1590	1590	1240	0	690	1930	0	1800	1800
1000	90	0	0	1590	1680	1150	130	690	1970	0	1680	1680
1500	260	0	0	1590	1850	980	380	690	2050	0	1420	1420
2000	460	0	0	1590	2050	780	670	690	2140	0	1130	1130
2500	670	0	0	1590	2260	570	970	690	2230	0	830	830

EXIT RAMP VOLUME = 3040 VPH

FREEWAY VOLUME = 5320 VPH

TABLE XIII
VOLUME DISTRIBUTION RAMP 25 TWO-LANE ENTRANCE RAMP SPOT VOLUME

Dist. Downstream	LANE 3			LANE 2			LANE 1		
	Lane A	Thru	Total	Lane A	Lane B	Total	Lane B	Thru	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
0	0	1590	1590	0	0	690	0	0	0
500	0	1590	1590	1170	0	690	1800		1800
1000	470	1590	2060	700	720	690	1080	0	1080
1500	800	1350	2150	370	1220	560	580	370	950
2000	960	1190	2150	210	1480	460	320	630	950
2500	1010	1140	2150	160	1550	440	250	700	950

ENTRANCE RAMP VOLUME = 2970 VPH

FREEWAY VOLUME = 5250 VPH

TABLE XIV

VOLUME DISTRIBUTION RAMP 27 TWO-LANE ENTRANCE RAMP SPOT VOLUME

Dist. Downstream	LANE 1			LANE 2			LANE 3		
	Lane B	Thru	Total	Lane B	Thru	Total	Lane A	Thru	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
0	0	0	0	0	0	690	0	1590	1590
500	1800	0	1800	0	1240	690	0	1590	1590
1000	1080	0	1080	720	740	690	500	1590	2090
1500	580	370	950	1220	400	2185	840	1345	2185
2000	360	590	950	1480	220	2185	1020	1165	2185

ENTRANCE RAMP VOLUME = 3040 VPH

FREEWAY VOLUME = 5320 VPH

TABLE XV

VOLUME DISTRIBUTION RAMP 28 TWO-LANE EXIT RAMP SPOT VOLUME

Dist. Upstream	LANE 3			LANE 2			LANE 1	
	Lane A	Thru Vol.	Total	Lane A	Lane B	Thru Vol.	Total	Total
Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
0	0	1590	1590	0	0	690	690	1800
500	0	1590	1590	1170	0	690	1860	1800
1000	80	1590	1670	1060	130	690	1880	1680
1500	250	1590	1840	930	380	690	2000	1420
2000	430	1590	2020	740	670	690	2100	1130
2500	630	1590	2220	540	970	690	2200	830

EXIT RAMP VOLUME = 2970 VPH

FREEWAY VOLUME = 5250 VPH

TABLE XVI
VOLUME DISTRIBUTION RAMP 7
ONE-LANE EXIT RAMP SPOT VOLUME

Dist. Upstream	LANE 1		Total
	Exit Volume	Thru Vol.	
Feet	VPH	VPH	VPH
0	0	180	180
500	1410	180	1590
1000	1310	180	1490
1500	1110	180	1290
2000	880	180	1060
2500	650	180	830
3000	410	180	590
3500	220	180	400
4000	155	180	335

EXIT RAMP VOLUME = 1410 VPH

FREEWAY VOLUME = 4400 VPH

TABLE XVII
VOLUME DISTRIBUTION RAMPS 8 & 9
ONE-LANE ENTRANCE RAMP SPOT VOLUME

Dist. Downstream Ramp 8 Ramp 9		LANE 1			
		Entrance Vol. Ramp 8	Entrance Vol. Ramp 9	Thru Vol.	Total Vol.
Feet	Feet	VPH	VPH	VPH	VPH
0	0	0	0	180	180
500	0	950	0	180	1130
1000	0	570	0	180	750
1500	500	300	950	180	1430
2000	1000	170	570	180	920
2500	1500	130	300	180	610
3000	2000	110	170	180	460
3500	2500	100	130	180	410
4000	3000	95	110	180	385
	3500	95	100	180	375
	4000	95	95	180	370

ENTRANCE RAMP 8 = 950 VPH

ENTRANCE RAMP 9 = 950 VPH

FREEWAY VOLUME = 4890 VPH

TABLE XVIII
VOLUME DISTRIBUTION RAMP 12
ONE-LANE ENTRANCE RAMP SPOT VOLUME

Dist. Downstream	LANE 1		
	Entrance Vol.	Thru Vol.	Total Vol.
Feet	VPH	VPH	VPH
0	0	180	180
500	1410	180	1590
1000	850	180	1030
1500	450	180	630
2000	250	180	430
2500	200	180	380
3000	170	180	350
3500	160	180	340
4000	140	180	320

ENTRANCE RAMP VOLUME = 1410 VPH 0

FREEWAY VOLUME = 4400 VPH 0

TABLE XIX
VOLUME DISTRIBUTION RAMPS 13 & 14
ONE-LANE EXIT RAMPS SPOT VOLUME

Dist. Upstream		LANE 1			
Ramp 13	Ramp 14	Exit Vol. Ramp 13	Exit Vol. Ramp 14	Thru Vol.	Total Vol.
Feet	Feet	VPH	VPH	VPH	VPH
0	0	0	0	180	180
500	0	950	0	180	1130
1000	0	880	0	180	1060
1500	500	750	950	180	1880
2000	1000	600	880	180	1660
2500	1500	440	750	180	1370
3000	2000	270	600	180	1050
3500	2500	150	440	180	770
4000	3000	100	270	180	550
	3500	100	150	180	430
	4000	100	100	180	380

EXIT RAMP 13 VOLUME = 950 VPH

EXIT RAMP 14 VOLUME = 950 VPH

FREEWAY VOLUME = 4890 VPH

TABLE XX

VOLUME DISTRIBUTION RAMPS 3 & 4

ONE-LANE LEFT-HAND ENTRANCE AND EXIT RAMP SPOT VOLUMES

Dist.		LANE 1				LANE 2				AUXILIARY LANE			
Upstr. Ramp 4	Downstr. Ramp 3	Entr. Ramp Vol.	Exit Ramp Vol.	Thru Vol.	Total Vol.	Entr. Ramp Vol.	Exit Ramp Vol.	Thru Vol.	Total Vol.	Entr. Ramp Vol.	Exit Ramp Vol.	Total Vol.	
Feet	Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
1500	0	0	200	300	500	0	750	110	860	1400	0	1400	
1000	500	0	50	300	350	920	300	110	1330	490	600	1090	
500	1000	360	0	300	660	950	80	110	1140	100	870	970	
0	1500	440	0	300	740	970	0	110	1080	0	950	950	

ENTRANCE RAMP VOLUME = 1410 VPH

EXIT RAMP VOLUME = 950 VPH

FREEWAY VOLUME = 2770 VPH

TABLE XXI

VOLUME DISTRIBUTION RAMPS 18 & 19

ONE-LANE LEFT-HAND ENTRANCE AND EXIT RAMPS SPOT VOLUMES

Dist.		LANE 1				LANE 2				AUXILIARY LANE			
Upstrm. Ramp 18	Downstr. Ramp 19	Entr. Ramp Vol.	Exit Ramp Vol.	Thru Vol.	Total Vol.	Entr. Ramp Vol.	Exit Ramp Vol.	Thru Vol.	Total Vol.	Entr. Ramp Vol.	Exit Ramp Vol.	Total Vol.	
Feet	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
0	1500	300	0	370	670	650	0	40	690	0	1410	1410	
500	1000	240	0	370	610	640	110	40	790	70	1300	1370	
1000	500	0	70	370	440	620	450	40	1110	330	890	1220	
1500	0	0	300	370	670	0	1110	40	1150	950	0	950	

ENTRANCE RAMP VOLUME = 950 VPH

EXIT RAMP VOLUME = 1410 VPH

FREEWAY VOLUME = 2770 VPH