

**BASIC NUMBER OF LANES AND LANE BALANCE:
THEIR USE IN URBAN FREEWAY DESIGN**

by

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INTRODUCTION

The urban traffic problem, like most problems, arises out of the frustration of trying to reconcile a number of partly incompatible goals. Urbanites would like to move about their areas; a) quickly; b) comfortably; c) cheaply; d) mostly at the same time; and e) mostly to or from the same places. (4) Since a majority of trips, 80-90% during the peak hour (5) are to work and shop, time spent in transit is time lost from a productive activity. Urban movement, then, is largely an experience to be done with as quickly as possible. Minimum travel time becomes a prime objective and traffic congestion, which increases travel time, the main problem.

During the peak hour, almost all congestion is caused by traffic demands exceeding the capacity of a few bottleneck sections. In the bottleneck, traffic flow is smooth. However, when the arrival rate exceeds the service rate, a queue will form upstream from the bottleneck, i.e. congestion. Traffic flow in the system may be described as similar to sand in an hour glass. In the neck, the sand flows freely. However, the sand upstream from the neck flows very slowly, the last grain being delayed an hour. (3)

Removing these bottlenecks from the freeway would serve to reduce overall traveltime on the entire transportation system. Federally funded projects, such as TOPICS (Traffic Operations Programs to Increase Capacity and Safety) are presently being undertaken to eliminate existing bottlenecks.

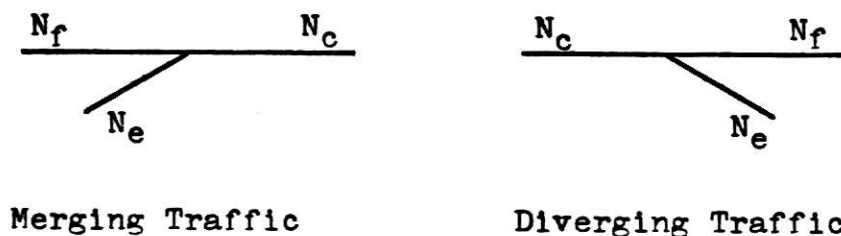
The ultimate, however, should be the elimination of these bottlenecks during the initial design of the freeway.

At the 1965 Canadian Good Roads Association Convention, Jack Leisch presented a paper entitled "Lane Determination Techniques for Freeway Facilities." (1) In this paper Leisch introduced two new concepts into the field of freeway design: basic number of lanes and lane balance. These two concepts provide a systematic method to strategically provide additional lanes to a freeway which would serve to remove bottlenecks.

Leisch maintains that the number of lanes on a freeway facility cannot be determined by relating highway capacity to estimated traffic volume alone. To provide well-balanced freeway design, the following techniques must all be considered:

A. Volume-Capacity Relationships - to determine the number of lanes required to carry forecast traffic volumes.

B. Lane Balance - to ensure efficient operation and to realize the indicated capacity potential where merging, diverging, and weaving take place. The basic relationship used in determining lane balance is: $N_c \geq N_e + N_f - 1$



Relationships of Lane Balance

(Figure 1)

where: N_c is the number of lanes succeeding an entrance ramp or preceding an exit ramp;

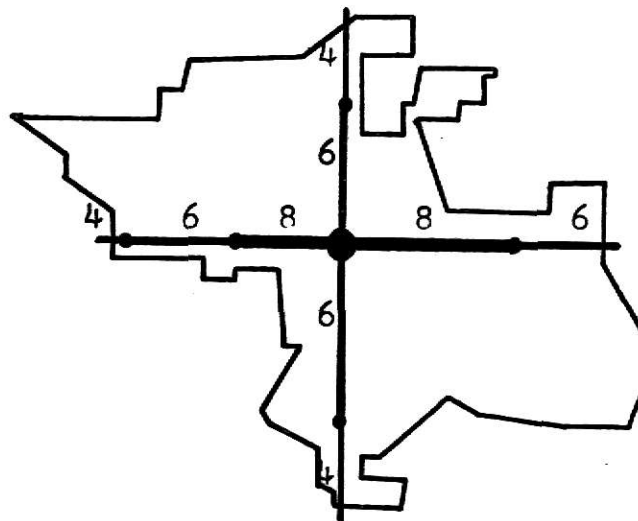
N_e is the number of lanes on the entrance or exit ramp;

N_f is the number of lanes preceding an entrance ramp or succeeding an exit ramp.

That is, the number of lanes leaving a merging section is greater than or equal to the number of freeway lanes preceding the merge plus the number of lanes on the ramp minus one.

Similarly, the number of lanes approaching a diverging section must be equal to or greater than the total number of lanes on the exit ramp and the freeway beyond the point of divergence, minus one.

C. Basic Number of Lanes - to maintain a certain consistency in the number of lanes provided along a route. The basic number of lanes is defined as a minimum number of lanes designated



Basic Number of Lanes Concept

(Figure 2)

and maintained over the whole of a freeway route or over a significant length of it, irrespective of changes in traffic volume and requirements in lane balance.

D. Special Auxiliary Lanes - Auxiliary lanes have three major purposes in freeway design:

1. to harmonize the techniques of lane balance and basic number of lanes by adding auxiliary lanes to, or removing them from, the basic number of lanes to achieve lane balance.

2. to improve the flexibility of a freeway by strategically adding an extra lane to the basic number of lanes.

3. to apply the principle of "one more lane going away" to interchanges. This principle of having an extra lane at the point of divergence is a form of escape hatch that would facilitate the necessary traffic operations to negotiate the interchange by providing greater exit capacity than entrance capacity.

Leisch concludes that by basing a freeway design strictly on the volume-capacity relationships, possible changes in the pattern and volume of traffic are being ignored. An unforeseen concentration of development, such as a shopping center or an industrial plant may significantly increase traffic volumes. Weekend travel may produce different traffic loadings than normal peak hour traffic. Stage construction or partial freeway network development may alter traffic patterns. Accidents or extensive maintenance operations either on the freeway or on intersecting or parallel facilities may cause

increased traffic buildups. It is hypothesized that by incorporating the techniques of lane balance, basic number of lanes, and special auxiliary lanes into the design, the operational flexibility necessary to handle these unexpected developments will be built into the freeway system, usually at little increased cost.

To this author's knowledge, no testing of the hypothesis has been conducted on an existing freeway system. This report presents such a test on a section of freeway in Kansas City, Kansas. The purpose of this study was to determine if Leisch's concepts would have improved traffic operations had they been considered in the original design. It is hoped that this report will provide a basis for a new methodology in the design of urban freeways.

PROCEDURE

The basic plan of attack to test Leisch's method of design was to select a section of freeway in a metropolitan area and then incorporate the four techniques, volume-capacity, lane balance, basic number of lanes, and special auxiliary lanes, into a hypothetical design. This hypothetical design could then be compared to the existing freeway layout to determine if it would significantly improve traffic operations on the system.

The first step, the selection of a section of freeway, was dealt with after discussion with Kansas Highway Commission personnel who were familiar with the metropolitan regions of Kansas City and Wichita. The following criteria were used to judge a section's acceptability, listed in order of decreasing importance:

- a) the original design information and plans were readily available;
- b) more planned construction was to follow, to determine the effects of partial development of the freeway system;
- c) traffic congestion was presently a reality;
- d) a large, unforeseen industrial park, sports stadium, or shopping center, had been built near the freeway since it was constructed;
- e) an extensive maintenance project was planned on or near the selected section in June, 1970;
- f) the number of lanes in the section varied;
- g) another freeway intersected the selected freeway section.

After the study section was selected, a search into the vaults at the Kansas Highway Commission uncovered the original design traffic volumes, as supplied by the Planning Department, and the final design, as conceived by the Design Department. Further discussion with personnel in the Highway Commission's Design, Planning, Construction, and Right-of-Way Departments and the Kansas City, Kansas Traffic Engineering Department unveiled further information useful for this study.

The study section was then analyzed using Leisch's method and the 1950 Highway Capacity Manual, the manual available at the time of the original design. Up to this point no use was made of the knowledge of existing traffic conditions. Every step was carried out as a designer in the 1950's could have proceeded if Leisch's methods had then been used.

When the hypothetical design was completed, the traffic operations on the existing freeway were analyzed and an attempt was made to predict what effect the additional lanes provided in the hypothetical design would have on existing 1970 conditions.

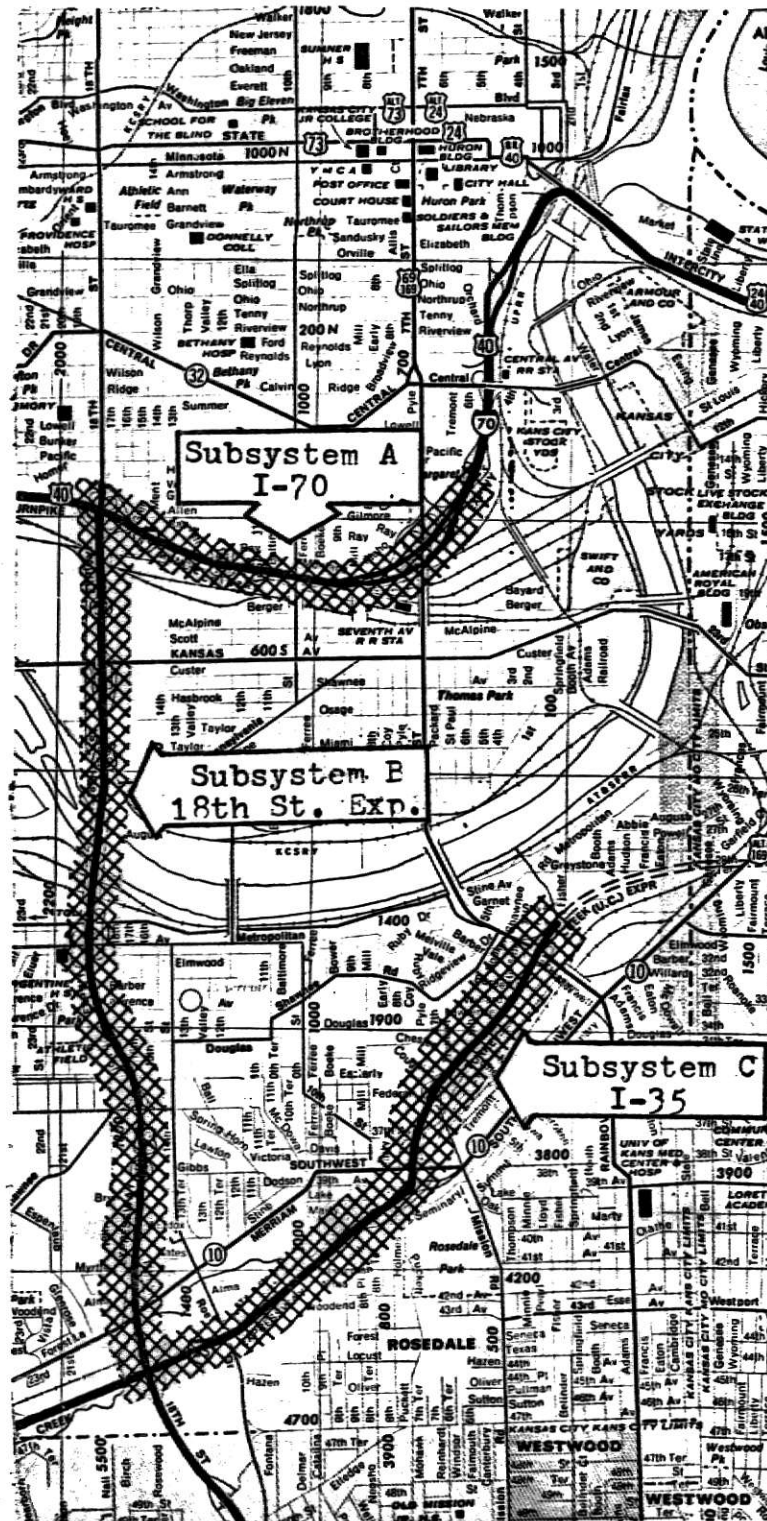
THE STUDY AND IT'S RESULTS

Selection of the Study Area

The cross-hatched areas in fig. 3 show the selected study system. The system provides service from downtown Kansas City, Kansas and Missouri to Kansas City, Kansas to the West and Johnson County to the South. For study, the system was divided into three subsystems. Subsystem A was defined as Interstate 70 (the Kansas Turnpike) from 7th Street to 18th Street Expressway. The 18th Street Expressway from I-70 to I-35 was denoted Subsystem B, and I-35 from 7th Street to 18th Street Expressway was defined as Subsystem C.

The selected system satisfies 5 of the 7 selection criteria, including the 3 most important. Criteria d and e, unforeseen development and maintenance operations, were not satisfied. The desirable, for this study, traits:

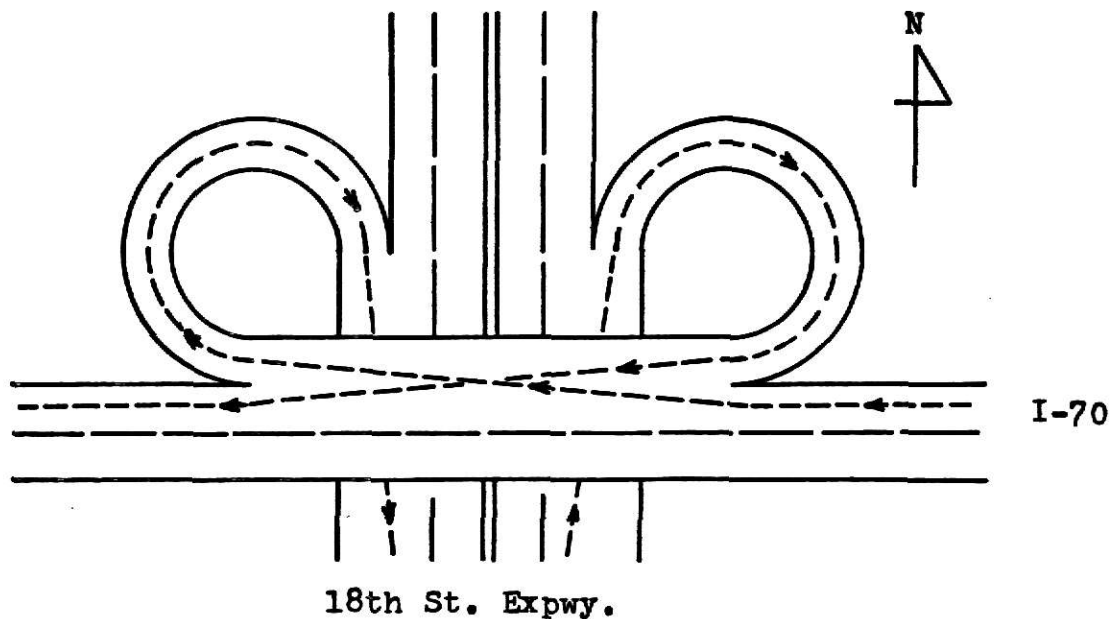
- a) The original design information and plans were available from the Kansas Highway Commission.
- b) Partial development of the freeway system could be very effectively studied. I-35, East of 7th Street was not opened until March, 1970. Therefore, current information was available on the operating characteristics of the system both partially and fully developed.
- c) Traffic congestion is definitely a problem. Before I-35 opened a bottleneck at the intersection of 18th Street Expressway and I-70 during the afternoon peak hour created serious traffic congestion. The intersection is a clover-



Map of the Study Area

(Figure 3)

leaf. The P.M. peak produces very heavy traffic volumes leaving downtown Kansas City, Kansas Westbound on I-70. Many of these vehicles desire to turn South on the 18th Street Expressway towards Johnson County, which means they must traverse a leaf of the intersection after weaving with vehicles making a South to West turn. (see fig. 4) The opening of I-35 siphoned some of the



Bottleneck at I-70 and 18th Street Expressway
(Figure 4)

traffic off I-70 but at the same time created a problem similar to that of I-70 and 18th Street Expressway at the I-35 and 18th Street Expressway intersection, also a cloverleaf.

- f) The number of lanes in the section varies from 2 to 4.
- g) The system includes 2 intersections of urban freeways.

Since the major congestion in this system occurred during the

afternoon peak, Westbound design of I-70 and I-35 and the Southbound design of 18th Street Expressway were selected for detailed study.

Design Criteria

The original design volumes were obtained from the plans. Most were forecast for 1975. Figure 5 shows the forecast volumes together with the 1968 and 1970 traffic counts. With each forecast the following information was given:

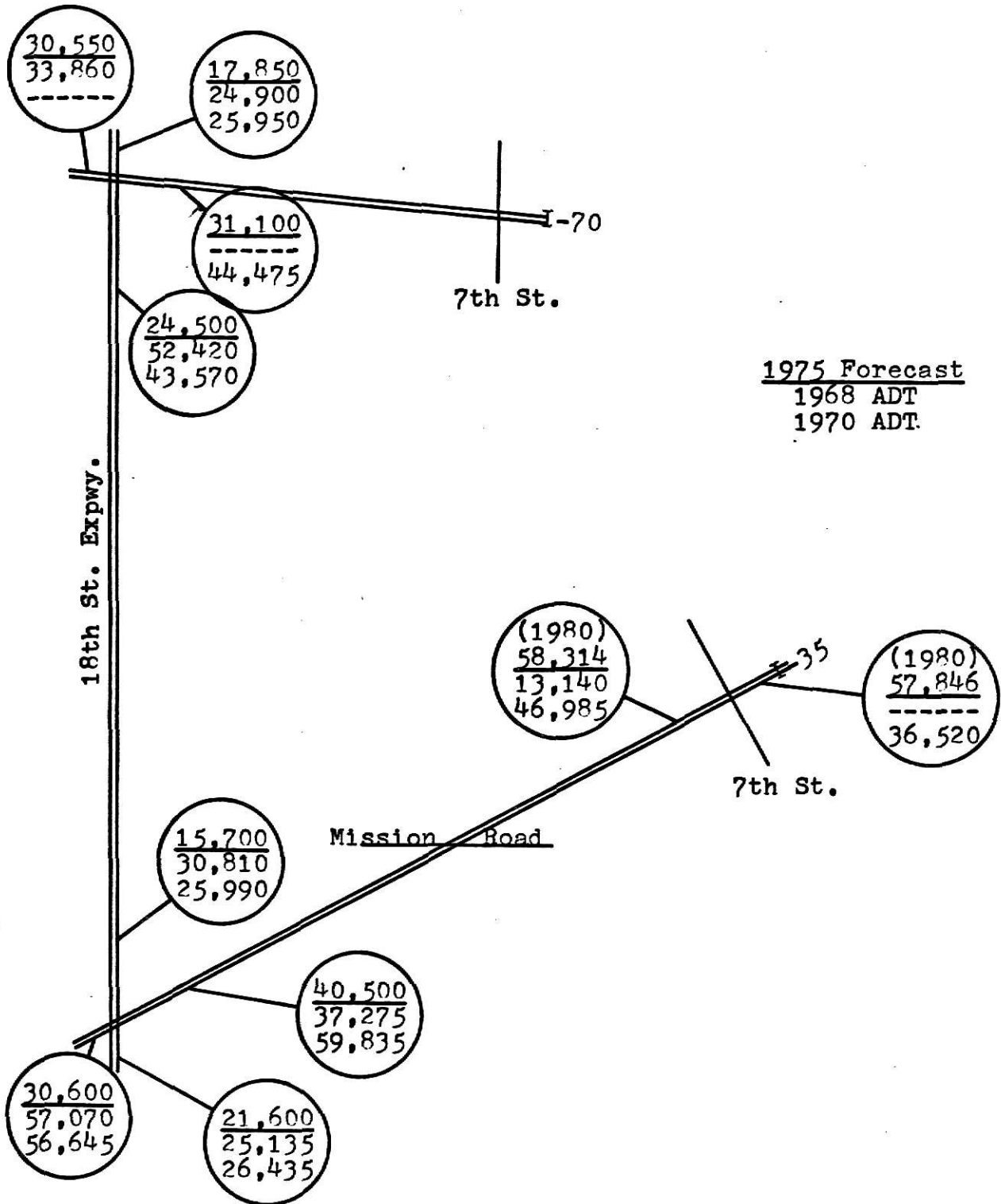
(Design Hourly Volume) DHV = 10% of ADT (Average Daily Traffic)

(Trucks) T = 5% of DHV

(Directional Split) DS = 60-40 during the peak hour

The following are design criteria used from the 1950 Highway Capacity Manual:(2)

- a) A 450 foot weaving section will accomodate 1500 passenger cars per hour at 30 miles per hour.
- b) A truck can be considered as 2 passenger cars. Forecast volumes must be properly adjusted.
- c) A normal ramp will accomodate 1200 to 1500 passenger cars per hour.
- d) The basic capacity for uninterrupted flow is 2000 passenger cars per lane per hour. This assumes adequate sight distance, adequate lateral clearance, no commercial vehicles, at least 2 exclusive lanes for use in one direction, and minimum speeds of 30 to 40 miles per hour.
- e) With 20 to 25% of the traffic leaving the freeway, it can be assumed that the traffic is split 50-50 between the two lanes.



Traffic Forecasts and Counts

(Figure 5)

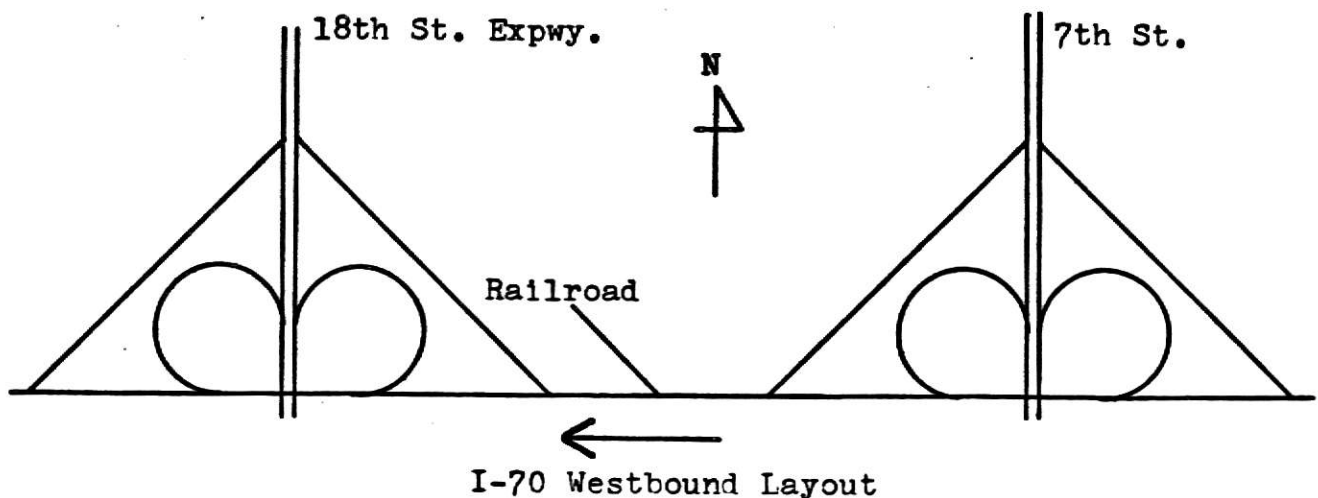
Design Procedure

To effectively analyze the study system, Subsystems A and C, I-35 and I-70, were analyzed separately. Then 18th Street Expressway was analyzed, incorporating the recommended designs of I-70 and I-35 at their respective interchanges.

The recommended design procedure has 5 steps: basic number of lanes, weaving, lane balance, ramps, and operational flexibility. These steps are detailed in the I-70 design procedure. The design of I-35 and 18th Street Expressway are given shorter, more general treatment than that of I-70.

I-70 Design

Figure 13, page 22, shows 5 schematic representations of I-70 between 7th and 18th, Westbound. This section consists of cloverleaf intersections at 7th and 18th and an access exit to



(Figure 6)

the railroad yard. The first 4 schematics of fig. 13, schemes A through D, show the number of lanes provided during various steps of the design procedure. The final scheme depicts I-70

as it is now operating. The following 5 step design procedure was done with forecast data for the original design made in 1956. The 1950 Capacity Manual was used.

A. Basic Number of Lanes

The basic number of lanes was determined by volume-capacity relationships. The following criteria were used:

$$ADT = 31,100 \text{ (fig. 5)}$$

$$DHV = 10\% \text{ of the ADT}$$

$$T = 5\%$$

$$DS = 60-40$$

- 1) The peak hour volume is 10% of the average daily traffic.

$$\text{Peak Hour Volume} = 31,100 \times 0.10 = 3110 \text{ vph}$$

- 2) The number of trucks during the peak hour is 5% of the peak hour volume.

$$\text{Trucks} = 3100 \times 0.05 = 155$$

Each truck is equivalent to 2 passenger cars.

$$\text{Equivalent Passenger Cars} = 155 \times 2 = 310$$

- 3) The design peak hour volume equals the peak hour volume minus the trucks, plus the passenger car equivalents.

$$\text{Design PHV} = 3110 - 155 + 310$$

$$= 3265 \text{ pcph (passenger cars per hour)}$$

- 4) The design volume, traffic in the major direction, equals 60% of this number.

$$\text{Design Volume} = 3265 \times 0.60 = 1960 \text{ pcph}$$

One lane cannot carry this traffic since 2 lanes are required to carry 2000 vehicles per hour. Therefore, I-70 requires

2 basic lanes over the entire section. Scheme A shows the basic number of lanes as 2 in all sections except section 10, which requires 3 lanes, carried over from the design East of 7th Street.

B. Weaving

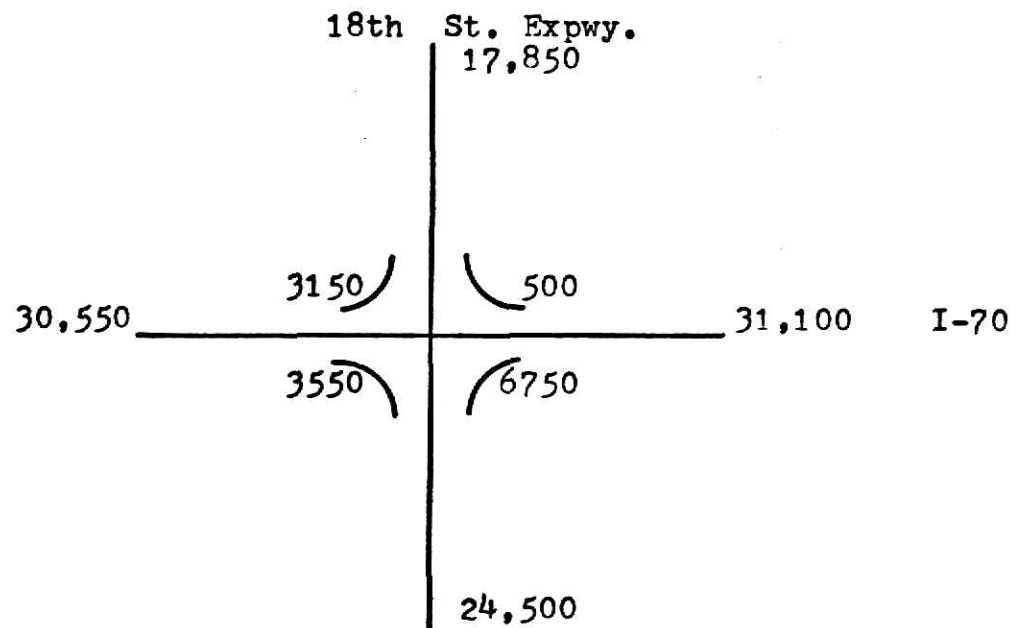
Examination of the schematic reveals 3 potential weaving sections. Table 1 (page 22) supplies the lengths of these sections:

<u>Weaving Section</u>	<u>Length</u>
3	400 ft
6	4400 ft
8	400 ft

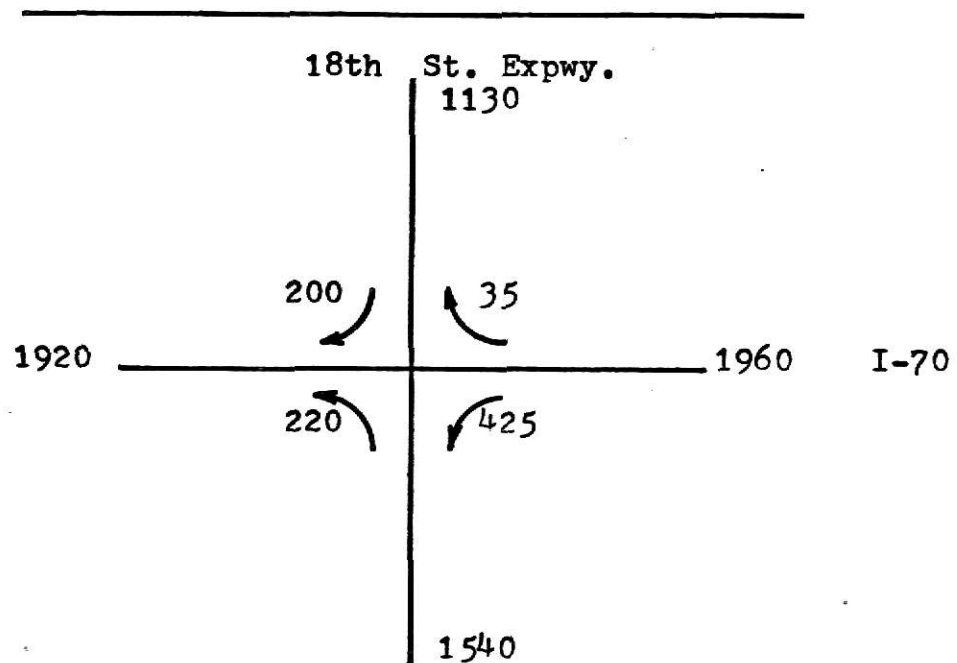
Because of the length of section 6 and very few turns at the railroad yard exit, it can be considered as a simple merging and then diverging movement, and does not have to be considered as a weaving section. However, a weaving analysis must be conducted for sections 3 and 8.

Section 3 is at the intersection of I-70 and 18th Street Expressway. Figure 7 shows the original traffic forecast for this intersection. The design volumes, fig. 8 were obtained by the same series of calculations outlined in part A of the I-70 design procedure.

The weaving section under study is represented in fig. 9. With 22% (425 of 1925) of the traffic leaving the freeway, it can be assumed that the traffic is split 50-50 in the 2 through lanes. Both lanes, therefore, carry 967 pcph ($\frac{1}{2}$ of 1925).

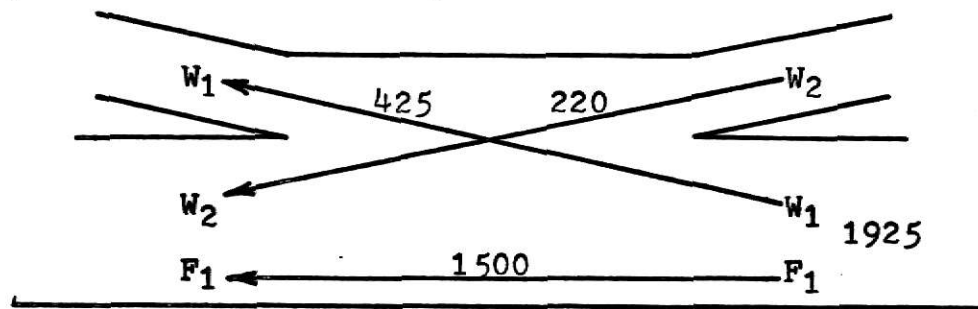


Original Traffic Forecast - I-70 and 18th Street Expressway
(Figure 7)



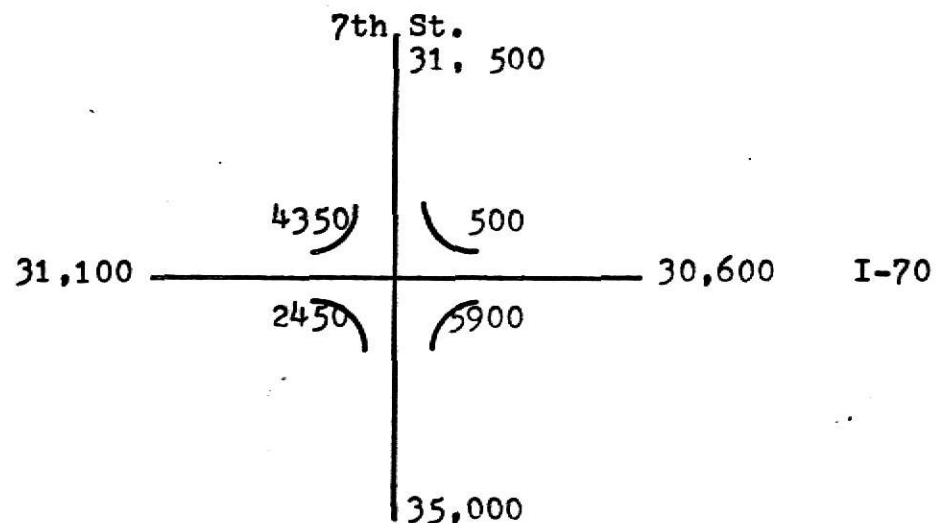
Design Volumes - I-70 and 18th Street Expressway
(Figure 8)

The 645 (425 + 220) weaving vehicles must contend with 542 (967 - 425) through vehicles. This is a total of 1187 vehicles in the weaving section. One additional lane should be adequate to handle the weaving traffic, although at a reduced speed from other portions of the freeway.

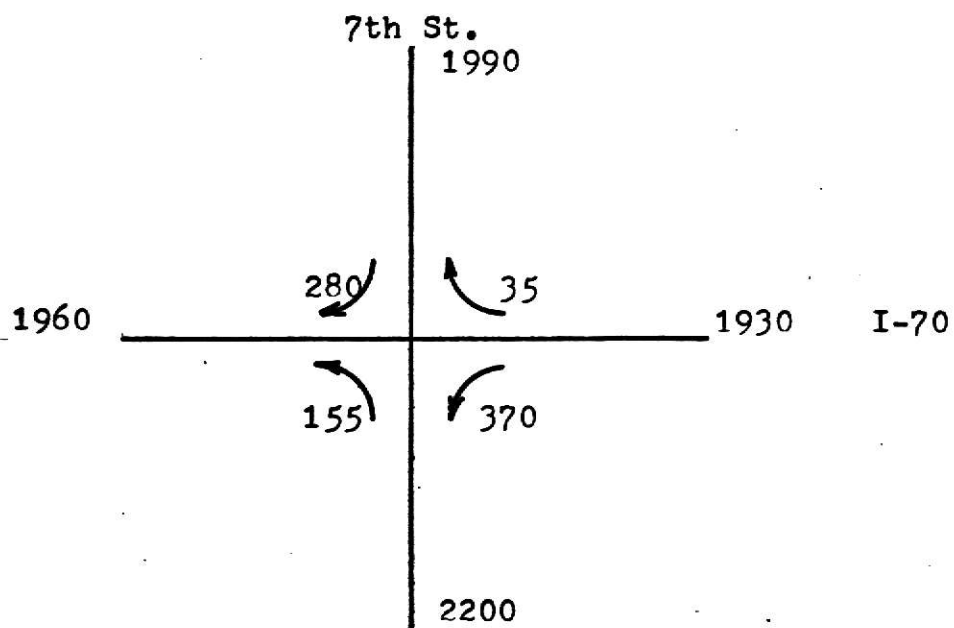


I-70 and 18th St. Expwy. Weaving Movements
(Figure 9)

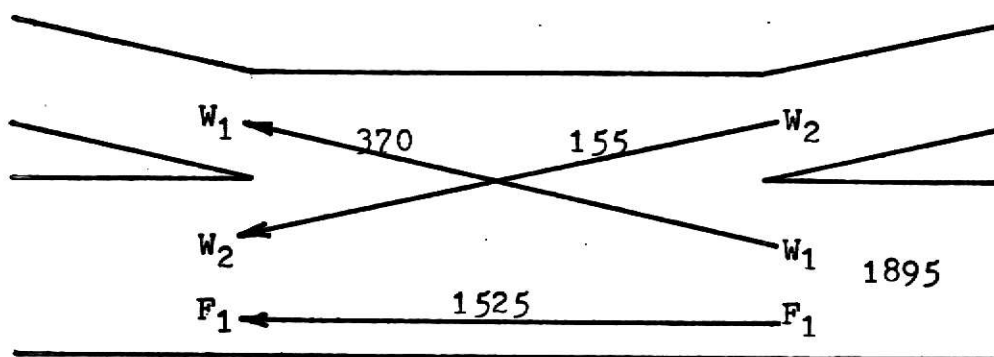
The forecast traffic volumes for section 8, the intersection of I-70 and 7th Street are shown in fig. 10, the design volumes in fig. 11 and the weaving movements are shown in fig. 12.



Original Traffic Forecast - I-70 and 7th Street
(Figure 10)



Design Volumes - I-70 and 7th Street
(Figure 11)



I-70 and 7th Street Weaving Movements
(Figure 12)

Following an argument similar to that above, a total of 1097 vehicles will use the weaving section, again requiring one additional lane. Scheme B shows the third lane added in sections 3 and 8.

C. Lane Balance

Reviewing the formula for lane balance:

$$N_c \geq N_e + N_f - 1$$

where: N_c is the number of lanes succeeding an entrance ramp or preceding an exit ramp;

N_e is the number of lanes on the entrance or exit ramp;

N_f is the number of lanes preceding an entrance ramp or succeeding an exit ramp.

The procedure of lane balance is not a cookbook method for lane determination. It requires that the designer be familiar with the study area and apply Engineering judgment to the positioning of the additional lanes.

The following analysis will start in section 10 and work from the right to the left in the direction of traffic flow.

Section 10 has 3 lanes. Therefore, section 9 plus ramp J must total at least 4 lanes:

$$N_c(10) \geq N_e(J) + N_f(9) - 1$$

$$N_c(10) + 1 \geq N_e(J) + N_f(9) - 1 + 1$$

$$4 = 3 + 1 \geq N_e(J) + N_f(9)$$

A one-lane ramp is sufficient, therefore section 9 must have 3 lanes. (see scheme C)

Assuming ramp I needs 1 lane, plus the 3 lanes of section 9

minus 1 requires at least 3 lanes for section 8. Since the basic number of lanes and weaving analysis require 3 lanes, there is no change in section 8.

Section 7 plus ramp H must have a total of 4 lanes since section 8 has 3 lanes. Beyond 7th Street, the forecast traffic volumes do not require more than 2 lanes, therefore to satisfy the lane balance requirement of 4 lanes, 2 lanes will be assigned to both section 7 and ramp H.

Sections 4, 5, and 6 all require 2 lanes with one-lane ramps E, F, and G. However, section 3, although requiring only 2 lanes for lane balance needs 3 lanes to satisfy the basic number of lanes and weaving. These 3 lanes in section 3 dictate 4 lanes for section 2 plus ramp C. Again, because of no forecast need for more than 2 lanes on I-70, 2 lanes will be assigned to both section 2 and ramp C. Section 1 requires 2 lanes with a one-lane ramp B.

The inclusion of lane balance with the basic lanes and weaving has added 1 additional lane to section 9 and made all ramps 1 lane, with the exception of ramps C and H which require 2 lanes. The composite design is shown in scheme C, fig. 13.

D. Ramps

The 1950 Capacity Manual used as the only design criteria for ramps a volume of 1200 pcph/lane. No ramp is forecast to exceed this volume, therefore no additional lanes are needed on the ramps.

E. Operational Flexibility

The inclusion of operational flexibility involves the principle of "one more lane going away." This step again requires Engineering judgment and a feel for traffic operations on the freeway in it's application. When combined with all the other methods for determining the number of lanes, this step produces significant operational flexibility on freeways in handling traffic loads beyond design hourly volumes.

Scheme D shows the final recommended design based upon all factors. Extra lanes, beyond scheme C, are provided in sections 6, 7, and 8. The extra lane in section 8 is necessary to provide smooth traffic flow through the weaving section. With 3 lanes approaching in section 9 and the one-lane ramp I merging, an extra lane is desirable to enable sufficient weaving to take place before the 2 lane exit.

Lane balance dictates the extra lane in sections 6 and 7. Without the extra lane in section 7, traffic from ramp I would have to weave through 2 lanes of traffic in approximately 400 feet to avoid exit ramp H.

The final schematic of fig. 13 depicts I-70 as it is operating today. By comparing with scheme D, it is noted that the only additions brought about by Leisch's method are the addition of one lane to each of ramps C and H. The significance of this will be analyzed after the design of the other segments of the study system are discussed.

I-35 Design

The methodology for the design of I-35 Westbound between

OVERSIZED DOCUMENT

**THE FOLLOWING DOCUMENTS ARE BEING
FILMED IN SECTIONS.**




**THE FOLLOWING IMAGES WILL BE TAKEN
FROM LEFT TO RIGHT, TOP TO BOTTOM.
SEE EXAMPLE BELOW:**

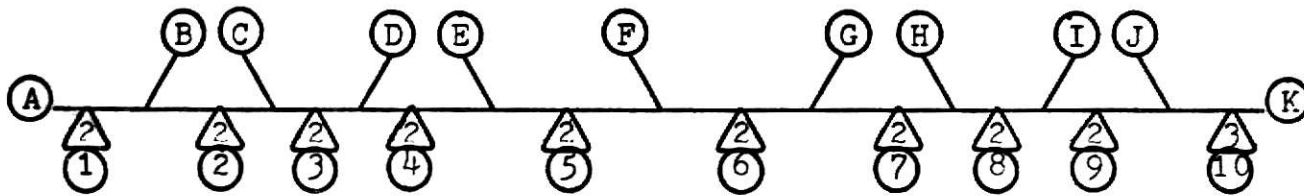
1	2	3
4	5	6
7	8	9

<u>Section</u>	<u>Length</u>
1	
2	500
3	400
4	500
5	4200
6	4400
7	600
8	400
9	500

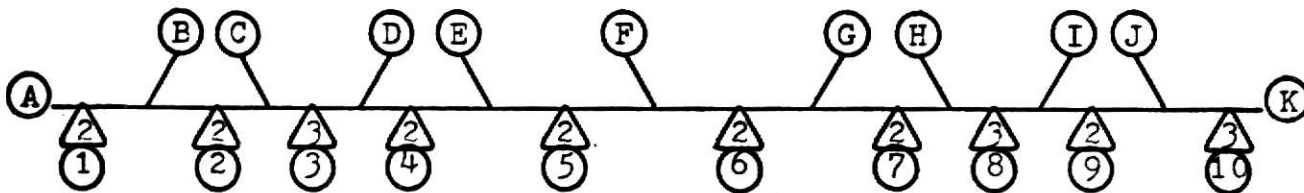
I-70 Westbound Section Lengths
(Table 1)

Legend

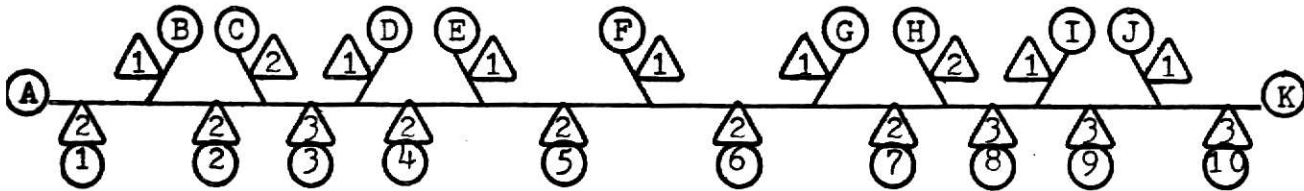
-  Number of Lanes
-  Section Identification
-  Ramp Identification



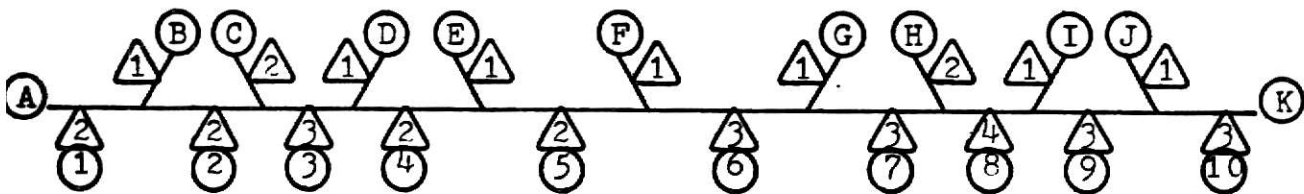
Scheme A: Basic Lanes



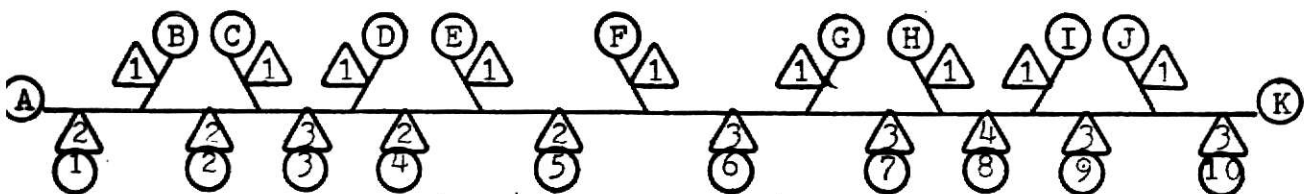
Scheme B: plus Weaving



Scheme C: plus Lane Balance



Scheme D: plus Operational Flexibility

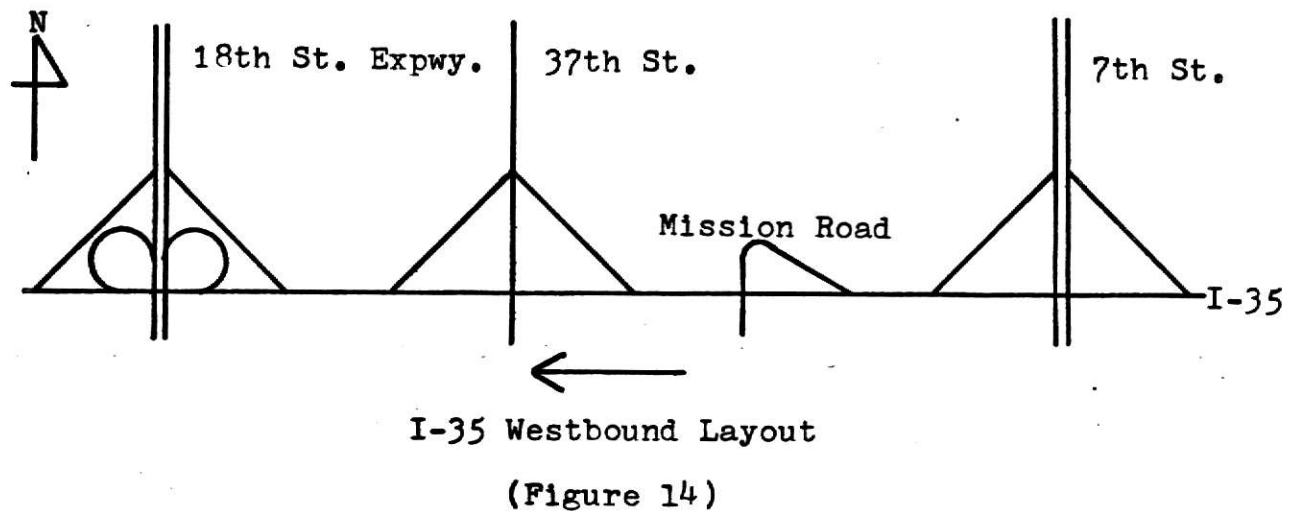


Existing Design

I-70 Westbound Schematics for Design

(Figure 13)

7th Street and 18th Street Expressway is the same as that for I-70. The 5 schematics are pictured in fig. 15 on page 25. Working right to left in the direction of traffic flow, I-35 intersects 7th Street with a diamond type interchange, a single off ramp at Mission Road, a diamond at 37th Street, and a clover-leaf at 18th Street Expressway.



A. Basic Number of Lanes

The forecast traffic volumes on I-35, fig. 5, indicate that East of Mission Road, 58,314 ADT requires 3 basic lanes, and West of Mission Road, 40,500 ADT requires 2 basic lanes. See scheme A.

B. Weaving

From the schematic, potential weaving sections are:

<u>Weaving Section</u>	<u>Length</u>
3	650 ft
5	5670 ft
8	5810 ft

Table 2 (page 25) supplies the required lengths. The lengths of sections 5 and 8 place them out of the realm of weaving, leaving only section 3 to consider. An analysis identical to those conducted for the weaving sections on I-70 will result in the need for 1 additional lane to handle the weaving maneuver in section 3. Scheme B depicts this third lane.

C. Lane Balance

Lane balance results in the addition of one extra lane in sections 4 and 5, and an additional lane on ramp C. Again the extra ramp lane was needed to bring the total number of lanes of section 2 and ramp C to 4, satisfying the need resulting from 3 lanes in section 3 and the lack of need for a 3 lane facility beyond 18th Street Expressway on I-35.

D. Ramps

No forecast volumes exceed 1200 pcph, therefore no additional ramp lanes are required.

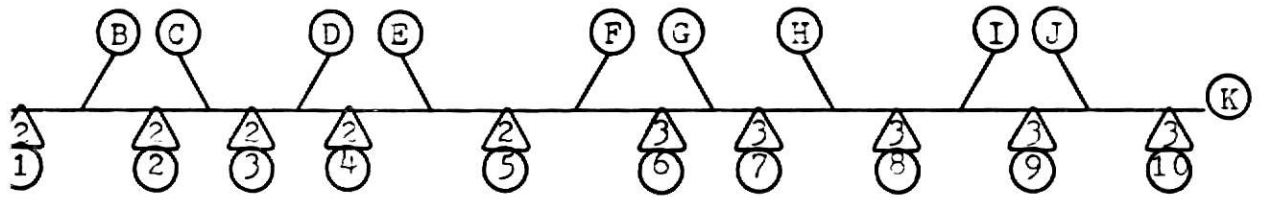
E. Operational Flexibility

To achieve operational flexibility, one additional lane is required in sections 1, 2, and 3. The need for the extra lane is again dictated by the 2 lane ramp, similar to the intersection of I-70 and 18th Street Expressway.

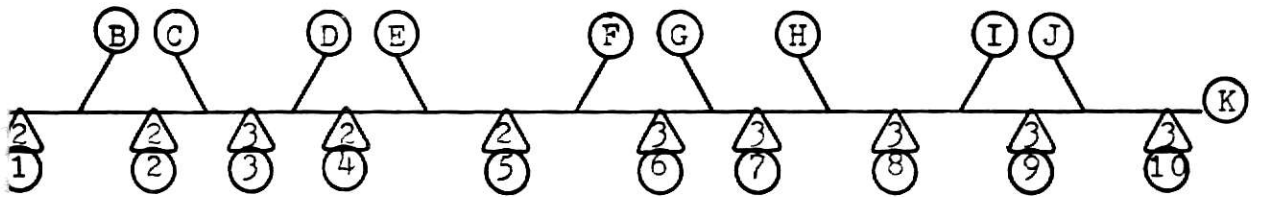
The final schematic of fig. 15 depicts I-35 as it is presently constructed. Again, the only difference between the existing and the hypothetical designs is the addition of 1 lane to a ramp, ramp C in this case, making it a 2 lane ramp.

18th Street Expressway Design

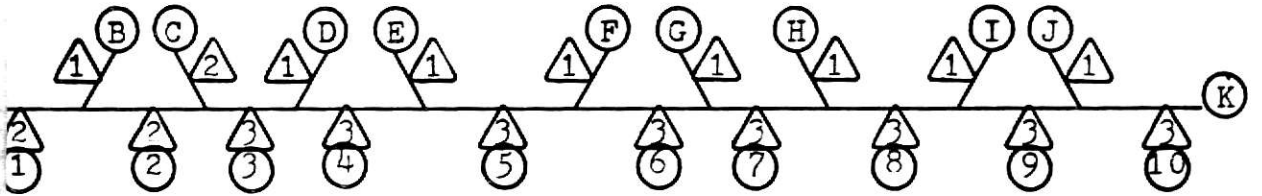
Introducing 2 lane ramps at the intersections of the 18th



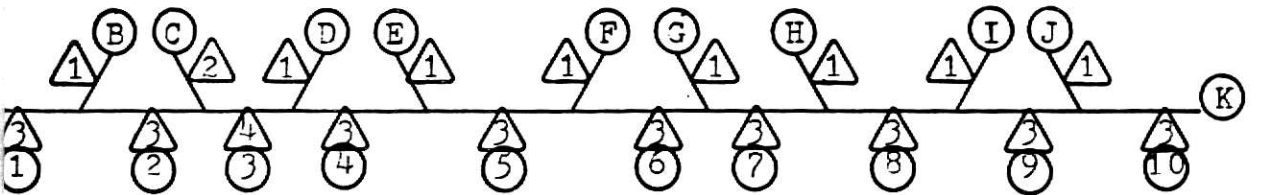
Scheme A: Basic Lanes



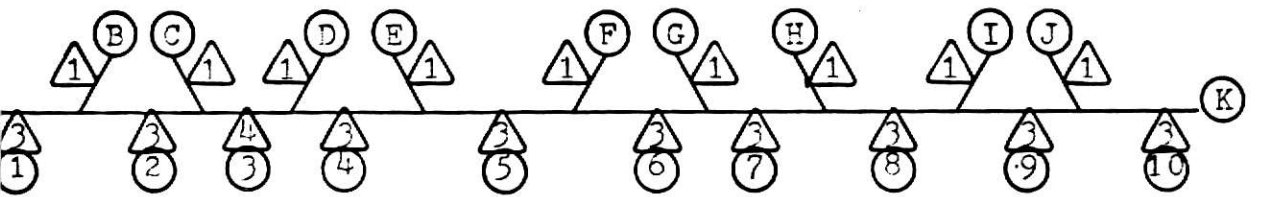
Scheme B: plus Weaving



Scheme C: plus Lane Balance



Scheme D: plus Operational Flexibility



Existing Design




I-35 Westbound Schematics for Design

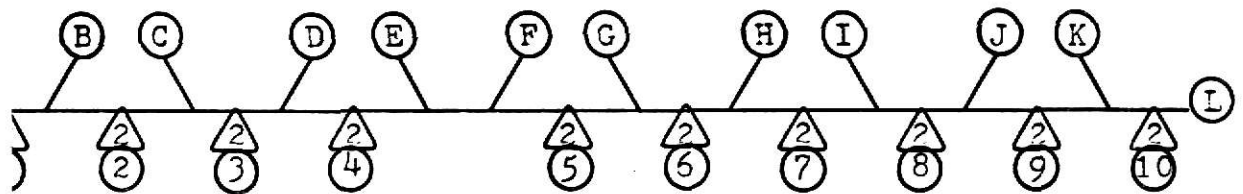
(Figure 15)

<u>Section</u>	<u>Length</u>
1	
2	175
3	650
4	175
5	5700
6	1600
7	1100
8	5800
9	1600

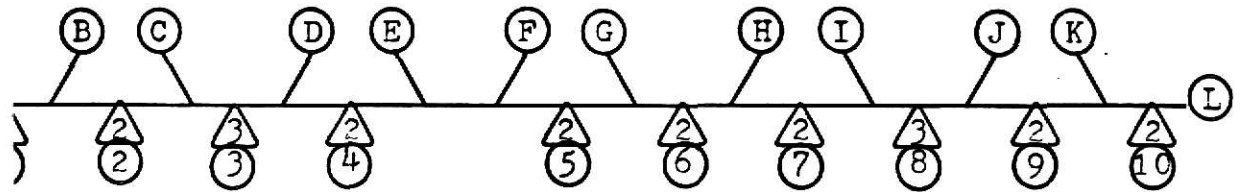
I-35 Westbound Section Lengths
(Table 2)

Legend

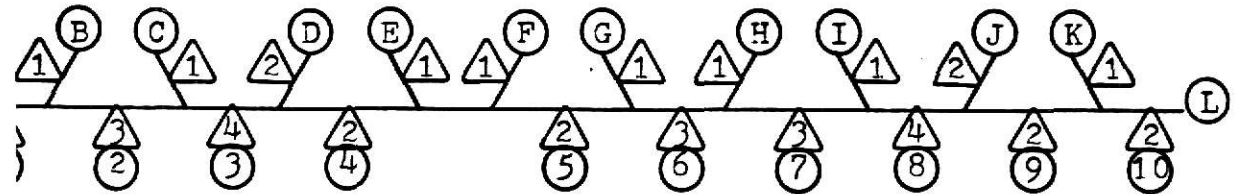
-  Number of Lanes
-  Section Identification
-  Ramp Identification



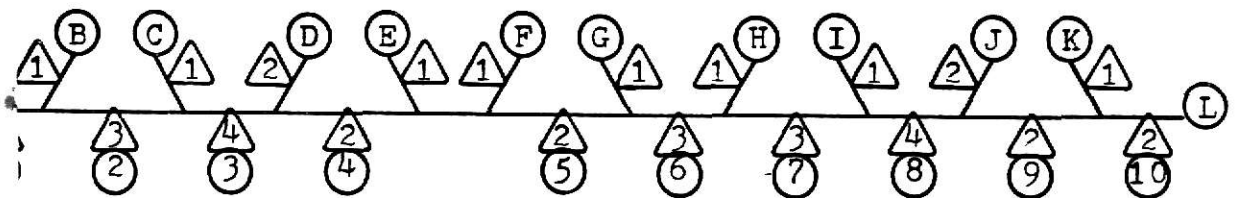
Scheme A: Basic Lanes



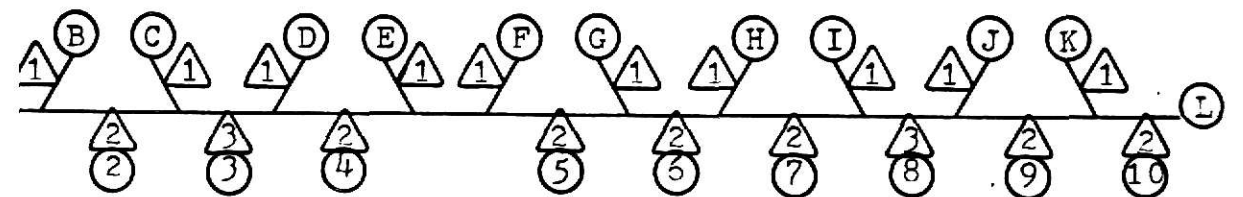
Scheme B: plus Weaving



Scheme C: plus Lane Balance



Scheme D: plus Operational Flexibility



Existing Design




8th Street Expressway Southbound Schematics for Design

(Figure 16)

<u>Section</u>	<u>Length</u>
1	2000
2	400
3	375
4	525
5	1100
6	2000
7	500
8	400
9	500

18th Street Expressway Southbound Section Lengths
(Table 3)

Legend

-  Number of Lanes
-  Section Identification
-  Ramp Identification

END

OF

OVERSIZE

DOCUMENT(S)

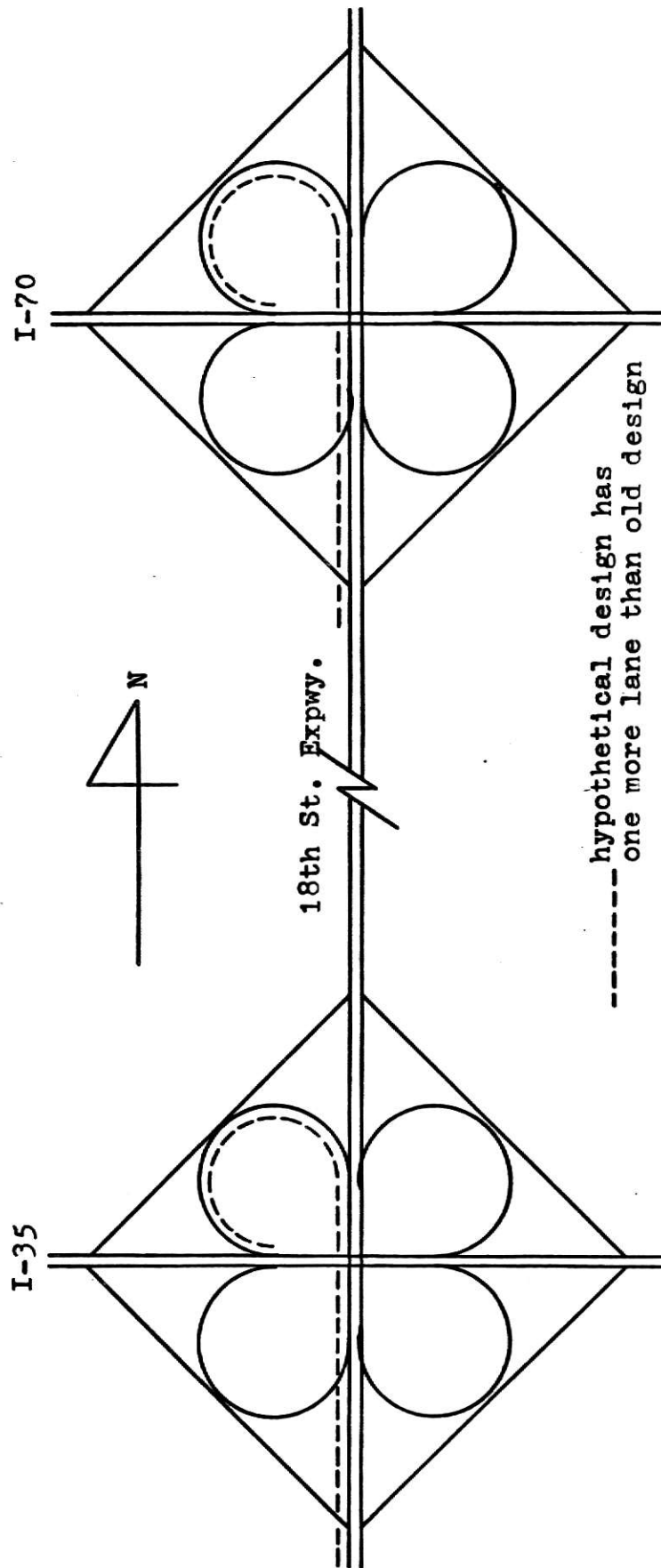
Street Expressway with I-35 and I-70 necessitates some design changes on 18th Street Expressway. Figure 16 on page 26 shows the step-by-step procedure of design used in the two previous subsystems applied to this subsystem. The final design, scheme D, when compared to the existing design reveals that to accommodate the additional ramp lanes, an extra lane is needed in sections 1, 2, 3, 11, 12, and 13.

The New Design and It's Implications

Figure 17 on page 28 presents 18th Street Expressway from I-70 to I-35 showing both the existing number of lanes and the resulting increase in the number of lanes if Leisch's method of design had been used. The question now before us is: Would the increased number of lanes improve the level of service of the freeway system?

Obviously, an increase in the number of lanes is going to permit more vehicles to pass a certain point in a specified period of time, thereby increasing the capacity of the freeway at that point. But, as stated in the introduction to this report, traffic congestion is caused by demand exceeding the capacity of a few bottleneck sections. Hence, the critical question is: Are these additional lanes strategically placed on the system so as to tend to alleviate the strain on these bottlenecks? The answer is yes!

This study area was selected because of the traffic congestion caused by vehicles desiring to make an East to South movement during the P.M. peak hour, the very movement that would make use of the ramp that provides 2 lanes when using Leisch's method.



Comparison of Old and Hypothetical Design

(Figure 17)

With the addition of this 2 lane ramp, the freeway would provide about double the capacity that presently exists for traffic leaving downtown Kansas City, destination Johnson County, when turning from either I-70 or I-35 onto 18th Street Expressway.

Having physically established justification for the extra lanes, the economics of their addition now confronts us. A rough cost figure for the construction of concrete pavement in 1959 was \$10 per square yard. The length of the additional lanes on 18th Street Expressway is approximately 2900 feet at each intersection. The length of the ramps is approximately 800 feet. Assuming a 12-foot expressway lane and a 16-foot ramp lane:

$$2900 \times 12 = 34,800 \text{ s.f.}$$

$$800 \times 16 = \underline{12,800} \text{ s.f.}$$

$$47,600/27 = 1763 \text{ sq. yd.}$$

Thus, the additional cost for each intersection is approximately \$18,000.

To compare this \$18,000 cost with a benefit, let us calculate approximate time costs saving if the additional lane were provided on the ramp at the intersection of 18th Street Expressway and I-35. From fig. 5, in 1970 there was an ADT of 59,835 East of 18th Street Expressway on I-35. Multiplying by 10% peak hour and 60% major direction produces a traffic volume of 3590 traveling west on I-35 during the P.M. peak hour.

Presently these vehicles are moving about 20 mph. With the additional lane, estimated speeds of 35 mph might be

attained. Time costs at 20 mph are 6.8 cents/veh-mile, time costs at 35 mph are 3.8 cents/veh-mile. (6) This is a saving of 3 cents/veh-mile. Assuming a conservative average queue of $\frac{1}{2}$ mile in which vehicles travel at 20 mph, total saving is:

$$3590 \text{ vehicles} \times \frac{1}{2} \text{ mile} \times 3 \text{ cents/veh-mile} = \$54/\text{day}$$

The resultant saving is \$54/day or \$216/week or \$11,232/year.

This saving, on an \$18,000 investment, yields a return of 60% with only a 10 year life, a very worthwhile return on any investment.

CONCLUSION

Based upon this study, the inclusion of lane balance and the basic number of lanes techniques into the design procedure for urban freeways would appear to improve the traffic operations of the entire freeway system. Certainly, the test section of this study would operate more efficiently if Leisch's methods had been incorporated into the original design, with only a moderate increase in the overall cost of the projects.

The addition of the extra lanes might also serve to increase the safety of the freeway. The first five months of this year, 1970, there were 20 daytime accidents, 3 resulting in injuries, at the intersection of I-70 and 18th Street Expressway. The relatively few injury accidents, 5 out of 32, on facilities with speed limits of 55 to 60 mph indicates the lower speeds of the vehicles involved, implying turning vehicles. With extra lanes provided for merging and diverging traffic, more through lanes are supplied, removing some of the conflict between through and turning vehicles. It seems that this would surely reduce accidents.

The flexibility provided by the extra lanes would also prove useful when vehicles either stalled or involved in an accident blocked a lane. Under present conditions, an accident during the peak hour on the ramp serving the East-South movement would have a disastrous effect on the freeway system. The resulting queue might stretch for miles creating chaos at intersections upstream from the actual location of the accident. However, with 2 lanes, the second lane could maintain operations and

also provide access for emergency vehicles.

However, it must be mentioned that any future design is based upon traffic forecasts. Without a reasonably close forecast, no design procedure will supply sufficient future system capacity. A glance at fig. 5 reveals the ineptness of some forecasts. As can be seen, most of the present volumes are well in excess of the forecast volumes, the only exception being at the intersection of I-35 and 7th Street where forecasts were made for 1980.

The art of traffic forecasting is very sensitive to future changes. One of the major problems with the aforementioned forecasts was the population forecast for Johnson County for 1975, which has already been well surpassed. Any change in land use, a large sports complex, a shopping center, an industrial park, are all going to change the volume of traffic wishing to utilize the facility.

Traffic forecasts must be made with a thorough knowledge of the metropolitan region involved. The forecaster, with the aid of the City Planners, must attempt to accurately predict what future conditions will be. Through the location of freeway facilities and various traffic generators, an attempt must be made to shape the demand, rather than let the land develop around freeways without the forecasters having already considered their effects upon the traffic. The great uncertainty of the future is a good argument for the operational flexibility built into a freeway system by incorporating basic number of lanes and lane balance into the design.

SUMMARY

This project was started with the single aim of applying Leisch's methods to the design of a section of freeway. However, a need for some digression soon became apparent.

While discussing this project with interested parties, a question was raised about convincing politicians of the need for additional lanes. It seems that the inclusion of strategically located additional lanes on one particular freeway would be preferable to an underdesigned freeway which would require another freeway nearby to help carry future traffic, especially at such a low additional cost.

The design and the implementation of that design requires more than one department being involved. From several comments, it was deduced that no department involved in freeway design is completely satisfied with either their final product or information supplied from other departments. The solution would appear to be in a team approach to not only freeway design, but to any large engineering undertaking. The structure of existing hierarchies, which dictates a circular flow of information, just doesn't have it. A memo requesting information written by a subordinate, checked by a supervisor, signed by a department head, sent to another department head, and passed down 2 or 3 steps to the poor guy who must decipher the message and return some answer - through the same channels - will not satisfy either party involved. It would seem that if all interested parties involved, in this case Planners, Traffic Engineers, Designers, and Politicians, would sit down together and discuss the project

and all it's consequences, a much more effective design could be arrived at and ultimately implemented.

Further Studies Suggested

The test section used in this study presently has no more than 3 lanes along it's entire length. The methods tested have been designed for wider freeways, 6 to 8 lanes with 2 or 3 lane ramps. A check of a facility this size might prove interesting, possibly a section where no great traffic problems occur.

A more detailed study of this area might also prove interesting. The scope of this study limited research to simply forecast and present traffic counts. Determining turning movements, percent trucks, and other traffic characteristics would definitely aid in the final analysis.

However, the author feels, that even without further testing these methods have merit and should be incorporated into the design of future urban freeway systems. The ultimate test will be the operational capabilities of a freeway network designed with the techniques of lane balance and the basic number of lanes.

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BASIC NUMBER OF LANES AND LANE BALANCE:
THEIR USE IN URBAN FREEWAY DESIGN

by

MICHAEL CHARLES CONNORS

B.S., University of Nebraska, 1968

AN ABSTRACT OF A MASTER'S REPORT

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requirements for the degree

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Kansas State University
Manhattan, Kansas

1970

The transference of people and goods from one point to another in present day urban areas is becoming an increasingly complex problem. In almost all cases the trip can be considered as a joint commodity, secondary to the real purpose, be it work, shop, social, or whatever. Therefore, the trip should be completed as quickly as possible. Traffic congestion, caused by bottlenecks on the system, delays this movement and therefore an attempt must be made to eliminate it.

When freeway design is based strictly upon volume-capacity, as most are today, the greatest importance is placed upon the traffic forecast. This forecast, usually 20 years in the future, is based upon other forecasts, namely population and land use. Either one of these forecasts may be completely inaccurate, thus resulting in an inaccurate traffic forecast. Even with accurate population and land use forecasts, the process of forecasting traffic is not completely foolproof. To base a design strictly on a foundation as instable as this doesn't make sense. Some method to provide more flexibility into the design would seem to be desirable.

Five years ago, Jack Leisch proposed two new concepts for the process of freeway design. These tools, lane balance and basic number of lanes, seem to provide a systematic method for ironing out the bugs that appear in a strict volume-capacity design.

This paper presents the results of a test of this method conducted in Kansas City. It appears that the new techniques give very satisfactory results. The new hypothetical design provides additional ramp lanes, at very low cost, at the two bottleneck

interchanges in the study system. Perhaps lane balance and basic number of lanes provide the factor of safety prevalent in other Engineering design, but seemingly lacking in highway design.