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FINAL REPORT

CORRIDOR ANALYSIS FOR LEVEL OF  
SERVICE DESIGN

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Research Report 30-3F

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## DISCLAIMER

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## INTRODUCTION

As the major urban areas of Texas continue to grow in population and land area, the need for consideration of traffic service on a total corridor basis takes on much greater importance. The fiscal, social and environmental constraints on totally new freeway development require that the highway engineer achieve maximum utility from present freeway corridors. However, when by applying the most innovative concepts and modern design features, it is obvious that the existing freeway system in large urban areas, by itself, will be unable to efficiently serve ever-increasing volumes of vehicular traffic without experiencing a concomitant degradation of efficient and free-flowing operation, particularly during peak hours. Thus, it has become necessary that operational restraints be imposed on freeways to preserve an acceptable level of service, and that the traffic thus diverted through the restraining actions be accommodated on other facilities within the transportation corridor. Further, this possibility must be evaluated at the earliest planning stage so that alternative actions may be considered. These alternatives must also be explored as they would apply to variable possibilities of land use and development within the influence of the transportation corridor.

To provide an acceptable quality of service within the total corridor, it has become necessary to alter and expand the design process to encompass the coordination of planning, design and operations on all facilities within the corridor, and to develop methods and techniques of obtaining the information necessary to support the corridor design process.

This research has been conducted in an effort to improve the design process for transportation corridor facilities. Part of the research dealt with identifying and evaluating the current design recommendation process, while another phase dealt with functional classification, qualitative measures of traffic service, and the effects of mid-block access on traffic operations.

## Study Objectives

The research proposal states a general objective as follows:

"The objective of this study is to develop cooperatively a design recommendation process which effectively coordinates planning, traffic data, design, and operation to provide effective levels of service for the urban corridor."

After meeting with an advisory committee to the study, it was decided that the study should be divided into two specific tasks:

### TASK A - EVALUATION OF THE DESIGN RECOMMENDATION PROCESS

Task Objective - To identify the design recommendation process now being followed in selected districts of the department with particular emphasis on traffic data and corridor analysis procedures.

### TASK B - A STUDY OF TRAFFIC SERVICE MEASURES FOR ARTERIAL HIGHWAYS

Task Objective - To analyze the factors affecting the capability of urban highway routes to handle traffic in relation to the service provided.

TASK A  
EVALUATION OF THE DESIGN RECOMMENDATION PROCESS

The planning/design process is handled, to a large degree, by the personnel in various district offices. Understandably, the procedures vary from district to district, depending on the background and experience of district personnel, and the nature of local design problems. Therefore, the department felt that the first phase of the study should be devoted to identifying the design recommendation process in several of the districts. Such a study may provide information to other districts on how their process may be improved. Further, the study should reveal some of the technical problems that may be treated in Task B of this study.

Study Procedures

To collect information relative to the design recommendation process, preliminary interviews were conducted in District 2 (Fort Worth), District 12 (Houston), District 19 (Atlanta), and District 24 (El Paso). After the preliminary interviews, it was decided that detailed studies should be concentrated in two districts (District 2 and District 24) which represent basically different approaches to the design process. Results of the detailed interviews are reported separately.

It should be recognized that all district offices provide planning/design/operations functions, but the organizational structure to accommodate these functions varies considerably. In the Fort Worth district the planning and operations functions are combined, with the services provided by the district traffic engineer. From all indications, this arrangement is preferred because it provides for the direct input of traffic operations requirements at the earliest possible stage. Throughout the design process there is constant coordination between design and planning/traffic.

In the El Paso District, the planning engineer is a part of the design group. Because of the sequence of events in the planning/design/operations process, early input of traffic operations requirements is not inherent; the design group must have traffic operations expertise within the design group or establish a continuous review process to involve traffic operations personnel in the planning decisions.

#### District 2 (Fort Worth)

For the purpose of this study, two design projects being conducted in the district were selected for study. These projects were a section of Interstate 820 in northwest Fort Worth, and FM 157 - Matlock Road as parallel roadways constituting a system in Arlington, Texas. From the standpoint of utilizing traffic data in the design process, the two projects are not greatly different, except in the process of considering alternative designs. In the case of the interstate highway, the class of facility is established; the major design effort pertains to the location and geometric design of the facility. In the case of the FM 157 - Matlock the planning/design process involves the consideration of different classes of facilities as well as the location and geometric design of these facilities. For example, the alternatives considered for the FM 157 - Matlock system are as follows:

1. The FM 157 - Matlock system with both as arterial streets.
2. The FM 157 - Matlock system with Matlock as a boulevard type facility.
3. The FM 157 - Matlock system with Matlock as a freeway type facility.

The analysis of these alternatives is done at the local level with the coordinated efforts of design and traffic groups of the district.

The "design recommendation process" is assumed to begin after a project is programmed and includes the many design decisions which lead to the completion of a Route Study Report and ultimately to the preparation of final plans for the project. Although it is recognized that such a project is extremely complex,



involving many disciplines, the major concern in this study is the use made of traffic data and the manner in which it is applied to achieve a design that is responsive to projected traffic needs. Therefore, many of the unrelated facets of the design process may be omitted.

The design recommendation process begins in the district design office, referred to as "Design," with the preparation of a "Geometric," a very preliminary plan of the proposed route. This plan will be modified and expanded as additional design information is gathered.

The initial preparation of the Geometric is based on the basic traffic assignment of the Urban Transportation Study and the Comprehensive Plan. Design requests from the district traffic and planning office referred to as "Traffic," volume data for the proposed route. Traffic furnishes ADT data from the Comprehensive Plan to set in motion a more or less continuous flow of traffic data, up-dated and expanded as the project progresses. Such projects may take several years to complete, and therefore it is necessary to keep the design information as current as possible.

The traffic group immediately begins an analysis of factors that will influence traffic data and in turn, influence the design decisions relating to the project. These include changes in land development, and changes in the street system. In the case of I-820 in northwest Fort Worth there were some significant changes in the development of the General Dynamics Plant facilities, and in the land development in the area. These changes are reflected in the ADT data furnished design.

The Traffic group requests from the Planning Survey Division (D-10) design year volume estimates for the proposed route. Accompanying this request is the information described above relating to changes in development and land use.

Thus, D-10 is provided with an on-site observation of growth rate and traffic generation characteristics that can be reflected in the volume projections.

The information provided by D-10 in response to this request consists of ADT values for the design year for the main lanes and for the interchanges. Before the volume projections are transmitted to design, they are checked for reliability by the traffic group on the basis of the on-site observations of the land use and development.

At times the Design group may be considering stage development alternatives and request design data for some year other than the design year. Such a request is handled in much the same manner as the request for design year volume estimates. The important point is that the Traffic group assists the Design group in the analysis of local conditions, communication with the central planning agency, and evaluation of the reliability of volume estimates based on their knowledge of local conditions.

As the Design group progresses through the early stages of preparing the Geometric, they are constantly considering various alternative route locations, analyzing the relationship of these alternatives to the highway network and development. The proposed route begins to take form through the reduction of alternatives and the establishment of interchange types required to handle the estimated traffic volumes and serve the highway network and land development. Realistic ADT values serve the preliminary processes quite adequately, but more specific data are needed as the proposed route begins to take on a specific form. In order to achieve more specific volume estimates, the traffic group again prepares revisions in the traffic forecast and a zone map of the major traffic generators in the general area. This information, along with the preliminary Geometric of the proposed route is submitted to D-10 as the basis for up-dating traffic estimates. With this volume estimate, the district is furnished

values for D, directional distribution of traffic, K, the percent of traffic during the peak hour for the design year, and T, the percent of trucks in the peak hour during the design year. This detail of information provides for the determination of demand volumes for the main lanes and interchange movements. Thus, the proposed route can be "sized" on the basis of a level of service analysis. In fact, the Design group will perhaps prepare alternative interchange layouts for traffic analysis.

At this point, the traffic group is requested to analyze the interchange alternatives for operational efficiency. This analysis procedure is much more extensive than a level of service analysis. The traffic group must consider the traffic flow characteristics of the interface between the proposed route and the existing street system. Further, the capability of the street system to accommodate the estimated demand volumes must be analyzed. In essence, the traffic group must analyze the corridor as it relates to the proposed route.

To perform the analysis of the corridor area, the traffic group must have information on projected development of the city street system. This information is frequently difficult to obtain, because some cities may not plan sufficiently. Their process could be described as reactionary rather than preparatory. They respond to immediate needs rather than future needs.

Through a continuous process of design, analysis, and refinement of traffic data, a proposed project is methodically "boiled down" from several broad alternatives to a preliminary design to be presented for further consideration through the public hearing process, and eventually to the construction stage. The success of the project is obviously dependent upon the proficiency of the design group; however, the proficiency of the design group depends to a great degree on its capability to obtain sufficient traffic data and the correctness of interpreting

and applying traffic data. The Fort Worth District has found that a close coordination of the design and traffic/planning groups greatly enhances the design process. Because the design process for any given project spans several years, there are several operations that are fundamental to the coordination of the activities of the two groups. These are summarized as follows:

1. All requests for traffic data are channeled through the traffic group.
2. The traffic group recognizes the need for expediency in providing traffic data, and therefore it handles requests to whatever extent possible from the Urban Transportation Study and Comprehensive Plan.
3. The traffic group recognizes the constantly changing conditions (development and land uses) that affect traffic forecasts, and constantly update their files through on-site observations.
4. The traffic group handles all communication with the Planning Survey Division (D-10) in requests for design traffic data. They also provide D-10 with up-dated projections of traffic generation characteristics.
5. As the design group revises its design through the various preliminary stages, the traffic group requests up-dated traffic data. On a more or less routine basis, the traffic group supplies information to the central planning agency in order to maintain a current data bank.
6. The traffic group maintains a continuing communication with the city in order to integrate any changes in the city street system into the traffic data file.
7. The design group calls upon the traffic group for analysis of specific design alternatives from the standpoint of operational efficiency. This step gives the traffic group the opportunity to develop the traffic control plan simultaneously with the geometric design of the facility.

8. On the subject of the sufficiency of the traffic assignment process, both the design and traffic groups feel that the value of traffic assignment is totally dependent upon local input. Without the continuous review and up-dating process provided by the traffic group, the traffic assignment process would be of very limited value.

9. The design group has pointed out that the traffic assignment process as used in the district has, in general, made it possible to design and build a roadway that is reasonably sufficient. From their viewpoint, there was no acceptable alternative available to them.

#### District 24 (El Paso)

As a basis for the interview in the El Paso, two proposed highway projects were selected. These were a freeway-type facility along the general path of Montana Street, to replace the Carlsbad highway, and Dyer Street, an eleven-mile TOPICS project to modernize the design of an existing facility. At the time of this study, the freeway-type facility had not progressed beyond the preliminary consideration of alternative actions and alternative routes. However, there was sufficient progress to ascertain the general design recommendation process.

First, there are some major differences in the district organization as compared to the Fort Worth district, and these differences should be recognized. The design process is carried out within the design office, except for operational reviews which are conducted by the traffic group on request. The planning engineer and planning staff are a part of the design group. The planning engineer has the responsibility for the transportation study and the transportation plan. He coordinates the land use and population projections which are performed by the city, develops environmental impact statements and provides input to the traffic assignment process. He handles communication with the Planning Survey Division (D-10) and provides interpretation of traffic data for the design group.

The planning staff performs the capacity and level-of-service analysis, utilizing computer procedures available. Traffic Operations input is used when applicable, primarily in the stage where operations (intersection control) is largely a determinant of design.

In the El Paso district, much of the preliminary work that is generally considered design is carried out in the transportation planning phase. It is difficult to separate transportation planning and design in the El Paso district, but it appears that transportation planning is the process of selecting and comparing various alternatives up to the point of reducing the alternatives to a tentative location and geometric form. Design then lays out the geometry of the facility and provides the geometric detail of the facility and its interchanges and connections to the existing street or highway system.

The design project originates through the consideration of the results of the network assignment for the El Paso area for the year 1990. The network assignment indicates that there will be possible 350,000 daily trips in the major corridor east of the CBD, along the Carlsbad highway. This projection represents a very significant increase over current demand, and intuitively there is a need for considering alternatives for accommodating this demand. Characteristically there are three basic alternatives:

1. Do nothing.
2. Make maximum use of existing facilities.
  - a. Improve operation on existing arterials.
  - b. Increase the number of arterials by adding connecting links.
  - c. Develop public transportation services.
3. Construct a freeway along the major desire path.

Alternative Number 1 - Do nothing. This alternative is not considered realistic in the long range consideration. It is an accepted responsibility of

the governmental jurisdictions to provide transportation services to the public. Within a democratic society, the society itself dictates the transportation form within the constraints of the available resources.

Alternative Number 2 - Make maximum use of existing facilities. Upgrading of existing facilities to satisfy increased demand is a natural alternative. There are two principal judgment criteria that must be considered: 1) is there an external influence for a specific type of service, such as a section of the Interstate system, and 2) can the projected demand be accommodated within the available rights-of-way and with the operational measures applicable to the existing types of facilities? In this particular case, there is no external influence that requires freeway type operation within the corridor, since I-10 more or less parallels the corridor. In response to the second question, the 1990 forecast indicates a daily corridor movement of approximately 350,000 trips. To accommodate these trips on the existing arterial system means that the arterials would be carrying 60-70,000 vehicles per day. Since these volumes far exceed the capabilities of normal arterial streets, it is obvious that new arterials must be added to the system, and major improvements made to the existing arterials. A jurisdictional problem arises here, because the department assumes the responsibility for facilities on the state system, and the city assumes the responsibility for facilities not on the system. This is not an uncommon or insurmountable problem but it does require that the agencies combine their efforts toward a common objective.

Alternative Number 3 - Construct a freeway along the major desire path. Because of the magnitude of the 1990 traffic projections, this is the most realistic alternative. Although the freeway should not be expected to accommodate the entire 1990 projected traffic, it will relieve the pressure from the arterial

system so that it may better serve the area. However, it is essential that the freeway and the arterial system be developed as a complete system rather than two separate systems.

As the consideration of these three basic alternatives progresses, the design group "homes in" on a freeway type facility as being the most practical solution. This is based to a large degree on a "feel" for the local situation as well as the available planning data. However, other alternatives cannot be ruled out until further study of the situation is completed. Further study involves two basic questions "Will a freeway fit in the corridor?" and "What are its effects on the area and the street network?" These questions are resolved in part by working with a mosaic print of aerial photographs. A schematic of a freeway is fitted to the existing street system and land development.

The use of traffic assignment data begins, as indicated, with the definition of the problem. The network assignment shows a major movement in the corridor. Data from the network assignment are generally sufficient for the process of comparing the basic alternatives, and for the study of the preferred alternative up to the point where the location and type of facility is established.

As the preliminary design of the facility is developed, additional, more specific information is needed. The planning engineer handles the procurement of data. The planning engineer obtains from the city the land use and population projections, analyzes the reliability of recent traffic assignments within the corridor, and up-dates the traffic forecasting file for the Planning Survey Division (D-10). He then requests a full complement of projected traffic assignment data from D-10. This includes design year ADT, D, K, and T. These data are checked by the planning engineer and adjusted according to local experience. In some cases, the modifications are referred back to D-10 for adjustments.



This first route assignment provides the designer with the data needed to develop the geometric layout of the roadway and interchange elements. The planning group provides the capacity and level-of-service analysis required in the design process.

As the preliminary plan is revised to fit the area and the local street system, additional assignments may be required. They are handled in basically the same manner as the first. The planning engineer updates the forecasting data and submits it to D-10 along with a schematic of the proposed facility. D-10 updates the assignment and the planning engineer goes through the process of interpreting the assignment data for design application.

Time is a major factor in the design process. From inception to completion a project will take several years. It is necessary that the traffic data be up-dated as local conditions change. The design life of the facility is constant but the design year changes with time. Thus, it is necessary that traffic assignments be up-dated on a periodic basis. These up-dates may be a part of up-dating the total network assignment, but intermediate assignments may be necessary for a particular project.

In the El Paso district, it appears that operational analyses are performed within the design group. The traffic engineering group is called upon to provide input when the analysis relates to some form of traffic control. Thus, it appears that the design recommendation process is carried out within the district design office. The design office calls for input as needed from other units of the district and the department. This is in contrast with the Fort Worth district where it appears that the design recommendation process involves a coordinated effort of the design and traffic/planning group.

#### Summary Evaluation

Based on the interviews with the two district offices relative to the des

recommendation process and the use of traffic data, the following points are summarized:

1. The two districts interviewed appear to feel that the current procedure for traffic data is satisfactory. The form of the data requires interpretation and verification by district planning personnel, but this is an expected requirement. The district designer should not take the Planning Survey Division estimates from the assignment process literally. They should be interpreted and adjusted at the local level by people who are intimately familiar with the development processes of the urban area.

2. Both districts feel that the reliability of the assignment data is dependent upon the local input to the forecasting process. Unless the district has an organized procedure for updating the land use and traffic generation characteristics of an area, they cannot expect realistic traffic estimates.

3. At the district level, there is no alternative to the traffic assignment process. Even though some may feel that the process is inadequate, district designers tend to give the process credit for providing information to justify a facility that is generally large enough to satisfy public need. In other words, the designer has difficulty in getting approval of a sufficient number of lanes on a given facility unless he has the projected traffic data to support his decision.

4. The design recommendation process involves the establishment of alternatives, and the systematic reduction of these alternatives to the one that best satisfies the public need. Then this alternative is developed through the stage of preliminary design, constantly establishing sub-alternatives (location, interchange types, etc.) and reducing these alternatives to the one that best fits the system and satisfies the need. A traffic data system must be flexible and more or less continuous in nature in order to serve the design process.

5. The design recommendation process involves three major disciplines: planning, geometric design, and traffic operations. Each plays an integral part in the process, and to reduce the emphasis on the input of any one of the disciplines will likely result in a lesser quality end product than could have been achieved.

6. A major part of the design recommendation process consists of fitting the proposed facility in with the existing street system. Particularly if the proposed facility is a freeway, the interface is important. The freeway is dependent upon the surface street system for the distribution of traffic and for the handling of the overflow from the freeway. The old adage "you cannot design a freeway within the R-O-W lines" is still true. Planning, design, and operations must blend the freeway into the existing (or improved) network to comprise a corridor system.

7. The multi-jurisdictional problem of providing a corridor system must be overcome. The Urban System created in the 1973 Highway Act appears to provide a means of treating this problem.

## TASK B

### A STUDY OF TRAFFIC SERVICE MEASURES FOR ARTERIAL HIGHWAYS

The principal objective of this phase of the study was to analyze the factors affecting the capability of urban highway routes to handle traffic in relation to the service provided. This phase was divided into three sub-objectives as follows:

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1. To devise a method of sub-classifying arterial streets within a corridor on the basis of street functions and service measures, and to suggest possible design criteria for each sub-classification. This research is reported herein.

2. To evaluate present measures of quality of service on arterial streets and suggest new ones. This research is reported in Research Report 30-1, and a summary of the report is included in a subsequent section of this report.

3. To determine the effect of midblock access on the quality of traffic service on arterial streets. This research was reported in Research Report 30-2, included in a subsequent section of this report.

## FUNCTIONAL SUBCLASSIFICATION OF ARTERIAL STREETS WITHIN THE URBAN CORRIDOR

### Introduction

An urban corridor consists of arterial, collector, and local streets, and sometimes an expressway. Within this corridor these facilities provide for a variety of trips ranging from short shopping trips to cross town, home-to-work trips. While the types of trips are fairly well segregated on expressways as well as local and collector streets, the urban arterial is often required to carry both local and through trips. Because it would be expected that the design requirements for arterials would depend upon the function performed by the arterial street, a portion of this research was directed toward the development of a method for subclassification of arterials as to their function within the corridor.

### Data Collection

In order to provide a real life background for developing the subclassification process, nine sections of arterial streets in the city of Houston were surveyed. These sections were chosen so that access control, general type of development, number of lanes, and cross-section were uniform throughout each section. Also, sections were chosen to provide a wide range in functions. Vehicle volume counts, block lengths, traffic signal timing, and intersection drawings were provided by the City of Houston. Data collected by TTI personnel included additional vehicle volume counts, a land use survey, and an inventory of the number and length of curb cuts along each arterial. An estimation of the quality of service provided by each arterial was also made by various members of the research team.

The following paragraphs contain a brief description of each of the nine study sites.

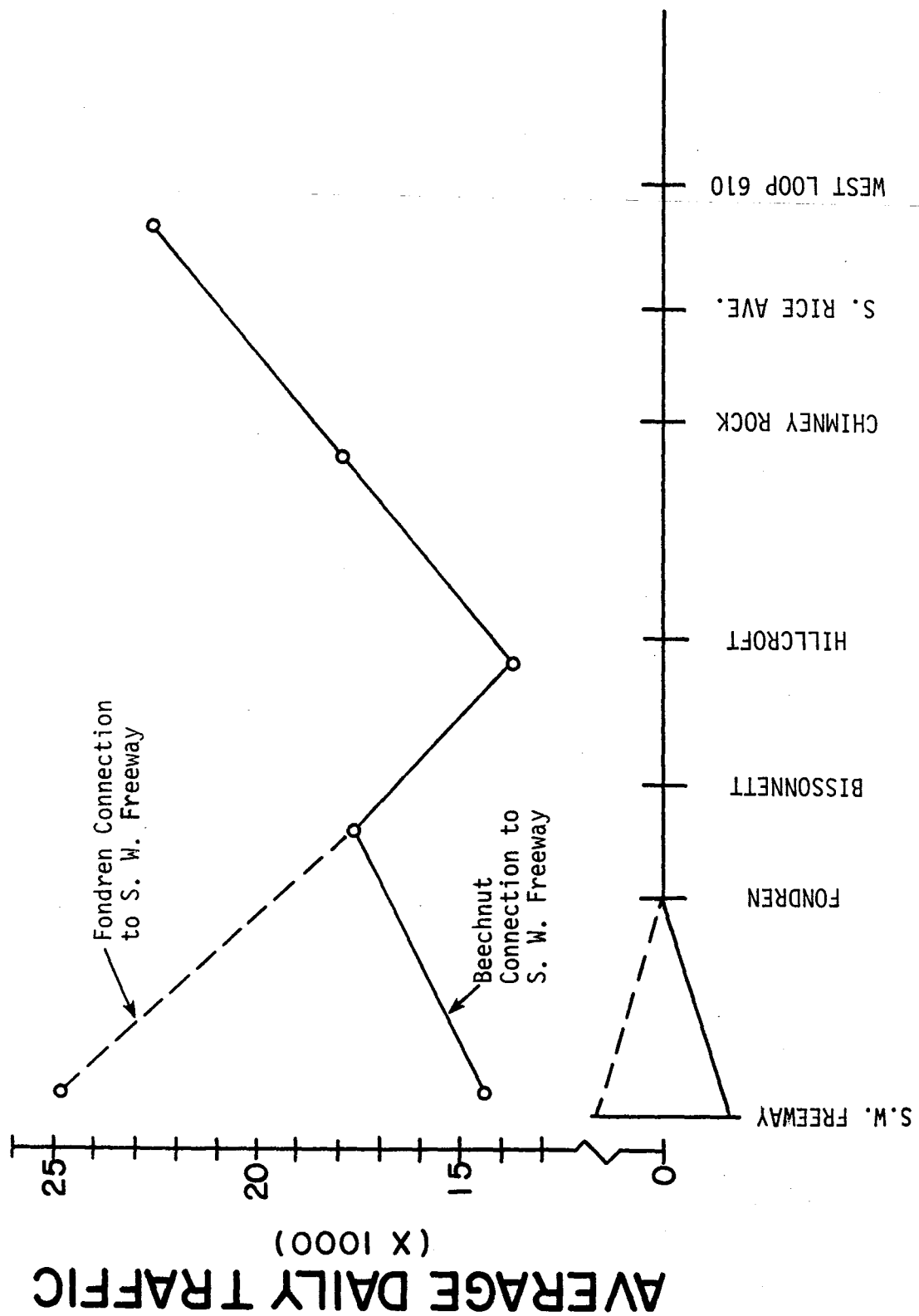
- Beechnut. The general corridor studied here connects West Loop 610 and the Southwest Freeway. For this study, however, only the 2.13-mile section of Beechnut between Bissonnet and S. Rice Avenue was surveyed. From Figure 1 it is apparent that ADT increases near the freeways as trips from the adjacent residential area are attracted to the freeway. It should be noted that the connection to the Southwest Freeway is made predominantly on Fondren, represented by the dashed line.

The lower ADT value of about 13,600 near the center of the section reflects the amount of vehicles moving between the two freeways. One-way peak hour volumes ranged from 650 to 1600 vehicles per hour depending again on the proximity to the freeways. Directional splits on this four-lane divided facility range from 51-74 percent during the peak hour.

Very little commercial development is present with 82 percent of the abutting property being residential. A total of 220 drives or curb cuts and 29 intersections were recorded resulting in an average driveway spacing of 90 feet. These drives are mainly residential, and cause rather low traffic volume generation.

Afternoon peak traffic flow appears to be quite orderly and smooth. The wide median, left turn lanes, and lack of commercial driveways seem to give the street an open end through appearance. Figure 2 is a typical scene on Beechnut.

- Buffalo Speedway. Buffalo Speedway, between Bissonnet and Westheimer, is a four-lane divided facility, about 1.2 miles long. Development along this arterial is approximately 49 percent office buildings with the remainder being divided mainly among high density residential, small retail, and service



**FIG. 1 AVERAGE DAILY TRAFFIC ON BEECHNUT**



Figure 2. Beechnut at Rice



Figure 3. Buffalo Speedway at Westheimer



stations. The northern end of the facility narrows to a two-lane street at Westheimer which, in turn, terminates at Chevy Chase. For this reason, ADT volumes increase from 10,390 at Westheimer to 25,640 near the Southwest Freeway. Peak hour volumes range from 600 to 1400 vehicles per hour. A total of 61 driveways and 11 intersections on this street gives a rather large average driveway spacing of 169 feet. Many of these driveways, however, serve high-volume traffic generators resulting in a large number of accessing vehicles, especially during the peak periods. Peak hour traffic flow is fairly smooth except near the Southwest Freeway where congestion may occur for short periods of time. Figure 3 is a view looking south on Buffalo Speedway at Westheimer.

- Long Point. This 1.4-mile section of four-lane undivided roadway was chosen primarily due to its high degree of commercial development. The section from Bingle to Wirt Road has two 11-foot lanes in each direction with no left turn lanes or left turn phases except for the Bingle intersection where left turn lanes were recently added. One-way peak hour volumes range from about 900 to 1100 vehicles per hour. Varying ADT values within this section indicate the lack of a predominant through movement. Through traffic movement in this corridor is provided for by IH 10 which parallels Long Point approximately 1.1 miles to the south.

Development in this area is almost totally commercial with small retail stores comprising 30 percent of the land use. An average driveway spacing of 81 feet is the result of 173 driveways and streets for this 1.4-mile section.

Of the nine sites studied, Long Point probably had the worst peak hour operating conditions. The lack of a raised median plus the abundance of curb cuts results in frequent turning movements which greatly reduces the throughput of the street. Drivers avoiding the chance of being delayed by left turners form substantial queues in the curb lane. A typical scene on Long Point showing a left turning vehicle and the high degree of development is shown in

Figure 4.

- Richmond. Richmond Avenue is a six-lane divided arterial with observed volumes of 1800 vehicles per hour during peak periods. The section studied is approximately 0.9 miles long and runs eastward from Buffalo Speedway to S. Shepherd Drive paralleling the Southwest Freeway in the same corridor.

ADT volumes on this section increase from 15,600 to 23,600 approaching Loop 610. Outside the study section, City of Houston traffic data reveals volumes increasing on Richmond until, at Loop 610, the ADT volume is about 31,400. Turning vehicles at Kirby and Buffalo Speedway make up as much as 48 percent of the total traffic volume. From this it appears that this arterial street is providing for: 1) access to parallel Southwest Freeway, 2) access to Loop 610, and 3) a fair amount of through traffic.

The Richmond Avenue study site is located in the midst of rather heavy office building development which comprises 66 percent of the adjacent land use. The remainder is made up of residential, small retail, and some residential development. While access is somewhat limited near high traffic generators such as high rise office buildings, the other types of development have more driveways resulting in an average driveway spacing of 116 feet.

During various visits to this site throughout the course of the study, extensive congestion was never apparent. Relatively high peak hour flows are handled quite well by this six-lane divided facility. At several intersections right turn lanes have been added to improve access to the nearby Southwest Freeway. Many return trips from work appear to be made shortly before 5:00 p.m., thus reducing the usual 5-6 p.m. peak. Figure 5 shows this facility during off-peak conditions

- San Felipe (West). Two sections of San Felipe were selected as study sites. The western portion of San Felipe is a high-type four-lane divided



Figure 4. Long Point at Huge Oaks

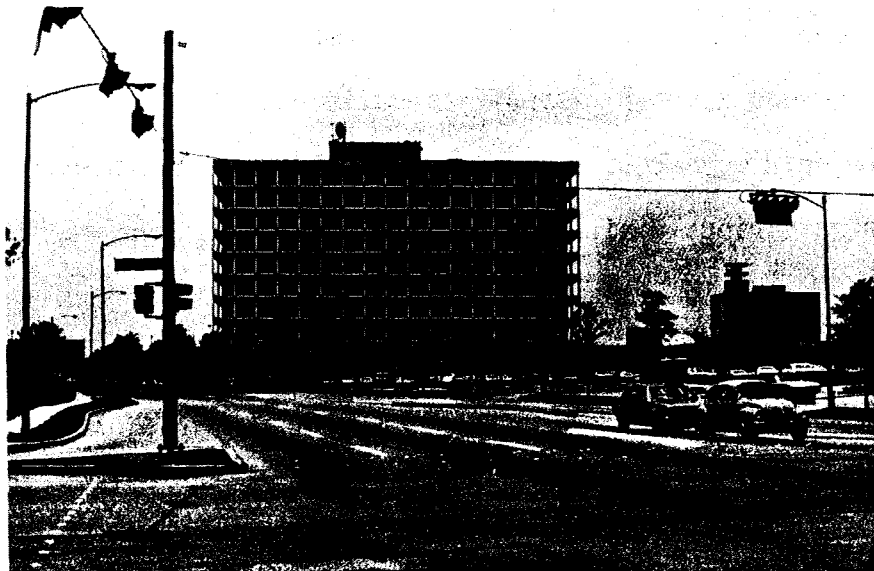


Figure 5. Richmond at Buffalo Speedway

arterial approximately 2.3 miles long. This entire section is outside Loop 610 and has only Westheimer as a parallel facility of any consequence. Peak hour volumes ranged from 1750 vehicles per hour near Loop 610 to 850 at Voss, the western end of the study section. ADT values decrease from 20,750 near Loop 610 to 13,700 at Voss. Directional splits as high as 83 percent were recorded during the time home-to-work trips were being made. San Felipe and its six-lane partner Westheimer appear to form a single corridor and carry a large number of home-to-work trips. Development along San Felipe seems to be much more residential (58 percent) than Westheimer. The remainder of land use on San Felipe is in the form of schools and churches (12 percent), retail establishments (15 percent), and undeveloped land (14 percent). An average driveway spacing of 128 feet results from 160 driveways and 28 intersections on this relatively long study section. Figure 6 is typical of this area.

Traffic flow is quite smooth on this facility with good traffic signal progression. As with Beechnut, the effect of residential-type drives is minimal during the peak periods resulting in little delay being caused by accessing vehicles.

● San Felipe (East). A second portion of San Felipe was studied to determine the characteristics of a four-lane undivided street in a residential area. While only a relatively short section (0.7 miles) was studied due to the boundaries of the traffic signal system, the entire length of San Felipe between Kirby Drive and West Loop 610 is more or less homogeneous. ADT volumes of 15,500 vehicles per day indicate that this is a reasonably busy arterial street. Traffic loads of this magnitude on this quiet residential street appear to be due to San Felipe being the first through street south of Memorial Park. As with other arterials, the ADT increases near West Loop 610 in this case to about 26,600.



Figure 6. San Felipe at Post Oak Lane



Figure 7. San Felipe at Kirby

Because the majority (87 percent) of the development is residential and the remainder made up of schools, very little accessing and turning traffic is present. While a number of curb cuts exist, the rather large home and lot sizes result in an average driveway spacing of 154 feet. These factors permit this undivided roadway to perform quite well with the traffic volumes present. Figure 7 is typical of this residential street.

Unlike Long Point, San Felipe, although undivided, exhibits much less congestion and disruption of flow. While ADT on Long Point may be slightly higher, it appears that the type of development on San Felipe creates conditions more suitable to smooth traffic flow.

- South Shepherd. South Shepherd Drive from Richmond Avenue to San Felipe was chosen as another example of a four-lane undivided street. It varies, however, from the other four-lane undivided streets in that left turns are banned during the morning and afternoon peak periods within the study section chosen (San Felipe to Richmond). This street acts as a major connecting link between IH 10 to the north and South Loop 610 to the south and parallels West Loop 610 which is about 3 miles west of S. Shepherd. Although lesser arterials parallel it, S. Shepherd appears to be the core of the arterial system in the corridor. Within the one-mile study section, ADT volumes remain about 21-22,000 vehicles per day. Development along South Shepherd is composed mainly of restaurants and small retail business making up 60 percent of the development with shopping centers and gasoline stations making up another 25 percent. An average driveway spacing of 82 feet results form 105 driveways and 24 intersections within the one-mile length. The banning of left turns appears to have improved traffic conditions on this facility considering the amount of commercial development and daily traffic. Figure 8 is typical of South Shepherd.

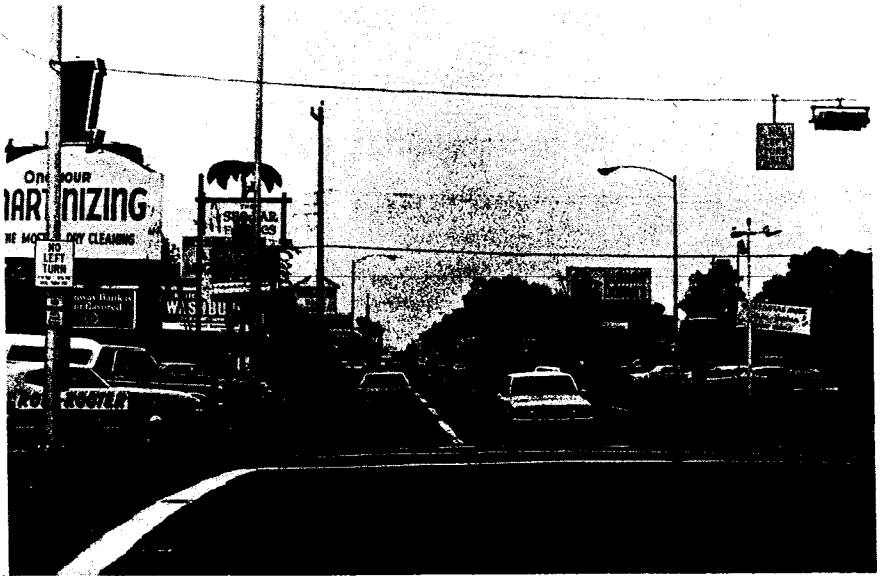


Figure 8. Shepherd at Westheimer



Figure 9. Westheimer (East) at Kettering

● Westheimer (East). Two sections of Westheimer were selected for study, one of which extends from Kettering east to Wesleyan. This four-lane divided facility provides for access to West Loop 610 as well as through traffic. Within the study section, ADT values ranged from 20,900 to 26,500 depending on the proximity to West Loop 610. One-way peak hour volumes were 1100-1300 vehicles per hour.

Development on Westheimer is fairly equally divided among shopping centers, gasoline stations, small retail stores, residential, and restaurants, resulting in driveway spacings of about 110 feet. A typical scene is shown in Figure 8.

With respect to placement within the corridor, this portion of Westheimer appears to act together with San Felipe and another lesser arterial, West Alabama, to form a single east-west corridor.

During peak periods traffic conditions on this arterial, especially close to West Loop 610, deteriorate greatly. Sizeable queues are formed near the freeway and extend eastward into the site selected for study. In addition, a number of apartment complexes in the area attract large numbers of trips during the peak periods.

● Westheimer (West). This section of six-lane divided facility has the highest volume of the nine arterials surveyed in this study. Typical peak hour volumes range from 1840 to 2500 vehicles per hour, while ADT values for the study section vary from 41,400 to 44,700 vehicles per day. Westheimer does not appear to have a parallel facility except for San Felipe which is not continuous to the west. Neither IH 10 three miles to the north or the Southwest Freeway to the south are alternate routes for Westheimer traffic due to their distance from Westheimer. Westheimer and San Felipe then form a corridor in which the combined ADT is about 65,000 vehicles per day.



Development along Westheimer is mainly commercial in the form of offices, shopping centers, and small retail businesses. This type of development results in a larger number of internally produced trips than as is the case on San Felipe where the development is mainly residential. An average driveway spacing of 160 feet shows some amount of access control on the 1.4-mile study section.

As with the eastern portion of Westheimer, this section also experiences rather long delays due mainly to high traffic volumes even though it is a six-lane facility.

Figure 10 shows a portion of Westheimer.

#### Conduct of the Field Studies

In conducting studies on the nine arterial streets, an attempt was made to gather data that would relate to the function performed by the facility. In all, eleven characteristics were chosen which seemed best for this purpose. These characteristics and the data for each arterial surveyed are presented in Table 1.

The following paragraphs give a brief description of each of the eleven characteristics as well as the reason for selecting them.

- ADT--Higher ADT values will usually be found on through type arterials rather than on those providing mainly access. This is due to a large number of home-to-work and other longer trips made during the peak periods. ADT's are quite high on arterials in those corridors that do not contain an expressway. Lower ADT's and a wide variation in ADT indicate access streets which, while having a reasonable amount of activity over a long period of time, do not have sizeable morning and afternoon peaks.

- PHV/1/2ADT Ratio--In analyzing the traffic volume data collected for the study, it appears that a relationship exists between the daily traffic



Figure 10. Westheimer (West) at Chimney Rock

TABLE 1  
FIELD STUDY DATA

CHARACTERISTIC	ARTERIAL STREET								
	Beechnut	Buffalo Speedway	Long Point	Richmond	San Felipe (West)	San Felipe (East)	Shepherd	Westheimer (East)	Westheimer (West)
ADT	18,100	18,000	22,600	19,600	17,200	19,500	22,000	23,800	43,000
PHV/½ADT	14.6	11.4	9.0	12.8	15.0	10.0	9.2	10.0	10.4
Curb Cut Ratio	23.8	18.6	35.8	24.0	18.5	14.6	31.1	25.0	21.4
Curb Cuts/Mile	51.6	26.3	60.5	39.2	35.2	29.2	52.5	42.8	28.9
Intersections/Mile	7.3	5.6	8.9	7.4	6.6	5.2	12.9	6.4	4.9
Signalized Intersections/Mi.	1.9	3.5	2.6	3.4	2.2	3.0	3.0	4.3	3.5
Number of Lanes	4	4	4	6	4	4	4	4	6
Lane Width (feet)	12	12	11	11	12	10	10	11	12
Speed Limit (mph)	35	35	30	35	35	30	35	35	40
Lane Configuration	4-lane divided	4-lane divided	4-lane undivided	6-lane divided	4-lane divided	4-lane undivided	4-lane undivided	4-lane divided	6-lane divided
Median Openings/Mile	11.7	15.5	N/A	13.6	13.2	N/A	N/A	21.4	16.2

and the traffic occurring during the peak hour. A higher ratio of PHV to ADT indicates that a larger proportion of trips are made during the peak hour as would be expected on an arterial carrying heavy home-to-work traffic. On the other hand, arterials providing mainly access will have substantial traffic volumes in the off-peak periods when shopping and business trips are made, thus reducing the ratio.

Because peak hour data were more readily available for only the major approach, the ADT was assumed to be split equally in each direction. Thus the actual ratio used was  $PHV/\frac{1}{2}ADT$ .

- Curb Cut Ratio--From observations at each of the nine study sites, it was felt that the number of curb cuts, especially in areas of commercial development, greatly affected the smoothness of traffic flow. For this reason, a characteristic referred to as "curb cut ratio" was chosen to reflect the amount of access provided. Data were collected with respect to the length of each drive along the study section. The individual widths of each of the drives were totaled and this value was then divided by the length of the study section minus the width of intersecting streets and expressed in percent.

- Curb Cuts/Mile--A slightly different approach to evaluating access control is accomplished by dividing the number of driveways by the total length of the section. While this measurement does not take into account the actual width of drives such as the Curb Cut Ratio does, data collection is much simpler as only the number of drives need be counted. For a comparison, both the Curb Cut Ratio and Curb Cuts/Mile were evaluated in this research.

- Intersections Per Mile--For arterials away from CBD grid system, the frequency of intersecting streets indicates the number of potential conflict

points with other vehicles. On access type arterials, intersecting streets must be provided along with private drives to provide access to abutting property. Movement to abutting property on primarily through type streets is provided at only a few major intersections.

- Signalized Intersections/Mile--The frequency of signalized intersections affects the efficiency of a progressive signal system. On arterials intended for heavy through traffic movements, the number of traffic signals per mile will be small.

- Number of Lanes--The majority of arterial streets are 4- or 6-lane facilities with a few having two or eight lanes. In addition, the continuous, two-way left turn lane has been defined as a five-lane street in this study. The distinction made for this characteristic is that streets with heavy through movements will often have more lanes.

- Lane Width--Practical lane widths vary from 10 to 13 feet on most arterials. As determined in another portion of this research project, lane width does not have a great effect on saturation flow (capacity) in the 10- to 13-foot range. At higher speeds than those measured at near capacity conditions, driver comfort seems to be improved with the use of wider lanes. Because the through traffic type arterial is expected to be of higher type design, wider lanes are deemed appropriate.

- Posted Speed Limit--Operating speed on an arterial often reflects the quality of service being provided. Operating speed, however, is difficult to generalize due to its variability with time of day and traffic and environmental conditions. For this reason the speed limit was chosen as the measure of the speed characteristic. This was done assuming that high type design arterials serving predominantly through traffic will have higher design speeds due to improved geometric features. Access streets subject to a higher

proportion of turning vehicles as well as more intense development close to the traveled way will likely have lower posted speeds.

- Lane Configuration--On through arterials the need for raised medians and left turn lanes is much more pronounced due mainly to higher operating speeds and the need to separate conflicting traffic flows. On arterials providing access also, the flush median or two-way left turn lane is appropriate because it provides more opportunities for access to property.

- Median Openings/Mile--The frequency of median openings and the turning movements permitted at them can do much to affect the smoothness of flow along an arterial street. The current practice of using offset intersections in suburban areas to discourage through traffic on side streets creates a larger number of potential median breaks. The partial or full restriction of left turns at median cuts is not very common, probably due to lack of self-enforcement. For this reason, it appears that, for high type, through traffic arterials, the number of median openings would be kept to a minimum.

These eleven characteristics then were chosen as the basic descriptors of an arterial street. The next step in the research involved the formulation of a subclassification system for arterial streets utilizing the eleven characteristics listed above.

#### The Subclassification Process

An attempt was made to divide all arterial streets into five types according to the function provided by the street. A semantic differential scale of 1 to 5 was used to rate what would be expected on varying types of arterials. The five types are numbered 1 to 5 with "1" being an arterial which provides mainly access, and "5" carrying mainly through or long distance traffic. As shown in Table 2 boundary conditions for each type arterial were established for each of the eleven characteristics. These boundaries were based mainly on

the Houston data and were tempered somewhat by the research staff.

The input data for each characteristic and arterial from Table 1 were then given a 1 to 5 rating according to the boundary condition as set forth in Table 2. The result of this step is shown in Table 3 which shows the individual ratings according to type for each characteristic and street.

In Table 3, it should be noted that a factor or multiplier has been used to emphasize those characteristics that were thought to be more significant. The value of these multipliers are shown in the "Factor" column. Due to the limited number of sites studied and the quasi-quantitative nature of some of the variables, an extensive correlation-regression study was not attempted.

At the bottom of Table 3 the total score for each arterial is shown. Dividing the range of the possible score (14 to 70) into equal parts as shown below gives the limits for each of the five types of arterials.

<u>Composite Score</u>	<u>14-24</u>	<u>25-36</u>	<u>37-47</u>	<u>48-59</u>	<u>60-70</u>
Arterial Type	1	2	3	4	5

In reviewing the findings for the nine sample locations as shown at the bottom of Table 3, the majority of the facilities studied were types 2, 3, and 4. This is probably fairly reasonable due to the fact that few purely access or through traffic type arterials can be found. Also, the nine sites selected were chosen for use in other areas of this research and for this reason may not exhibit as extreme a value as could possibly be found elsewhere.

In the preceding section, a method has been suggested for the subclassification of arterial streets according to function. While a tool of this type may be helpful to the planner in laying out a street network, it gives less direction to the street designer. For this reason, the next section it

TABLE 2  
LIMITS OF SEMANTIC DIFFERENTIAL SCALES

CHARACTERISTIC/ROAD TYPE	ACCESS <span style="float: right;">→</span> THROUGH				
	1	2	3	4	5
ADT	< 10,000	10-20,000	20-30,000	30-40,000	> 40,000
PHV/½ADT	< 9%	9.0-10.9	11.0-12.9	13.0-14.9	≥ 15.0
Curb Cut Ratio	≥ 40	30-39	20-29	10-19	< 10%
Curb Cuts/Mile	> 50	30-50	15-30	5-15	0-5
Intersections/Mile	> 16	12.5-16.0	8.5-12.4	4.1-8.4	≤ 4
Signalized Intersections/ Mile	> 12.0	9.5-12.0	6.5-9.4	4.1-6.4	≤ 4.0
Number of Lanes	< 4		4		> 4
Lane Width (feet)	10		11		≥ 12
Speed Limit (mph)	< 30	30	35	40	≥ 45
Lane Configuration	Two-Lane Undivided	Undivided Multilane	Undivided with Left turn lanes at major intersec- tions	Continuous Left Turn Lanes	Divided w/ left turn lanes and raised median
Median Openings/Mile	> 20	15-20	10-14	5-9	4



TABLE 3  
APPLICATION OF SEMANTIC DIFFERENTIAL  
RATING SYSTEM TO NINE STUDY SITES

CHARACTERISTIC	Factor	STUDY SITES								
		Beechnut	Buffalo Speedway	Long Point	Richmond	San Felipe (West)	San Felipe (East)	Shepherd	Westheimer (East)	Westheimer (West)
ADT	1.0	2	2	3	2	2	2	3	3	5
PHV/½ADT	1.0	4	3	2	3	5	2	2	2	4
Curb Cut Ratio	1.0	3	4	2	3	4	4	2	3	3
Curb Cuts/Mile	2.0	2	6	2	6	4	8	2	4	8
Intersections/Mile	2.0	8	8	6	8	8	8	4	8	8
Signalized Intersections/ Mile	1.0	5	5	5	5	5	5	5	4	5
Number of Lanes	1.0	3	3	3	5	3	3	3	3	5
Lane Width	1.0	5	5	3	3	5	1	1	3	5
Speed Limit	1.0	3	3	2	3	3	2	3	3	4
Lane Configuration	2.0	10	10	4	10	10	4	4	10	10
Median Openings/Mile	1.0	3	3	1	3	3	1	1	1	3
Total		48	52	33	51	52	40	30	44	60
Arterial Type		4	4	2	4	4	3	2	3	5

presented to assist the design engineer in the selection of design criterion to fit the intended functions for an arterial street.

### Design Recommendations

Admittedly, the function for which an arterial is designed may be altered due to changes in land use, development, or the addition of other street facilities to the corridor. The design engineer does, however, have the power to greatly affect the function of the arterial by using or deleting features such as curb cuts, raised medians, and median openings. Given the function which the street is to perform the designer should be able to call upon the following design criteria for aid in proper arterial design.

- Type 1 Arterials. These arterials which have some characteristics similar to collector streets provide mainly access to abutting property. Some two-lane streets of this type exist, but the majority are four-lane. Four-lane facilities have over 20 median openings per mile or be undivided. Curb cuts may be as high as 50 per mile on each side and there may be more than 16 intersections with 12 of them signalized. This large number of curb cuts, median openings, and intersections allow drivers frequent opportunities to gain access to property. Because of this amount of turning and entering traffic, operating speeds will probably be 30 miles per hour or less. Movement of through traffic will be restricted at times by accessing vehicles.

- Type 2 Arterials. Although greatly oriented toward access, this type of arterial provides for a larger amount of through traffic than Type 1. For this reason, two-lane roadways which may be blocked by a single turning vehicle are not acceptable, and left turn lanes may be used occasionally. Median openings are in the range of 16 to 20 per mile and from 30 to 50 curb cuts per mile may exist. As many as 10-12 intersections may be signalized out of a total of 13 to 16 per mile. Speeds will usually be 30 miles per

hour or slightly higher.

- Type 3 Arterials. This type carries about an even mix between access and through traffic. Four through lanes are necessary with about 10-15 median openings per mile. Left turns should be provided for by left turn lanes at all major intersections. Curb cuts should be restricted to 15 to 30 per mile in order to insure a reasonable possibility of obtaining operating speeds of about 35 miles per hour. Where cross street traffic is heavy, as many as seven to nine intersections may be signalized out of a total of 9 to 12.

- Type 4 Arterials. A large proportion of higher volume arterials fall into this class where provision of access is a secondary requirement. Roadways in excess of four lanes may occur in this category, but four-lane ones prevail. Median openings and curb cuts should be restricted to about 10-15 and 15-30 respectively per mile. Major intersections should have left turn lanes or the two-way continuous left turn may be employed. Intersection spacing should range from 1/4 to 1/8 miles with not more than six per mile signalized. Good operating conditions on this type of arterial should allow speeds of about 40 miles per hour.

- Type 5 Arterials. This type of arterial is primarily intended for the movement of high peak hour volumes of traffic and will therefore probably have at least 6 and maybe 8 through lanes. Optimally there would only be an intersecting street every one-fourth mile which, in turn, would require only four median openings per mile and a maximum of four signalized intersections. All intersections should have adequate length left turn lanes and right turn lanes may be added where needed. Internal circulation should be accomplished on abutting property reducing the need for curb cuts to a maximum of five per mile. Speeds for this type of arterial should be 45 miles per hour or slightly greater.

A summary of these design criteria is shown in Table 4.

These design criteria should provide another input for the design process along with other engineering, social, and economic factors. While few streets may ever be designed to fit each of the eleven characteristics for the type of arterial precisely, general direction is at least provided.

Throughout the course of this study, two general observations tended to stand out concerning traffic operation within the corridor on arterial streets. These are:

- The need for left turn lanes at major intersections on arterial streets, and
- The effect of location of the arterial within the corridor.

The need for minimum design criteria is exemplified by a separate study of one intersection--that of Long Point at Bingle. Long Point, as noted before, has a high degree of commercial development which attracts a large number of turning and accessing vehicles. The street is 44 feet wide with two lanes of traffic in each direction and no median. Left turns at midblock and at intersections cause drivers to stay in the curb lane. This essentially reduces the four-lane, undivided facility to a two-lane facility with two continuous left turn lanes.

During the course of this study, the Long Point Road approaches at Bingle were modified to provide for a left turn lane approximately 100 feet long. As shown in Figure 11, the narrowed lanes range from 8 feet, 6 inches to 9 feet in width. Figures 12 and 13 show vehicles on the westbound approach to the signal before and after the installation of the left turn lane. Drivers appear to be somewhat apprehensive of these narrow lanes at operating speeds (25-30 miles per hour) and drive in an offset pattern. However, during peak periods when volumes are increased and

TABLE 4  
SUGGESTED DESIGN CRITERIA FOR VARIOUS ARTERIAL STREET FUNCTIONS

	ARTERIAL TYPE				
	Access <span style="font-size: 2em;">→</span>				Through
	1	2	3	4	5
Through Lanes (Number)	< 4		4		> 4
Median Openings/Mile	> 20 or No Median	16-20	10-15	5-9	≤ 4
Left Turn Lanes	None	Few	Major In- tersections	2-way left turn lane	All Inter- sections
Curb Cuts (Per Mile)	50	30-50	15-30	5-15	0-5
Intersections/Mile	> 16	13-16	9-12	5-8	≤ 4
Signalized Intersections/ Mile	> 12	10-12	7-9	5-6	≤ 4
Speeds	< 30	30	35	40	45

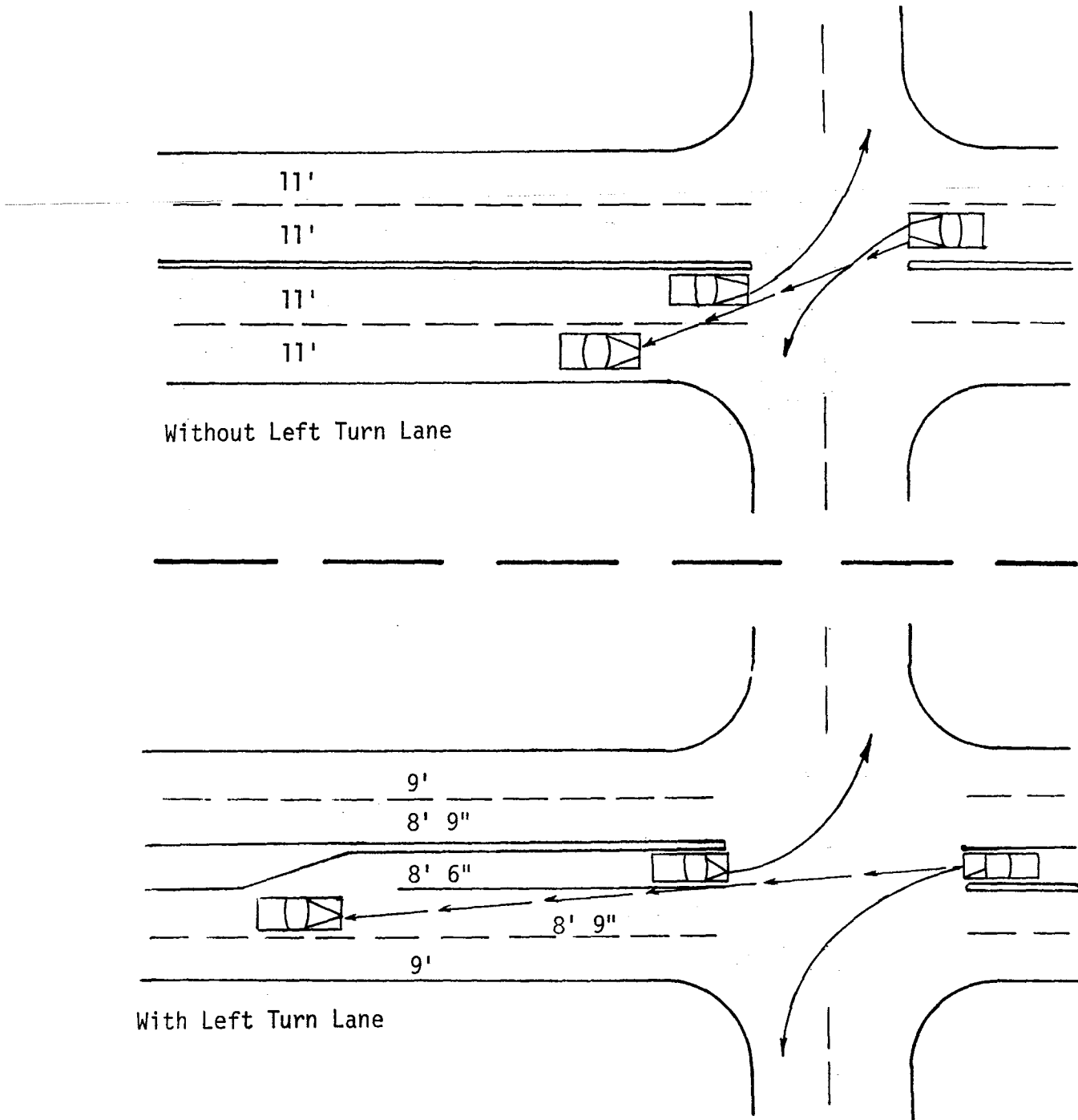


FIGURE 11. Improved Sight Distance on Long Point at Bingle

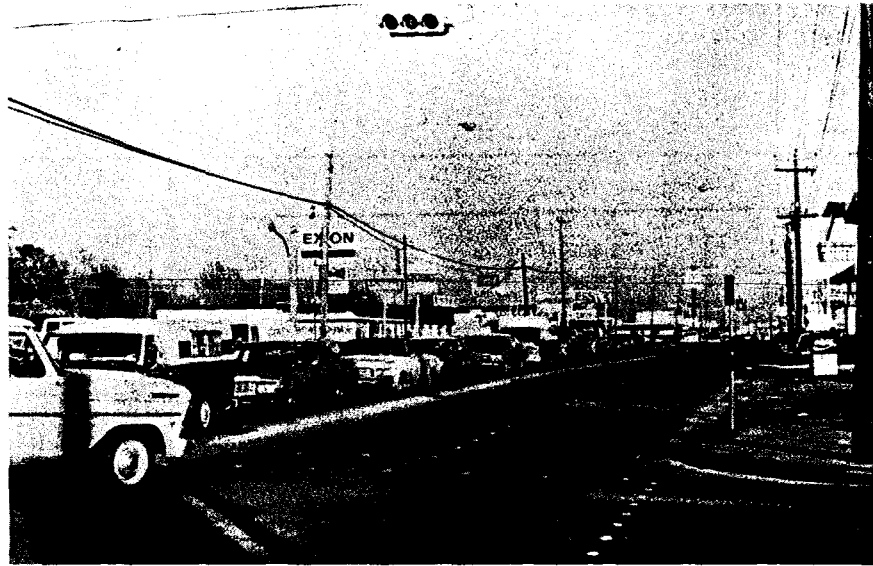


Figure 12. Long Point at Bingle Before Modification



Figure 13. Long Point at Bingle After Modification

speeds are down, drivers utilize both the through and combination through-left lanes equally. While lanes of this width are not recommended for use in design, this does show the importance of the left turn lane.

In addition to increasing the capacity of the intersection, it would appear that the added left turn lane also increases safety. This is probably due largely to increased sight distance for left turning vehicles as shown in Figure 10. Accident records from the City of Houston show nine left turning accidents at the Long Point and Bingle intersection for the period of January 1, 1974 to April 23, 1974, during which time the left turn lane had not yet been added. Between April 23, 1974 and July 10, 1974, after the lane was added, no accidents of this type occurred. No increase in other types of accidents seem obvious from the accident records. While these are relatively short periods for accident record statistics, there does appear to be a marked improvement.

Based on this, it is judged that steps taken to prevent accessing and turning vehicles from blocking through traffic are of major importance to orderly traffic flow.

Arterials in a corridor perform differently depending on their relationship to other higher type facilities. While some variations may exist these major types stand out.

- Arterials parallel to the corridor acting with another arterial or an expressway. Westheimer (West) and San Felipe (West) fit this class rather well. Both of them lead out away from West Loop 610 and the downtown area. Traffic volumes tend to decrease in a stair-step fashion moving out away from major traffic generators. In corridors where freeways do not exist, traffic flow must be provided for by the arterial which increases the need



for good design and traffic control.

- Arterials perpendicular to the corridor perform as connectors between the main facility in the corridor and other lesser streets. As in the case of Buffalo Speedway and Beechnut, volumes become quite high near the corridor core.

- Arterials parallel to the corridor but somewhat removed from it often have fairly light through traffic. A portion of the volume on these arterials is carried to the core of the arterial by perpendicular arterials. Occasionally, however, as in the case of Long Point, high commercial development will cause substantial vehicles volumes. In the IH 10 corridor, for example, Long Point has average daily traffic of about 20,000 while Westview between Long Point and IH 10 is of a higher type design, yet has only an ADT of about 8,000.

From this it appears that consideration should be given to placement within the corridor to prevent capacity bottlenecks near freeways and to provide for heavy turning volumes as perpendicular streets. Also, arterials paralleling the corridors may have varying amounts of traffic at times depending on the surrounding land development.

A P P E N D I X

Capacity and Quality of Service of  
Arterial Street Intersections

by David J. Berry

Urban corridors, as they exist today, often include a freeway with a supporting network of arterial, collector, and local streets. In some cases, a freeway may not be present, leaving arterial streets as the main carriers of long distance trips. The importance of the arterial street is also shown by the fact that large urban freeway building programs are no longer being carried on in many of the major U.S. cities, thus placing an even greater load on existing and future arterials.

Experience indicates that the definition of, and boundaries for, quality of service and capacity for freeways as set forth in the 1965 Highway Capacity Manual are deemed adequate for the highway design engineer's use. There appears, however, to be less confidence and uniformity evident in the use of similar criteria for arterial streets. For this reason a portion of this research study deals with the capacity and quality of service on arterial streets.

The research study reported herein recognized the importance of the signalized intersection as an element in determining overall corridor level of service, and to this end a part of the research was set aside to review the state-of-the-art and recommend methods of determining levels of service at signalized intersections. The study examined a number of aspects of intersection capacity and its principal findings were as follows:

- a. A saturation flow approach somewhat similar to the Australian, British, or critical lane analysis technique is recommended.
- b. A study of saturation flows conducted at 16 intersections in Austin, College Station, and Houston found no significant difference in saturation flows for lanes 10, 11, and 12 feet wide. Preliminary

saturation flow data shown in Table A are recommended for sub-urban arterial streets.

TABLE A. SATURATION FLOW DATA

Lane Width	9'	10' to 12'
Lane Type	Saturation Flows	Through Car Units/hr.
Through & Through Right	1600	1750
Through Left		1550
Left		1700

- c. To convert vehicle counts to through car units (T.C.U.'s), the conversion factors shown in Table B are recommended.

TABLE B. THROUGH CAR UNIT (T.C.U.) FACTORS

One truck or bus	=	2.0 passenger cars (p.c.)
One left turn (p.c.)	=	3.0 T.C.U.'s
One right turn (p.c.)	=	1.25 T.C.U.'s
One through (p.c.)	=	1.0 T.C.U.'s

- d. Except for the cases when intersections were operating under pressure, the duration of saturation flows varied across the traffic lanes. Consequently, the saturation flows across all lanes should be taken as 90% of the summation of anticipated flow rates for each lane in computing delays and probabilities of clearing queues.

- e. Delays should be held to a reasonable minimum by the selection of cycle lengths within the range of 85-125 percent of those calculated using Webster's method. Phase lengths should preferably be apportioned using Webster's method. Frequently signal system considerations and the need to satisfy minimum pedestrian phase lengths will result in some deviation for these criteria. Delays should be estimated for each approach and for the intersection as a whole using Webster's method.
- f. The probability of clearing queues and Volume/capacity ratio are recommended as descriptors of level of service for operations and design, respectively. The recommended boundary values for the various levels of service are given in Table C.
- g. The sum of the ratios of demand volume (in T.C.U.'s) to saturation flows for conflicting phases which has been termed the "Y" value provides a useful general descriptor for rapid evaluation of alternative designs. The following approximate limits of Y values are suggested:

- Two-phase operation Y < 0.70
- Three-phase operation Y < 0.66
- Four-phase operation Y < 0.63
- Diamond interchange, four-phase overlap, with total overlap less than 16 seconds Y < 0.75
- Diamond interchange, four-phase overlap, with total overlap equal to 16 seconds Y < 0.80
- Diamond interchange, four-phase overlap, with total overlap greater than lost time Y < 0.85

TABLE C

RECOMMENDED LEVELS OF SERVICE  
FOR OPERATIONS AND DESIGN CONSIDERATIONS

LEVEL OF SERVICE	FLOW DESCRIPTION	RECOMMENDED VALUES PROBABILITY OF CLEARING QUEUES	RECOMMENDED VALUES VOLUME/CAPACITY RATIO
A	Free Flow	$P_0 > 0.95$	$\leq 0.60$
B	Satisfactory Operation. Vehicles Wait For  Second cycle < 15% of time	$0.90 < P_0 \leq 0.95$	$\leq 0.70$
C	Satisfactory Operation. Defines the lower limit of satisfactory Operation	$0.75 < P_0 \leq 0.90$	$\leq .80$
D	Potential Instability, Unsatisfactory Operation; Vehicles frequently waiting two or more cycles	$0.50 < P_0 \leq 0.75$	$\leq .90$
E	Unstable Flow; Unsatisfactory Operations; extensive queues formed	$P_0 \leq 0.50$	$\leq 1.0$

h. The following framework is suggested for determination of levels of service at signalized intersection:

1. Prepare a sketch plan of the approach under study.
2. Record the signal phasing and phase lengths (where these are not known it is suggested that trial cycle lengths and phase lengths be determined using Webster's (5) method.
3. Obtain design volumes including percentage of trucks. If these are hourly volumes, convert them to equivalent peak quarter hourly volumes by division by the appropriate peak hour factor.
4. Convert volumes to equivalent through car equivalents using the following factors:

1 Bus or truck = 2 cars

1 Right turn vehicle = 1.25 through car equivalents

1 Left turn vehicle = 1 through car equivalent  
(Separate turn lane and phase)

1 Left turn vehicle =  $E_{LT}$  (Calculated using Miller's expression)

Where the signal phasing is not known,  $E_{LT}$  may be approximated as 3 for the purpose of initial evaluations.

5. Calculate  $y$  values for all approaches and phases. Sum the maximum  $y$  values for each phase to obtain  $Y$  and check against suggested limits.
6. If cycle length is not fixed, calculate Webster's optimum cycle length and phase length. Adjust them to satisfy minimum requirements for phase lengths.
7. Calculate average delay on the approach (Note: For this calculation, the volume  $q$  should be in vehicles per second.).

8. Calculate the probability of clearing queues and compare to values in Table C.

#### IMPLEMENTATION

The results of this research should supplement current methods of analyzing the capacity and quality of service at intersections. The saturation flow model, as suggested in this report, promises to be a more rational approach to calculating intersection capacity. Further calibration of the saturation flow model will, however, be needed before it is fully functional.



## SUMMARY OF RESEARCH REPORT 30-2

### A Simulation Study of Mid-Block Access Effects on Arterial Streets

by J. O. Exter, Vergil G. Stover, and N. J. Rowan

The combined function of the urban arterial, that is, providing for traffic movement and land access, continues to be a major problem. Arterials are designed and built to serve primarily the movement function. As the abutting land develops, access to individual land parcels tends to reduce the effectiveness of the arterial in serving its primary function.

Transportation engineers recognize the incompatibilities of movement and access on the arterial, but are unable to measure the effects distinctly because of the lack of objective measures. The research reported herein is an effort to identify measures of the effects of access on traffic movement through the application of the UTCS - I Simulation Program developed by the Federal Highway Administration.

In this research, three typical arterial designs were studied to facilitate a comparison of traffic operational measures related to access provisions of each of the designs. The designs studied are described as follows:

- Design A: 4-lane undivided arterial street with channelization to provide left-turn lanes at the street intersections. Channelization does not restrict mid-block left-turns.
- Design B: 4-lane arterial with a barrier type median to restrict mid-block left-turns. Separate left-turn lanes were provided at the intersections.
- Design C: The same 4-lane arterial as Design B, except individual access drives permitting right turns into businesses were also eliminated.

Intuitively, the simulation results showed that Design B (4-lane divided with a barrier to restrict left-turns substantially improved traffic operations on the test facility. The elimination of right turns (Design C) showed only slight improvement over Design B. It should be recognized however, that

these results pertain only to traffic operation on the test facility. They do not reflect the deterioration of service as a result of denying access which was previously permitted. Therefore, these results should be interpreted as the achievements that could be realized if a barrier type median were provided on a new facility. Experience has shown that it is impractical to restrict mid-block left-turn access after the land development pattern has already been formed. The two-way left-turn lane concept which permits left turns to be made at mid-block locations without interference with through traffic, has been used successfully in the up grading of the traffic operations on arterial streets where individual access drives are permitted.

It is unfortunate that a two-way left-turn lane design alternative was not included in the simulation study; however, the operational effects on through traffic are essentially the same for both designs--the barrier median and the two-way left-turn lane. Whereas the barrier median restricts turns, the two-way left-turn lane permits turning movements to be made without impeding traffic. The only differences which might be measurable would be the deceleration of a turning vehicle just prior to entering the turn lane, and possibly some impediments to opposing traffic due to the turning vehicle crossing opposing traffic. Since the turns are otherwise expected to occur at designated intersections, these impediments would certainly be negligible, and in fact, may be nonexistent.

One advantage of the two-way left-turn that possibly could have been measured using the simulation techniques is the reduction of left-turn demands at signalized intersections. If left-turns are permitted at mid-blocks, then there is a reduced demand at the intersections, resulting in reduced delay and more green time available for through movement.

The UTCS - I model was developed for use in evaluating control strategies for sophisticated signal systems and networks. It can also be used to assess the effects of proposed alterations to existing streets as well as the effects of temporary conditions such as weather, detoured traffic, or construction zones.

The model also demonstrates potential for analysis and evaluation of various alternative medial and marginal designs for arterial streets. It is recommended that UTCS - I be considered for adoption as an evaluation tool in the arterial street design process. It is suggested that a workshop be arranged with the developers of the model so that key personnel might obtain a detailed knowledge of the model.

In application as design evaluation tool, it is recommended that the following aspects of the model receive additional study with a view towards improving its performance and utility:

- (1) Review the several submodels employed in UTCS - I and evaluate the appropriateness of the various parameter values selected.
- (2) Investigate the sensitivity of the model relative to effects of marginal friction and explore, if appropriate, modifications to more effectively simulate the effect of left and right turns to and from driveways.
- (3) Investigate and if feasible modify the model so that output can be obtained for through and turning traffic separately; also to provide an option to output data by traffic lanes.

Application of the UTCS - I model reported herein, demonstrates the potential of this simulation approach as a design evaluation tool. This application also indicates that flexibility should be an inherent feature in the design of arterial street intersections. Such flexibility is essential if operational and design changes are to be made in response to unknown and unprojectable changes in traffic.