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16. Abstract

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 distinctlv 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.

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A SIMULATION STUDY

OF

MID-BLOCK ACCESS EFFECTS ON ARTERIAL STREETS

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Research Report 30-2

Corridor Analysis for Level of
Service Design
Research Study No. 2-10-73-30

Sponsored by the
State Department of Highways and
Public Transportation
in cooperation with the
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Federal Highway Administration

TEXAS TRANSPORTATION INSTITUTE
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College Station, Texas

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SUMMARY

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 these 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.

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INTRODUCTION

The subdivision of the circulation system of urban areas into various elements according to their primary function has become accepted as desirable and necessary for the orderly development of these areas. The inter-relationship between transportation and land use is being recognized by an increasing number of transportation and urban planners. Recognition of this concept is implied in the National Highway Functional Classification Study Manual (1,2):

> "The Transportation system is a major structural element of the community. It serves as a circulatory system providing travel mobility and it serves equally as a skeletal system providing a relatively permanent framework which delineates and influences the pattern of land development within which residential neighborhoods and other land uses may develop and function. The preservation of neighborhoods, the stabilization of desirable land uses, and the encouragement of orderly development are among the basic considerations in the development of functional street systems. The concept of streets as a land use is also important in functional classification. In the same manner that industrial activities usually make undesirable neighbors for residential districts, but make suitable neighbors for railroads, so must streets and traffic be viewed in terms of their impact upon, as well as service to, adjacent land uses."

The late Thomas H. MacDonald considered that transportation has a basic dual nature; (a) service, and (b) power. The formulation of public policy has traditionally considered transportation to be a service only. Service being defined as "any result of useful labor which does not produce a tangible commodity." (3). Power, the second basic component, as a motive force is the ability to do or perform something.

The National Committee on Urban Transportation established certain criteria to be used in the appraisal of service and to guide designers. They based these criteria on the following general premises (4):

- Good street transportation depends on the establishment of a networks of streets divided into systems, with each system accommodating either movement and/or access to a varying but distinctively different degree.
- The purpose of the street must govern the structural characteristics, the geometry and the use of control devices, if the basic service of each system is to be maintained and improved.
- Terminal facilities are an integral part of the street, and must be considered in providing satisfactory service.

The Committee suggested a four element hierarchy that includes Freeways and Expressways, Major Arterials, Collector Streets, and Local Streets. Each element caters to movement and/or access to a varying but distinctively different degree.

Arterials

The functional element that is being considered in this paper is the Arterial. The Arterial includes all designs below a Freeway and above a Collector. Although the upper limit is well defined because the freeway designation is quite specific, the lower limit is indistinct and must be made far more explicit before the arterial designation will have specific significance (2).

Criteria for the differentiation of arterials versus collectors include trip length, continuity, traffic volume, neighborhood identification, spacing between routes, and others. Whereas collector streets penetrate neighborhoods and collect traffic from the local streets; arterials surround neighborhoods, form a continuous network to serve trips of moderate length at relatively high speeds and high volumes.

The Arterial element of the hierarchy has been further subdivided into two sections: Primary Arterials and Secondary Arterials. Secondary Arterials, while intended to have movement as a predominant function, also do provide some access. Urban Secondary Arterials serve areas of less traffic generation than those served by the Primary Arterials; such areas include neighborhood and community shopping centers, smaller industrial areas, and residential neighborhoods (6).

Existing "arterials", however, generally cater to various proportions of through and access demand simultaneously. Most of these arterials carry the burden of continuous strip development with frequent or even almost continuous curb cuts on both sides. Most owe their designated classification more to the demand for through movement than to their capability to meet the function of an arterial class street.

While volumes of multipurpose urban "arterials" may not decrease due to the access activity, the discomfort and danger to road users and accident potential does increase. An example of a highway experiencing a high accident rate coupled with a proliferation of access points is the U.S. 52 Bypass at Lafayette, Indiana (6,8), the southbound roadway of which had a large number of high volume driveways. Accident information for 1967 for four of the control sections on the Lafayette Bypass is given in Table 1. The difference in the accident rates in the northbound and southbound roadways of the four-lane sections is a result of the larger number of high volume driveways along the southbound roadway.

QUANTIFYING THE EFFECTS OF ACCESS CONDITIONS

Preserving the integrity of the arterial street is a most important aspect of providing a functional street networks. Arterials are built to accommodate the movement function, with access as a secondary function. As the land area develops, the demands for access are yielded, little by little and finally, the integrity of the system is destroyed. The traffic engineer is then called in to cope with the problem by exercising different forms of control. These methods are only partially effective. The proper improvement is of a preventive nature--design for a given function and then maintain that function through regulation of access.

Why then do we permit the integrity of the system to be destroyed? The problem is principally due to lack of factual data. No one has yet produced objective measures of highway performance. Such measures are needed, and further, they must be in such a form that they may be applied in a rational manner.

A street is often classified as an arterial only to be immediately called upon to provide all functions except those of a freeway. Such an infinitely

TABLE 1 - ACCIDENTS EXPERIENCE ON SELECTED CONTROL SECTIONS

OF THE U.S. 52 BYPASS AT LAFAYETTE, INDIANA

			Accident Experience in 1967		
	Section Length (Miles)	ADT	Total No.	Per 100 Million Vehicle Miles	Number Per Mile
SR 25 to SR 26	2.12	19,900	114	740	53.7
SR 26 to the 2-lane to 4-lane transition	0.85	22,300	40	580	47.0
2-lane to 4-lane transition to SR 38	0.35				
Northbound roadway		10,800	10	720	28.5
Southbound roadway		10,800	33	2,380	94.2
SR 38 to Lafayette	0.33			810	33.3
city limits				1,540	57.5
Northbound roadway		10,200	10		
Southbound roadway		10,200	19		

Source: Traffic Engineering Division, Indiana State Highway Commission varying range of demands on an arterial should not be necessary in a properly designed system. The lack of objective measures, however, makes it difficult for the highway engineer to defent the integrity of the arterial and even the sub-classification into Primary and Secondary Arterials does not help to stem the tide of access-hungry property users.

A system to measure the rate at which local access is substituted for capacity for service to through traffic and to more precisely quantify the cost imposed on the traffic stream by medial and marginal access would provide the highway administrator with further valuable information to be used as a basis for designating the degree of access control on a particular facility (6).

Mid-Block Characteristics

In order to be able to make quantitative measurements of traffic performance in the field and determine the effects of mid-block design aspects, it would be necessary to find different sites in which only one variable was altered at a time. The necessary measurements could then be taken and analyzed.

It is impossible to find pairs of sites between which there was only one difference and even if it had been possible, the field work would have been time consuming and costly.

Before and after studies on selected streets to evaluate the effect of experimental alternations have been used in previous studies (11,12). Such an approach would involve a substantial expenditure of funds.

Because of the difficulty in finding sites suitable for empirical study as well as time and finding limitations, a series of simulation studies were designed for use in evaluating the mid-block effects of various types of access control on traffic flow characteristics.

SIMULATION STUDIES

A series of simulation studies was conducted to facilitate the comparison of performance characteristics of an arterial under three different stages of access control. The basic design descriptions associated with the simulated stages of access are as follows:

Design A: 4-lane undivided arterial street. Channelization provided left-turn lanes at the intersections, but did 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. Individual access drives were permitted for all businesses.

Design C: 4-lane arterial with a barrier-type median to restrict mid-block left-turns, and individual access drives to businesses were eliminated. Access was provided through connections to side streets.

Site Selection

It would be feasible to design a hypothetical site for use in a simulation study. However, little extra effort is involved in using an existing site; most of the data needed for a simulation study is readily available from the normal records kept by highway authorities. After considering various alternative locations, a portion of Texas Avenue (State Highway 6) in Bryan, Texas was selected for the following reasons:

It is a four-lane arterial.

The two-way peak traffic is approximately 2,000 vehicles/hour.

The abutting land is not yet fully developed and so there is scope for an amended design philosophy to be applied.

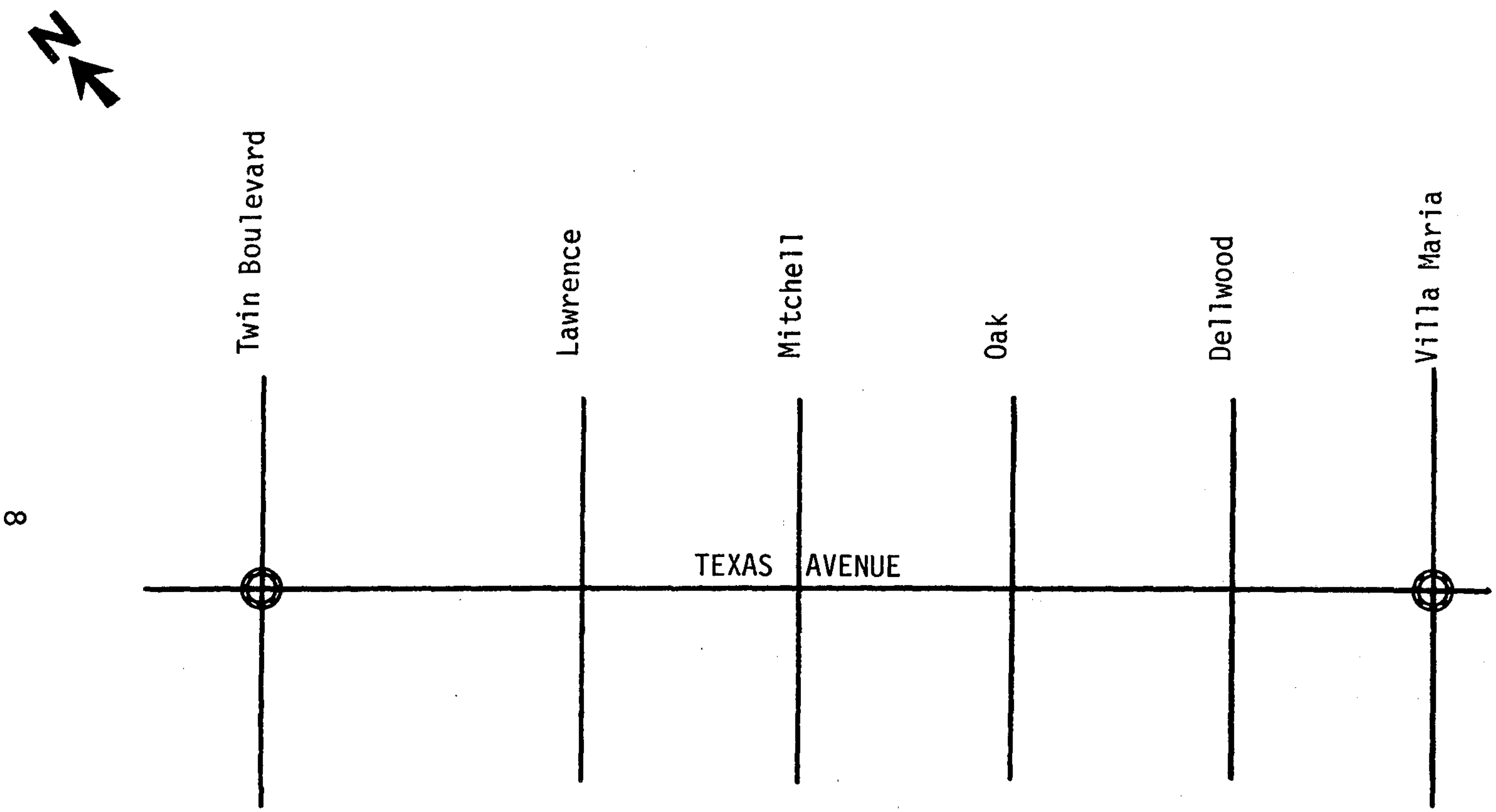
The section selected for study was approximately one-half mile in length, being the section of Texas Avenue between Twin Boulevard and Villa Maria Road (see Figure 1). This selection was included in an earlier study (13) which illustrated the practicability of improving access design along an existing arterial already burdened by strip development.

The Texas Highway Department District Office provided traffic counts made during June, 1972 as well as signal timing data. At the time this study was performed, the Villa Maria Road was a 3-legged intersection. Because plans are under way for the extension of Villa Maria Road as an arterial, traffic volumes at the intersection were adjusted on the basis of the current traffic projections used in the design of the extension. Driveway and some intersection turning counts were made by TTI personnel. Turning movement counts were taken at Dellwood, Mitchell, and Lawrence Streets during June, 1974.

The City of Bryan Planning Department provided 1"=100' scale area; photographs as well as 1'=100' scale plan of property boundaries.

The street geometry was obtained by using the 1"=100' scale photographic maps.

The hourly traffic at three intersections (Twin Boulevard, Oak Street, and Villa Maria Road) was plotted from the Texas Highway Department data and is shown in Figure 2. The evening peak is the highest in each case and the busiest 15-minute period is from 5:00 to 5:15 p.m. This period was therefore chosen for simulation. The peak hour traffic was found to contain approximately 2 percent commercial vehicles.



Scale: 1 inch = 400 feet

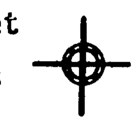
Signalized Intersections 

FIGURE 1 - SCHEMATIC DIAGRAM OF SECTION OF TEXAS AVENUE USED IN SIMULATION

Driveway Activity

A survey of driveway activity was carried out during June, 1974. Some driveways were observed to be inactive during the fifteen-minute period commencing at 5:00 p.m.

At those driveways with activity during the peak 15-minute period on the arterial, the flow varied from four vehicles/hour to 36 vehicles/hour. Most turning movements were right turns, either onto or from Texas Avenue, there being 12 percent left turns onto Texas Avenue and 27 percent left turns off Texas Avenue. For the simulations it was assumed that the left and right turns, either in or out of driveways, were equal.

The trip generation data shown in Table 2 were taken from the results of an Ohio Study (16); Table 3 gives typical driveway volumes and is based on data from a study by Paul C. Box and Associates (17).

Where a business had more than one driveway, consolidation of driveways was investigated with a view to reducing the number of driveways and this was found to be possible in some cases (13). It was also decided that driveways without activity during the 15-minute survey period would be ignored in the simulation studies.

The area along Texas Avenue has considerable room for further development. As this expansion occurs, it can be expected to cause driveway activity to increase at a greater rate than the through traffic. For this reason it was not desirable to use the present driveway traffic in the simulation study, but rather to use higher values. Three levels of driveway activity were chosen as being appropriate for study:

- 40 vehicles/hour
- 80 vehicles/hour
- 120 vehicles/hour

No commercial vehicles were observed during the survey and so no provision was made for commercial vehicles to be generated at driveways. There was, however, a possibility that commercial vehicles could leave Texas Avenue to enter a driveway during a simulation run.

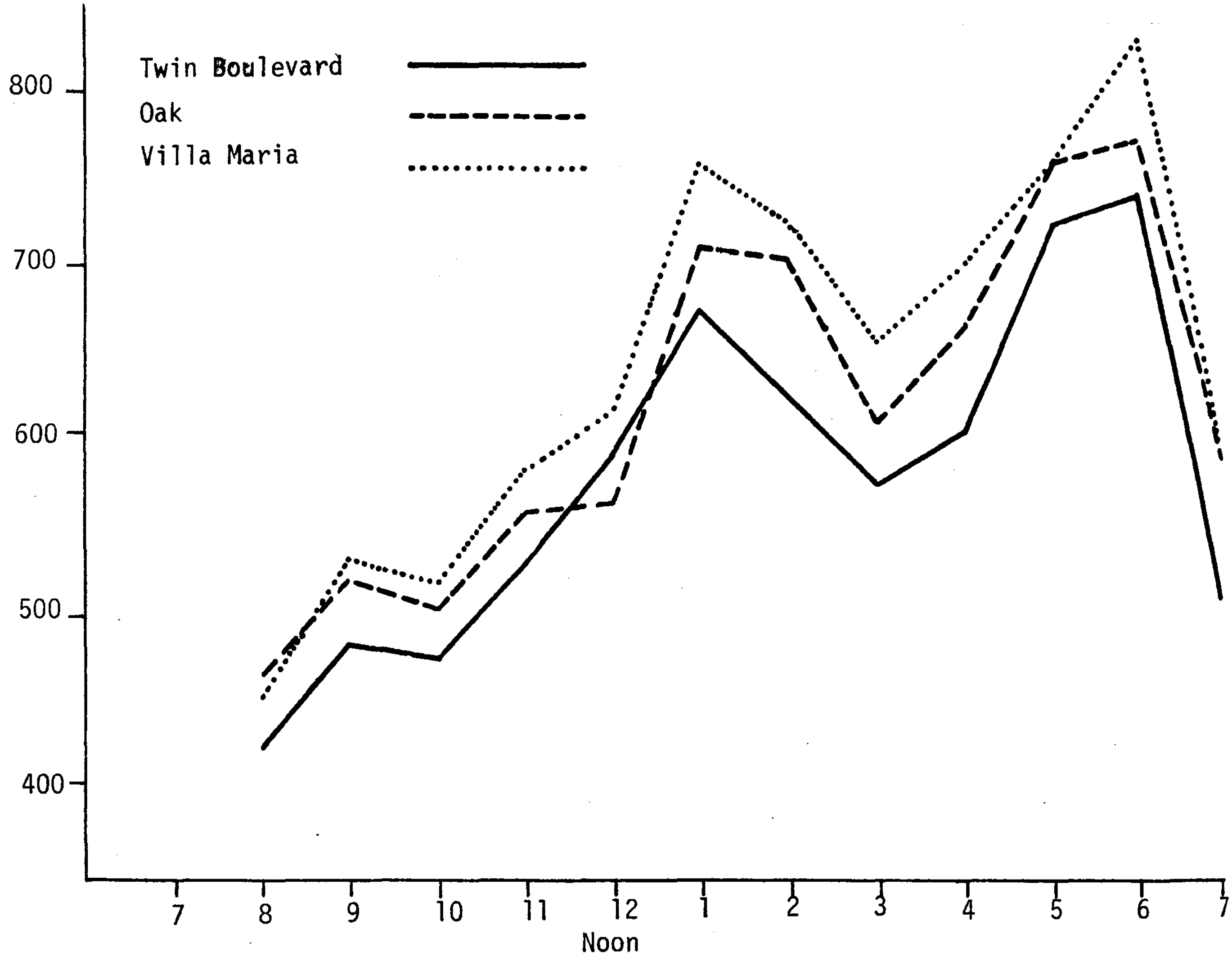


FIGURE 2: HOURLY TRAFFIC VOLUMES ON TEXAS AVENUE

TABLE 2 - TRIP GENERATION RATES

Land Use	Average GFA 1,000 sq.ft.	Average Vehicle Generation	
		Peak site hour Two-way trips 1,000 sq.ft.GFA	Average two-way trips in peak site hour
Fast food Restaurants	2.65	73	193
Sit-down Restaurants	4.40	33	145
Discount Stores	84.1	6.7	563
Community Shopping Center	180.0	4.2	756
Regional Shopping Center	690.8	1.5	1036
Food Store	21.6	16.6	358
Auto Supply Store	2.4	10	24
Suburban Office	82.0	2.5	205
Service Stations	1.3	43	55

TABLE 3 - TYPICAL DRIVEWAY VOLUMES

Land Use	Land Area (1,000 sq.ft.)	Two-Way Volumes (vph) P.M.	
		Total	Volume per 20,000 sq.ft. Land Area
Drug Store	25	175	140
Market or Grocery	35	179	102
	14	53	76
		190	
	42	98	47
	31	78	50
Mean			83
Drive-in Restaurant	22	76	69
	-	130	-
Shopping	32	213	133
	23	176	153
	41	81	40
Mean			99
Motel	-	78	-
Restaurant	10	47	94
	18	76	84
Mean			89
Liquor	10	173	346

Turning Speeds

The existing driveways are neither well-designed nor well-maintained and the turn speeds were chosen to reflect existing conditions; i.e., left turns 11 feet/second and right turns 7 feet/second or 7.5 miles per hour and 4.8 miles per hour, respectively.

Right turn slots with a capacity of two cars each were coded for all street intersections in an attempt to compensate for these slow turn speeds.

It would have been desirable to have included "normal" turn speeds as another level, but this was unfortunately not possible due to time and cost limitations.

Traffic Control

New signals that will be interconnected into a progressive system will soon be installed on Texas Avenue and the proposed timing was obtained from the Texas Highway Department (18). The peak hour timing calls for a 70-second cycle giving a progression speed of 31 miles per hour in each direction with equal band widths of 25 seconds. Two signalized intersections are included in the study section, Twin Boulevard and Villa Maria Road. Peak hour timing was used in the simulations. It should be noted that the effective band width in this study was wider than 25 seconds because signals beyond the limit of the study section were not included. Stop/yield control was assumed at all other intersections, including driveways.

Pedestrian activity is almost nonexistent on Texas Avenue and no allowance was therefore made for pedestrians in the simulations.

Simulation Runs

The UTCS - I Traffic Simulation Model (14,15) was used in the simulation studies. The experimental design was based on the various aspects discussed above and is summarized in Table 4. The simulations that were carried out are listed in Table 5. The test network is identified in Figure 1.

Seven runs were made for the existing street geometry, highway Design A, to serve as "base-cases" for comparison with the subsequent runs for different conditions of highway design, driveway activity, and increased traffic volume. In calculating the "future" traffic all volumes were increased in the same proportion.

The results of the simulation runs for each traffic volume level and driveway activity level are summarized in Tables 6 through 11. The sets of measures of effectiveness included in the tables are based on the standard statistical output generated by the UTCS - I simulation mode. The statistical comparisons of link statistics are based on the paired-comparison students "t" tests included in the UTCS - I Post-Processor.

Discussion of Results

From a generalized review, the results of the simulation study showed h that traffic operation on the test facility was improved significantly by the use of a barrier median. Further slight improvements were noted when right turns into individual driveways were eliminated. These improvements are significant to the planning and design process for new facilities, but are not practical for the solution of problems on existing arterials where access has been granted already. A subsequent section of this report deals with the possible application of the two-way left-turn lane on existing arterials.

Detailed examination of the individual link statistics revealed that the summary statistics of the measures of effectiveness for the overall simulation tend to mask significant changes in link performance. Improvement in performance for links at increased distance from the two signalized intersections was noted. Average link speeds for mid-block links and for each of the three blocks between Lawrence and Dellwood were extracted as well as the southbound traffic on the Dellwood-Villa Maria block and are shown in Table 6. There are no driveways between Oak and Dellwood at the present time. The speeds between

TABLE 4 - EXPERIMENTAL DESIGN FOR SIMULATION RUNS

Variable of Classification	Assigned Values	Number of Levels
Highway Type	4-Lane undivided 4-Lane with median 4-Lane with median and no individual driveways	Three
Traffic Volume Level	As existing: 500 vph/lane 625 vph/lane (125% of existing) 750 vph/lane (150% of existing)	Three
Intensity of Driveway Activity (Two-way Traffic)	40 vph 80 vph 120 vph (Basic flows with existing road traffic)	Three
Driveway Turn Speeds	Right turns 7 ft/sec Left turns 11 ft/sec Right turns 13 ft/sec Left turns 22 ft/sec (for no individual driveway test only)	One

TABLE 5 - LISTING OF SIMULATION RUNS BY MID-BLOCK ACCESS CONTROL AND TRAFFIC VOLUME

Variations in Mid-Block Access Control	Driveway Activity (Vehicles/hour)	Traffic Volumes Existing 500 vph/lane (100%)	Future 625 vph/lane (125%)	Future 750 vph/lane (150%)
A Four Lane Undivided	40	#10 #80		
	80			#27
	120	#40 #40A*	#41	#42
B Four Lane with Median (No left turn)	40	#15 #85		
	80			#32
	120	#45 #115		
C Four Lane with Median and no indivdual driveways (No left or right turn)	40	#6 #76		
	80			#56
	120	#50 #120 #50A*	#51	#99

*30 mph right turn speed; right turn speeds for other simulation runs are 4.8 mph.

TABLE 6 - MEASURES OF EFFECTIVENESS AT EXISTING ARTERIAL VOLUME

AND 40 VEHICLE PER HOUR DRIVEWAY TRAFFIC

	A Existing		B No Left Turns			C No Left or Right Turns			Comparison of B and C
	Run No.	Value	Run No.	Value	t-test	Run No.	Value	t-test	t-test
Vehicle Trips	10	255.00	15	248.11	***	6	249.76	—	—
	80	248.22	85	246.91	—	76	256.20	***	***
Travel Time/Vehicle (minutes)	10	4.08	15	3.94	***	6	3.95	*	—
	80	3.99	85	4.00	—	76	3.96	—	—
Delay Time/Vehicle (minutes)	10	1.69	15	1.49	***	6	1.54	**	—
	80	1.57	85	1.58	—	76	1.53	—	—
Average Speed (mph)	10	20.88	15	21.44	***	6	21.53	***	—
	80	20.91	85	21.21	—	76	21.62	***	**
Stops/Vehicle	10	0.10	15	0.08	***	6	0.09	***	—
	80	0.10	85	0.09	—	76	0.09	**	—
Percent Stop Delay	10	15.85	15	12.18	***	6	11.77	***	—
	80	16.20	85	12.58	***	76	11.82	***	—
Average Saturation	10	11.35	15	10.65	***	6	10.89	—	—
	80	10.89	85	10.74	—	76	11.07	—	—
Moving Time / Total Travel Time	10	0.69	15	0.73	***	6	0.72	***	—
	80	0.70	85	0.72	*	76	0.73	***	*
					Increase			Increase	Increase
Average Link Speeds Mid-Block (mph)	10	22.00	15	22.60	+3	6	22.70	+3	0
	80	21.90	85	22.40	+2	76	22.80	+4	+2
Dellwood - Villa Maria (Southbound)	10	17.00	15	17.30		6	17.20		
	80	18.20	85	16.60		76	18.20		
Oak - Dellwood	10	26.00	15	25.70	-1	6	25.50	-2	-1
	80	26.10	85	25.70	-2	76	25.70	-2	0
Mitchell - Oak	10	22.20	15	23.20	+5	6	23.40	+5	+1
	80	21.50	85	23.10	+7	76	23.30	+8	+1
Lawrence - Mitchell	10	21.90	15	22.10	+1	6	22.10	+1	0
	80	21.80	85	22.0	+1	76	22.20	+2	+1

TABLE 6 - CONTINUED

		Run No.	Value	Run No.	Value	Change	Run No.	Value	Change	Change
Vehicle Miles	(i)	10	236.52	15	729.94		6	229.99		
		80	230.67	85	228.53		76	236.70		
Vehicle Minutes	(i)	10	795.30	15	751.30		6	761.80		
		80	759.50	85	758.10		76	781.30		
Vehicle Trips (Est.)	(i)	10	720.00	15	711.00		6	681.00		
		80	705.00	85	711.00		76	713.00		
Stops/Vehicles	(i)	10	1.68	15	1.37	-18%	6	1.53	-9%	+12%
		80	1.54	85	1.41	- 8%	76	1.42	-8%	+ 1%
Moving Time / Total Travel Time	(i)	10	0.592	15	0.625	+	6	0.607	+	-
		80	0.610	85	0.609	-	76	0.612	+	+
Average Speed (mph)		10	17.84	15	18.36	+ 3%	6	18.11	+2%	- 1%
		80	18.22	85	18.09	- 1%	76	18.18	-	-
Mean Occupancy		10	52.60	15	49.70		6	50.40		
		80	50.30	85	50.10		76	51.70		
Average Delay/Vehicle (seconds)		10	27.07	15	23.80	-12%	6	26.35	-3%	+11%
		80	25.21	85	25.00	- 1%	76	25.48	+1%	+ 2%
Total Delay (minutes)		10	324.90	15	282.10	-13%	6	299.10	-8%	+ 6%
		80	296.30	85	296.30	-	76	302.80	-	+ 2%
Delay/Vehicle Mile (min/vehicle mile)		10	1.37	15	1.23	-10%	6	1.30	-5%	+ 6%
		80	1.28	85	1.30	+ 2%	76	1.28	-	- 2%
Travel Time-Vehicle Mile (min/vehicle mile)		10	3.36	15	3.27	- 3%	6	3.31	-1%	+ 1%
		80	3.29	85	3.32	+ 1%	76	3.30	-	- 1%
Stop Delay as Percent of Total Delay		10	51.10	15	50.40		6	52.50		
		80	49.80	85	51.30		76	52.80		

Levels of Significance:

* 95%
** 98%
*** 99%

TABLE 7 - MEASURES OF EFFECTIVENESS AT EXISTING ARTERIAL VOLUME

AND 120 VEHICLE PER HOUR DRIVEWAY TRAFFIC

	A Existing		B Curbed Median			C Curbed Median No Driveways			Comparison of B and C
	Run No.	Value	Run No.	Value	t-test	Run No.	Value	t-test	t-test
Vehicle Trips	40	244.46	45	237.52	—	50	247.0	—	—
			115	248.48		120	247.41		—
Travel Time/Vehicle (minutes)	40	4.01	45	3.94	—	50	3.77	*	—
			115	3.93		120	3.94		—
Delay Time/Vehicle (minutes)	40	1.57	45	1.53	—	50	1.39	—	—
			115	1.50		120	1.53		—
Average Speed (mph)	40	20.26	45	21.18	***	50	22.31	***	***
			115	21.36		120	21.69		—
Stops/Vehicle	40	0.09	45	0.07	***	50	0.06	***	—
			115	0.07		120	0.07		—
Percent Stop Delay	40	17.72	45	8.58	***	50	9.40	***	—
			115	9.63		120	10.78		—
Average Saturation	40	10.70	45	9.57	—	50	10.22	—	—
			115	10.59		120	10.72		—
Moving Time / Total Travel Time	40	0.69	45	0.72	***	50	0.74	***	*
			115	0.73		120	0.73		—
					Increase			Increase	Increase
Average Link Speeds Mid-Block (mph)	40	21.2	45	22.5	+6	50	23.5	+11	+4
			115	22.4	+6	120	23.0	+ 8	+3
Dellwood-Villa Maria (Southbound)	40	19.1	45	16.2		50	17.3		
			115	19.1		120	15.9		
Oak - Dellwood	40	25.4	45	26.4		50	25.6		
			115	26.0		120	25.2		
Mitchell - Oak	40	21.0	45	23.1	+10	50	24.3	+16	+5
			115	22.4	+8	120	23.2	+10	+3
Lawrence - Mitchell	40	21.0	45	22.3	+6	50	23.0	+10	+3
			115	22.4	+7	120	22.5	* 7	0

TABLE 7 - CONTINUED

	A		B			C			Comparison of B and C
	Existing		Curbed Median			Curbed Median No Driveways			
	Run No.	Value	Run No.	Value	Change	Run No.	Value	Change	Change
Vehicle - Miles	40	227.00	45 115	227.75 229.41		50 120	226.60 227.13		
Vehicle - Minutes	40	753.9	45 115	742.2 752.0		50 120	724.1 757.2		
Vehicle - Trips (Est.)	40	968	45 115	979 983		50 120	918 918		
Stops/Vehicle	40	1.07	45 115	0.87 0.83	-19% -22%	50 120	0.83 0.93	-22% -13%	-5% +12%
Moving Time / Total Travel Time	40	0.613	45 115	0.620 0.621	+ +	50 120	0.626 0.603	+ -	+ -
Average Speed	40	18.07	45 115	18.41 18.30	+2% +1%	50 120	18.78 18.00	+4% -	+2% -2%
Mean Occupancy	40	49.7	45 115	48.9 49.5		50 120	47.7 49.9		
Avg. Delay/Vehicle (seconds)	40	18.08	45 115	17.30 17.38	-4% -4%	50 120	17.72 19.64	-2% +9%	+2% +13%
Total Delay (minutes)	40	291.7	45 115	282.3 284.7	-3%	50 120	271.1 300.5	-7%	-4% +6%
Delay/Vehicle Mile (min./vehicle mile)	40	1.28	45 115	1.24 1.24	-3% -3%	50 120	1.20 1.32	-6% +3%	-3% +6%
Travel Time/Veh. Mile (min./Vehicle mile)	40	3.32	45 115	3.26 3.28	-2% -1%	50 120	3.20 3.33	-4% -	-2% +2%
Stopped Delay as Percent of Total Delay	40	46.9	45 115	47.3 48.9	-	50 120	50.4 52.8	+	+ +

Levels of Significance
* 95%
** 98%
*** 99%

TABLE 8 - IMPROVEMENT IN LINK PERFORMANCE WITH NO TURNS WITH ARTERIAL TRAFFIC 125 PERCENT OF CURRENT VOLUME AND 120 VEHICLES PER HOUR DRIVEWAY TRAFFIC

	Existing Condition (Run #41)	No Left or Right Turns (Run #51)	t-test	Increase
Vehicle Trips	298.83	294.83	-	
Travel Time/Vehicle (min)	4.56	5.32	-	
Delay Time/Vehicle (min)	2.14	2.90	-	
Average Speed (mph)	19.07	19.47	-	
Stops/Vehicle	0.12	0.13	-	
Percent Stop Delay	22.75	17.31	-	
Average Saturation	14.65	18.57	--	
Moving Time / Total Travel Time	0.64	0.66	-	
Average Link Speeds				
Mid-Block	20.2	22.0		+9%
Dellwood-Villa Maria southbound	15.3	3.4		
Oak-Dellwood northbound	24.5	24.6		
Oak-Dellwood southbound	26.1	18.4		
Mitchell-Oak	19.4	23.0		+23%
Lawrence-Mitchell	20.1	21.7		+8%

*Levels of Significance
95% *
98% **
99% ***

TABLE 9 - AVERAGE LINK SPEEDS AT ARTERIAL TRAFFIC 150 PERCENT OF CURRENT VOLUME AND 80 VEHICLES PER HOUR DRIVEWAY TRAFFIC

	Existing (Run #27)	No Left Turns (Run #32)		No Left or Right Turns (Run #99)		Comparison of B & C
	Speed	Speed	Increase	Speed	Increase	Increase
Mid-Block	20.3	21.2	+4%	21.9	+8%	+3%
Dellwood-Villa Maria-southbound	14.3	9.8		2.6		
Oak-Dellwood						
northbound	24.9	25.4		24.1		
southbound	25.7			5.7		
Mitchell-Oak	20.7	21.6	+4%	22.2	+7%	+3%
Lawrence-Mitchell	19.9	20.9	+5%	21.1	+6%	+1%

TABLE 10 - AVERAGE LINK SPEEDS AT ARTERIAL TRAFFIC 150 PERCENT OF CURRENT VOLUME AND 120 VEHICLES PER HOUR DRIVEWAY TRAFFIC

	Existing (Run #42)	No Left or Right Turns (Run #99)	
	Speed	Speed	Increase
Mid-Block	19.7	21.7	+10%
Dellwood-Villa Maria southbound	4.0	2.9	
Oak-Dellwood			
southbound	16.4	7.6	
northbound	24.2	24.8	
Mitchell-Oak	19.9	22.0	+11%
Lawrence-Mitchell	20.0	21.2	+ 6%

TABLE 11 - SIMULATION EFFECT OF IMPROVED DRIVEWAY DESIGN WITH 120 VEHICLES PER HOUR DRIVEWAY TRAFFIC

Average Link Speed - miles per hour

	Turns Permitted			No Left or Right Turns		
	Existing Operation	Existing Operation	Increase Increase	Existing Operation #50	Existing Operation #50A	Increase Increase
Mid-block	21.2	21.7	+2%	23.5	23.4	—
Oak - Dellwood	25.4	25.9	+2%	25.8	25.8	—
Mitchell - Oak	21.0	21.8	+4%	23.8	24.0	+1%
Lawrence - Mitchell	21.0	21.6	+3%	22.8	23.1	+1%

Oak and Dellwood fluctuated between 25.5 and 26.1 miles per hour in the case of the 40 vehicles per hour driveway volumes and between 25.2 and 26.4 miles per hour for the 120 vehicles per hour driveway volumes. The speeds on the street as a whole and on the other two selected blocks all, however, showed increases which were largest for the 120 vehicles per hour driveway volume tests and ranged up to 16 percent better than for the existing type street (3.3 miles per hour increase between #40 and #50). The 120 vehicles per hour driveway volume tests also showed a difference of up to 5 percent (1.2 miles per hour increase between #45 and #50) between highway Design types B and C. Therfore, it is concluded that the elimination of both left and right turns at driveways resulted in a significant improvement over the elimination of left turns only.

A comparison of the results for the two different driveway volumes showed that more improvement was obtained at the higher driveway volume. The mid-block average speeds in particular showed a marked difference between the type B and the type C Design which indicates that superior operation should be obtained on a divided arterial having varying potential driveway activity and without individual driveways as compared with a divided arterial having unlimited access. Since the driveway is merely an uncontrolled intersection, it follows that in the design of a street system it would not help to simply deny direct access to the arterial without concomitant attention to improvement of street intersection operation and the arterial must therefore be considered and treated as part of a system and not as an isolated entity.

Future Traffic - 125 Percent of existing volume

The overall network statistics did not show any improvements and the Post Processor statistical analysis output for Runs #41 and #51, street Design types A and C respectively, indicated no significant differences between the respective link performances. The only two measures which seemed to have improved were the average speed and the moving time to total time ratio. Examination of the individual link statistics did, however, suggest that there was an improvement. The average speeds were again extracted for the same sections as was done for the existing traffic level. The speeds between Oak and Dellwood again fluctuated, this time between 18.4 and 26.1 miles per hour, the other two speeds being 24.5 and 24.6 miles per hour. The low speed of 18.4 miles per hour can be attributed to congestion extending back from Villa Maria Road. The overall average link speed showed an increase of 9 percent while the improvement for the section between Lawrence and Mitchell was 8 percent and for the section between Mitchell and Oak was 12 percent.

The fact that the midblock improvements in performance are masked by the poor results at the signalized intersections highlights the importance of the unified design mentioned earlier.

Future Traffic - 150 Percent of existing volume

The Post-Processor analysis was rendered meaningless by the congestion at Villa Maria Road with simulations of 150 percent of current traffic volumes.

Examiniation of link statistics showed the same type of results as with lower volumes and extracts are summarized in Tables 9 and 10. The improvements between Designs A and C (#27 and #56) were not as great as at the 125 percent level. There was an improvement in speed from Design B to Design C (#32 to #56 and #42 to #99); this was about the same as that noted for the 120 vehicles per hour driveway volume at the 100 and 125 percent levels, respectively. Comparison of the results for the two levels of driveway activity again showed that more improvement far afforded at the higher driveway volume.

Improved Driveway Design - In order to test the effect of improved driveway design which would allow turning traffic to exit and enter the arterial at higher speeds, two simulation runs were carried out using a 30-mile-per-hour right turn speed. The results are shown in Table 11 where they are compared with the corresponding original runs.

The results showed a slight improvement for design types A but virtually no difference between the two runs for Design C. The improvement in type A with the higher right turn speed can be attributed to the fact that many driveways are involved and there is thus a lot of room for improvement. The smaller improvement for Design C is not surprising since a relatively small number of intersections are involved and the original simulation was carried out with a right turn speed of 13 feet/second, which was double the right turn speed used for the original Design A run.

Intersection Design - Although no variations in intersection design were made between simulations, the need for improvement in intersection performance to balance improved design and especially to cater to increased traffic was made very evident by the performance on the southbound approach to Villa Maria Road. Southbound speeds on the three blocks immediately north of Villa Maria Road are plotted in Figure 4 against traffic volume. The speed on the block closest to Villa Maria Road drops drastically as the volume increases; the higher speed, at 1,500 vehicles/hour on the approach, is more than 10 miles per hour less on the preceding block. It should be noted that the speed for Design C is better than that for Design A in the Mitchell-Oak block which has driveways in Design A. Furthermore, this speed is fairly well maintained as traffic increases because this section is far enough upstream from Villa Maria Road.

ANALYSIS AND CONCLUSIONS

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 <u>new facility</u>. 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 <u>through traffic</u> 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 nonexistant.

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-block, 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 a 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.

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