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16. Abstract

With the dwindling of fundings for new highway construction, greater efforts have to be placed on maintaining and improving existing facilities. The impact of any capacity improvement on adjacent land use or on traffic volume growth rates is a subject of concern to transportation officials. Previous studies on the subject do not draw conclusive results because of small data sets used. The present study attempts to study the same subject by constructing two regression models using an expanded data base. The first model is a land use regression model which relates each land use, in percentage of total acreage, to time. In addition to capacity improvements, factors affecting the relationship include median treatments, neighboring traffic, highway type and city differences. Estimation by Ordinary Least Squares, OLS, reveals that both capacity and median improvements impact adjacent land use and that the impact varies according to the type of land use. Based on estimated results, a procedure for predicting land use is outlined and an example is given.

The second model is a traffic volume regression model that relates ADT to time. In addition to factors studied in the land use prediction model, the stage of area development is added. A log-log function is used and estimated by OLS. Results indicate that while any capacity improvement induces additional traffic, any median treatment hinders it. Also ADT is found to grow faster in less developed areas. By applying the regression results, a procedure for predicting ADT is developed and outlined. An example is given for its application.

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land use or traffic volume predictions in the planning or evaluation processes.

PREDICTING THE EFFECTS OF ROADWAY IMPROVEMENTS ON LAND USE AND TRAFFIC VOLUMES

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Economics of Highway Design Alternatives

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PREFACE

The authors wish to express their appreciation to those who have assisted or facilitated this study. Special acknowledgement is given to Mr. Jim Barr and Mr. James R. Farrar, Jr. of the Texas State Department of Highways and Public Transportation for their valuable comments. Other SDHPT personnel that were especially helpful in furnishing data or assistance to the study are: Messrs. Phillip R. Reeder, Basil T. Cearley, Otto W. Wehring, Fred Stutz, and Walter Hejl of the Transportation Planning Division (D-10); Messrs. Roy M. Roberson and George Kirkwood of District 10; Messrs. Montie G. Wade and William M. Runnels of District 19; Mr. Charles M. Kitchell of District 8, Mr. Joe Cotton of District 9; Messrs. D. D. Williamson and Roger Barnes and Mrs. Peggy Krohn of District 17; Mr. Francis X. Fallwell and Ms. Miriam O. Grayson of District 18; and Messrs. Don Walden and Bill Bugleholl of the Dallas/Fort Worth Regional Planning Office. Also Messrs. Roscoe H. Jones and Joseph C. Chow of the Houston City Planning Department and Mr. Lee Roy George of the Abilene City Planning Department were helpful in providing information. Special thanks are due to Mr. Eric Schulte for preparing the graphs and Ms. Patti McClurg for typing the manuscript.

ABSTRACT

With the dwindling of fundings for new highway construction, greater efforts have to be placed on maintaining and improving existing facilities. The impact of any capacity improvement on adjacent land use or on traffic volume growth rates is a subject of concern to transportation officials. Previous studies on the subject do not draw conclusive results because of small data sets used. The present study attempts to study the same subject by constructing two regression models using an expanded data base. The first model is a land use regression model which relates each land use, in percentage of total acreage, to time. In addition to capacity improvements, factors affecting the relationship include median treatments, neighboring traffic, highway type and city differences. Estimation by Ordinary Least Squares, OLS, reveals that both capacity and median improvements impact adjacent land use and that the impact varies according to the type of land use. Based on estimated results, a procedure for predicting land use is outlined and an example is given.

The second model is a traffic volume regression model that relates ADT to time. In addition to factors studied in the land use prediction model, the stage of area development is added. A log-log function is used and estimated by OLS. Results indicate that while any capacity improvement induces additional traffic, any median treatment hinders it. Also, ADT is found to grow faster in less developed areas. By applying the regression results, a procedure for predicting ADT is developed and outlined. An example is given for its application.

Both models are seen to be useful to officials who require land use or traffic volume predictions in the planning or evaluation processes.

SUMMARY OF FINDINGS

Two regression models are developed in this study to estimate the effects of roadway improvements, one on land use development and the other on traffic volumes. In an attempt to overcome some of the difficulties and limitations of models developed in two previous studies using small data bases, an expanded data base consisting of 187 study points from six Texas cities are used in this study. These study points are broken down into categories based on their initial land use percentages or initial ADT levels.

In the land use regression model, the percentage of each land use is related to time (year), and binary variables are used to identify the various initial land use categories and to test the effects of various roadway improvements. Results obtained from using ordinary least squares (OLS) reveal that a capacity improvement of a roadway affects each land use differently. Construction of a new facility attracts commercial use and initially discourages industrial use but enhances its growth. Improving the capacity of an existing facility has a positive effect on the growth in residential use. A raised median has a negative effect on the levels of residential and commercial uses but a positive effect on their growth rates. On the other hand, the continuous left turn lane treatment is found to deter industrial use. Other significant effects on land use development include neighboring traffic, city and highway type differences. Effects differ according to the type of land use. From the estimation results obtained, a prediction procedure is outlined for predicting land use and an example is given for its application.

Following a similar technique, the traffic volume regression model attempts to relate the level of ADT to time (year), using a log-log functional form. Binary variables are used to identify the various initial ADT level categories and also the effects of roadway improvements. The findings of the analysis confirm that any capacity improvement tends to induce additional traffic to use the improved facility. Between new and existing facilities, ADT grows faster on a newly constructed roadway than on an existing roadway with added capacity. Both the raised median and the continuous left turn lane treatment are found to hinder ADT, with the former having a greater negative effect. The stage of area development plays a significant role in affecting ADT. Traffic volumes experience the fastest growth in undeveloped areas, the slowest in developed areas, and a moderate growth in developing areas. Other significant factors found are city differences and neighboring traffic. From the regression results, a prediction procedure is outlined for predicting ADT growth and an example is given to illustrate its application.

Both models are seen to be useful for land use prediction for city or region planning purposes or for ADT prediction which can be incorporated into the revised Highway Economic Evaluation Model (HEEM-II) as one of input requirements.

IMPLEMENTATION STATEMENT

This report presents two regression models of predicting the effects of roadway improvements, one on land use development and the other on traffic volumes. Other effects on land use development and traffic volumes are also examined. The findings can be implemented immediately for more accurate estimates of projected land use or ADT.

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INTRODUCTION

Purpose and Objective of Study

Because of the very limited funding for new highway construction, greater effort is being made by the State Department of Highways and Public Transportation to improve existing facilities by adding extra lanes, adding or changing medians, etc. in order to provide greater capacities to roadway users. It is expected that the undertaking of any roadway improvement impacts various elements in the surrounding environment. Among them, adjacent land use and traffic growth represent the two major concerns to transportation officials. In an early study by Rollins, Memmott and Buffington [1], the impact of roadway improvements on adjacent land use are examined, and in a later study, Memmott and Buffington attempt to predict traffic volume growth rates resulting from highway capacity improvements and land use development [2]. However, results obtained in both studies are inconclusive because of the small data base used.

The main objective of the present study is to attempt to determine, with greater precision, the effects of roadway improvements, such as capacity improvement and median treatments, on adjacent land use and on traffic growth using an expanded data set. The larger data base should help to provide information for developing and specifying regression models and enhancing the ability of such models to estimate significant relationships between land development or traffic growth and various influencing factors. From the regression results, prediction procedures can be developed for predicting land use or traffic volumes.

Contents of Report

The report consists of two major sections. The first section presents a regression model of land use as affected by roadway improvements. A description of the data base and its limitations are presented. The regression model is described in detail and the findings of the analysis are presented. The application of the results is demonstrated by the development of a prediction procedure which is outlined in a step-by-step procedure and an example is also included in this section.

The second section of the report contains a regression model of traffic volume growth rates as affected by roadway improvements. It includes a description of the data base together with a discussion on its limitations. The regression model is described and the findings of the analysis are presented. Lastly, this section is concluded with the application of the model by developing a traffic volume prediction procedure which is outlined and illustrated by an example.

Sources of Data

The land use data base used in the analysis are from the files of SDHPT division or district planning offices or from city planning offices. The traffic, highway design, and construction data are from files or maps maintained in the SDHPT division or district planning offices.

PREDICTING THE EFFECTS OF ROADWAY IMPROVEMENTS ON LAND USE

A regression model is built in the attempt to estimate the effects of roadway improvements on surrounding land use development. A fairly large data set consisting of cross-sectional data is used for the analysis. A description of the data base together with its limitations are discussed in this section. In addition, a description of the regression model and the results of the analysis are presented. Lastly, an application of the results is given to illustrate how the model is used for prediction purposes.

Limitations and Description of Data Base

To overcome the limitations expressed in the study by Rollins, Memmott and Buffington [1], greater efforts are undertaken in the current study by developing a larger cross-sectional data base and by including control data whenever possible. However, such efforts are fraught with difficulties and other limitations as exemplified in the variations of data sources and the choice of adopting a shorter study period instead of a longer one as desired. These difficulties and limitations together with a description of the data base are presented in this section.

Data Limitations

The data base used in this study is subject to two limitations, namely the lack of annual data and a short study period. Since this study involves an analysis of the effects of roadway improvements on adjacent land use over time, theoretically, time series of annual data are the most desirable to use. However, in the process of data gathering, it is found that land use data before 1970 are scarce and incomplete, with most of such data being kept on aerial maps. Data from aerial maps can only be obtained by painfully measuring with rulers or a planimeter, a job that is both time consuming and tedious. In addition, the existing land use data bases are updated only every four or five years. Since 1970, most cities use computers to store and update data. As a result, land use data are more systematically kept and easier to access. To use cross-sectional data representing different years appears to be the alternative left for building an expanded data base. Yet, variability may also arise from the different data sources, i.e., different cities. However, this limitation is partially taken care of in the analysis by using binary variables to detect city differences, if any, in the generalized linear regression estimation procedure.

The second limitation results from the lack of usable land use data for certain years prior to 1970 from some of the cities chosen for this study. Even though a longer study period is preferred, the current study has to limit its study period to be from 1970 to 1980 because that is the period for which pertinent data are available from all the cities with usable data bases.

Description of Data Base

Subject to the above data limitations, the data base for the study consists of 187 traffic points in six cities in Texas, covering a study period from 1970 to 1980. Each traffic point chosen represents a traffic count station on a highway segment either with or without a change in capacity. Those with capacity changes implemented during the study period are defined as study points while those without are considered to be control points. In general, the control points are located in the vicinity of the study points or are on the same highway or along similar highway segments as the study points.

The study area of each traffic point is defined as the area within a one-half mile radius from the point. The amount of land in each study area by type of use represents the sum of that land use for all survey zones or serial zones which lie totally or partially within the one-half mile radius. Whenever available, survey zone data are preferred to serial zone data because survey zones represent smaller areas than serial zones do and, consequently, reduce calculating errors.

In addition to the 82 traffic points in Dallas identified by Memmott and Buffington in their study on traffic growth rates prediction, 15 more traffic points are used, giving a total of 97 traffic points in Dallas. Land use and traffic data obtained from District 18 of the SDHPT in Dallas are for the years 1970, 1975 and 1977. The land use and traffic data for all of these 97 traffic points meet the same definitions set forth in the building of the total data base.

Nine traffic points are located in Bryan-College Station. The land use data and traffic data obtained from District 17 of the SDHPT in Bryan are for the years 1970, 1975, 1977 and 1980. Only five traffic points are from Fort Worth and the land use and traffic data are for 1970, 1975 and 1978. Tyler has 37 traffic points and the land use and traffic data are for 1970, 1975 and 1980. Texarkana has 15 traffic points and the land use and traffic data are for 1970 and 1980. Houston has a total of 24 traffic points and the land use and traffic data are for 1970, 1975, 1978 and 1980.

Considering that data for each year are separate observations, the 187 traffic points yield a total of 583 observations for each variable identified in the data base, with a few observations containing missing data on one or more variables. However, the least number of observations used in the regression is 490. Tables A1-A5 show the locations and general traffic characteristics of the traffic points chosen. It is believed that such a large data base should minimize the limitations of the data base used by Rollins, Memmott and Buffington in their attempt to measure the effects of roadway improvements on adjacent land use [1].

Description of Land Use Regression Model

The regression model developed in this study attempts to examine the relationship between the percentage of total area in each type of land use and time (measured in years) when impacted by other factors, such as different types of roadway improvements. In general, land use along the improved section of a roadway is believed to react either positively or negatively to the improvement, depending on the type of land use. Previous techniques of predicting land use changes often relate land use changes directly to some continuous variables such as average daily traffic (ADT) or population, [1]. In other words, these studies try to answer questions of "What happens to residential land use (or other types of land use) at a given level of ADT if an improvement of a roadway is to be made?" or "What happens to residential land use (or other types of land use) at a given level of population if a roadway improvement is to be made?"

However, during the roadway improvement impact evaluation process, transportation officials are not really looking at answers to these questions. It is believed that they are more interested in finding out "What happens to the various land uses if an improvement is to be made on a particular roadway segment next year or in 1985?" Time is the relevant variable in their decision-making. Although it is true that both ADT and population change over time, to predict the level of ADT or population in a future year involves the use of a completely different approach before trying to predict changes in land use as

ADT or population changes. Unless projected ADT or population for a future year is readily available, the extra work means additional time and cost which most current tight budgets in transportation cannot afford. In addition, unnecessary error is introduced into the land use predictions, since errors in the preliminary ADT or population projections would be incorporated into the land use projections. Therefore, time measured in years is chosen as the continuous variable in the land use regression model. Other continuous variables, such as ADT, are also used as explanatory variables, in an attempt to show the relationship between each land use and time (year) at different levels of ADT.

Besides the effects of roadway improvements, other factors influencing the relationship between land use changes and time, such as the period when an improvement is made, metropolitan area differences, median treatment, highway type, and adjacent traffic are also examined. In addition to these factors, the effects of initial levels of land use development by land use type are also measured in the model. Not only are the level adjustments (changes in the intercept) examined, but the slope adjustments are also explored.

Actually, there are three possible effects that could happen to the percentage of land use over time due to any factor. For instance, a capacity improvement made on a roadway could cause: (1) an initial surge in land use development but with no change in the underlying rate of development; or (2) a change in the underlying rate of development but with no initial surge in land use development; or (3) an initial surge in land use development together with a change in the underlying rate of development. Figure 1 illustrates these possible effects of a capacity improvement on a residential land use (RAP). Following Kmenta's peacetime and wartime consumption function [3] as an example, a residential land use development function is given as follows:

$$RAP = a + bt + c(E_t) + d(E_t)(t),$$

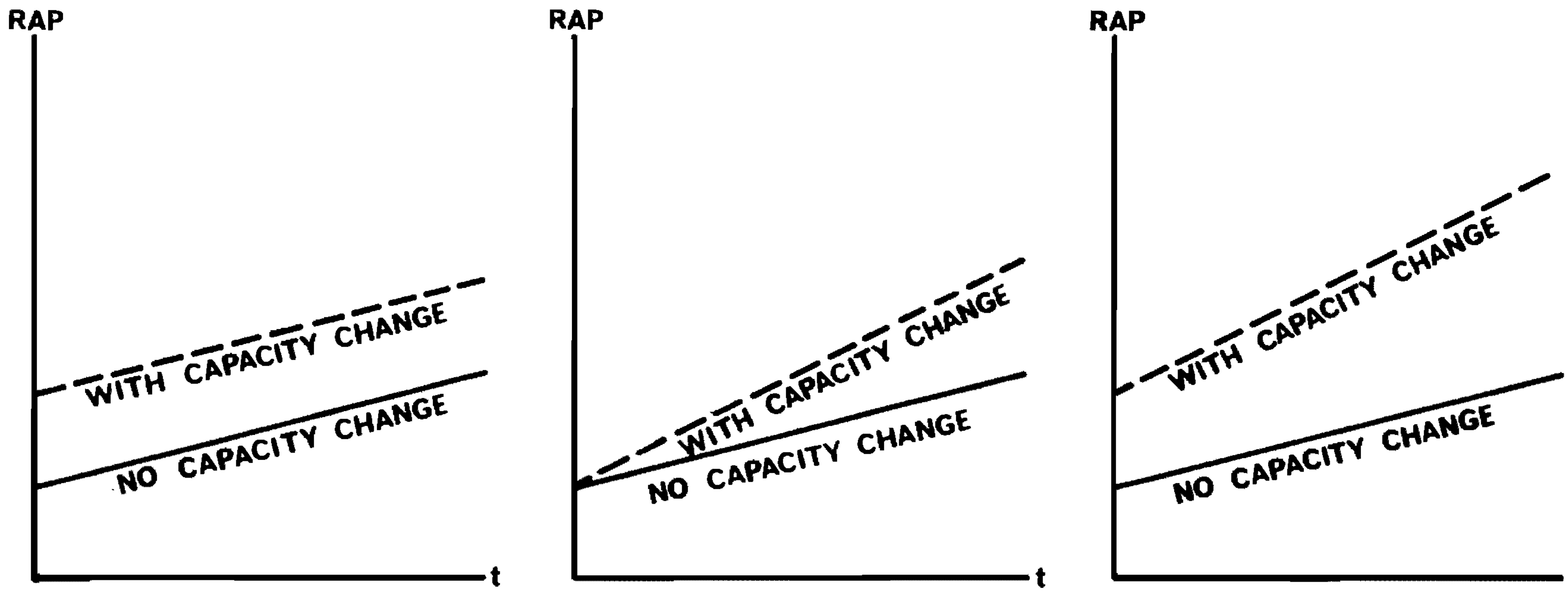

FIGURE 1.1 FIGURE 1.2 FIGURE 1.3

Figure 1. Illustrations of the Three Possible Models of the Effects of a Capacity Improvement on Residential Land Use (RAP).

where RAP = percent of residential acreage to total acreage,

t = year and

E = binary variable representing capacity improvement.

The three aforementioned possible effects resulting from a capacity improvement can be expressed in the following three equations, respectively:

(1) $RAP = a_1 + b_1t + c_1(E_t)$,

(2) $RAP = a_1 + b_1t + d_1(E_t)(t)$ and

(3) $RAP = a_1 + b_1t + c_1(E_t) + d_1(E_t)(t)$.

After adoption of the appropriate values for the binary variable, E_t, to Equation 1 the first possible effect takes on the following model and is illustrated in Figure 1.1:

$RAP = a_1 + b_1t$ (with no capacity change) and

$RAP = (a_1 + c_1) + b_1t$ (with capacity change).

Similarly, the second possible effect as expressed in Equation 2 can be represented by the following model and is shown in Figure 1.2:

$RAP = a_1 + b_1t$ (with no capacity change) and

$RAP = a_1 + (b_1 + d_1)t$ (with capacity change).

Lastly, the third possible effect as shown by Equation 3 can be expressed by the following model and is graphically shown in Figure 1.3:

$RAP = a_1 + b_1t$ (with no capacity change) and

$RAP = (a_1 + c_1) + (b_1 + d_1)t$ (with capacity change).

Often binary variables are found to be very useful tools in regression analysis for testing the mean difference in the dependent variable between the presence and absence of the characteristic being tested. It is hoped that the above discussion has helped in providing a good background for understanding how binary variables are used in this study.

The land use prediction model takes on the general functional form as follows:

Land Use Acreage by Type/Total Acreage = f(Year, Initial Condition of Land Use by Type, Other Explanatory Factors).

The variables are discussed under two categories: the dependent and the exogenous variables. Table 1 lists both categories of variables together with their definitions. Ordinary least squares (OLS) is used to estimate the coefficients in the model, the results will be unbiased and consistent.

Dependent Variables

Three dependent variables representing three major land use are defined, with one for each of the three functions to be estimated.

Percentage of Residential Land Use (RAP). Total residential land use, in acres, of a study area as a percentage of the total acres of the same study area, is used as the dependent variable in the estimation function for residential land use.

Percentage of Commercial Land Use (CAP). Total commercial land use, in acres, of a study area as a percentage of the total acres of the same study area, is used as the dependent variable in the estimation function for commercial land use.

Percentage of Industrial Land Use (IAP). Total industrial land use, in acres, of a study area as a percentage of the total acres of the same study area, is used as the dependent variable in the estimation function for industrial land use.

Table 1. Symbols and Definitions of Variables
Used in the Land Use Prediction Model

Variable	Definition
RAP	Percentage of residential acreage to total acreage in study area
CAP	Percentage of commercial acreage to total acreage in study area
IAP	Percentage of industrial acreage to total acreage in study area
YR	Year, from 0, 1, 2, ..., n (1970 = 0)
ADT	Average daily traffic volume
DRAP1	= 1 if initial residential development category is II, = 0 otherwise
DRAP2	= 1 if initial residential development category is III, = 0 otherwise
DRAP3	= 1 if initial residential development category is IV, = 0 otherwise
DRAP4	= 1 if initial residential development category is V, = 0 otherwise
DRAP5	= 1 if initial residential development category is VI, = 0 otherwise
DRAP6	= 1 if initial residential development category is VII, = 0 otherwise
(The base initial residential development category is I.)	
DCAP1	= 1 if initial commercial development category is II, = 0 otherwise
DCAP2	= 1 if initial commercial development category is III, = 0 otherwise
DCAP3	= 1 if initial commercial development category is IV, = 0 otherwise
DCAP4	= 1 if initial commercial development category is V, = 0 otherwise

Continued

Table 1. Symbols and Definitions of Variables Used in the Land Use Prediction Model (Continued)

Variable	Definition
DCAP5	= 1 if initial commercial development category is VI, = 0 otherwise
DCAP6	= 1 if initial commercial development category is VII, = 0 otherwise
(The base initial commercial development category is I.)	
DIAP1	= 1 if initial industrial development category is II, = 0 otherwise
DIAP2	= 1 if initial industrial development category is III, = 0 otherwise
DIAP3	= 1 if initial industrial development category is IV, are equal to 0.)
DIAP4	= 1 if initial industrial development category is V, = 0 otherwise
DIAP5	= 1 if initial industrial development category is VI, = 0 otherwise
DIAP6	= 1 if initial industrial development category is VII, = 0 otherwise
(The base initial industrial development category is I.)	
CAPO	= 1 if there is capacity improvement on existing facility, = 0 otherwise
CAPN	= 1 if there is capacity improvement on new facility, = 0 otherwise
(The base capacity improvement is no capacity improvement for which CAPO and CAPN are equal to 0.)	
DMED1	= 1 if there is a raised median treatment, = 0 otherwise

Continued

Table 1. Symbols and Definitions of Variables Used in the Land Use Prediction Model (Continued)

Variable	Definition
DMED2	= 1 if there is a continuous left turn median treatment, = 0 otherwise
(The base median treatment is no median treatment for which DMED1 and DMED2 are equal to 0.)	
HWY1	= 1 if highway type is a U.S. or state highway, = 0 otherwise
HWY2	= 1 if highway type is a farm road, = 0 otherwise
HWY3	= 1 if highway type is a spur or loop, = 0 otherwise
HWY4	= 1 if highway type is a city street, = 0 otherwise
(The base highway type is an interstate highway for which HWY1, HWY2, HWY3, and HWY4 are equal to 0.)	
METRO1	= 1 if the city is Bryan-College Station, = 0 otherwise
METRO2	= 1 if the city is Houston, = 0 otherwise
METRO3	= 1 if the city is Texarkana, = 0 otherwise
METRO4	= 1 if the city is Tyler, = 0 otherwise
METRO5	= 1 if the city is Fort Worth, = 0 otherwise
(The base city is Dallas for which METRO1, METRO2, METRO3, METRO4 and METRO5 are equal to 0.)	
DPART	= 1 if there is neighboring parallel traffic, = 0 otherwise

Continued

Table 1. Symbols and Definitions of Variables Used in the Land Use Prediction Model (Continued)

Variable	Definition
DVERT	= 1 if there is neighboring intersecting traffic, = 0 otherwise
(The base neighboring traffic is no neighboring traffic for which DPART and DVERT are equal to 0.)	
PROD1	= 1 if it is in the during construction period, = 0 otherwise
PROD2	= 1 if it is in the after construction period, = 0 otherwise
(The base period is the before construction period for which PROD1 and PROD2 are equal to 0.)	

Exogenous Variables

Exogenous variables which are assumed to have potential effects on the three land use listed for the dependent variables include two continuous variables, namely, year and ADT, and seven sets of binary variables, one for each of the following effects: capacity improvement, median treatment, period difference, city difference, highway type difference, neighboring traffic and initial land use development condition. Each of these exogenous variables is discussed below.

Initial Land Use Development Level. The initial land use development level is defined as the percentage of land use (residential, commercial or industrial) to total acreage of a study area in the first study year. Initial land use development levels of all traffic points chosen for study are classified into seven categories, each representing a specific range of percentages of a land use in the first study year. For each land use analysis, six binary variables, one for each category, with the seventh category serving as the base category, are used. Table 2 shows the percentage ranges of initial land use developments and binary variables and bases defined for each initial land use category, by type of land use.

The principal reason for using the above sets of binary variables in the regression analysis is to provide a basis from which land use changes experienced over time in a study area can be detected. A lack of a reference point for each traffic point arises from two elements in the regression. First, in this study, the absolute percentages of land use are used instead of the annual percentage change. The two are not to be confused. The absolute percentage of a land use to total acreage is defined as:

Table 2. Ranges of Percentages for Initial Land Use Development Categories Defined for Binary Variables or Bases, by Type of Land Use.

Initial Land Use Category	Binary Variable and Base	Range of Initial Land Use (in Percent)
Residential Use		
I	Base	0.00 to 7.30
II	DRAP1	7.30 to 13.30
III	DRAP2	13.30 to 19.30
IV	DRAP3	19.30 to 30.10
V	DRAP4	30.10 to 36.60
VI	DRAP5	36.60 to 62.10
VII	DRAP6	62.10 to 100.00
Commercial Use		
I	Base	0.00 to 1.35
II	DCAP1	1.35 to 2.30
III	DCAP2	2.30 to 4.20
IV	DCAP3	4.20 to 6.40
V	DCAP4	6.40 to 9.00
VI	DCAP5	9.00 to 19.00
VII	DCAP6	19.00 to 100.00
Industrial Use		
I	Base	0.00 to 0.01
II	DIAP1	0.01 to 1.11
III	DIAP2	1.11 to 1.71
IV	DIAP3	1.71 to 4.11
V	DIAP4	4.11 to 11.11
VI	DIAP5	11.11 to 20.00
VII	DIAP6	20.00 to 100.00

$$\frac{A_{kji}}{TA_j}$$

where A_{kji} = Acreage of the k^{th} land use in the j^{th} study area in i^{th} year and

TA_j = Total Acreage of the j^{th} study area,

whereas the annual percentage change is defined as follows:

$$\frac{A_{kji} - A_{kji-1}}{A_{kji-1}}$$

where A_{kji} = Acreage of the k^{th} land use in the j^{th} study area in i^{th} year and

A_{kji-1} = Acreage of the k^{th} land use in the j^{th} study area in $(i-1)^{th}$ year.

In the case of the annual percentage change, a common comparison basis is present and that is the previous year. The current land use acreage is measured against the same land use in the previous year. In the case of the absolute percentage, such a basis is absent. Every study area in the data set is independent.

The adoption of absolute percentage of land use for the analysis of this study is more of a necessity rather than of a choice. Undoubtedly, the analysis is a lot simpler if annual percentage change is used, but that analysis requires the loss of one year's data. With the knowledge of the scarcity of land use data and the difficulties in obtaining them, to forgo one year's data appears to be imprudent for the study. In addition, since data are not available for each year, changes in land use development which occur between two study years would be difficult to isolate, because a single annual percentage change throughout the entire period between the two study years would be used.

For each set of initial land use, binary variables serve the purpose of isolating the land use changes over time for traffic points belonging in the same initial development level. The current land use level for each observation in the group has a common reference point at the initial level.

Secondly, because cross-sectional data are used in this study, more than one location in a city and also more than one city are involved. Each traffic point occupies a unique position as far as its initial land use development level is concerned. For example, traffic point X may be located in a residential area, which means that it has a low percent of commercial use to the total area (CAP), say 0.5%, while traffic point Y is located in a more commercially developed area, meaning that it has a high CAP, say 5.0%. In year t, CAP in the area of traffic point X increases to 5.0% because the two-lane roadway segment where X is located is improved to a four-lane roadway and commercial activities are increased along the segment. Meanwhile, traffic point Y with no improvement made, remains at 5.0% CAP in year t. If both of these points are used in the commercial land use regression equation, the effect of a roadway improvement will be impossible to detect. Hence, ideally, it is best to be able to trace the land use development of each traffic point through the years. One way to accomplish this task is to individually identify each traffic point through the study years. Binary variables can be used to represent each traffic point. The regression line obtained will take into account adjustments for each traffic point starting with a different initial land use development level.

However, in a large data set with a sample size that yields reliable regression estimates, an equally large number of binary variables are needed, making it difficult to be handled in a regression analysis. Therefore, the numbers of binary variables for each land use are kept to a reasonably small number, with each binary variable representing a category of initial land use development level which covers a designated range of the initial level of the given land use. Of course some random error is introduced since each data point will be compared to the average of the group, rather than the actual initial land use development for that individual point, but the categories are defined in an attempt to minimize that error. It should be remembered that random errors lower the significance of the regression estimates.

Because of the limitations of the data set, it is believed that setting up these initial land use categories is a relevant step in the regression analysis so that the estimated results have more practical meaning or can shed some light to the problem under study.

Year (YR). The year is a continuous variable which runs from year 0, to year 1 and so on. It represents the time element in the model equation. The significant roll it plays in the model has been discussed in the opening paragraphs of this section and is not repeated here. Its estimated coefficients from the regression analysis reveal the magnitudes of land use percentage changes over time under a specific set of conditions as represented by the presence of other exogenous variables in the model equation.

ADT. Annual average daily traffic volume is another continuous variable which may affect some of the land uses studied.

Capacity Improvement Effect. Capacity improvements can be separated into two major categories, one for capacity improvements on existing facilities such as adding extra lanes to the current roadways, and the other for new location construction where there is no existing road before the capacity improvement is made. A set of two binary variables is used which include CAPO and CAPN, representing capacity improvement on existing facilities and capacity improvement on new facilities, respectively. The base effect for these two variables is one from no capacity improvement. CAPO or CAPN is zero in any year before the completion of the improvement, and is equal to 1 after completion of the project.

Median Treatment Effect. Two types of median treatments are of interest in this study and they are the raised median and the continuous left turn lane treatments. Two binary variables, DMED1 and DMED2, are used with the former representing the presence of a raised median and the latter a continuous left turn lane. The base effect for them is the absence of a median treatment. 0 and 1 values are given to DMED1 or DMED2 in the same manner as for capacity improvements. DMED1 or DMED2 is 0 in any year before the completion of the median treatment and is equal to 1 after the completion of the median treatment.

Period Difference. The period refers to the time of construction, if any, of a capacity improvement. Three periods are identified: the before, during and after construction periods. It is believed that each of these periods may affect land use differently. PROD1 and PROD2 are the two binary variables for this effect, with PROD1 for the during period and PROD2 for the after period. The base period is the before period.

City Difference. Because cross-sectional data are used in the analysis, it is thought city characteristics of and data sources from each city may contribute some significant variations which should be identified. Therefore, five binary variables, METRO1, METRO2, METRO3, METRO4 and METRO5 are defined to represent Bryan-College Station, Houston, Texarkana, Tyler and Fort Worth, respectively, with Dallas as the base city.

Highway Type Difference. Five highway types are identified in the data base, and it is assumed that different highway types may affect differently each of the three land use categories under study. Four binary variables, HWY1, HWY2, HWY3 and HWY4 are used for a US/state highway, farm road, spur/loop and city street, respectively, with an interstate as the base highway type.

Neighboring Traffic. The intersecting and parallel traffic are the two neighboring traffic types under study. Within the half-mile circle of a study area, any highway or major arterial that intersects the studied roadway segment is considered to be the intersecting neighboring traffic while any highway or major arterial that lies parallel to the studied roadway segment to be the parallel neighboring traffic. DVERT and DPART represent the two binary variables for intersecting and parallel neighboring traffic effect, respectively. The base type is no neighboring traffic effect.

Findings of the Analysis

In each of the land use equations, the continuous variable year (YR) and the set of binary variables for initial development levels of the same land use are always present. The continuous variable (ADT) and other binary variables are selectively included, depending on the significance of their estimated coefficients. Those variables with statistically insignificant coefficients are eliminated. The final equations for residential, commercial and industrial uses with the estimated coefficients and their levels of significance of the selected variables are shown in Tables 3, 4 and 5, respectively. The overall results indicate definite improvements from the earlier study [1]. Clearly the large sample size of the present data set yields information not detected by that study. Also, some of the improvement comes from the use of the categorical binary variables, and the use of percentage land use rather than rates of change. As a result, the R^2's in each of the OLS equations are much higher ranging from .8717 to .9343 as compared to the range of .1575 to .4480 obtained earlier.

Table 3. Estimated Coefficients from Regression on Residential Land Use

Dependent Variable	Intercept	Exogenous Variable																R^2
		YR	DRAP1	DRAP2	DRAP3	DRAP4	DRAP5	DRAP6	ADT	HWY2	HWY4	METRO2	METRO3	DMEDI	DMEDI*YR	DMERT	YR*CAPO	
RAP	2.6607* (4.37)[a]	.2384* (3.48)	8.2312* (12.58)	12.6564* (15.59)	19.5690* (29.37)	30.5550* (32.57)	43.9125* (64.96)	65.1691* (34.85)	-1.0149×10^{-5}** (-1.63)	6.6407* (7.15)	10.0726* (5.63)	2.6967* (4.12)	-3.2044* (-3.01)	-0.8168* (-2.07)	.9707** (1.61)	.0333* (1.83)	.2076* (2.09)	.9343

[a] t statistic is listed below each coefficient in parentheses.

* significant at 5 percent level

** significant at 10 percent level

Table 4. Estimated Coefficients from Regression on Commercial Land Use

Dependent Variable	Intercept	Exogenous Variables															R^2
		YR	DCAP1	DCAP2	DCAP3	DCAP4	DCAP5	DCAP6	ADT	DMED1	DMED1*YR	CAPN	HWY2	METRO3	DPART	DVERT	
CAP	0.2495 (0.75)[a]	.1045* (2.84)	.9384* (2.01)	3.6038* (9.62)	4.4470* (10.47)	7.0488* (15.46)	12.0885* (26.64)	23.6545* (43.35)	8.4584×10^{-6}* (2.36)	-2.6264 (-1.12)	.5900* (1.73)	1.5612* (2.66)	1.4286* (2.94)	-1.5576* (-2.69)	-.6729** (-1.57)	.4553* (1.72)	.8717

[a] t statistic is listed below each coefficient in parantheses.
* significant at 5 percent level
** significant at 10 percent level

Table 5. Estimated Coefficients from Regression on Industrial Land Use

Dependent Variable	Intercept	Exogenous Variables											R^2
		YR	DIAP1	DIAP2	DIAP3	DIAP4	DIAP5	DIAP6	CAPN	CAPN*YR	DPART	DMED2	
IAP	-.2137 (-.71)[a]	.1107* (3.40)	.6108* (1.77)	1.3778* (2.56)	3.4114* (9.83)	7.1113* (18.59)	16.8800* (26.52)	36.9805* (55.97)	-4.3737* (-1.98)	.5198* (1.75)	.9109* (2.25)	-1.4089* (-2.81)	.8823

[a] t statistic is listed below each coefficient in parantheses.

* significant at 5 percent level

** significant at 10 percent level

Percentage of Residential Land Use/Total Acreage (RAP)

Initial Residential Use Development Levels. RAP is found to have positive and significant estimated coefficients for all six of the DRAP's, a result that is not surprising (Table 3). What the DRAP's do is to separate the regression line into seven parallel lines, each representing one category of initial residential land use development level. The estimated coefficients of each DRAP indicates the magnitude of the difference in initial residential land use effect between each of the categories and the base category. Figure 2 shows the seven lines, each representing the estimated growth in percentages of residential acreage over time under the base conditions (i.e. no capacity improvement, interstate highway, Dallas, no mediam treatment, no neighboring traffic) at 1,000 ADT, in the defined initial residential use category.

ADT. ADT is shown to have a negative effect on RAP and is statistically significant. In general, residential developments tend to avoid high traffic areas. Congestion, noise and pollution are the main reasons behind the decision. For an increase of 10,000 ADT, RAP decreases by 0.1 percentage point.

Highway Type. Among the highway types, farm roads and city streets are found to have a positive and significant effect on RAP. The mean percentage of residential acreage is 6.6 percentage points significantly higher in areas with farm roads and 10.1 percentage points for city streets than in areas with interstate highways. Accessibility to residents by the first two types of highways appears to be the contributing factor. Interstate highways are more suitable for intercity and interstate travel.

City Difference. Some city influences are significant on RAP. The mean percentage of residential acreage is found to be 2.7 percentage points higher in Houston but 3.2 percentage points lower in Texarkana than in Dallas.

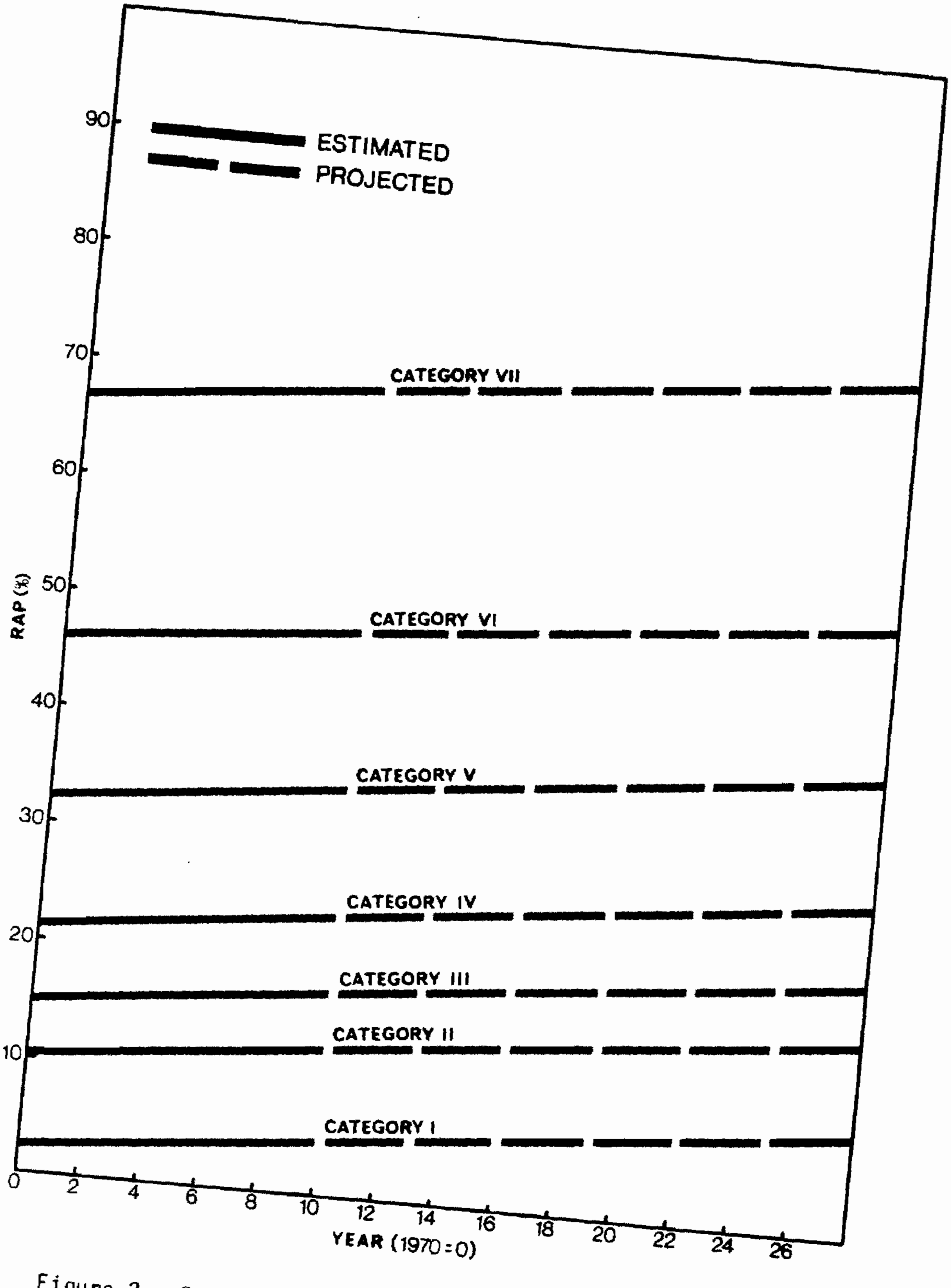

Figure 2. Growth in Percentage of Residential Acreage Over Time Under Base Conditions of Other Significant Effects and ADT Level of 1,000, by Initial Residential Development Category.

Median Treatment. The raised median treatment is found to significantly affect RAP. It has a negative effect on the level of RAP and a positive one on its growth rate. Apparently, raised medians cause an initial drop on RAP once it is constructed, but it helps to accelerate the growth in residential development. Perhaps the inconveniences experienced initially by residents as a result of the implementation of a raised median proves to be unfavorable. However, as time goes on, once residents find their alternate routes and are used to the new routes, the raised median is viewed as being needful to control traffic and control undesirable commercial areas. The mean RAP is about 8.82 percentage points lower but experiences a higher annual rate of change of .97 percentage points in areas with raised median than in areas without median treatments. Implementation of a continuous left turn lane is found to be non-significant.

Neighboring Traffic. For the neighboring traffic effect, only the intersecting traffic is found to have a positive and significant influence on RAP. The mean RAP is .83 percentage points higher in areas with intersecting traffic than in areas without intersecting traffic. The result may indicate the importance of accessibility in choosing a place of residence.

Capacity Improvement. Capacity improvements on existing facilities are found to have an influence on the growth rate of RAP, but not the level of RAP. As compared to areas with no capacity improvement, the annual rate of change of RAP over the years is found to be .21 percentage points higher in areas where a capacity improvement has been made on an existing facility. The positive and significant estimated coefficient of YR*CAPO reveals the fact that improvements in capacity along existing roadway induce growth in RAP. The effect of capacity improvements on new facilities is found to be insignificant for both the level and slope adjustments.

Period Difference. Surprisingly, period differences by themselves are found to be insignificant in influencing RAP. This finding does not support the hypothesis that inconveniences during construction might cause a decrease in RAP, while in the before period, anticipation of the construction might prompt more developments. It also does not support the hypothesis that increased accessibility as a result of the construction should bring an increase in RAP during the after period. Apparently the change, if any, is not significant enough in this sample to be detected for any period.

Percentage of Commercial Land Use/Total Acreage (CAP)

Initial Commercial Use Development Levels. All the estimated coefficients of the DCAP's are found to be positive and significant. Explanations for the behavior of the DRAP's in the residential land use can be applied here also. The DCAP's are smaller in magnitude than those of the DRAP's, but then, in general, the size of a RAP is much larger than that of a CAP. The average RAP in the data set is about 23% while the average CAP is 7.3%. Figure 3 shows the estimated growth of the seven initial commercial development categories (levels) in percentages of commercial acreage over time under all the base conditions of the studied effects (i.e. in initial commercial development category I, Dallas, no neighboring traffic, no capacity improvement and no median treatment) and at an ADT level of 1,000. It is interesting to note that the second line from the bottom representing the category of $1.35 \leq CAP < 2.3$, falls below the initial level it belongs to in year 0. An examination of the data reveals that within this category, there is one point in 1977 with a CAP of 8.6 and two points in 1978 with a CAP of 5.9 and 5.0, respectively, which are much higher than the other points over all study years. In order to fit these three points together with the others, the intercept of the regression line is pushed to a

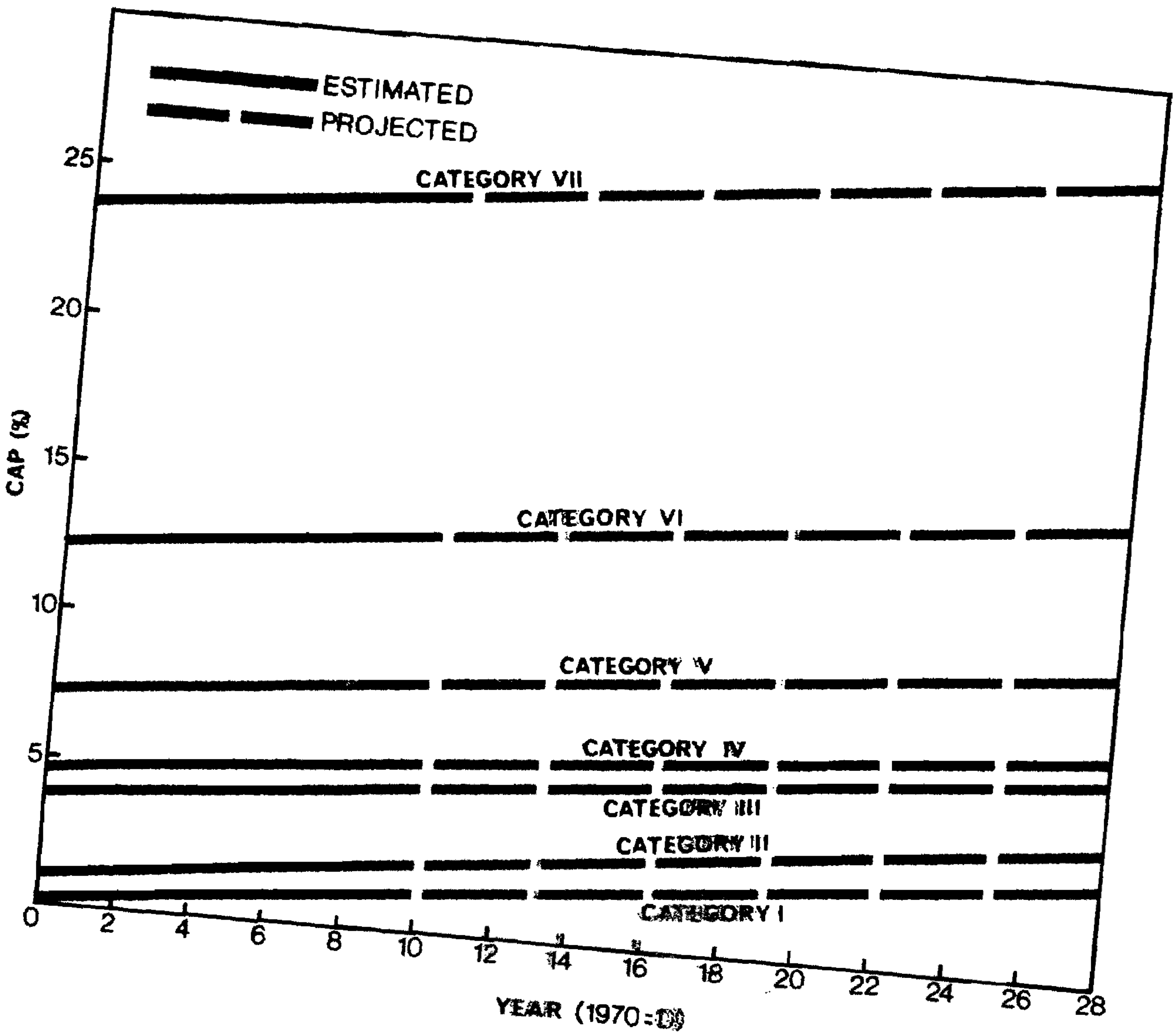

Figure 3. Growth in Percentage of Commercial Acreage Over Time Under Base Conditions of Other Significant Effects and ADT Level of 1,000, by Initial Commercial Development Category.

lower level to represent the average effect of all the points. Since this particular category has a very narrow range of CAP, this average effect is able to push the initial development level out of its own category.

ADT. As expected, ADT positively and significantly affect CAP. Shopping and most work trips are major trip generators, causing an increase of ADT. The estimated coefficient of $8.46x10^{-6}$ is interpreted as an increase of 10,000 in ADT causes a .08 percentage point increase in CAP. Although the increase is small, it is significant.

Highway Type. Among the highway types, farm roads have a positive and significant effect on CAP. The mean CAP is about 1.43 percentage points higher in areas that have farm roads than in areas that have interstate highways. In Texas, farm roads do play a rather important role in accommodating the rapid growth which the state has experienced in the past ten years or so. FM1960 in Houston is an excellent example, and so is FM157 in Fort Worth. The growth in the northwest part of Houston centers around FM1960, along which commercial (as well as residential) developments have been phenomenal. The through traffic on interstate highways appears to have a lesser attraction for this land use.

City Difference. The city of Texarkana, once again, shows to have a smaller effect on the development of commercial land use than Dallas. The mean CAP is 1.56 percentage points lower in Texarkana than in Dallas. Other cities fail to show any significant effect.

Neighboring Traffic. Both the parallel and intersecting traffic play a significant role in influencing commercial land use development even though their effects are opposite in direction. The parallel traffic has a negative effect while the intersecting traffic has a positive one. This result is not difficult to explain. While intersecting traffic provides accessibility to the major highway segment, the parallel traffic actually takes away commercial developments from the major highway segment and induces its own commercial developments instead. As compared to areas without neighboring traffic, the mean CAP is .67 percentage point lower in areas with parallel traffic and .46 percentage point higher in areas with intersecting traffic.

Capacity Improvement. The effect of capacity improvements on new facilities is found to be positive and significant on CAP. The mean CAP is 1.56 percentage points higher in areas with capacity improvements on new facilities than in areas without any capacity improvement. Apparently, the construction of a new highway segment results in more commercial developments than an improved highway segment does. Along an existing highway facility, land is usually fairly well developed. Any additional land use development resulting from a capacity improvement is insignificant.

Median Treatment. The raised median treatment is found to have a negative but statistically insignificant effect on the level of CAP, but it has a positive and statistically significant effect on the growth of CAP. In other words, when a raised median is built, the level of CAP is lowered but the rate of growth of CAP is increased. The results are surprising since it is thought that a raised median would limit access to development on the opposite side of the road and as a result, it should deter additional commercial development. Apparently the expected response of CAP to a median treatment is based on observing the behavior of CAP more along the frontage of the improved roadway, whereas the results indicate CAP response in the half-mile study area, an area extending beyond the frontage strips. Perhaps, in a study area, CAP responses to median treatment are the same as that of RAP. As residential developments grow, commercial acreage has to increase in order to provide retail and service needs for residents.

The mean CAP of 2.63% is insignificantly lower in areas with raised median than in areas without median treatment, but the mean annual rate of change of CAP of .59% is significantly higher in the former areas than in the latter areas.

In addition to the effects listed above, period differences are found to be insignificant.

Percentage of Industrial Land Use/Total Acreage (IAP)

The regression results on IAP are not as enlightening as those obtained in the last two land uses. Many of the variables are found to be insignificant, namely ADT, city differences, highway type and period differences. It appears that industrial land use is not significantly affected by such factors. Those effects found to be influential to this land use are discussed separately below.

Initial Industrial Use Development Levels. Like the DRAP's and the DCAP's, all the estimated coefficients of the DIAP's are positive and significant. The average IAP in the data set is about 4.0%, close to the average of the CAP mentioned before. Therefore, the magnitudes of the DIAP's are small, like those of the DCAP's. Figure 4 shows the estimated growth of the seven initial industrial development categories in percentages of industrial acreage over time under the base condition of the studied effects. The botton line representing IAP = 0 again falls below its category at year 0. This behavior is most likely attributed to the earlier explanation given to the category II regression line in Figure 3.

Capacity Improvements. Only the effect of capacity improvements on new facilities is found to have a significant effect on industrial use. It has a negative effect on the level of IAP, but a positive effect on the rate of

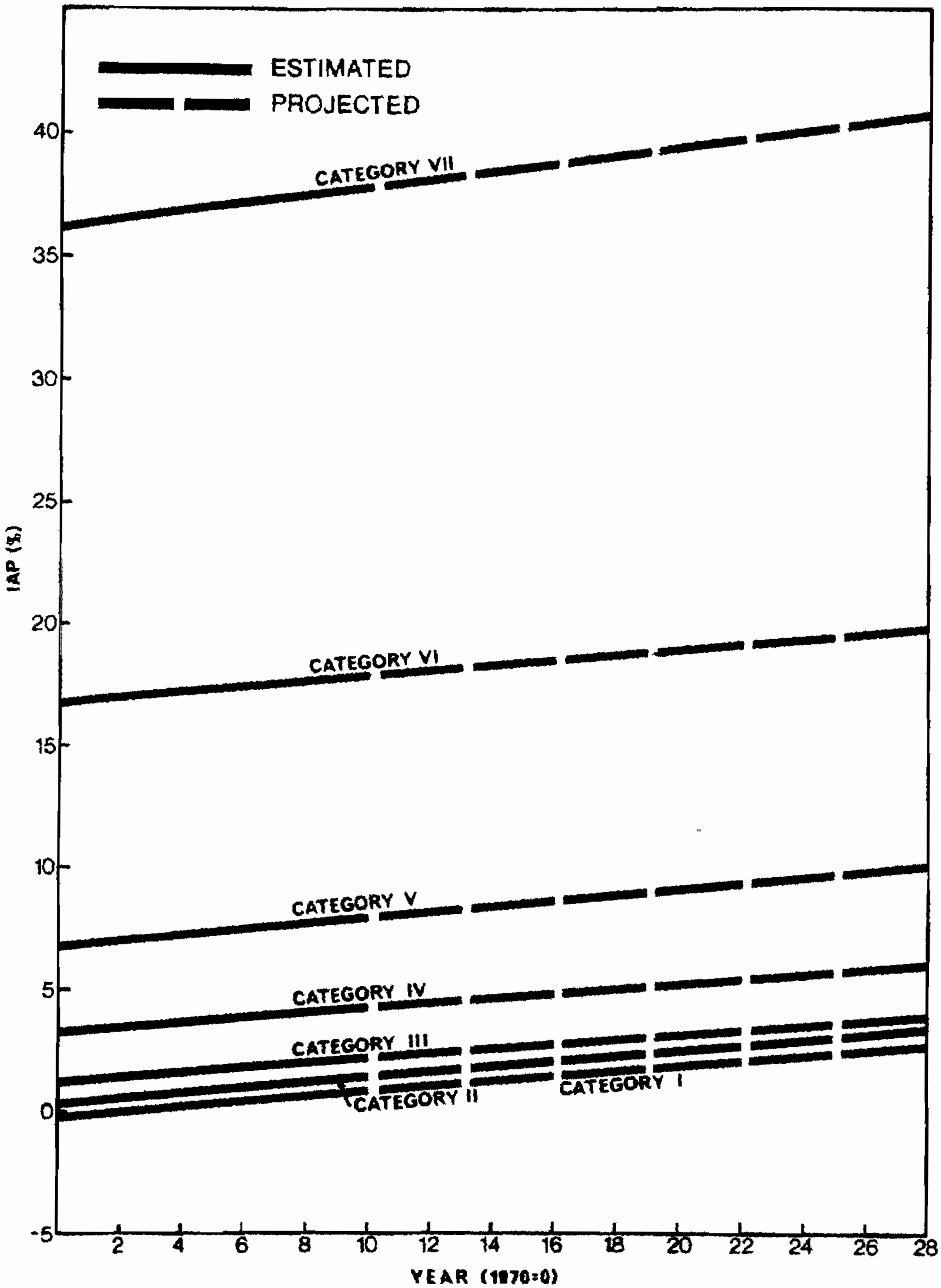

Figure 4. Growth in Percentage of Industrial Acreage Over Time Under Base Conditions of Other Significant Effects and ADT Level of 1,000, by Initial Industrial Development Category.

change of IAP. The mean IAP is about 4.37 percentage points lower in areas where there are new highway segments constructed than in areas without any capacity improvement. However, the mean annual rate of change is about .52 percentage point higher in the former areas than in the latter. Unlike commercial land use, industrial land use developments initially appear to avoid areas where there are new highway facilities. It is possible that the high land value along or in close proximity of a new highway may be uneconomical for firms to locate their plants or factories in those areas, but over time, the accessibility provided by a new highway apparantly proves to be an attractive factor for industrial development. Improving capacity on an existing facility is found to have no significant effect on IAP.

Median Treatment. Raised median treatments are found to have an insignificant affect on IAP, while continuous left turn median treatments are found to have a negative and significant effect. The mean level of IAP is 1.41 percentage points lower in areas with continuous left turn lanes than in areas without any median treatment. The continuous left turn median treatment thought to attract commercial and residential uses may relate more to areas of higher land prices which are more suitable for commercial use than for industrial use, or to areas of residential developments which are negatively affected by being near polluting and unsightly manufactoring plants and factories.

Neighboring Traffic. The effect of parallel traffic is the only neighboring traffic effect found to be significant and positive. The mean IAP is about .91 percentage point higher in areas with parallel traffic facilities than in areas without any neighboring traffic facilities. Apparently, areas near the parallel traffic facilities are more attractive to industrial use because of lower land prices. Hence, manufacturing plants or factories are likely to be located near a parallel route of a major highway instead of near or along the major highway where accessibility is excellent but prices of land use are too high for industrial use.

Summary

In summary, the capacity improvement of a roadway affects each land use differently. Construction of a new facility attracts commercial use and while it initially discourages the level of industrial use, it later encourages the growth of industrial use. Improved capacity of an existing facility positively affects the growth in residential use. The raised median negatively affects the residential and commercial uses but positively their growth rates. The continuous left turn median treatment has a negative effect on industrial use. There are some city differences, highway type differences in residential and commercial uses, but none are found in industrial use. Period differences are insignificant across all uses. Finally neighboring traffic is found to have a significant effect on each of the three land uses. Intersecting traffic has a positive effect on residential and commercial uses while parallel traffic is found to have a negative effect on commercial use but a positive effect on industrial use.

Application of the Results

The regression results obtained can be applied for predicting land uses. Two sets of prediction equations (the prediction model) are derived and the accuracy of the model is tested. The procedure for applying the prediction model is outlined, followed by the presentation of an example. Each of these items is discussed in this section.

Prediction Model

From the regression results obtained and shown in Tables 3, 4, and 5, two sets of equations, one for the do-nothing situation and the other for the improvement situation, are derived and can be used for the purpose of land use prediction. Given the current (or the most recent) land use data (RAP_o, CAP_o and IAP_o) at year o (YR_o), projected land use percentages (RAP_t, CAP_t and IAP_t) for any year t (YR_t), can be calculated from the following equations. Definitions of other variables are listed in Table 1.

<u>For the Do-Nothing Situation</u>

$$(4)\quad RAP_t = RAP_o + .2384(YR_t - YR_o) - 1.0149\times10^{-5}(ADT_t - ADT_o),$$

$$(5)\quad CAP_t = CAP_o + .1045(YR_t - YR_o) + 8.458\times10^{-6}(ADT_t - ADT_o),$$

$$(6)\quad IAP_t = IAP_o + .1107(YR_t - YR_o);$$

<u>For the Improvement Situation</u>

$$(7)\quad RAP_t = RAP_o + .2384(YR_t - YR_o) - 1.0149\times10^{-5}(ADT_t - ADT_o) + DMED1[.9707(YR_t - YR_o) - 8.8168] + .2076(CAPO)(YR_t - YR_o),$$

$$(8)\quad CAP_t = CAP_o + .1045(YR_t - YR_o) + 8.458\times10^{-6}(ADT_t - ADT_o) + DMED1[.5900(YR_t - YR_o) - 2.6264] + 1.5612(CAPN) \text{ and}$$

$$(9)\quad IAP_t = IAP_o + .1107(YR_t - YR_o) - 1.4089(DMED2) + CAPN[.5198(YR_t - YR_o) - 4.3737].$$

Because data sources for this study came from urban and urban fringe areas, these equations are applicable for predicting land uses in these areas. Rural areas may experience different growth.

Application of Land Use Prediction Model

To illustrate how the prediction model is used, a step-by-step procedure is outlined, followed by the presentation of an example.

Procedure. The following steps are described for applying the prediction model for land use prediction.

Step I. Obtain the most current residential, commercial and industrial acreages as percentages of total acreage within a half-mile radius of the study point.

Step II. Obtain roadway information on the study point, such as the before and after condition of a capacity and/or median treatment improvement, for the study period between the year when data of current land use acreages are available, and the projected year.

Step III. Obtain current ADT and projected ADT at the study point if readily available. (Do not go into great trouble to obtain these. If they are not readily available, simply drop the term which contains the difference in ADT between the current year and the projected year. Unless the differential is extremely large, this term will not significantly affect the projected land use percentages because of the very small magnitude of its estimated coefficient in the prediction model.)

Step IV. Assign the appropriate values of 0 or 1 to the roadway improvement binary variables (DMED1, DMED2, CAPO and CAPN) based on roadway information gathered in Step II.

Step V. Insert the current land use percentages obtained in Step I, the study period, the values of the binary variables assigned in Step IV, and the current and projected ADT gathered in Step III, into the respective land use equations. Use the do-nothing set of equations if there is no roadway improvement done during the study period; use the improvement set of equations, otherwise.

Step VI. Calculate the projected residential percentage (RAP_t), the projected commercial percentage (CAP_t) and the projected industrial percentage (IAP_t) from equations described in Step V.

An Example. An example is given here which takes the user through the above steps. A traffic count station A situated about 3.5 miles from Loop 610, on Hempstead Road in Houston, is chosen. Supposedly, the most current land use data available are in 1980. In 1980, the segment of Hempstead Road on which traffic count station A is located is a 4-lane state highway. Suppose that the rapid growth of north Houston is predicted to push the recently completed NW Freeway (US 290) to full capacity by 1994. The Highway Department is considering improving Hempstead Road by adding four more lanes to the present four lanes in 1994 and the effect of this improvement on the adjacent land uses in 1995 is one of the concerns of the Department in the project evaluation process (Step II). Since an improvement is to be made during the study period, the set of equations for the improvement situation is used to predict land use percentages. In 1980, the percentages of residential, commercial and industrial acreages of the total area which covers the half-mile radius from A were 33.3%, 5.1% and 6.2%, respectively (Step I). The 1980 ADT is 18,000 and the projected ADT for 1995 is 50,000 (Step III).

Based on roadway information obtained, binary variables for median treatments (DMED1, DMED2) and capacity improvements on new facilities (CAPN) all have values of 0 while binary variables for capacity improvements on existing facilities have values of 1 (Step IV). By inserting the 1980 land use percentages, the year difference between 1980 and 1995, the 1980 ADT and the projected 1995 ADT into Equations 7, 8 and 9 (Step V), the 1995 land use percentages are predicted to be:

$$RAP_{95} = 33.30 + .2384(1995-1980) - 1.149\times10^{-5}(50,000-18,000)$$
$$+ .2076(1)(1995-1980)$$
$$= 39.62\%,$$

$$CAP_{95} = 5.10 + .1045(1995-1980) + 8.458\times10^{-6}(50,000-18,000)$$
$$= 6.92\% \text{ and}$$

$$IAP_{95} = 6.20 + .1107(1995-1980)$$
$$= 7.86\%.$$

Thus, it has been demonstrated that the model can be used to facilitate officials and planners in transportation in predicting effects of roadway improvements on adjacent land uses.

Accuracy of Land Use Prediction Model

Using the prediction model described, the combined commercial and industrial use of each of 33 count stations in Dallas is predicted for 1985. Percentage errors in the predictions for each of the count stations are calculated, following the same procedure adopted by Memmott and Buffington in their analysis of ADT projections [2]. These errors are then compared to those reported by these authors who used projections made by the State Department of Highways and Public Transportation (SDHPT) for 1985. It is found that the average percentage error is about 21 percentage points lower for the current model than the one adopted by the SDHPT. Therefore, it can be concluded that the current prediction model has a higher degree of accuracy in this sample over the one used by the SDHPT. Table 6 lists the percentage errors in projections of the combined commercial and industrial use made by the SDHPT and by the current prediction model for each of the count stations and the average percentage errors across all 33 count stations.

Table 6. Comparison of Percentage Errors in Dallas Land Use[a] Projections Made by SDHPT and the Prediction Model

Count Station	Percentage Error in Combined Commercial and Industrial Land Use Projections	
	SDHPT	Prediction Model
5999	16.68	53.96
6088	45.18	30.06
6306	226.85	9.47
6313	139.82	107.06
6370	59.88	20.16
6372	31.08	58.20
6387	25.91	10.47
6393	113.63	58.54
6509	62.81	58.78
6566	16.07	28.44
6568	2.82	44.08
6574	16.16	9.90
6578	16.18	24.88
6586	26.75	22.22
6618	77.83	65.05
6621	83.54	81.81
6686	17.96	62.44
6749	59.13	56.97
6755	102.34	91.43
6758	35.47	35.71
6790	41.79	13.05
6830	15.44	124.81
6841	16.21	44.41
6850	109.26	163.15
6856	6.30	23.61
6864	16.92	11.36
6868	69.29	63.52
6975	42.50	112.17
6978	66.81	60.83
7042	74.97	81.45
7043	233.57	80.81
7045	543.42	76.43
7047	88.64	16.92
Average	75.79	54.61

[a] Only the combined total of commercial and industrial uses is represented here.

PREDICTING THE EFFECTS OF ROADWAY IMPROVEMENTS ON TRAFFIC VOLUMES

The traffic growth prediction model attempts to project changes in ADT over time, especially when a roadway improvement is to be made. To project ADT has always been an important consideration of the Highway Department. It enables them to plan adequate roadways with sufficient capacities to meet future needs. The general practice for projecting ADT is by predicting the number and location of vehicle trips by origin and destination based on some trip generation factors. Two of the factors used are land use and population which, in turn, need to be forecasted by local agencies. It is known that errors are introduced whenever a forecast is made. When several forecasts are needed to develop a projection, errors may be compounded and magnified. Projection errors on ADT, land use and population are examined and discussed in the study on predicting traffic volumes growth rates by Memmott and Buffington [2]. In addition to the errors introduced, current methods require a sizeable amount of data and are fairly time consuming. The simple model proposed in the Memmott and Buffington study offers an alternative which can be used with a minimum of time and data. Therefore, an expanded data set is used in this study to examine the effects of capacity improvements and other traffic related factors on traffic volumes and to improve the Memmott and Buffington model.

Description and Limitations of Data Base

To study the effects of roadway improvements on traffic volumes, a data base consisting of 187 traffic count stations in six cities of Texas is used. These are the same traffic count stations used for a data base to develop the land use regression model. ADT data obtained for the ten-year period of 1971 to 1980 from the RI-2TLog (Roadway Inventory and Traffic) of 1982 developed by

File D-10 also form a part of the data base. The study period chosen is mainly for the purpose of matching the ADT data to the roadway improvements data obtained for the land use prediction study. The 187 traffic count stations with ten years data yields a large data set consisting of 1870 observations, with a few having missing information on one or more variables. The least number of observations used in the regression is 1809.

The organized and readily available ADT data provided by the RI-2TLog eliminate some of the limitations experienced in the land use regression model. In every RI-2TLog, ADT data are entered for the current year and for the previous nine years. Therefore, a time series of at least ten years of ADT is available. Since the data base covers a wide spectrum of 187 study points and controls, a ten year study period is considered adequate for the purpose of this study.

Description of Regression Model

The traffic growth regression model relates ADT to time (year), under the roadway improvements and other traffic related factors which are of interest to transportation officials. The two functional forms used are given below:

$$(10)\ \mathrm{Log}(ADT_t) = a + bt + c(E_t) + d(E_t)(t) \text{ and}$$

$$(11)\ \mathrm{Log}(ADT_t) = a + b\mathrm{Log}(t) + c(E_t) + d(E_t)\mathrm{Log}(t),$$

where E_t represents capacity improvement (or some other studied effects), c stands for the magnitude of intercept adjustments and d for the slope adjustments. The last term in each of the equations is included because it is thought that the various studied effects may affect not only the intercept, a, but also the slope, b, in the above equations. The mechanisms and the implication of the binary variables used in this model are discussed in the first section of this report.

Both the log-linear (Equation 10) and the log-log functions (Equations 11) are estimated using ordinary least squares (OLS). Most of the effects discussed in the land use model formulation with the exception of highway type differences are also examined here. Also, the effects of initial ADT levels are studied instead of the effects of initial land use development levels. However, the effect of stages of development is the additional effect examined in the current traffic growth model. Table 7 lists the symbols and definitions of the variables used in the model. To avoid repetition, the discussion of those effects which have been explored in the land use model are not repeated here. Only the effects of initial ADT levels and of stages of development, together with the dependent variable, ADT, are discussed separately below.

Average Daily Traffic (ADT). Absolute ADT volumes are used. Even though ADT data are easier to obtain than the land use data and a time series of ten years' ADT is readily available in the RI2T-Log, to use percentage changes in ADT should not present as much problem as to use percentage changes in land use in the land use prediction model. However it is believed that it is best to attempt using the maximum number of years whenever possible. From the regression results presented in this section, the relatively high R^2 value and the high levels of significance in most of the explanatory variables indicate that the use of absolute ADT levels is adequate.

Initial ADT Levels. The initial ADT level is defined as the level of ADT in the first study year. Initial ADT levels for all the points of study are separated into seven categories and a set of six binary variables is used, with each variable representing one category and the seventh category serving as the base category. Like the three sets of binary variables for initial land use

Table 7. Symbols and Definitions of Variables Used in the Traffic Volumes Prediction Model

Variable	Definition
ADT	Average daily traffic volume
YR	Year, from 1, 2, ..., n (1971 = 1)
CAPO	= 1 if there is capacity improvement on existing facility, = 0 otherwise
CAPN	= 1 if there is capacity improvement on new facility, = 0 otherwise
(The base capacity improvement is no capacity improvement for which CAPO and CAPN are equal to 0.)	
DMED1	= 1 if there is a raised median treatment, = 0 otherwise
DMED2	= 1 if there is a continuous left turn median treatment, = 0 otherwise
(The base median treatment is no median treatment for which DMED1 and DMED2 are equal to 0.)	
PROD1	= 1 if it is the during construction period, = 0 otherwise
PROD2	= 1 if it is the after construction period, = 0 otherwise
(The base period is the before construction period for which PROD1 and PROD2 are equal to 0.)	
STAG1	= 1 if the area is in the developing stage of overall development, = 0 otherwise
STAG2	= 1 if the area is in the developed stage of overall development, = 0 otherwise
(The base stage is the undeveloped stage of overall development for which STAG1 and STAG2 are equal to 0.)	
DPART	= 1 if there is parallel neighboring traffic, = 0 otherwise

Continued

Table 7. Symbols and Definitions of Variables Used in the Traffic Volumes Prediction Model (Continued)

Variable	Definition
DVERT	= 1 if there is intersecting neighboring traffic, = 0 otherwise.
(The base neighboring traffic is no neighboring traffic for which DPART and DVERT are equal to 0.)	
METRO1	= 1 if the city is Bryan-College Station, = 0 otherwise
METRO2	= 1 if the city is Houston, = 0 otherwise
METRO3	= 1 if the city is Texarkana, = 0 otherwise
METRO4	= 1 if the city is Tyler, = 0 otherwise
METRO5	= 1 if the city is Fort Worth, = 0 otherwise
(The base city is Dallas for which METRO1, METRO2, METRO3, METRO4 and METRO5 are equal to 0.)	
DADT1	= 1 if initial ADT level category is II, = 0 otherwise
DADT2	= 1 if initial ADT level category is III, = 0 otherwise
DADT3	= 1 if initial ADT level category is IV, = 0 otherwise
DADT4	= 1 if initial ADT level category is V, = 0 otherwise
DADT5	= 1 if initial ADT level category is VI, = 0 otherwise
DADT6	= 1 if initial ADT level category is VII, = 0 otherwise
(The base initial ADT level category is I.)	

development levels, the set of binary variables representing initial ADT levels is included in each regression equation. The reason for requiring the presence of this set of binary variables in each regression equation is the same as that discussed earlier in the land use regression model. Since the same data set of 187 different locations is involved here, a common base is needed from which ADT changes experienced over time can be detected.

The six binary variables, DADT1, DADT2, DADT3, DADT4, DADT5, and DADT6 represent their respective ranges of initial ADT levels as shown in Table 8. The base category for this set of binary variables is Category 1, with an initial ADT level of less than 1,000.

Stage of Overall Development (STAG). The stage of overall development is defined as the total developed acreage as a percentage of the total acreage of an area. An area is termed developed if, in the first study year, total developed acreage to total acreage is greater than 80%, developing if it is between 20% and 80% and undeveloped if less than 20%. A set of two binary variables, namely STAG1 and STAG2, is defined to study this effect. STAG1 represents the developing stage and STAG2 for the developed stage while the base stage is the undeveloped stage. It is reported by Memmott and Buffington [2] that the stage of overall development appears to affect the growth rate of ADT but no definitive conclusions are made due to the small sample in the data base used in their study. It is hoped that the present data set with a much larger sample will be able to confirm observations of the Memmott and Buffington study.

A large number of variables are tested to identify those that have statistically significant relationships with ADT. On some of the binary variables, all three possible effects discussed earlier, the intercept adjustment, the slope adjustment and the combined intercept and slope adjustment, will be explored.

Table 8. Ranges for Initial ADT Level Categories Defined for Binary Variables or Bases

Initial ADT Level Category	Binary Variable and Base	Range of Initial ADT
I	Base	less than 1,000
II	DADT1	1,000-7,000
III	DADT2	7,001-13,000
IV	DADT3	13,001-27,000
V	DADT4	27,001-63,500
VI	DADT5	63,501-82,000
VII	DADT6	82,001 and up

Findings of the Analysis

Table 9 presents the results of the regression. The log-log function (Equation 11) is found to be an overall superior model and is chosen for presentation and discussion. The growth rate of ADT derived from the following log-log function:

$$\log(ADT_t) = a + b\log(t)$$

is b/t. Therefore, when each of the binary variables present in the current regression model is under base condition, the growth rate of ADT is estimated to be .2840/t, representing a fairly rapidly declining rate. The results of the analysis and interpretations of the various effects on ADT are presented below.

Initial ADT Level. The set of binary variables for initial ADT levels, DADT1, ..., DADT6, is found to be very significant. All, except DADT1 and DADT2, are positive. In other words, the line for the category represented by DADT1 falls below the line for the base category while the other five lines represented respectively by DADT2, DADT3, DADT4, DADT5 and DADT6 stand above the line for the base category. Because the model uses a log-log function, the lines are not parallel to one another as those in the land use regression model. Figure 5 shows the estimated relationship between ADT and time (years) for each of the seven categories under the base conditions (i.e. Dallas no capacity improvement, no median treatment, in the undeveloped stage of overall development and, lastly, no neighboring traffic).

Capacity Improvement. Capacity improvements on either existing or new facilities are found to significantly affect the growth of ADT. The estimated coefficient of .1660 for CAPO*Log(YR) indicates that, when holding all other significant effects at base conditions and when a capacity improvement is made

Table 9. Estimated Coefficients from Multiple Regression on ADT

Dependent Variable	Intercept	Exogenous Variable														
		Log(YR)	DADT1	DADT2	DADT3	DADT4	DADT5	DADT6	METRO2	METRO3	Log(YR)*CAPO	Log(YR)*CAPN	DMED1	DMED2	STAG1	STAG2
Log(ADT)	8.6694* (96.29)[a]	.2840* (6.70)	-.3177* (-5.32)	.2937* (5.07)	.8509* (15.08)	1.6619* (28.62)	2.3214* (35.69)	2.6835* (37.28)	.1489* (4.49)	-.1957* (-4.42)	.1660* (7.07)	.2844* (11.34)	-.1722* (-3.36)	-.1164* (-2.12)	.2168* (2.84)	.1657* (1.82)

(Continued)

Table 9. (Continued)

Dependent Variable	Exogenous Variable				R^2
	Log(YR)*STAG1	Log(YR)*STAG2	DPART	DVERT	
Log(ADT)	-.1331* (-2.99)	-.1707* (-3.22)	-.1205* (-3.31)	-.0316** (-1.46)	.8273

[a] t statistic is listed below each coefficient in parentheses.
* significant at 5 percent level
** significant at 10 percent level

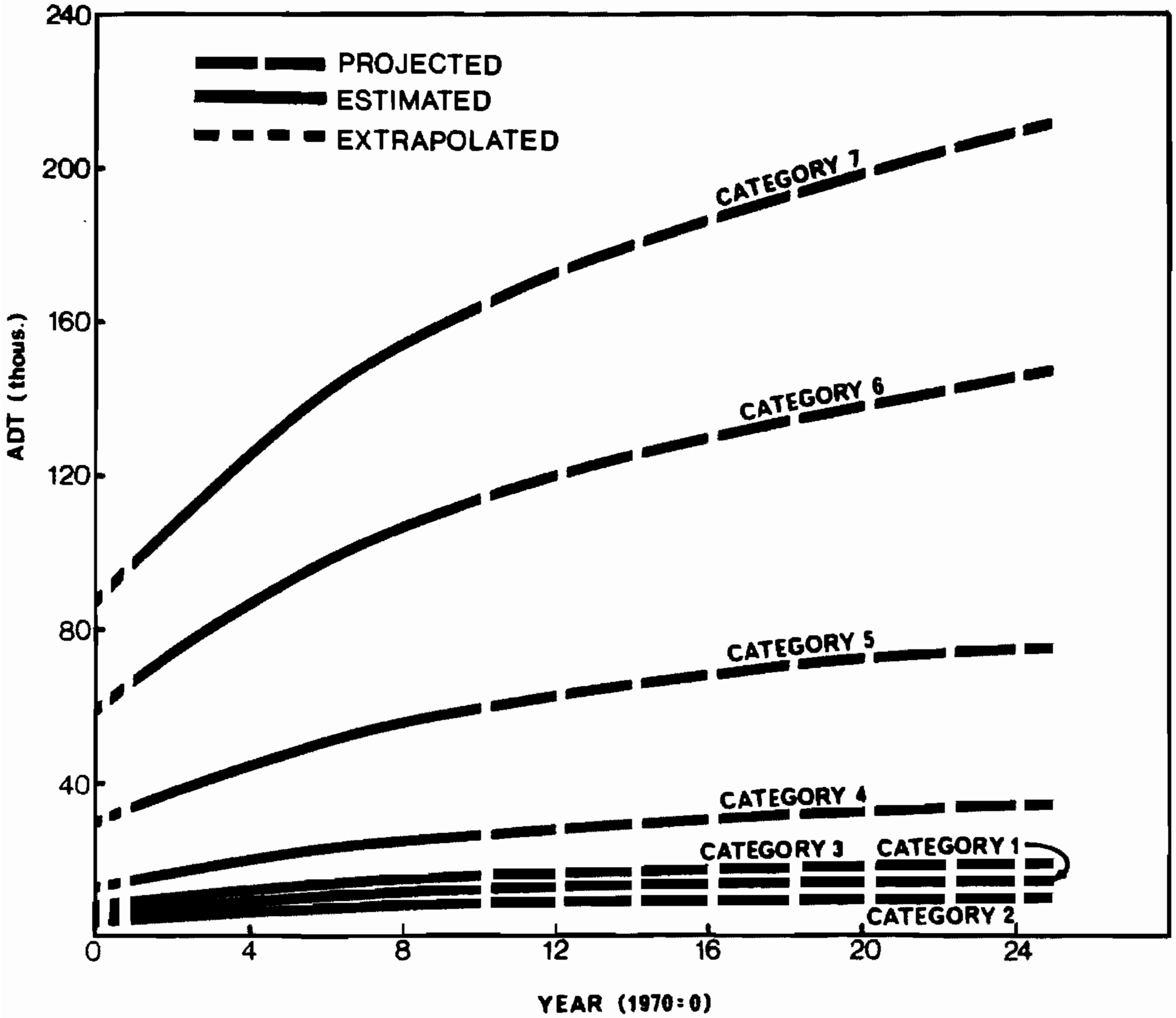

Figure 5. ADT Growth of the Seven Initial ADT Level Categories Over Time Under Base Conditions of Other Significant Effects.

on an existing facility, initially, the mean ADT experiences 16.6 percentage points higher than in areas without any capacity improvement but this differential declines over the years. In 20 years, it will be less than 1 percentage point. Similarly, in the first year, ADT is found to be 28.44 percentage points higher in areas with newly constructed roadways than in areas without capacity improvements. Therefore, any capacity improvement tends to induce traffic growth, with the rate being higher for the newly constructed roadway than for the improved old roadway. ADT on newly constructed roadways grows faster because they start from a much lower base, especially in the beginning years after the roadway is opened, whereas an old facility is fairly close to capacity before an improvement is made and as a result, the base for ADT growth is higher. Figure 6 illustrates the effects of capacity improvements on the two types of roadways under base conditions of other significant effects (i.e. initial ADT level category I, Dallas, no median treatment, no neighboring traffic and undeveloped stage).

Median Treatment. Both the raised median and the continuous left turn lane treatments are found to have a negative and significant effect on ADT, and the effect is greater for the raised median than for the continuous left turn lane treatment. When either type of median treatment is put in, ADT experiences an initial drop, and the drop is greater for the raised median than for the continuous left turn lane treatment. Figure 7 shows the effects of both types of median treatments on ADT growth under base conditions of other significant effects (i.e. initial ADT level category I, Dallas, no capacity improvement, no neighboring traffic and undeveloped stage).

The results confirm the hypothesis that the raised median prevents accessibility to minor side streets on the other side of the roadway, tending to discourage traffic to use that road. On the other hand, the results do not

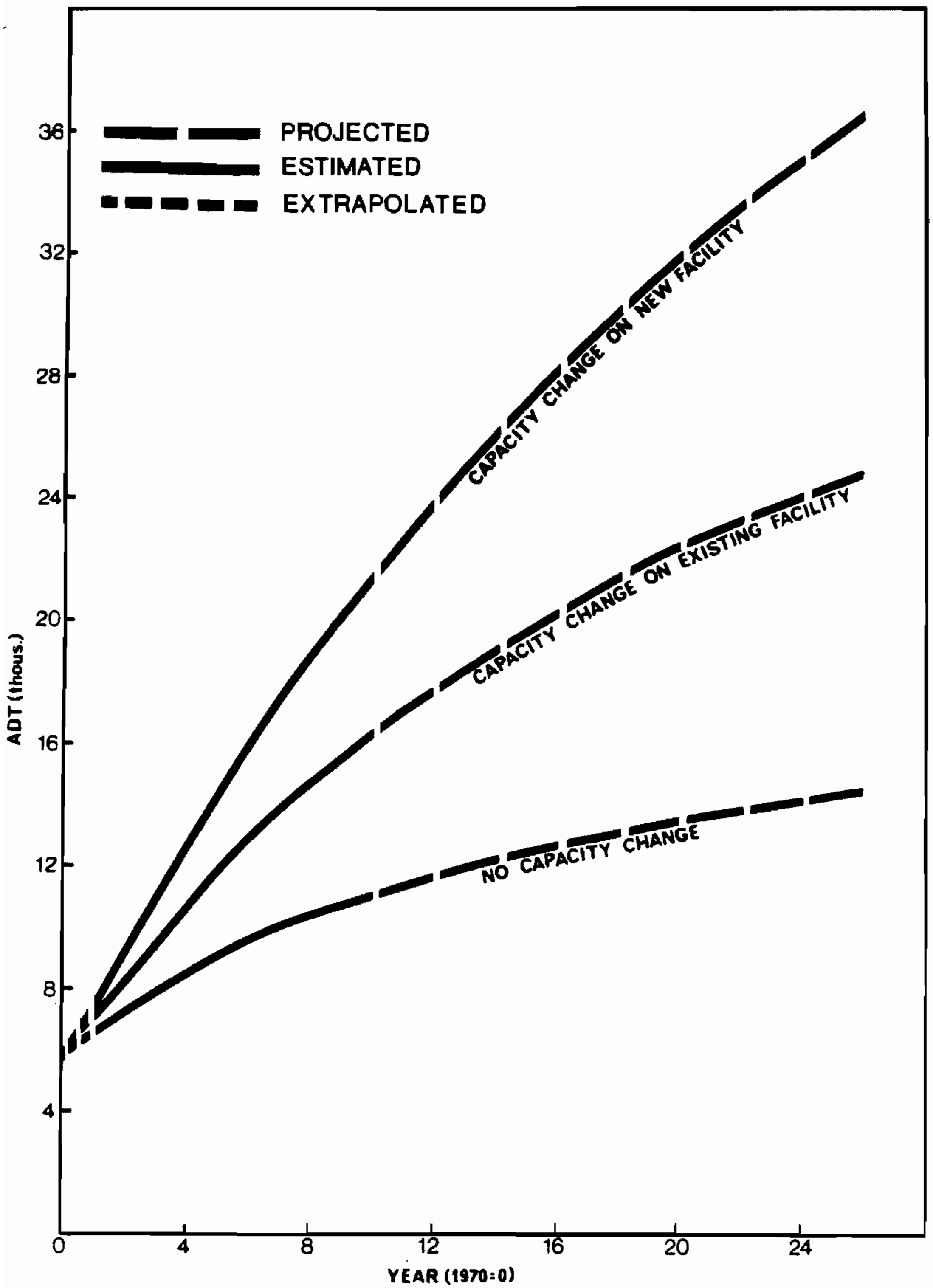

Figure 6. Effects of Capacity Improvements on ADT Growth Under Base Conditions of Other Significant Effects.

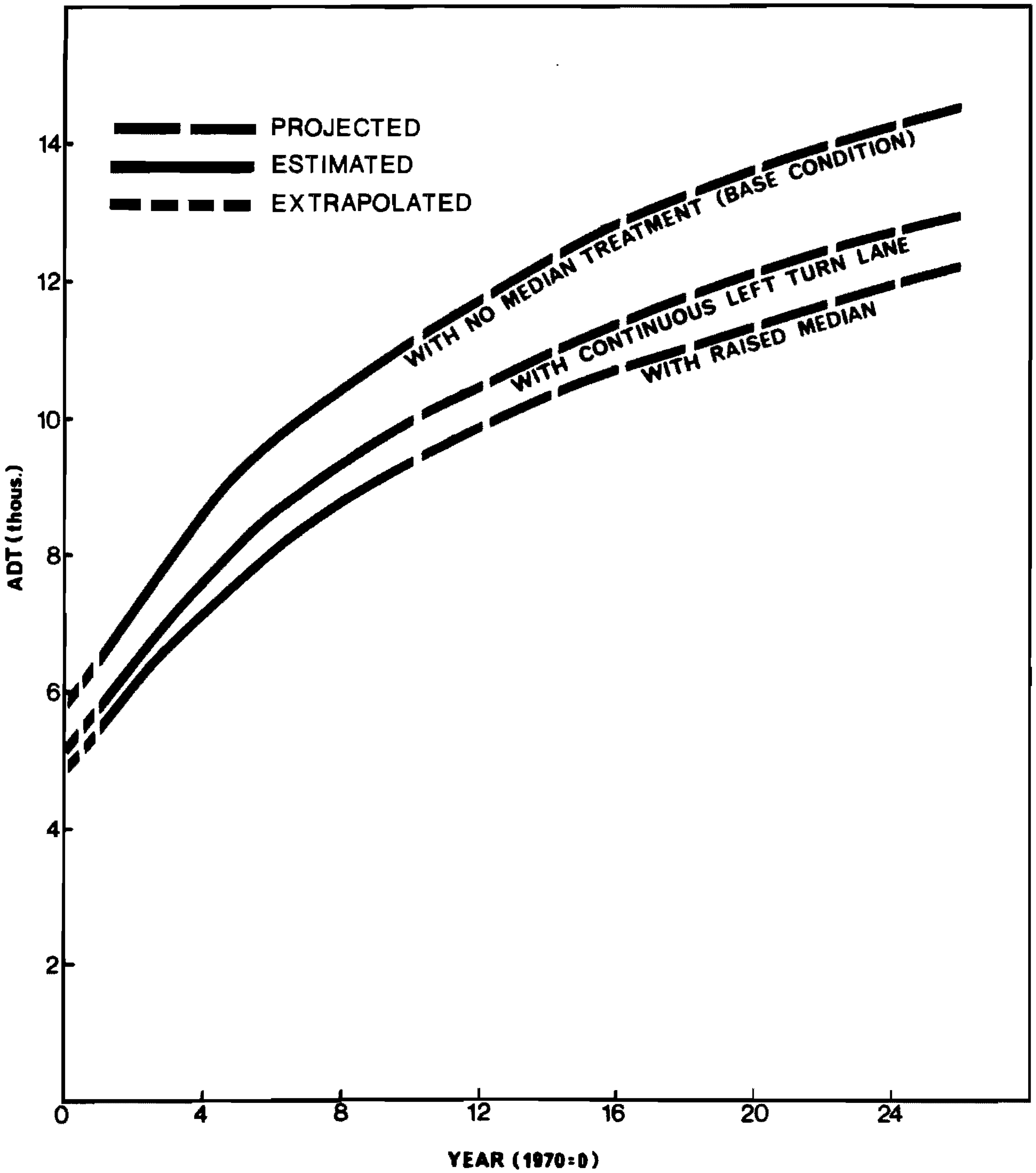

Figure 7. ~~Effects of Median Treatments on~~ ADT Growth Under Base Conditions of Other Significant Effects.

support the hypothesis that continuous left turn treatment will improve the flow of traffic to the opposite side of the roadway, tending to encourage traffic to use that road.

Stage of Overall Development. The developing and developed stages of overall development affect both the intercept and the slope of the estimated function. The combined effect of each of these stages on ADT is shown in Figure 8 under the base conditions of all other effects (i.e. initial ADT to be less than 1,000, Dallas, no capacity change, no median treatment and no neighboring traffic). Among the three stages of development, as expected, the undeveloped area is seen to experience the highest growth, followed by the developing area and lastly by the developed area. ADT is observed to be higher in the first few years for the developing and developed areas than for the undeveloped area. However, the faster growth of ADT in the undeveloped areas (especially in the earlier years) enables them to catch up with the growth of ADT in the developing and developed areas in only a few years.

Neighboring Traffic. Both the parallel and the intersecting traffic are found to have a negative and significant effect on ADT. In other words, both types of neighboring traffic appear to reduce traffic on the main route. The result is expected for the parallel traffic since it is hypothesized that parallel traffic routes serve as alternate routes to the main route. However, the result for intersecting traffic is unexpected since it is hypothesized that intersecting routes should draw more vehicles on the main route. The effects of those two types of traffic on ADT are small in magnitude even though significant.

City Difference. Among the cities chosen for study, Houston and Texarkana are the two cities found to affect ADT growth significantly differently from Dallas which serves as the base city for all the binary variables of city

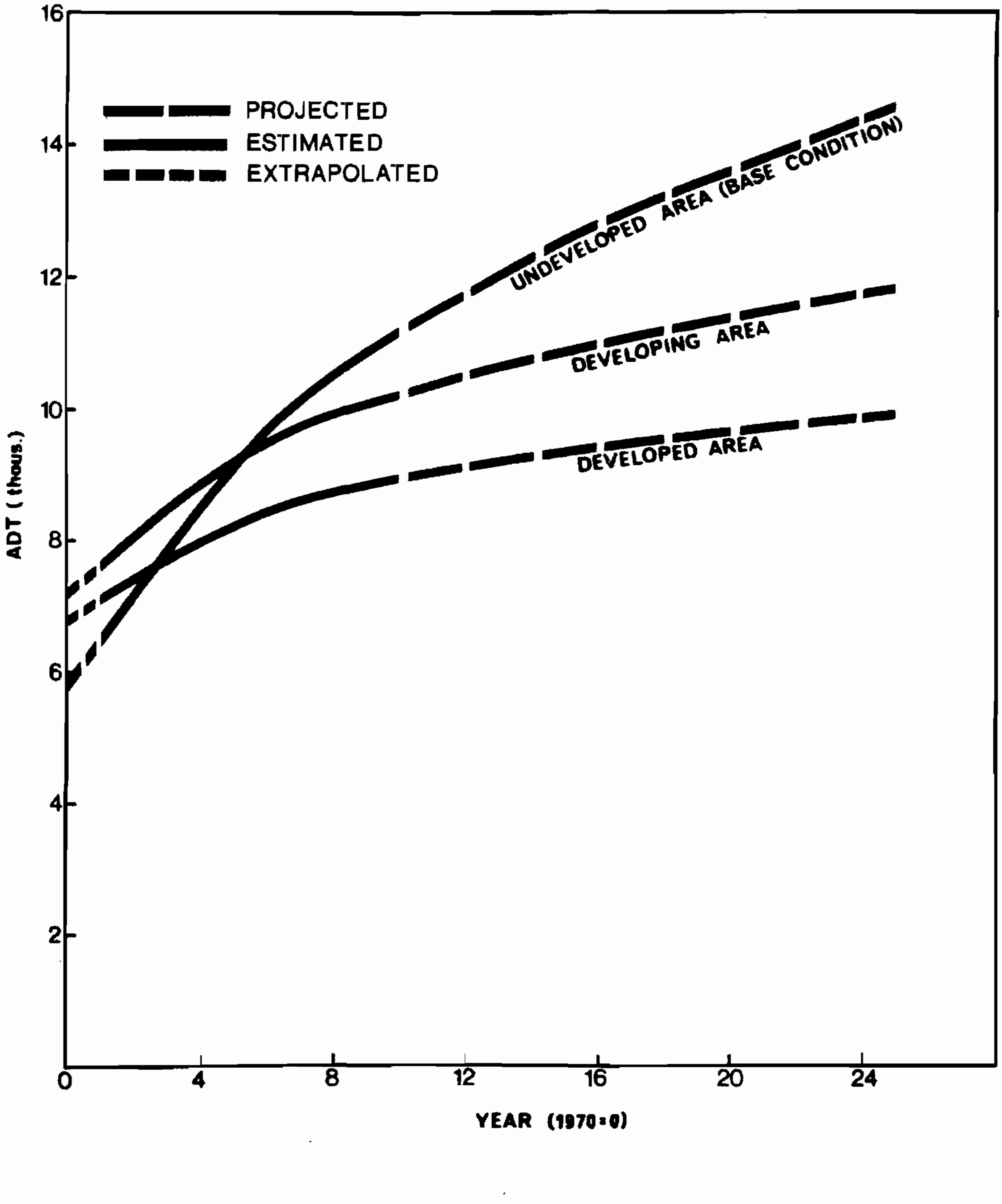

Figure 8. Effects of Stage of Development in an Area on ADT Growth Under Base Conditions of Other Significant Effects.

differences, METRO1, ..., METRO5. The mean Log(ADT) is .1489 higher in Houston while .1722 lower in Texarkana than in Dallas.

Summary

Several factors believed to be influential to ADT growth rates are evaluated in the model, and the findings are summarized here. Among them, capacity improvements are found to induce traffic. ADT grows faster on a newly constructed roadway than on a widened old roadway. Both raised median and continuous left turn treatments have negative effects on the levels of ADT. The negative effect is greater for raised median than for continuous left turn treatments. As observed in Memmott and Buffington's study [2], the stage of development of an area is found to affect ADT growth. Undeveloped areas experience the fastest ADT growth, developed areas experience the slowest and developing areas, in between. Other significant factors found are city differences, neighboring traffic and initial ADT level category differences.

Application to the HEEM-II

The revised Highway Economic Evaluation Model (HEEM-II) [4] is designed to evaluate highway projects on a highway segment, route or system basis by means of some defined economic and mobility measures. The traffic growth prediction model developed in this study as seen capable of playing a limited role in the application of the HEEM-II. One of the input data requirements for the HEEM-II is current and projected corridor ADT which are used to determine ADT growth pattern up to the projected year. Results of the regression model developed in this study can be used to develop a prediction procedure which, in turn, can be used for corridor traffic projection. Even though the prediction procedure is designed to project only roadway segment traffic, projected ADT from all major routes in the corridor can be aggregated to yield projected ADT of the corridor which can then be used in the HEEM-II input. Current practices on the adoption of projected ADT rely on some externally assumed figures which are then used to determine the growth pattern to fit the projection. The two sets of ADT growth prediction equations derived can be used to project ADT and its growth pattern simultaneously, and consequently, estimates made by the HEEM-II will be improved. Presentation of these prediction equations (the prediction model), together with the testing of its accuracy is included in this section. In addition, a procedure for applying the prediction equations is outlined, followed by the illustration of an example.

ADT Prediction Model

From the regression results obtained and shown in Table 9, two sets of equations, one for the do-nothing situation and the other for the improvement situation, are derived for the use of ADT prediction. Given the current (or the most recent) ADT data (ADT_o) at year o (YR_o), projected ADT (ADT_t) for any year t (YR_t) can be calculated from the equations listed below. Definitions of other variables are listed in Table 7.

For the Do-Nothing Situation - An equation is given for each of the three different stages of area development:

1. Undeveloped Areas:

   (12) $ADT_t = ADT_o(YR_t - YR_o + 1)^{.284}$,

2. Developing Areas:

   (13) $ADT_t = ADT_o(YR_t - YR_o + 1)^{.1509}$ and

3. Developed Areas:

   (14) $ADT_t = ADT_o(YR_t - YR_o + 1)^{.1133}$;

For the Improvement Situation - An equation is given for each of the three different stages of area development:

1. Undeveloped Areas:

$$(15)\ ADT_t = ADT_0(YR_t - YR_0 + 1)^{\alpha_1}(e^{\beta})$$

where $\alpha_1 = .284 + .166(CAPO) + .2844(CAPN)$ and

$\beta = -.1722(DMED1) - .1164(DEMD2)$,

2. Developing Areas:

$$(16)\ ADT_t = ADT_0(YR_t - YR_0 + 1)^{\alpha_2}(e^{\beta})$$

where $\alpha_2 = .1509 + .166(CAPO) + .2844(CAPN)$ and

3. Developed Areas:

$$(17)\ ADT_t = ADT_0(YR_t - YR_0 + 1)^{\alpha_3}(e^{\beta})$$

where $\alpha_3 = .1133 + .166(CAPO) + .2844(CAPN)$.

It is stressed here that these equations are applicable for traffic prediction of urban and urban fringe areas and not applicable for rural areas because of the data sources used for this study.

Application of ADT Prediction Model

Application of the ADT prediction model is outlined in a step-by-step procedure, followed by the presentation of an example.

Procedure. The following steps are described for applying the ADT prediction model:

Step I. Obtain current ADT (ADT_0) and roadway information on the study point, such as the before and after condition of a capacity and/or median treatment improvement, for the study point between the current year and the projected year.

Step II. Obtain current total developed acreage as the percentage of total acreage within a half-mile radius of the study point to determine the area development stage of the study point.

Step III. Assign the appropriate values of 0 or 1 to the roadway improvement binary variables (DMED1, DMED2, CAPO and CAPN) based on roadway information gathered in Step I.

Step IV. Decide on the set of equations to be used. Use the do-nothing set if there is no roadway improvement done during the study period; use the improvement set, otherwise.

Step V. Choose the appropriate equation in the set decided in Step IV based on the area development stage determined in Step II.

Step VI. Insert the current ADT (ADT_0) obtained in Step I, the study period and the values of the binary variables assigned in Step III, into the equation chosen in Step V.

Step VII. Calculate the projected ADT (ADT_t) from the equation described in Step VI.

An Example. The same traffic count station as described in the example for applying the land use prediction model is used. In addition to the current ADT and roadway information given, developed acreage in 1980 is 75% of the total acreage of the study point. Hence the study point is in the developing stage in 1980 (Step II). Equation 16 which is for an improvement situation in a developing area is chosen to predict ADT in 1995 (Steps IV and V). The current ADT (ADT_0) is inserted into Equation 16, together with the year difference between the current and the projected years, and a value of 1 for the binary variable CAPO (Step VI). Equation 16 becomes as follows:

$$ADT_{95} = 18,000(95-80+1)^{.284+.166}$$
$$= 62,680$$

and hence, ADT in 1995 is predicted to be 62,680.

Accuracy of ADT Prediction Model

The ADT prediction model described above is tested on the same data used by Memmott and Buffington to test their multiple regression model [2]. The same procedure which was developed to calculate percentage errors of the projected ADT is followed here. Table 10 lists percentage errors in ADT projections by SDHPT, by the multiple regression model and by the present prediction model for 19 count stations in Dallas and their average. The overall error of 19.79% resulted from using the present prediction model compares favorably to the average SDHPT error of 22.22% and is only slightly higher than the multiple regression model's error of 18.57%. In this respect, it may seem that the multiple regression model is a superior model. However, the present prediction model is observed to have the advantage of requiring only a current (or the most recent) ADT, whereas the multiple regression model requires several years of historical ADT in order to estimate the coefficients. In addition, the present prediction model can be used for new location constructions, as well as median treatment improvements, both of which cannot be handled with the other model. All in all, the present prediction model may represent a more useful model.

Table 10. Comparison of Percentage Errors in ADT Projections by SDHPT, the Multiple Regression Model and the Prediction Model

Count Station	Percentage Errors in ADT Projections		
	SDHPT	Multiple Regression Model	Prediction Model
6381	29.40	24.04	21.10
6387	36.48	20.85	9.28
6393	24.68	6.27	14.54
6461	39.80	3.79	21.94
6509	36.61	8.29	4.97
6578	22.78	8.73	23.98
6586	8.36	25.84	11.78
6586	7.06	31.34	17.94
6618	25.50	42.92	35.94
6621	17.58	29.02	26.67
6631	29.62	28.47	6.72
6686	9.92	8.68	21.74
6749	28.58	20.90	63.10
6790	13.50	13.99	20.72
6830	31.15	35.49	26.05
6841	12.36	21.85	7.15
6850	22.21	8.96	9.07
6856	18.36	8.44	10.29
Average	22.22	18.57	19.79

CONCLUSIONS AND RECOMMENDATIONS

The findings from this study reveal several conclusions and based on these conclusions, recommendations are made.

Conclusions

This study identifies the effects of roadway improvements on adjacent land use and on traffic volume growth rates. Tables 11 and 12 summarize the results of these identified effects on land use and on traffic volume growth rates, respectively. Findings from the land use regression model reveal that each land use is affected differently by a capacity improvement on a roadway and that the effect varies depending on the type of capacity improvement. Construction of a new roadway segment attracts commercial use while it initially discourages industrial use but encourages such use over time. Residential developments react favorably to a widened existing facility. As revealed from the findings of the traffic growth regression model, either type of capacity improvements is found to induce traffic growth. ADT grows faster on a newly constructed highway than on a widened existing facility.

As for median treatments, the study reveals that raised medians impact negatively the levels and positively the rates of change in residential and commercial uses, and that adding continuous left turn lanes negatively influences industrial use. On the other hand, both types of median treatments are found to discourage traffic. The negative effect is greater for a raised median treatment than for a continuous left turn lane treatment.

Other influencing factors studied for land use development include city differences and highway type differences, both of which are found to be

Table 11. A Summary of Roadway Improvement Effects on Lane Use

Effect	Land Use					
	Residential		Commercial		Industrial	
	Level	Growth	Level	Growth	Level	Growth
Construction of New Facility	None	Positive	Positive	None	Negative	Positive
Improved Capacity on Existing Facility	None	Positive	None	None	None	None
Raised Median	Negative	Positive	Negative	Positive	None	None
Continuous Left Turn Lane	None	None	None	None	Negative	None
City Differences	Mixed	None	Mixed	None	None	None
Highway Type Differences	Mixed	None	Mixed	None	None	None
Period Differences	None	None	None	None	None	None
Intersecting Traffic	Positive	None	Positive	None	None	None
Parallel Traffic	None	None	Negative	None	Positive	None
ADT	Negative	None	Positive	None	None	None

Table 12. A Summary of Roadway Improvement Effects on ADT

Effects	ADT Growth	
	Direction	Order of Impact
Capacity Improvement	Positive	New Facility > Existing Facility
Median Treatment	Negative	Raised Median > Continuous Left Turn
Stage of Development	Positive	Undeveloped > Developing > Developed
City Differences	Mixed	--
Neighboring Traffic	Negative	Parallel > Intersecting

significant only for residential and commercial uses. Neighboring traffic is another factor examined. The intersecting traffic encourages residential and commercial uses while parallel traffic is found to have a negative effect on commercial use but a positive one on industrial use.

From the traffic growth regression model, the stage of area development is identified to be a significant factor influencing ADT. Undeveloped areas are found to experience the fastest ADT growth, the developed areas the slowest, and developing areas are in between these two areas. Both types of neighboring traffic are found to have a negative but small impact on ADT. City differences are shown to play a significant role in influencing ADT.

Using the results from the analysis of the land use regression model, two sets of equations are derived and they are referred to as the land use prediction model. Similarly, a ADT prediction model is derived from the results of the ADT regression model. Both of the prediction models require only current land use and ADT data, together with some relevant roadway information.

Recommendations

Based on conclusions drawn from the findings presented in this report, it is recommended that the prediction models developed in this study should be used to predict land use development or traffic volumes because of their simplicity in data requirements. It is believed that they can better serve transportation officials when they make decisions concerning roadway improvements or when they use the HEEM-II for highway project evaluations.

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APPENDIX TABLES

Table A1. General Roadway Information on Traffic Count Stations in Houston Chosen for Study

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
703	US 290	50-9	0	4	-	Raised	'67	'70 (FR)	-	Yes
704	US 290	50-9	0	4	-	Raised	'69	'75 (FR)	-	-
705	US 290	50-9	0	4	-	Raised	'71	'75 (FR)	-	-
706	Loop 610	271-4	0	8	-	-		'63	-	Yes
709,710	FM 1960	1685-1	2	4	-	-	'74	'76	-	-
711	FM 1093	1258-4	2	6	-	Raised	'66	'67	-	-
712	FM 1093	1258-4	2	6	-	Raised	'66	'68	-	-
713	FM 1093	1258-4	2	6	-	Raised	'71	'72	-	Yes
715	IH 10	508-1	0	8	-	-		'58	-	Yes
717	IH 10	271-7	0	10	-	-		'68	-	-
718	US 59	27-13	0	10	-	-	'58	'61	-	-
719	US 59	27-13	0	8	-	-	'58	'62	-	-
720	US 59	27-13	0	8	-	-	'60	'62	-	Yes
721	US 59	27-13	0	6	-	-	'60	'62 (FR) '65 (ML)	-	-
722	US 59	27-13	0	6	-	-	'60	'62 (FR) '65 (ML)	-	Yes
726,728,729	US 90A	27-9	2	2	-	-	old		-	Yes
727,730	US 90A	27-9	2	2	-	-	old		-	-
732	IH 610	271-17	0	8	-	-	Before '62	'63 (FR) '66 (ML)	-	-
735	IH 10W	271-7	4	6	-	-	Before '62	'63	-	-
737	IH 610E	271-14	4	8	-	-	'68	'70 (FR) '75 (ML)	Yes	Yes

[a] Presence of major arterial(s) or highway(s) within half a mile of study point.
"-" represents none.

Table A2. General Roadway Information on Traffic Count Stations in Tyler Chosen for Study

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
1,2,3	Loop 323S	2075-2	2	4	-	CLT	6/65	3/67	-	-
4,5	Loop 323E	1790-2	2	4	-	CLT	6/65	3/67	-	-
6	Spur 364	2833-1	0	2	-	-	5/65	8/66	-	-
7	FM 2964	3021-1	2	2	-	-	1/68	7/69	-	Yes
8	US 271	165-1	2	4	-	CLT	6/67	10/69	Yes	Yes
9	US 271	165-1	2	4	-	CLT	6/67	10/69	-	-
11,12	Loop 323W	2075-1	2	4	-	CLT	9/66	10/67	-	Yes
14,15	US 69	190-5	2	2	-	CLT	9/71	12/73	-	Yes
			2	4						
16	US 271	165-1	4	2	-	CLT	7/69	7/71	-	-
				2						
17	US 271	165-1	4	2	-	CLT	7/69	7/71	-	Yes
				2						
18	US 31	165-1	2	4	-	CLT	11/71	4/75	-	Yes
19,20	US 31	165-1	2	4	-	CLT	11/71	4/75	-	-
21,22	Loop 323N	2075-1	2	4	-	Depressed	6/68	3/70	-	-
23,24	Loop 323N	2075-1	2	4	-	Depressed	6/68	3/70	-	Yes
25,26	Loop 323E	1790-2	2	4	-	Depressed	2/67	7/68	-	Yes
27	Loop 323E	1790-2	2	4	-	Depressed	2/67	7/68	-	-
29,30,32	Loop 323S	2075-2	2	4	-	Depressed	6/68	11/70	-	Yes
31	Loop 323W	2075-2	2	4	-	Depressed	6/68	11/70	-	-

Continued

[a] Presence of major arterial(s) or highway(s) within half a mile of study point.
"-" represents none.
"CLT" represents continuous left turn lane.

Table A2. General Roadway Information on Traffic Count Stations in Tyler Chosen for Study (Continued)

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
33	Loop 323W	2075-1	2	4	-	CLT	6/68	7/68	-	Yes
35,36	US 110S	345-1	2	4	-	CLT	9/73	11/75	-	Yes
37,38	US 110S	345-1	2	4	-	CLT	9/73	11/75	-	-
39	US 69S	191-1	2	4	-	CLT	10/72	9/75	-	Yes
40	US 64E	245-6	2	2	-	CLT	5/75	10/77	-	Yes
41	Spur 248	2558-1	2	4	-	CLT	11/76	10/77	-	-

[a] Presence of major arterial(s) or highway(s) within half a mile of study point.
"-" represents none.
"CLT" represents continuous left turn lane.

Table A3. General Roadway Information on Traffic Count Stations in Texarkana Chosen for Study

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes- Before	Capacity -Lanes- After	Median Before	Median After	Letting	Completion		
200	Loop 14	46-8	2	4	-	CLT	1/69	5/70	-	Yes
201	State 93	945-1	0-2	4	-	CLT	7/69	11/70	-	Yes
202	FM 559	1020-1	2	4	-	CLT	8/77	11/78	-	Yes
203	US 82	46-6	4	6	-	CLT	5/75	5/77	-	-
204	US 67	10-13	2	4	-	CLT	5/71	3/73	-	-
205	US 82	46-6	4	6	-	CLT	5/75	5/77	-	Yes
206,207,208	State 93	945-1	0-2	4	-	CLT	7/69	11/70	-	Yes
209,210	Spur 14	46-8	2	4	-	CLT	1/69	5/70	-	-
211	US 82	46-6	4	4	-	CLT	7/73	3/74	-	Yes
212	US 59	217-2	4	4	-	CLT	2/72	12/74	-	Yes
213,214	US 59	217-2	4	4	-	CLT	2/72	12/74	-	-

[a] Presence of major arterial(s) or highway(s) within half a mile of study point.
"-" represents none.
"CLT" represents continuous left turn lane.

Table A4. General Roadway Information on Traffic Count Stations in Fort Worth and Bryan/College Station Chosen for Study

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
601	FM 157[b]	747-3	2	4	-	CLT	3/74	6/75	-	-
602	FM 157[b]	747-3	4	5	-	CLT	NA	'69	-	-
603	FM 157[b]	747-4	NA	2	-	-	NA	Before '70	-	-
610	US 377[b]	81-2	NA	2	-	-	NA	Before '70	-	-
612	US 377[b]	80-7	NA	2	-	-	NA	Before '70	-	-
101,102	Spur 507[c]	49-9	2	4	-	-	6/66	5/67	-	Yes
103	Spur 507[c]	50-1	2	4	-	-	NA	7/58	-	-
104	Spur 507[c]	50-1	2	4	-	CLT	10/72	11/74	-	Yes
105	Spur 507[c]	50-1	2	6	-	CLT	10/72	11/74	-	-
106	SH 21[c]	116-4	2	4	-	-	10/73	10/74	-	Yes
107	SH 30[c]	2446-1	2	4	-	CLT	4/72	4/74	-	-
108	FM 60[c]	506-1	2	4	-	-	NA	'72	-	-
109	FM 60[c]	506-1	2	2	-	-	NA	'72	-	-

[a] Presence of major arterial(s) or highway(s) within half a mile of study point.
[b] Fort Worth
[c] Bryan-College Station
"-" represents none.
"NA" represents not available.
"CLT" represents continuous left turn lane.

Table A5. General Roadway Information on Traffic Count Stations in Dallas Chosen for Study

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
5988	US 80	8-8	NA	NA	NA	NA	old		-	-
5991	US 80	8-8	4	6	Raised	Raised	NA	7/67	-	-
5999	US 80	8-8	4	6	Raised	Raised	4/70	4/72	-	-
6081	US 67	9-11	0	8	-	-	10/60	9/62	-	Yes
6088	US 67	9-11	0	4	-	-	4/49	11/50	-	Yes
6093	IH 30	9-11	0	4	-	-	old		-	Yes
6139,6142	US 75	47-7	0	4	-	-	old		-	-
6145,6150,6152	US 75	47-7	0	4	-	-	old		-	Yes
6174	US 75	47-7	0	6	-	-	old		-	-
6289,6291	US 75	91-1	0	6	-	-	old		-	Yes
6321,6323,6329	US 75	92-2	2	4	-	Raised	old		Yes	Yes
6306,6313	US 75	92-2	2	4	-	Raised	old		-	-
6370	IH 45	92-2	0	6	-	-	NA	11/73	Yes	Yes
6372	IH 45	92-14	0	6	-	-	1/73	10/75	Yes	Yes
6384,6387	SH 183	94-3	4	6	Raised	Raised	6/70	7/73	-	-
6393	SH 183	94-3	4	6	Raised	Raised	6/70	7/73	-	Yes
6466	US 80	95-10	4	4	-	-	old		-	-
6477,6483	IH 35E	196-3	0	10	-	-	old		Yes	-
6489	IH 35E	196-3	0	8	-	-	old		-	Yes
6491,6497	IH 35E	196-3	NA	NA	NA	NA	old		-	-
6495	IH 35E	196-3	NA	NA	NA	NA	old		-	Yes
6501	IH 35E	196-3	0	4	-	-	old		Yes	Yes
6506,6509	IH 35E	196-3	4	6	-	-	12/72	9/76	-	-
6520,6525	SH 310	196-5	0	2	-	-	old		Yes	Yes

Continued

Table A5. General Roadway Information on Traffic Count Stations in Dallas Chosen for Study (Continued)

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
6530	SH 354	196-6	NA	4	-	-	old		Yes	Yes
6532	SH 354	196-6	NA	4	-	-	old		-	-
6535	SH 354	196-6	NA	4	-	-	old		Yes	Yes
6540	SH 354	196-6	NA	4	-	-	old		Yes	-
6543	SH 354	196-6	NA	4	-	-	old		-	-
6547	SH 354	196-6	NA	6	-	-	old		Yes	-
6555	SH 354	196-6	2	6	-	-	old		Yes	Yes
6566	US 175	197-2	0	6	-	-	7/61	1/64	-	Yes
6568	US 175	197-2	0	6	-	-	7/61	1/64	-	-
6574	US 175	197-2	4	6	Raised	Raised	10/66	11/68	-	-
6578	US 175	197-2	4	6	Raised	Raised	10/68	3/71	-	Yes
6586	US 175	197-2	2	4	Raised	Raised	11/69	1/72	-	-
6595	IH 635	2374-1	0	8	-	-	11/66	8/70	-	Yes
6606	US 67	261-2	2	4	-	-	3/71	7/74	-	Yes
6618	US 67	261-2	2	4	-	-	10/73	4/75	-	Yes
6621	US 67	261-2	2	4	-	-	2/74	7/75	-	Yes
6638	US 67	261-3	2	4	-	-	10/66	8/69	-	-
6656	SH 114	353-4	2	6	-	-	12/70	10/73	-	-
6658	SH 348	353-4	2	4	-	Raised	'72	8/75	-	-
6669	SH 348	353-4	2	4	-	Raised	'72	8/75	-	Yes
6676	Loop 12	353-5	4	6	-	Raised	1/68	11/70	-	Yes
6684	Loop 12	353-5	4	6	-	Raised	1/68	11/70	-	-
6689	Loop 12	353-5	4	6	-	Raised	5/60	12/61	-	Yes
6686	Loop 12	353-5	4	6	-	Raised	11/63	9/64	-	Yes

Continued

Table A5. General Roadway Information on Traffic Count Stations in Dallas Chosen for Study (Continued)

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
6693	Loop 12	353-5	4	6	-	Raised	5/60	12/61	-	Yes
6698	Spur 244	353-5	2	4	-	Raised	old		-	Yes
6749	IH 35E	442-2	2	4	-	Raised	10/61	11/63	-	Yes
6752	IH 35E	442-2	2	4	-	-	11/62	10/64	-	-
6754	IH 35E	442-2	2	6	-	-	12/63	10/65	-	Yes
6755	IH 35E	442-2	0	8	-	-	8/60	2/62	-	Yes
6758	US 67	261-3	2	4	-	-	10/66	8/69	-	Yes
6768,6773	Loop 12	581-1	2	6	-	Raised	old		-	Yes
6775,6785	Loop 12	581-1	4	6	-	Raised	9/76	8/78	-	Yes
6790	Loop 12	581-1	4	6	-	Raised	7/64	9/65	-	Yes
6791	Loop 12	581-1	4	6	-	Raised	8/63	5/64	-	-
6797,6802	Loop 12	581-1	4	6	Raised	Raised	9/64	9/65	-	Yes
6813	Loop 12	581-1	4	6	Raised	Raised	9/64	9/65	-	-
6820	Loop 12	581-1	2	6	-	Raised	4/62	11/63	-	-
6830	Loop 12	581-2	2	6	-	-	9/66	6/68	-	-
6841	Loop 12	581-1	0	6	-	-	12/71	8/75	-	Yes
6850	Loop 12	581-2	2	6	-	-	1/73	6/76	-	Yes
6856	Loop 12	581-2	2	6	-	-	1/73	6/76	-	-
6864	Loop 12	581-2	2	6	-	-	5/67	6/69	-	Yes
6868	Loop 12	581-2	0	6	-	-	8/68	10/70	-	Yes
6939	IH 635	2374-1	2	8	-	-	7/67	11/68	-	Yes
6957	IH 635	2374-1	2	8	-	-	7/67	11/68	-	-
6966	IH 635	2374-1	2	8	-	-	6/64	3/67	-	-
6975	IH 635	2374-1	2	8	-	-	6/64	3/67	-	Yes

Continued

Table A5. General Roadway Information on Traffic Count Stations in Dallas Chosen for Study

Count Station	Location		Improvement				Construction Date		Parallel Traffic[a]	Intersecting Traffic[a]
	Highway Number	Control-Section Number	Capacity -Lanes-		Median		Letting	Completion		
			Before	After	Before	After				
6978	IH 635	2374-1	2	8	-	-	5/66	10/69	-	Yes
6992	IH 635	2374-1	2	8	-	-	5/66	10/69	-	-
7000	IH 635	2374-2	0	8	-	-	11/66	8/70	-	Yes
7012	IH 635	2374-1	0	8	-	-	7/67	11/68	-	Yes
7022	IH 635	2374-3	0	8	-	-	12/69	9/71	-	Yes
7042,7043	IH 635	2374-4	0	8	-	-	12/71	8/74	-	Yes
7045	IH 635	2374-4	0	8	-	-	9/73	12/75	-	Yes
7047,7050	IH 635	2374-4	0	8	-	-	3/71	7/74	-	Yes

[a] Presence of major arterial(s) or highway(s) within half a mile of study point.
"-" represents none.
"NA" represents not available.