Predicting Traffic Volume Growth Rates Resulting From Changes in Highway Capacity and Land Development

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Research performed in cooperation with DOT, FHWA and SDHPT.
Research Study Title: Economics of Highway Design Alternatives

The magnitude of potential highway user benefits and costs resulting from proposed highway improvements must be estimated with a reasonable degree of accuracy for highway agencies to make rational decisions in the public interest. The Highway Economic Evaluation Model (HEEM) has been developed for that purpose. One of the important aspects of the model is the assumed growth rate pattern which average daily traffic volume (ADT) will exhibit during the projection period under consideration. This study examines 18 case study areas in Texas, along with a detailed look at Dallas County, to determine the factors which significantly affect ADT growth rates for use in the HEEM. The factors include highway capacity, and different categories of land development. The accuracy of ADT projections in Dallas County, along with population and land use projections, are examined, as well as factors which seem to be influencing the size of the errors. Various alternative changes to the HEEM's traffic growth rate formulas are proposed, along with a simple multiple regression model to project ADT. The data are reported in narrative, graphic, and tabular form. Implementation of the findings and recommendations of this report should result in more accurate estimates generated from the HEEM at a lower cost of running the model.

Highway traffic growth rates, Highway capacity changes, Land development, and Highway Economic Evaluation model

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Form DOT F 1700.7 (8-89)
PREDICTING TRAFFIC VOLUME GROWTH RATES RESULTING FROM CHANGES IN HIGHWAY CAPACITY AND LAND DEVELOPMENT

by

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Research Report 225-23
Research Study Number 2-8-77-225
Economics of Highway Design Alternatives

Sponsored by the State Department of Highways and Public Transportation

in Cooperation with the
Federal Highway Administration
U. S. Department of Transportation

January, 1981

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PREFACE

The authors wish to express appreciation to those who have assisted in this study. Special acknowledgement is due Mr. James W. Barr and Mr. James R. Farrar of the Texas State Department of Highways and Public Transportation (SDHPT). Mr. Francis X. Fallwell and Ms. Miriam O. Grayson of District 18 of the SDHPT were very helpful in providing materials and data. Mr. Don Walden, Mr. Bill Buglehall, and Mr. Arnold Breedon of the Dallas/Fort Worth Regional Planning Office of the SDHPT were also very helpful in providing information and data.

Mr. Dale Schafer, and his staff, of the Texas Transportation Institute, made a contribution to the study by performing some of the computer work. Mr. Eric Schulte skillfully prepared the map and graphs. Ms. Betty Benson and Ms. Sue Freedman receive special marks for typing the manuscript.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
ABSTRACT

The magnitude of potential highway user benefits and costs resulting from proposed highway improvements must be estimated with a reasonable degree of accuracy for highway agencies to make rational decisions in the public interest. The Highway Economic Evaluation Model (HEEM) has been developed for that purpose. One of the important aspects of the model is the assumed growth rate pattern which average daily traffic volume (ADT) will exhibit during the projection period under consideration. This study examines 18 case study areas in Texas, along with a detailed look at Dallas County, to determine the factors which significantly affect ADT growth rates for use in the HEEM. The factors include highway capacity, and different categories of land development. The accuracy of ADT projections in Dallas County, along with population and land use projections, are examined, as well as factors which seem to be influencing the size of the errors. Various alternative changes to the HEEM's traffic growth rate formulas are proposed, along with a simple multiple regression model to project ADT. The data are reported in narrative, graphic, and tabular form. Implementation of the findings and recommendations of this report should result in more accurate estimates generated from the HEEM at a lower cost of running the model.
SUMMARY OF FINDING

Data collected from the 18 case study areas receiving highway improvements were aggregated to find what effect factors such as stage of area development and capacity changes have on traffic growth rate patterns and to compare these patterns with those assumed in the HEEM. Also data collected from 47 improved highway segments in Dallas County were aggregated to determine the relationships among ADT, land use, and population projections and to determine what changes should be made to the assumed ADT growth rate formulas in the HEEM.

The findings for the 18 case study areas are summarized as follows:

1. There is no clear distinction between the growth rates in developing areas as contrasted to developed areas. The assumption in the HEEM of a constant growth rate for developing areas and a particular declining growth rate for developed areas is not supported in this sample.

2. Improvements of primary routes in developing areas in this study significantly affect traffic growth rates, but that effect diminishes rapidly over time. The effect is much smaller in developed areas.

3. The number of lanes added to capacity also seems to be a significant factor in the 18 case study areas. In general, the greater the capacity change, the larger is the initial impact on ADT, but that effect on the growth rate diminishes over time.
4. Improvements along primary routes affect growth rates for both parallel routes and intersecting routes within the study areas, with a relatively greater impact on the parallel routes. The effect is most pronounced in developing areas, but the impact on the ADT growth rate diminishes over time and almost disappears four (4) years after construction began on the primary route improvement.

The findings for ADT growth rates of the improved highway segments in Dallas County are as follows:

1. ADT projections prepared by the SDHPT have an average error of .2870 in this study. The average error is influenced by a number of factors.
   a. The average error declines from .3266 to .1515 if the projection was made after the improvement had been completed.
   b. The average error goes down as the time the projections were made approach the present. The average error for projections made in the 1950's is .3385, compared to .1629 for projections made in the 1970's.
   c. The stage of commercial and industrial land use also is significant with an average error of .3213 for developed areas, compared to an average error of .2770 for developing areas.
   d. The year the projection was made, the stage of
commercial/industrial land use, and the time of the projection in relation to completion of the highway project, can explain 24.5% of the variation in the ADT projection errors.

2. Population and land use projections are, in general, not very accurate. Population projections have an average error of .4658, and the land use projections have an average error of .8371.
   a. The average error for both population and land use projections declines somewhat if the projection was made after completion of the highway project.
   b. The average error drops in developed areas for both population and land use projections.

3. Overall, very little relationship is observed between errors in ADT projections, land use projections, and population projections. However, there are significant relationships in some categories of the projection errors.
   a. There is a significant positive correlation between errors in population and land use projections for total developed areas and for projections made before completion of the highway project in developed areas.
   b. There is a significant negative correlation between
errors in ADT projections and land use projections for projections made after completion of the highway project in developing areas.

4. The declining growth rate formula in the HEEM is deficient in a number of aspects.
   a. The large number of iterations currently required in calculating the declining growth rate formula can be reduced to a single iteration by using the formula presented in this study.
   b. Multiple projections currently cannot be incorporated into the HEEM. Two alternative declining growth rate models are presented in this study which can incorporate any number of projections and retain the feature of an assumed terminal growth rate.
   c. Use of an assumed terminal growth rate and arbitrary selection of a constant growth rate formula or a declining growth rate formula based upon stage of development does not seem appropriate. A superior method would allow the HEEM to choose from a variety of growth patterns the one which most closely fits available historical ADT data.

5. A multiple regression model for projecting ADT is presented which takes into account historical ADT data,
stage of development, and the effects of a capacity change. The model increases the accuracy of ADT projections, reducing the average error in this sample from .2222, with the SDHPT projections, to .1857, a reduction of about 16%, using the model presented in this study.
IMPLEMENTATION STATEMENT

This report relates the findings of an aggregative study of 18 case study areas and a separate study of Dallas County to determine the factors affecting traffic growth rate patterns. Alternative formulas are proposed to improve the current growth rate formulas used in the Highway Economic Evaluation Model (HEEM). The findings can be implemented immediately to improve the accuracy of estimates generated from the HEEM and reduce the computer time costs of running the model.
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INTRODUCTION

Purpose and Objective of Study

The near completion of the Interstate Highway System and the increasing shortage of funds for future highway construction have caused state highway agencies to concentrate on upgrading and increasing the capacity of existing streets and highways. Much research has been done in the past concerning the impacts of new highway construction, but little has been done to examine the effects where an existing highway is upgraded. In order to optimize net public benefits, highway agencies need information of this type to help predict the effects from an improvement on an existing facility.

Studies have been made in 18 different areas to determine the effects on land use and traffic volumes where an existing highway or street has been improved. This study aggregates the findings of these 18 individual case studies and looks at the effects those improvements have had on traffic growth patterns. The aggregated effects on land use are presented in Research Report 225-22 [19].

An important aspect of traffic growth rates is their use in the Highway Economic Evaluation Model (HEEM) to calculate the Economic Measure of a highway project. This study examines several highway projects in Dallas County in order to determine the suitability and possible improvements of the assumed HEEM growth rate formulas.

Objectives:

(1) To determine traffic volume changes resulting from various types of improvements.

(2) Develop a more accurate procedure for determining corridor traffic growth rates to be used in the HEEM that take into account changes in vehicle volume, vehicle capacity, abutting
land uses, and population experienced in the study corridor and highway system of which the corridor is a part.

Contents of Report

The report consists of two major sections. The first section includes an aggregative analysis of 18 case study areas [1-18]. This section covers several areas, including alternative functional forms for ADT, analysis of land use and capacity changes on traffic growth patterns. This section also examines the effects on parallel and intersecting routes from a capacity change on the primary route.

The second major section examines ADT growth rates in Dallas County. The accuracy of ADT projections are examined, along with the factors affecting the projection errors. The accuracy of land use and population projections are also examined, along with the relationship between the errors. The HEEM declining growth rate model is examined and alternative declining growth rate formulas are presented. In addition, a simple multiple regression model to project ADT is presented which slightly lowers the average projection errors.

Sources of Data

Data for the 18 Case Study Areas were taken from the individual reports on each area. The original data sources for each study are published separately in these reports [1-18].

Data for the Dallas County highway projects came from a variety of sources. Information on the improvement projects within Dallas County came from the District 18 Office of the State Department of Highways and Public Transportation (SDHPT).
ADT historical data came from the SDHPT's Planning and Research Division RI-2-T-Log and District Highway Traffic Maps. Projected ADT figures were taken from various reports prepared by the SDHPT's Planning and Research Division.

Historical land use and population data were obtained from a computer tape prepared by SDHPT's Dallas-Fort Worth Regional Planning Office. Projected land use and population figures were obtained from the Regional Transportation Study (RTS), Volume 2, prepared by the SDHPT [22], and unpublished raw data used in preparation of the RTS, for individual survey zones within Dallas County.
AGGREGATIVE ANALYSIS OF 18 CASE STUDIES

The location of the 18 case study areas are presented in Table 1. The 18 areas were broken down into a developing or developed category. The developed category is defined as 80 percent or more of the land not vacant within the study area. A particular count station was selected which most closely reflected the change in average daily traffic (ADT) volume along the study route, and for which the greatest amount of data were available.

Table 1 also presents the parallel routes and intersecting routes selected for use in this study. Each route and the count station associated with that route were selected based upon its location within or proximity to the study area and the availability of ADT data. In general, much less data were available for parallel routes and generally even less for intersecting routes. This restricted the accurate estimation of growth rates along those routes and would indicate a need for more frequent ADT counts along these less traveled routes, especially those off of the state or federal systems. The historical ADT data used in this study for aggregating the 18 case study areas are presented in Appendix A, Tables A2, A7, and A10.

Functional Form for Projected ADT

In any study concerned with forecasting or projections, the functional form of the dependent variable and its rate of change or growth rate is of prime importance. The Highway Economic Evaluation
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<th>Study Period</th>
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<th>Parallel Route</th>
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<td>Glade St.</td>
<td>S. of Holleman</td>
<td>FM 2818</td>
<td>M. of Texas</td>
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<td>3</td>
<td>29th Street, Bryan</td>
<td>2</td>
<td>1958 - 1977</td>
<td>20</td>
<td>NW of Haswell, SE of Coulter</td>
<td>Carter Creek Parkwy</td>
<td>SE of Texas NW of Coulter</td>
<td>Coulter Dr.</td>
<td>SW of 29th</td>
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<td>N. of N. Texas</td>
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<td>Long Point Rd.</td>
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<td>7</td>
<td>Antoine Dr., Houston</td>
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<td>1964 - 1978</td>
<td>15</td>
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<td>8</td>
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<td>1</td>
<td>1964 - 1978</td>
<td>16</td>
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<td>FM 157 #2, Arlington</td>
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<td>1963 - 1978</td>
<td>15</td>
<td>N. of US 80</td>
<td>SH 360 b</td>
<td>N. of IH 30</td>
<td>Lamar Blvd.</td>
<td>at Westheimer</td>
</tr>
<tr>
<td>13</td>
<td>FM 1093, Westheimer #3, Houston</td>
<td>1</td>
<td>1962 - 1978</td>
<td>15</td>
<td>N. of US 80</td>
<td>Memorial Dr. b</td>
<td>at Benigus</td>
<td>Fondren Rd.</td>
<td>at Buffalo Bayou</td>
</tr>
<tr>
<td>14</td>
<td>SH 352, Dallas</td>
<td>1</td>
<td>1958 - 1979</td>
<td>21</td>
<td>W. of Don</td>
<td>Military Parkway</td>
<td>E. of St. Augustine</td>
<td>F. of Tol.</td>
<td>at Buffalo Bayou</td>
</tr>
<tr>
<td>15</td>
<td>SH 356, Dallas</td>
<td>1</td>
<td>1958 - 1978</td>
<td>21</td>
<td>W. of Don</td>
<td>Military Parkway</td>
<td>E. of St. Augustine</td>
<td>F. of Tol.</td>
<td>at Buffalo Bayou</td>
</tr>
<tr>
<td>16</td>
<td>W. Berry St., Ft. Worth</td>
<td>2</td>
<td>1964 - 1978</td>
<td>15</td>
<td>U. of Forest</td>
<td>Seminary Dr. b</td>
<td>McGart and James</td>
<td>University</td>
<td>W. Berry and Park Hill</td>
</tr>
<tr>
<td>17</td>
<td>Vickery St., Ft. Worth</td>
<td>1</td>
<td>1964 - 1978</td>
<td>15</td>
<td>Montgomery and Hulen</td>
<td>Camp Bowie b</td>
<td>Halloran and Horn</td>
<td>University</td>
<td>W. Berry and Park Hill</td>
</tr>
<tr>
<td>18</td>
<td>Pipeline Rd., Hurst</td>
<td>2</td>
<td>1963 - 1978</td>
<td>16</td>
<td>E. of Precinct</td>
<td>SH 183 b</td>
<td>E. of Norwood</td>
<td>Precinct Line Rd.</td>
<td>at Pipeline Rd.</td>
</tr>
</tbody>
</table>

a 1 = Developing Area  
b 2 = Developed Area  
c 3 = Not in Study Area
Model (HEEM) uses two functional forms, depending on the stage of development in the area. One is a constant growth rate, which is to represent a typical developing area. The other is a declining growth rate where the terminal growth rate must be specified, which is to represent a typical highly developed area. Due to the specification of the model, the parameters of the second function must be iterated.

A more detailed look at the HEEM growth rate models is presented in the last section of this report, but it is sufficient at this time to mention that the functional form of the HEEM declining growth rate model prevents it from being used in a linear regression model to estimate growth rates of historical ADT data.

In addition, it is certainly not obvious that one particular functional form is applicable in all cases where the growth rate happens to be declining. Table 2 presents five different models of ADT as a function of time. Each can be estimated with a simple least-squares regression technique. In addition, the ADT growth rate is presented which is associated with each functional form. The first one has a constant growth rate, the other four have declining growth rates, with each one in general having a different rate of decline. The relative relationship of the models is presented in Figure 1, where ADT is assumed to increase from 10,000 to 20,000 in 20 years.

The selection of these five particular functional forms was arbitrary in the sense that there are virtually an infinite number to choose from. However, these five offer the advantages that their coefficients are easily calculated or estimated, as the situation warrants, and they offer a relatively wide range of variability in the
Table 2 Functional Forms for ADT Models

<table>
<thead>
<tr>
<th>Functional Form</th>
<th>Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $\ln \text{ADT}_t = a + bt$</td>
<td>$b$</td>
</tr>
<tr>
<td>2. $\ln \text{ADT}_t = a + b\ln t$</td>
<td>$\frac{b}{t}$</td>
</tr>
<tr>
<td>3. $\text{ADT}_t = a + bt$</td>
<td>$\frac{b}{a+bt} = \frac{b}{\text{ADT}_t}$</td>
</tr>
<tr>
<td>4. $\text{ADT}_t = a + b\ln t$</td>
<td>$\frac{b}{t(a+b\ln t)} = \frac{b}{t(\text{ADT}_t)}$</td>
</tr>
<tr>
<td>5. $\left(\frac{\text{ADT}_t}{10,000}\right)^2 = a + bt$</td>
<td>$\frac{b}{2(a+bt)} = \frac{(5\times10^7)b}{\text{ADT}^2}$</td>
</tr>
</tbody>
</table>

Where:  
ADT = Annual Average Daily Traffic  
t = Time Period (year)  
a, b = Parameters
estimated ADT values over the period under consideration. For example, in Figure 1, at the midpoint (1970), ADT varies by more than 1,500. (Table A1 in Appendix A gives the ADT figures for each functional form).

Ideally, the particular model or models selected would be based on some theoretical assumptions concerning the "true" relationship. In this case, no a priori information is available which would allow selection of one model versus another. However, their applicability to particular sample data can be observed, and for that reason the model with the highest $R^2$ value was used in this study to estimate the growth rate for a given set of historical ADT data.

Analysis of ADT on Primary Routes

The 18 case study areas were selected after a careful evaluation of a number of highway improvement projects. The 18 study areas were chosen based upon the following characteristics: (1) stage of area development; (2) type of highway or street; (3) predominate land use; and (4) type of setting (urban or suburban). In addition, each study area selected was required to have adequate historical experience after the improvement had been made.

As a result of this selection process, aggregating the study areas presented some difficulties. The case studies covered several different time periods (see Table 1) which includes varied study periods and length of periods. In addition, several gaps in the yearly ADT data are present.

To resolve these problems and make the data comparable, the historical ADT figures for each study area were normalized, to cover a
similar 15 year study period. Year five was used in each case to indicate the year before commitment was made to fund the project, final planning completed, and construction began. In that way, each study area would reflect the relative change in ADT resulting from the improvement during the same time frame and so that the 18 case study areas could be aggregated along with any subset of these areas.

The year when construction was completed could also have been used as the basis of comparison, but in most cases the construction period was relatively short (one or two years) and would not significantly affect the results. In addition, by using the year prior to the beginning of final planning and construction, it allows a clear comparison of time periods before and after improvements were made in order to examine the effects of these changes on the aggregated ADT figures.

Linear interpolation was used in most cases to fill in the gaps of the historical ADT figures for each study area. In the few instances where the normalized study period extended beyond available historical ADT figures, the estimated growth rate for the particular study area was used to estimate the required ADT figures (see Appendix A, Tables A3 and A4).

The aggregate ADT figures are presented in Table 3. These ADT figures represent an average of the ADT figures for each of the 15 years during the study period and are categorized by the previously described developed or developing areas and by all 18 study areas. The study areas in each category are listed at the bottom of the table.
<table>
<thead>
<tr>
<th>Year</th>
<th>Developing Areas a</th>
<th>Developed Areas b</th>
<th>Total Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8,970</td>
<td>8,550</td>
<td>8,830</td>
</tr>
<tr>
<td>2</td>
<td>9,580</td>
<td>8,350</td>
<td>9,170</td>
</tr>
<tr>
<td>3</td>
<td>10,820</td>
<td>9,100</td>
<td>10,250</td>
</tr>
<tr>
<td>4</td>
<td>11,380</td>
<td>9,970</td>
<td>10,910</td>
</tr>
<tr>
<td>5</td>
<td>12,070</td>
<td>9,790</td>
<td>11,300</td>
</tr>
<tr>
<td>6</td>
<td>12,620</td>
<td>9,580</td>
<td>11,610</td>
</tr>
<tr>
<td>7</td>
<td>13,110</td>
<td>10,030</td>
<td>12,080</td>
</tr>
<tr>
<td>8</td>
<td>14,060</td>
<td>10,140</td>
<td>12,750</td>
</tr>
<tr>
<td>9</td>
<td>16,310</td>
<td>10,550</td>
<td>14,390</td>
</tr>
<tr>
<td>10</td>
<td>18,750</td>
<td>11,110</td>
<td>16,200</td>
</tr>
<tr>
<td>11</td>
<td>20,660</td>
<td>11,830</td>
<td>17,720</td>
</tr>
<tr>
<td>12</td>
<td>22,360</td>
<td>12,510</td>
<td>19,080</td>
</tr>
<tr>
<td>13</td>
<td>24,600</td>
<td>12,400</td>
<td>20,530</td>
</tr>
<tr>
<td>14</td>
<td>26,170</td>
<td>12,950</td>
<td>21,760</td>
</tr>
<tr>
<td>15</td>
<td>28,290</td>
<td>13,690</td>
<td>23,420</td>
</tr>
</tbody>
</table>

**Table 3** Primary Route Averaged ADT, Classified by Stage of Development

* a Areas 1,2,4,6,8,9,11,12,13,14,15,17.

* b Areas 3,5,7,10,16,18
In addition, the entire study period was broken down into three segments. The first five years represent the period before final planning and construction took place. The second segment of five years represents the period of final planning, construction, and immediately following construction of the project. This period would capture the initial impact on traffic volume resulting from the improvement along the study route. The third segment represents the period after the initial impact has passed and after readjustments of traffic volume have occurred as a result of the improvement having taken place.

Figure 2 gives a graphical representation of the aggregated ADT figures. As would be expected, the developing areas show a much faster ADT growth than the developed areas. However, it is interesting to observe that the developed areas do not exhibit an obvious declining growth rate curve in this sample, which is assumed in the HEEM model. A larger sample size would be required to determine the exact relationship between stage of development and the pattern of ADT growth, and a longer sample period of 20 years may show a declining growth rate pattern for developed areas.

**Calculation of Growth Rates by Stage of Development**

Growth rates were then calculated for each of the three aggregated categories over the study period and are presented in Table 4. The actual growth rates are presented which represent the year-to-year change in the ADT figures. The growth rate was calculated using the
FIGURE 2 PRIMARY ROUTE AVERAGED ADT, CLASSIFIED BY STAGE OF DEVELOPMENT

ADT (in thousands)

YEAR

DEVELOPED AREAS

TOTAL AREAS

DEVELOPING AREAS
<table>
<thead>
<tr>
<th>Year</th>
<th>Actual Growth Rates</th>
<th>Overall Calculated Growth Rates</th>
<th>Divided Segments Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Developing</td>
<td>Developed</td>
<td>Total</td>
</tr>
<tr>
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<td>-.0234</td>
<td>.0385</td>
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<tr>
<td>2</td>
<td>.1294</td>
<td>.0898</td>
<td>.1178</td>
</tr>
<tr>
<td>3</td>
<td>.0517</td>
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<td>.0644</td>
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<td>4</td>
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<td>-.0201</td>
<td>.0357</td>
</tr>
<tr>
<td>5</td>
<td>.0456</td>
<td>-.0194</td>
<td>.0274</td>
</tr>
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<td>6</td>
<td>.0388</td>
<td>.0470</td>
<td>.0405</td>
</tr>
<tr>
<td>7</td>
<td>.0725</td>
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<td>.1258</td>
</tr>
<tr>
<td>10</td>
<td>.1019</td>
<td>.0648</td>
<td>.0938</td>
</tr>
<tr>
<td>11</td>
<td>.0823</td>
<td>.0575</td>
<td>.0767</td>
</tr>
<tr>
<td>12</td>
<td>.1002</td>
<td>-.0088</td>
<td>.0760</td>
</tr>
<tr>
<td>13</td>
<td>.0638</td>
<td>.0444</td>
<td>.0599</td>
</tr>
<tr>
<td>14</td>
<td>.0810</td>
<td>.0571</td>
<td>.0763</td>
</tr>
<tr>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
following formula:

\[ g_t = \frac{ADT_{t+1} - ADT_t}{ADT_t} \]

where: \( g_t \) = growth rate in year (%)  
\( ADT_t \) = Average Daily Traffic in Year \( t \)

The overall growth rates were estimated using ordinary least-squares on the functional form most closely fitting the data for the entire 15 year period. It is interesting to note all three aggregated categories have an overall estimated growth rate which is constant. Even though the growth rate for the developed areas is much lower than for the developing areas (3.23% compared to 8.39%), it would tend to suggest that rather than using a declining growth rate for developed areas, a small, but constant growth rate may be more appropriate.

This sample is too small to generalize the results to other areas in Texas outside these study areas, but it does cast some doubt on the HEEM's use of a declining growth rate without additional justification and study.

The segmented growth rates presented in Table 4 were estimated in the same manner as the overall growth rates except the growth rates for each segment were estimated separately. Figure 3 presents those segmented growth rates graphically. The developing areas show a declining growth rate for the first five years, then a high, constant growth rate of 10.1% during the initial impact period, then a declining
FIGURE 3
COMPARISON OF PRIMARY ROUTE SEGMENTED GROWTH RATES

GROWTH RATE (%)

YEAR

TOTAL AREAS
DEVELOPING AREAS

DEVELOPED AREAS

0 0.02 0.04 0.06 0.08 0.10 0.12

1 3 5 7 9 11 13 15

YEAR
growth rate during the last period.

The developed areas, on the other hand, show a far different pattern. The growth rate is constant during each segment, with a slight downward trend between segments. The growth rate goes from 4.44% in the first segment to 3.27% in the last segment. In this sample, the averaged ADT in the developed areas did not go up as a result of improvements along the study route, in sharp contrast to the large increase experienced in the developing areas. This result would suggest that some adjustment to the assumed growth rates should be made for improvements only in developing areas.

Effects of Capacity Change

A comparison of the 18 case study areas was also made for capacity changes. Table 5 presents the three capacity change categories and the study areas in each category are listed at the bottom of the table. The ADT figures for study areas in each category were averaged and are presented in Table 5. Unfortunately only one area fell into the no capacity change category which limits any generalizations or comparisons to other aggregated categories.

Figure 4 presents graphically the ADT figures for different capacity change categories. As expected, the 4-lane capacity change category has a much faster growth rate after the capacity change than the other categories. That observation is confirmed in Table 6 which presents the actual growth rates for each category along with the overall estimated growth rates and the estimated growth rates for each segment.
<table>
<thead>
<tr>
<th>Year</th>
<th>2 Lane Change $^a$</th>
<th>4 Lane Change $^b$</th>
<th>No Change $^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>11,100</td>
<td>14,770</td>
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<tr>
<td>2</td>
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<td>13,980</td>
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<tr>
<td>4</td>
<td>7,680</td>
<td>14,720</td>
<td>16,530</td>
</tr>
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<td>5</td>
<td>7,900</td>
<td>15,130</td>
<td>18,560</td>
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<td>15,570</td>
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<td>8,760</td>
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</tr>
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<td>9</td>
<td>9,760</td>
<td>19,760</td>
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<td>10,530</td>
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<td>24,510</td>
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</tr>
<tr>
<td>12</td>
<td>13,420</td>
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<td>24,660</td>
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<tr>
<td>14</td>
<td>15,470</td>
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</tr>
<tr>
<td>15</td>
<td>17,670</td>
<td>30,660</td>
<td>30,280</td>
</tr>
</tbody>
</table>

$a$ Areas 1,2,3,4,5,7,8,16,17,18

$b$ Areas 6,9,10,11,13,14,15

$c$ Area 12
FIGURE 4  PRIMARY ROUTE AVERAGED ADT, CLASSIFIED BY CAPACITY CHANGE

YEAR

AVERAGE ADT (in thousands)

4 LANE CHANGE AREAS
NO CHANGE AREA
TOTAL AREAS
2 LANE CHANGE AREAS

YEAR

1 3 5 7 9 11 13 15

25 29 33

13 17

5 9
<table>
<thead>
<tr>
<th>Year</th>
<th>Actual Growth Rates</th>
<th>Overall Calculated Growth Rates</th>
<th>Divided Segments Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 Lane Change</td>
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<td>No Change</td>
</tr>
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</tr>
<tr>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Overall the estimated growth rates are constant for both the 2-lane and 4-lane capacity change categories, with the 4-lane category having a slightly higher growth rate, 7.52% to 7.05%. The no change category exhibits an overall declining growth rate pattern going from 6.68% in year 1 to 3.26% in year 15.

The estimated growth rate pattern changes somewhat when the study period is broken down into segments. Those segmented growth rates are presented graphically in Figure 5. The 4-lane change areas exhibit a declining growth rate in both the initial and last segments, with a high constant growth rate (10.5%) during the initial impact segment.

The 2-lane change areas also have a declining growth rate during the initial segment and a higher constant growth rate (6.85%) during the middle segment, but then the growth rate is even higher to 9.11% during the last period. This is mainly due to the impact of case study areas 1 and 2, which are located in rapidly growing areas of College Station, Texas. This area has been characterized by a high constant, or even slightly increasing growth rate, during the last five to ten years.

In general, the results seem to support the conclusion that the greater the capacity change the larger is the initial impact on ADT, but that effect on the growth rate diminishes over time.
COMPARISON OF

FIGURE 5 PRIMARY ROUTE SEGMENTED GROWTH RATES BY CAPACITY CHANGE

GROWTH RATE (%)

YEAR

1 3 5 7 9 11 13 15

2 LANE CHANGE
TOTAL AREAS
NO CHANGE
4 LANE CHANGE

0 0.02 0.04 0.06 0.08 0.10 0.12
Analysis of ADT on Parallel Routes

It has been assumed in the past that all routes in a specific corridor exhibit similar types of growth patterns, in particular the same growth rate could be applied to both the primary route and secondary route(s). The HEEM, for example, calculates either a constant growth rate or a declining growth rate for the corridor traffic volume being examined. However the allocation procedure in the HEEM for distributing the projected traffic volume along the routes within the corridor is not affected by that assumed growth rate, so in effect, the same growth rate is applied to all routes within the corridor. The 18 case study areas were examined to provide some evidence as to the validity of the above assumption.

Aggregating parallel route ADT followed the same procedure outlined in the previous section for the primary routes. The historical ADT was normalized using the year before final planning and construction began (year 5) as the common reference point. The averaged ADT for the 18 case study parallel routes is presented in Table 7. Again, they were divided up into developed and developing categories in order to make them comparable to the primary routes.

The actual growth rates, along with the estimated overall growth rates and the segmented growth rates are presented in Table 8. The overall growth rates show a similar relationship already noted between the primary routes. Both the developed and developing areas have an estimated constant growth rate, with the developing areas having a much higher growth rate, 7.32% compared to the 2.59% growth rate for the developed areas.
Table 7  Parallel Routes Averaged ADT

<table>
<thead>
<tr>
<th>Year</th>
<th>Developing</th>
<th>Developed</th>
<th>Total Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7,460</td>
<td>12,590</td>
<td>9,170</td>
</tr>
<tr>
<td>2</td>
<td>8,260</td>
<td>12,760</td>
<td>9,760</td>
</tr>
<tr>
<td>3</td>
<td>8,700</td>
<td>13,130</td>
<td>10,180</td>
</tr>
<tr>
<td>4</td>
<td>9,150</td>
<td>13,480</td>
<td>10,590</td>
</tr>
<tr>
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<td>13,780</td>
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</tr>
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FIGURE 6
PARALLEL ROUTES AVERAGED ADT

ADT (thousands) vs. YEAR

DEVELOPING AREAS
TOTAL AREAS
DEVELOPED AREAS
<table>
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<tr>
<th>Year</th>
<th>Actual Growth Rates</th>
<th>Overall Calculated Growth Rates</th>
<th>Divided Segments Growth Rate</th>
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The segmented growth rates offer an interesting contrast to the primary routes. Looking at the middle segment in Table 8, when the initial impact from the primary route improvement is felt, a decline in the growth rates for both categories can be observed, though the decline is not as large in the developed areas. As expected, the positive initial impact on growth rates along the primary routes seems to be matched, at least to a certain extent, by a corresponding drop in the growth rates for parallel routes.

**Comparison to Primary Routes**

The difference in the growth rates between the primary routes and parallel routes for each of the several categories is presented in Table 9. The overall estimated growth rates show relatively little difference. The developing areas have a difference of 1.07% and developed areas .73%. The most significant differences appear in the segmented growth rate categories, where a large increase in the difference during the middle segment is evident for the developing areas.

Figure 7 depicts graphically the actual differences in growth rates between the primary routes and the parallel routes. Both the developing areas trendline and the developed areas trendline generally follow each other very closely, except for the initial impact segment from year 6 to year 10, where the difference is much larger for the developing areas than the developed areas.

Figure 8, showing the difference in segmented growth rates gives a
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<th>Difference in Segmented Growth Rates</th>
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Table 9: Difference in Growth Rates (%) between Primary Routes and Parallel Routes
COMPARISON OF THE DIFFERENCE OF ACTUAL GROWTH RATES BETWEEN PRIMARY ROUTES AND PARALLEL ROUTES

FIGURE 7

YEAR

GROWTH RATE (%)
FIGURE 8
COMPARISON OF ALL THE DIFFERENCE IN SEGMENTED GROWTH RATES BETWEEN PRIMARY ROUTES AND PARALLEL ROUTES

YEAR
DEVELOPING AREAS
TOTAL AREAS
DEVELOPED AREAS
similar result. The developing areas show a decline in the difference which becomes negative by year 5, the parallel routes are growing faster than the primary routes, during the initial segment. Then during the middle segment, years 6 to 10, a big jump in the difference can be observed. The difference then drops close to zero during the last segment. The developed areas exhibit quite different results. The difference is virtually constant during the first 10 years at about 2%, then drops to slightly below zero during the last segment.

These results would indicate the impacts from improvements along the study routes are most evident in the developing areas, but the impact on the growth rate diminishes over time and tends to disappear in about 5 years after construction is begun. This would suggest that when an improvement is made in a developing area, the underlying ADT growth rate would not have to be adjusted, since the effect on the growth rate would not tend to be permanent. However, the ADT volumes themselves should be shifted upward in the year the improvement is made.

Figure 9 depicts how that might be accomplished. Curve A exhibits a constant growth rate and is the same one used earlier in Figure 1. Curve B has exactly the same growth rate but has been shifted upward by 1,000 in the sixth year. By the 20th year, that difference becomes about 1,500. A measure of the magnitude of that shift is presented in Table 20 later in this study, but generally the shift should depend on the stage of development, especially commercial development, of the study area.
EFFECT ON DEVELOPING AREA ADT FROM AN IMPROVEMENT ALONG PRIMARY ROUTE

FIGURE 9

YEAR OF IMPROVEMENT

ADT (in thousands)
Analysis of ADT on Intersecting Routes

The effects of primary route improvements on intersecting routes within each case study area are examined in a similar fashion to the analysis of the parallel routes presented in the previous section. Table 10 presents the averaged ADT figures for the case study area in each category after the ADT figures had been normalized using the year before final planning and construction began as the common reference point. Those ADT categories are presented graphically in Figure 10.

Growth rates were then calculated for the intersecting routes which are presented in Table 11. The developing areas have an overall calculated growth rate which is a constant 5.8%. The developed areas have an overall declining growth rate which reaches .54% in year 15.

Looking at segmented growth rates, the developing areas exhibit a slightly declining growth rate during the first and last segments, and a constant growth rate during the middle segment. The developed areas have a slightly positive growth rate during the first segment, which becomes positive again during the last segment.

Any inferences which can be made from these data are very limited due to the lack of ADT data available on most intersecting routes and the small sample size of the study. However, it does seem the growth rates for intersecting routes have been affected by improvements along the primary routes.
### Table 10  
**Intersecting Routes Averaged ADT**

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<th>Total areas</th>
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a Excluding Case Study Area #18
FIGURE 10

INTERSECTING ROUTES AVERAGED ADT

YEAR

ADT (thousands)

DEVELOPED AREAS

TOTAL AREAS

DEVELOPING AREAS
Table 11

<table>
<thead>
<tr>
<th>Year</th>
<th>Actual Growth Rates</th>
<th>Overall Calculated Growth Rates</th>
<th>Divided Segments Growth Rate</th>
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</table>
Comparison to Primary Routes

Table 12 gives a detailed look at the differences in growth rates between the primary routes and intersecting routes for the 18 case study areas.

The differences in actual growth rates are presented in Figure 11. The trendlines for the developed and developing areas seem to follow each other fairly closely in the first and last segments, but they seem to have a significant divergence during the middle segment.

That relationship becomes clearer by looking at the differences in the segmented growth rates presented in Figure 12. The difference for the developing areas category is declining during the first segment, then increases to a constant 4.55% during the middle segment, then drops close to zero during the last segment. In contrast, the developed areas show an almost constant difference of about 4% for the first 10 years, then declines to about 2.5% during the last segment.

Comparison to Parallel Routes

It is interesting to note the similarity in the above described difference between the primary and intersecting routes, Figure 12, and the previously presented differences between the primary and parallel routes, Figure 8. Both exhibit a similar pattern, there is a negative impact on the growth rates for both the parallel routes and intersecting routes resulting from an improvement along the primary route in developing areas. The impact in developed areas is much smaller for both parallel routes and intersecting routes.
Table 12
Difference in Growth Rates between Primary Routes and Intersecting Roads (%)

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</table>
COMPARISON OF THE DIFFERENCE IN ACTUAL GROWTH RATES BETWEEN PRIMARY ROUTES AND INTERSECTING ROUTES

FIGURE 11

YEAR

DEVELOPED AREAS

TOTAL AREAS

DEVELOPING AREAS

GROWTH RATE (%)
COMPARISON OF THE DIFFERENCE IN SEGMENTED
GROWTH RATES BETWEEN PRIMARY ROUTES AND INTERSECTING ROUTES

FIGURE 12

GROWTH RATES

YEAR

GROWTH RATE (%)
Figure 13 provides a comparison of the segmented growth rates for the parallel routes and intersecting routes in the 18 case study areas. The difference for developed areas stays fairly constant throughout the study period varying only between about 1.5% and 3%. The developing areas offer a greater contrast. The difference between the parallel and intersecting routes increases moderately during the first five years, then drops rapidly during the next five years from about 3.4% to -1.1%. This would indicate improvements on the primary routes have a greater negative impact on the parallel routes than intersecting routes. After that initial impact has passed, the difference gradually returns to the approximate size observed during the initial period.

These findings would indicate that in developing areas both parallel routes and intersecting routes receive a negative impact on their growth rates when the primary route is improved, and that effect is greater for the parallel routes. However, developed areas do not seem to be as sensitive to primary route improvements as developing areas. In this sample, very little impact was observed on the developed area growth rates for both parallel routes and intersecting routes. In addition, there did not seem to be any significant difference in the relative impact between parallel and intersecting routes.
COMPARISON IN DIFFERENCE IN SEGMENTED GROWTH RATES BETWEEN PARALLEL RATES AND INTERSECTING ROUTES

YEAR

GROWTH RATE (%)
EXAMINATION OF ADT GROWTH RATES IN DALLAS COUNTY

A detailed examination of the factors affecting ADT growth rates was undertaken for Dallas County through a study of the accuracy of ADT, land use and population projections. In addition, an alternative model for projecting ADT is presented.

The HEEM currently uses only two growth rates, a constant growth rate designated for use in rapidly developing areas, and a declining growth rate, to be used when the constant growth rate is inappropriate. Due to the specification and particular method of calculating the declining growth rate, several iterations must be performed in order to calculate the growth rate and ADT for each year. In addition, a particular growth rate at the end of the projection period must be assumed. The calculated pattern of growth is quite sensitive to the assumed terminal growth rate.

The importance of the type of growth rate pattern used in the HEEM comes from the effect it has on the Economic Measure the HEEM calculates to access the desirability of a project. As the Guide to the Highway Economic Evaluation Model [20] points out:

with a constant rate of traffic growth, the bulk of traffic growth, and therefore growth in benefits, occurs during the last half of the planning horizon. Conversely, with a declining rate of growth, most of the growth in traffic, and therefore benefits occurs early in the planning horizon . . . (p. 2-2)

Since future benefits are discounted, the same benefits are worth "less" in present value terms the farther in the future they are received.
Therefore for any given ADT projection, use of the declining growth rate formula would result in a higher Economic Measure than using the constant growth rate formula. In addition, the HEEM provides very little guidance as to which growth rate formula is appropriate in any particular application. To a great extent, the model relies upon the discretion and judgement of the user.

This section attempts to identify the factors which influence the growth rate and suggest methods to improve the actual growth rates used in the HEEM.

**Analysis of ADT Projections**

Capacity changes on the Federal and State Highway System in Dallas County were identified in order to examine the effects those changes had on growth rates and the accuracy of ADT projections for those projects, prepared by the State Department of Highway and Public Transportation (SDHPT).

Limitations and deficiencies in the data severely restricted the size of the sample used in the study. Only a relatively few traffic count stations with adequate historical ADT data are available from District Highway Traffic Maps and the RI-2-T-Log.

Table 13 lists all highway segments used in this study. They are listed by an assigned segment number and include all segments for which ADT projections have been made and have historical ADT figures at least back to the year before the projection was made. Even with the above limitations on sample size, the sample includes 47 highway segments, with
Table 13  Dallas County Highway Segments Used in Study

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<th>Highway Number</th>
<th>Control Section Number</th>
<th>Project Number</th>
<th>Date of Letting</th>
<th>Date of Completion</th>
<th>Capacity and Design Before Project</th>
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* Date Project Started
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<td>7/74</td>
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<td>8 in, control access</td>
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</table>

* Date Project Started
34 different projects on 10 different highways within Dallas County. Historical ADT for these highway segments are presented in Appendix B, Table B1. Figure 14 shows the location of each highway segment in Dallas County.

Table 14 presents the projections on the above mentioned highway segments which are used in this study. There are 62 projections in all, since more than one projection has been made on some highway segments. The wide variety of projections, including the date when the projection was made, the projection period, and the number of projections within that period, presented some difficulties in determining the accuracy of those projections.

For some projections, which were projected to 1975, the error is calculated directly by using the following formula:

$$E = \frac{ADT_p - ADT_h}{ADT_p}$$

where $E$ = percentage error (in decimal form)

$ADT_p$ = projected ADT, and

$ADT_h$ = historical ADT.

The projected ADT is used in the denominator to give a smaller calculated error for overprojections than for the same absolute amount of under-projection.

One of the uses of ADT projections is to determine the required future capacity and presumably it is more desirable to have some amount of excess capacity than the same amount of under capacity. Therefore the formulas used for calculating projection errors will consistently favor over-
Figure 14

HIGHWAY STUDY SEGMENTS OF DALLAS COUNTY

NOTE: THE NUMBER OF EACH HIGHWAY SEGMENT IS SHOWN AND THE BOUNDARIES ARE DENOTED BY / /.
Table 14  Calculated Errors in SDHPT Projections

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<th>First ADT</th>
<th>Second Year</th>
<th>Second ADT</th>
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<th>Third ADT</th>
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### Table 14 (continued) Calculated Errors in SDHPT Projections

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In most cases, the projected year or years are still sometime in the future. To handle these cases, the ADT trend which the projection implies is compared to the historical ADT, since the projection was made, to estimate the error in the projection. When multiple projections were made, that trend is calculated using the following equation:

\[ \ln ADT_t = a + b \ln t + c \]

where \( ADT_t \) = ADT in year \( t \)

By using the historical ADT for the year before the projection was made, along with the multiple projections, the ADT trend is established by calculating or estimating the coefficients in the above equation. The projection error is then calculated by taking an average of the errors for each year since the projection was made. The formula is given as follows:

\[ E = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{ADT_{pt} - ADT_{ht}}{ADT_{pt}} \right| \]

where \( E \) = percentage error,

\( ADT_{pt} \) = projected ADT in year \( t \),

\( ADT_{ht} \) = historical ADT in year \( t \), and

\( n \) = number of years

Single projections with the projected year still in the future posed a problem. Only two data points were available, the historical
ADT for the year before the projection was made and the projected ADT. Of course, an infinite number of trendlines can pass between those two data points. Since it would be difficult, if not impossible, to determine what sort of trend was assumed when the projection was made, the actual historical ADT trend is used.

The same 5 functional forms for ADT, presented in Table 2, are used to find the one which most closely fit the historical data. That particular functional form is then used to estimate the trend of projected ADT and the projection error is calculated using the same procedure and formula described above for the multiple projection case.

Using the actual historical ADT trend rather than some unknown projected trend will tend to lower the calculated error, so some of the percentage errors presented in Table 14 probably have some downward bias. The size of the bias is unknown, but in most cases it shouldn't be very great.

Factors Affecting Errors in ADT Projections

In analyzing the variables which might affect the size of the errors, the highway segments and projections were divided up into the following categories: (1) time of projection, (2) stage of development, (3) stage of commercial/industrial development, and (4) size of capacity change. The average error for each category is presented in Table 15.

Overall, the ADT projections are very good, with an average error of .2870. Considering the difficulties in making any longrange forecasts, and in particular projecting 20 year traffic volumes for a small highway segment in a growing metropolitan area, the errors are very
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^a Study Points 2, 3, 4, 5, 6, 7, 16, 17, 33, 37, 42, 51, 53, 54

^b Segment Numbers 6387, 6566, 6574, 6684, 6686, 6758, 6790

^c Segment Numbers 6088, 6366, 6393, 6461, 6566, 6790, 6830, 6850, 6975, 7029

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small. In addition, the basic population, land use and other data used to make these forecasts were provided by local governments and other agencies in the area which may have introduced errors outside the control of the SDHPT.

It is interesting to note the significant change in the average percentage error if the projection was made after completion of the project and additional capacity had been added to the highway segment. The average error drops from .3266 to .1515 going from projections made before the project was completed to projections after the capacity had been added. This would tend to indicate capacity change does have a significant impact on the accuracy of ADT projections even though the size of the capacity change does not seem to exert a systematic effect in this sample.

The time period in which the projection was made also seems to have a significant impact on the average errors, going from .3385 in the 1950's to .1629 in the 1970's. Certainly a portion of that difference is due to the greater length of time the historical ADT has had to deviate from the projected trend, however some of the observed decline may be due to improvements in forecasting techniques and additional forecasting experience over time.

The stage of commercial and industrial land development also seems to be exerting an influence on the size of the errors. Developed commercial and industrial areas are defined as segments where 10% or more of the acreage abutting the highway segment is classified as commercial or industrial land use. The average error of .3213 is larger for developed areas than the average error of .2770 for developing commercial and industrial areas. The difference is especially pronounced among projections made
before completion of the project, where the average error for developing areas is .2985, compared to .5226 in the developed areas.

It would appear the level of economic activity in the area has an impact on the accuracy of ADT projections and is something which may not be adequately accounted for in current ADT forecasting procedures.

The stage of overall development in the area seems to be exerting some influence on the size of the average projection errors. However, that influence does not seem as strong as the effects observed from commercial and industrial development, and the effect goes in the opposite direction. In this sample, developing areas have a slightly higher average error, .2921, compared to .2468 average error for the developed areas.

A Model for Examining ADT Projection Errors

A multiple regression model was used to estimate which factors seem to be the most significant in influencing ADT projection errors and what proportion of the error can be explained by such factors. The model is given as:

\[ E = 0.78034^* - 0.01091^* T + 0.13694^* F + 1.48371^* D + e \]

(2.27) \hspace{1cm} (-2.14) \hspace{1cm} (2.33) \hspace{1cm} (2.37)

\[ R^2 = .2450 \]

where \( E \) = percentage error,
\( T \) = year projection made,
\( F = 1 \) if projection was made before end of project,
\( 0 \) otherwise, and
\( D \) = percentage of commercial and industrial land in 1970.

* indicates coefficients significant at 5% level, and ( ) includes the T-statistic for each estimated coefficient.
This model explains almost a fourth of the variation in ADT projection errors and each of the coefficients are statistically significant.

Figure 15 depicts graphically how the expected error, estimated in the above multiple regression model, changes as some of the factors affecting the error change. The estimated error declines as the year the projection was made approaches the present, and when the projection year passes the year the project is completed, the expected error drops by more than 13 percentage points. In addition, the stage of commercial and industrial development affects the error by increasing the error for any given projection year as the area becomes more developed.

In general the SDHPT projections were fairly good with an average error of .2870 in this sample. However, there are some factors which seem to be affecting the size of the errors which, if taken into account, could potentially increase the accuracy of those projections. Later in the report, a simple alternative model for projecting ADT is presented which takes into account some of the factors shown to be significant from this analysis of ADT projection errors and the analysis of the 18 case study areas presented previously in this report.

Analysis of Land Use and Population Projections

ADT projection methods have involved projecting the number and location of vehicle trips by origin and destination. A key component of this process is developing trip generation factors. Using these trip generation factors, and the trips assigned to a particular zone, the future trips produced by an area, and therefore the traffic volume, can be estimated. Among other things, two of the factors assumed to affect trip generation factors are land use and population.
FIGURE 15

COMPARISONS OF ESTIMATED ERRORS IN ADT PROJECTIONS

PERCENTAGE ERROR (%)

YEAR OF CAPACITY CHANGE

YEAR PROJECTION MADE

ESTIMATED ERROR WITH D=0.20

ESTIMATED ERROR WITH D=0.10

ESTIMATED ERROR WITH D=0
In order to project ADT, projections of both land use and population are required. It is therefore of interest to look at the accuracy of land use and population projections and examine if the errors in those projections are related to each other and to the previously presented ADT projection errors.

In 1964, population and land use projections for 1985 were prepared in Dallas County. Those projections were made by survey zone and included various categories of land use. In order to compare these projections with the ADT projections, the abutting survey zones were aggregated for each highway segment. Each area contains as closely as possible the survey zones within about a half of a mile of the highway segment, and an average of about two square miles in total area. (The survey zones for each area are listed in Appendix B, Table B2.)

Errors in population and land use projections are calculated in the same manner as those used in analyzing the ADT projections in order to make them as comparable as possible. Since total developed land for each survey zone was not projected, the land use projections errors represent commercial and industrial development rather than total development.

Table 16 lists the errors in population and land use projections by highway segment number. Some areas which are in the analysis of ADT projections are not included because reliable historical data could not be obtained for some survey zones, and the errors for those areas were not estimated.

Table 16 also contains the overall errors in Dallas County population and land use projections. The population projections show an
<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Population Error</th>
<th>Land Use Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>5999</td>
<td>.2032</td>
<td>.1668</td>
</tr>
<tr>
<td>6088</td>
<td>.7135</td>
<td>.4518</td>
</tr>
<tr>
<td>6306</td>
<td>.2966</td>
<td>2.2685</td>
</tr>
<tr>
<td>6313</td>
<td>.7391</td>
<td>1.3982</td>
</tr>
<tr>
<td>6366</td>
<td>.5173</td>
<td>2.9225</td>
</tr>
<tr>
<td>6370</td>
<td>.0377</td>
<td>.5988</td>
</tr>
<tr>
<td>6372</td>
<td>.0710</td>
<td>.3108</td>
</tr>
<tr>
<td>6387</td>
<td>.1552</td>
<td>.2591</td>
</tr>
<tr>
<td>6393</td>
<td>.9681</td>
<td>1.1363</td>
</tr>
<tr>
<td>6461</td>
<td>.4323</td>
<td>.3165</td>
</tr>
<tr>
<td>6509</td>
<td>.0667</td>
<td>.6281</td>
</tr>
<tr>
<td>6566</td>
<td>.2696</td>
<td>.1607</td>
</tr>
<tr>
<td>6568</td>
<td>.4553</td>
<td>.0282</td>
</tr>
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<td>6574</td>
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</tr>
<tr>
<td>6578</td>
<td>.2469</td>
<td>.1618</td>
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<tr>
<td>6586</td>
<td>.2217</td>
<td>.2675</td>
</tr>
<tr>
<td>6596</td>
<td>.4131</td>
<td>.2935</td>
</tr>
<tr>
<td>6618</td>
<td>.3906</td>
<td>.7783</td>
</tr>
<tr>
<td>6621</td>
<td>.2011</td>
<td>.8354</td>
</tr>
<tr>
<td>6686</td>
<td>.1230</td>
<td>.1796</td>
</tr>
<tr>
<td>6744</td>
<td>.2096</td>
<td>1.7608</td>
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<tr>
<td>6749</td>
<td>.4822</td>
<td>.5913</td>
</tr>
<tr>
<td>6755</td>
<td>.1532</td>
<td>1.0234</td>
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<tr>
<td>6758</td>
<td>.1161</td>
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<td>6790</td>
<td>.4460</td>
<td>.4179</td>
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<td>6830</td>
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<td>6850</td>
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<td>.0630</td>
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<tr>
<td>6864</td>
<td>.5960</td>
<td>.1692</td>
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<td>6868</td>
<td>4.6198</td>
<td>.6929</td>
</tr>
<tr>
<td>6975</td>
<td>.0799</td>
<td>.4250</td>
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<tr>
<td>6978</td>
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<td>.6681</td>
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<tr>
<td>7002</td>
<td>.4542</td>
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<td>7015</td>
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<td>7042</td>
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<td>7043</td>
<td>.4885</td>
<td>2.3357</td>
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<tr>
<td>7045</td>
<td>.9518</td>
<td>5.4342</td>
</tr>
<tr>
<td>7047</td>
<td>.8076</td>
<td>.8864</td>
</tr>
<tr>
<td>Dallas County</td>
<td>.2642</td>
<td>.0559</td>
</tr>
</tbody>
</table>
average error of .2642, and the land use projections show an error of only .0559. Projections for individual areas around the sample highway segments are, on average, not as accurate as the overall projections.

Table 17 gives a summary of the average error for each set of projections broken down into various categories. The average error for population projections in this sample is .4658 and .8371 for land use projections. This result would suggest a distributional effect on the accuracy of land use projections and, to a lesser extent on population projections. Overall, fairly accurate forecasts have been made for a large aggregated area of Dallas County. Much less success is observed for much smaller subunits, and errors would have been much larger if errors for individual survey zone projections had been calculated. Such a finding would cast some doubt on their reliability and use in origin and destination studies, even though the accuracy would improve as these zones are aggregated into larger areas.

Table 17 also depicts some of the same effects on population and land use projections previously observed in ADT projections. The average error for both sets of projections declines somewhat if the projection was made after completion of the highway project, even though, as expected, that influence does not seem to be as strong as previously described for ADT projections.

Stage of overall development in the area also seems to be exerting an influence. The average error for both sets of projections is much lower for developed areas compared to developing areas. However, contrary to the ADT results, the stage of commercial and industrial
<table>
<thead>
<tr>
<th>Category</th>
<th>Projection Made Before Project Completed</th>
<th>Projection Made After Project Completed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population Projections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage of Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed</td>
<td>0.2867</td>
<td>0.3687</td>
<td>0.3113</td>
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<tr>
<td>Developing</td>
<td>0.5466</td>
<td>0.4326</td>
<td>0.5191</td>
</tr>
<tr>
<td>Stage of Commercial and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed</td>
<td>0.4464</td>
<td>0.4718</td>
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<td>Developing</td>
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<td>0.4691</td>
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<td><strong>Total</strong></td>
<td>0.4838</td>
<td>0.4134</td>
<td>0.4658</td>
</tr>
<tr>
<td><strong>Land Use Projections</strong></td>
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</tr>
<tr>
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</tr>
<tr>
<td>Developed</td>
<td>0.4173</td>
<td>0.2640</td>
<td>0.3714</td>
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<tr>
<td>Developing</td>
<td>1.0126</td>
<td>0.9510</td>
<td>0.9977</td>
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<tr>
<td>Stage of Commercial and</td>
<td></td>
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<tr>
<td>Industrial Development</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Developed</td>
<td>1.0248</td>
<td>0.3097</td>
<td>0.7864</td>
</tr>
<tr>
<td>Developing</td>
<td>0.8282</td>
<td>0.9314</td>
<td>0.8523</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.8689</td>
<td>0.7449</td>
<td>0.8371</td>
</tr>
</tbody>
</table>
development in this sample does not seem to be exerting much influence on the average errors, although there is a slightly higher average error in developing commercial and industrial areas compared to the developed areas.

Relationship of Errors in AOT, Population and Land Use Projections

Comparison of errors in the various projections of AOT, population, and land use presents some difficulties. Population and land use projections can be compared directly since both were made about the same time and covered the same projection period. However, that is not the case for the AOT projections in this sample. These projections cover a wide variety of time periods, especially with respect to the time period when the projection was made. For that reason, only those AOT projections made between 1962 and 1965 are used in comparisons with population and land use projection errors.

Table 18 presents the correlation coefficients between the projection errors in various categories. Overall the projection errors show very little relationship, with the highest correlation coefficient of only .1411 between errors in land use and population projections. However, some correlation coefficients for specific categories are much higher and three are statistically significant.

There is a strong positive correlation in this sample between the errors in land use and population projections in developed areas, even though that relationship almost disappears when the developing areas are
Table 18  Correlation Coefficients of Errors in ADT, Population, and Land Use Projections

<table>
<thead>
<tr>
<th>Category</th>
<th>Projection Made Before Project Completed</th>
<th>Projection Made After Project Completed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relation of Errors in Land Use Projections to Population Projections</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed Areas</td>
<td>.9147*</td>
<td>.9557</td>
<td>.8289*</td>
</tr>
<tr>
<td></td>
<td>(25.61)a</td>
<td>(10.54)</td>
<td>(17.57)</td>
</tr>
<tr>
<td>Developing Areas</td>
<td>.1049</td>
<td>-.2909</td>
<td>-.0430</td>
</tr>
<tr>
<td></td>
<td>(0.22)</td>
<td>(0.46)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>Total</td>
<td>.1539</td>
<td>-.0430</td>
<td>.1411</td>
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<tr>
<td></td>
<td>(0.66)</td>
<td>(0.01)</td>
<td>(0.75)</td>
</tr>
<tr>
<td>Relation of Errors in ADT Projections to Population Projections</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed Areas</td>
<td>-</td>
<td>-</td>
<td>.6249</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.64)</td>
</tr>
<tr>
<td>Developing Areas</td>
<td>-.1298</td>
<td>-.1449</td>
<td>-.1411</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.04)</td>
<td>(0.26)</td>
</tr>
<tr>
<td>Total</td>
<td>-.1351</td>
<td>.0858</td>
<td>-.0800</td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.03)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>Relation of Errors in ADT Projections to Land Use Projections</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed Areas</td>
<td>-</td>
<td>-</td>
<td>-.2139</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.05)</td>
</tr>
<tr>
<td>Developing Areas</td>
<td>.0194</td>
<td>-.9267*</td>
<td>-.0800</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(12.16)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Total</td>
<td>.0298</td>
<td>-.4927</td>
<td>.0006</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(1.28)</td>
<td>(0.00)</td>
</tr>
</tbody>
</table>

*Significant at 10% level

aF Statistic is listed below each coefficient in parenthesis
included. This could be the result of the previously described distributional effects on projection errors. Presumably the distribution of future economic activity, as well as population, can more accurately be anticipated in areas which are already developed compared to areas where the structure and distribution of economic activity can only be predicted.

For example, a decision to locate a shopping center on a slightly different highway segment than had originally been anticipated could result in very large projection errors for each area, even though the overall effect on economic activity has been the same.

The only other significant correlation coefficient is for developing areas projection errors between ADT and land use projections made after completion of the highway project. The high, negative correlation between the errors is principally due to the small sample size and the large land use errors calculated in some of the survey zones.
Alternative Declining Growth Rate Formulas

The declining growth rate model used in the HEEM, as previously mentioned, assumes a given terminal growth rate at the end of the projection period, and the model goes through several iterations before the constants in the model are accurately estimated.

In addition, the model cannot be used to incorporate multiple projections. The ADT projections presented in this study include 20 multiple projections out of 62 total projections and 7 out of 8 since 1970. Disregarding the information provided by additional projections could significantly affect the final calculated economic measure in the HEEM for a proposed project alternative.

The HEEM declining growth rate model calculates the expected ADT and growth rate for any future year (t) up to the projected year, using the following formulas:

\[
ADT_t = ADT_1 + \frac{g_1 ADT_1}{A} (1 - e^{-A(t-1)})
\]

and

\[
g_t = g_1 \frac{ADT_1 e^{-A(t-1)}}{ADT_t}
\]

where \( g_t = \) growth rate in year \( t \), and 
\( A = \) constant.

Different values of \( g \) are tried, and each time \( A \) is iterated and the resulting calculated terminal growth rate, \( g_{n+1} \), is checked against the assumed terminal growth rate. That process continues until the calculated terminal growth rate is less than the assumed terminal growth rate.
The program can go through a maximum of 1,000 different iterations of A before the loop is terminated and an error message is printed out.

However it can be shown that the numerous, time-consuming iterations are not necessary, and A can be iterated directly using the following formula:

\[ A = \frac{g_{n+1} \cdot ADT_{n+1}}{ADT_{n+1} - ADT_1} (e^{A_n} - 1) \]

where \( n \) = number of years in projection period

The above formulation for A can be iterated very quickly using the same iteration technique used in the HEEM, known as Newton's Method, and offers the additional advantage that A must be iterated only once. Table B4 in Appendix B contains the program changes necessary to implement this alternative iterated formula in the HEEM.

Table 19 provides a comparison of the two iteration techniques, where ADT is assumed to increase from 10,000 to 20,000 in 20 years. With a terminal growth rate of 1%, both iteration methods give approximately the same results, the difference coming from the error introduced in the HEEM iteration by taking discreet values for \( g_1 \). The HEEM increases the value of \( g_1 \) by .0025 each loop, causing the error during the projection period.

The two methods deviate sharply as the terminal growth rate is increased for the same projected ADT. In this example, for any terminal growth rate greater than 2.38%, the HEEM will go through its iteration process only once, giving the results in Table 19. Any assumed terminal growth greater than 2.38% will not change the iteration and the resulting traffic distribution within the projection period will always be the
Table 19. Comparison of HEEM Declining Growth Iteration and Proposed Iteration\(^a\)

<table>
<thead>
<tr>
<th>Year(t)</th>
<th>HEEM Declining Growth Rate Iteration</th>
<th>Proposed Declining Growth Rate Iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Terminal Growth Rate</td>
<td>Terminal Growth Rate</td>
</tr>
<tr>
<td></td>
<td>1.00%</td>
<td>&gt;2.38%</td>
</tr>
<tr>
<td></td>
<td>(ADT_t)</td>
<td>(g_t)</td>
</tr>
<tr>
<td>1</td>
<td>10,000</td>
<td>0.01025</td>
</tr>
<tr>
<td>6</td>
<td>14,194</td>
<td>0.04763</td>
</tr>
<tr>
<td>11</td>
<td>16,964</td>
<td>0.02625</td>
</tr>
<tr>
<td>16</td>
<td>18,792</td>
<td>0.01570</td>
</tr>
<tr>
<td>21</td>
<td>19,999</td>
<td>0.00970</td>
</tr>
</tbody>
</table>

\(^a\)Assumes ADT goes from 10,000 to 20,000 in 20 years.
same, an approximate linear distribution.

The problem comes from the initial value assigned to the current growth rate, \( g_1 \). The initial value equals the average annual change in ADT plus the initial loop increment of 0.0025. After A is iterated, the terminal growth rate is calculated and checked against the assumed terminal growth rate. If the calculated value is less than or equal to the assumed value, then the looping stops and the ADT for each year during the projection period are calculated. In this example, any assumed terminal growth rate greater than 2.38% will cause the program to loop only once and produce identical results.

The proposed iteration technique offers the advantage that the information provided by an assumed terminal growth rate is not disregarded even if it is outside the range of the HEEM iteration. Table 19 provides some examples of the results which would be produced. With a terminal growth rate of 3.5%, the ADT distribution closely approximates a constant growth rate pattern, and with a rate of 4%, the distribution exhibits an increasing growth rate pattern. The proposed program will print out an error message if an increasing growth rate distribution does occur, indicating the assumed terminal growth rate is too high. This proposed program also offers the advantage of a lower error in the estimated values for ADT, since no error is introduced into the calculation for the value of the initial growth rate.

The above alternative iteration can result in a savings in computer time running the HEEM program, increased accuracy, and a greater range for the assumed terminal growth rate, but it still cannot incorporate multiple projections. Two alternative declining growth rate formulations which incorporate a given terminal growth rate are given as:
(1) Gamma Function

\[ \ln \ ADT_t - g_{n+1}t = a + b \left( \ln t - \frac{t}{n+1} \right) \]

\[ g_t = b \left( \frac{n+1-t}{t(n+1)} \right) + g_{n+1} \]

(2) Beta Function

\[ \ADT_t - g_{n+1}\ADT_{n+1}t = a + b \left[ 2(n+1)t - t^2 \right] \]

\[ g_t = \frac{2b(n+1-t) + g_{n+1}\ADT_{n+1}}{\ADT_t} \]

The coefficients a and b in either formula can very easily incorporate any number of projections, using simple linear regression or some other estimation technique.

Of course, each alternative will give, in general, a slightly different ADT trendline. As an example, suppose ADT is projected to double from 10,000 to 20,000 in 20 years, with a .01 terminal growth rate. Figure 16 depicts the ADT trendlines for both functions given above, along with the HEEM declining growth rate model. Both alternative functional forms give a slightly different ADT trendline from the HEEM declining growth rate function. The appropriate function to use, including the constant growth rate function, could be determined by the functional form which most closely fits the historical ADT for that particular corridor being examined.

However, making such a determination does not eliminate the problem these declining growth rate functions have in being very sensitive to the arbitrarily assumed terminal growth rate. For example, in Figure 16, if .03 were assumed as the terminal growth rate, instead of .01, all functions
FIGURE 16

COMPARISON OF DECLINING GROWTH RATES

YEAR

ADT (thousands)

10 11 12 13 14 15 16 17 18 19 20

GAMMA FUNCTION
HEMM FUNCTION
BETA FUNCTION
would become almost straight lines, and a terminal growth rate of .035 would make them almost identical to the constant growth rate function.

There is no distinct advantage to projecting a terminal growth rate in addition to the ADT. This conclusion is especially true for a single projected terminal growth rate representing a large geographical area. This study shows that a great variety of growth patterns can exist, and a single growth pattern for a large area is clearly inappropriate for all smaller units within that area.

In addition, this study suggests some factors which seem to have a significant influence on growth rates and ADT projections. The sample is too small in this study to make any definitive conclusions, but some patterns do seem to have emerged. The stage of overall development, along with commercial and industrial development seem to affect the growth rate pattern, but it does not seem appropriate to arbitrarily assign a particular declining growth rate to developed areas and a constant growth rate to developing areas.

The five simple functional forms presented in Table 2, and used throughout this study, give a far greater variety of declining growth rates, in addition to a constant growth rate, and could easily be expanded to include a greater variety of ADT growth patterns. Table 20 presents some of these alternative functional forms which could be used. In addition to the added variety, the arbitrary selection process could be eliminated by allowing the HEEM itself to pick the appropriate growth pattern by selecting the functional form most closely fitting the available historical ADT data for the highway corridor being examined.

This study indicates a significant ADT growth rate impact resulting from capacity changes along a particular highway corridor. The effect on
<table>
<thead>
<tr>
<th>Functional Form</th>
<th>Functional Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $\text{ADT}_t = a + b t^2$</td>
<td>10. $\left( \frac{\text{ADT}_t}{10,000} \right)^2 = a + b t^2$</td>
</tr>
<tr>
<td>2. $\text{ADT}_t = a - \frac{b}{t}$</td>
<td>11. $\left( \frac{\text{ADT}_t}{10,000} \right)^2 = a - \frac{b}{t}$</td>
</tr>
<tr>
<td>3. $\text{ADT}_t = a - b e^{-\frac{t}{10}}$</td>
<td>12. $\left( \frac{\text{ADT}_t}{10,000} \right)^2 = a - b e^{-\frac{t}{10}}$</td>
</tr>
<tr>
<td>4. $\text{ADT}_t = a + b e^{\frac{t}{100}}$</td>
<td>13. $\left( \frac{\text{ADT}_t}{10,000} \right)^2 = a + b e^{\frac{t}{100}}$</td>
</tr>
<tr>
<td>5. $\ln \text{ADT}_t = a + b t^2$</td>
<td>14. $\frac{1}{\text{ADT}_t} = a + \frac{b}{t}$</td>
</tr>
<tr>
<td>6. $\ln \text{ADT}_t = a - \frac{b}{t}$</td>
<td>15. $\frac{1}{\text{ADT}_t} = a + b e^{-\frac{t}{10}}$</td>
</tr>
<tr>
<td>7. $\ln \text{ADT}_t = a - b e^{-\frac{t}{10}}$</td>
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</tr>
<tr>
<td>8. $\ln \text{ADT}_t = a + b e^{\frac{t}{100}}$</td>
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</tr>
<tr>
<td>9. $\left( \frac{\text{ADT}_t}{10,000} \right)^2 = a + b \ln t$</td>
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</tbody>
</table>
the growth rate seems to be temporary, and after a few years the growth rate returns to its previous pattern. However, a capacity change could obviously affect the projected ADT, even if the underlying growth pattern were unaffected. This would suggest an improvement in the accuracy of ADT projections could potentially be achieved if those effects could accurately be accounted for in the projection process. The following section presents a simple ADT projection model and tests it against the same Dallas County data used in calculating SDHPT projection errors.

A Simple Model for Projecting ADT

Current methods of projecting ADT involve a relatively large amount of data, and are somewhat time consuming since a separate set of projections must be prepared for each project being studied. In addition, many projections are not very accurate. It would be of some benefit, therefore, if a simple model for projecting ADT could be developed which could be used with a minimum of time and data and which would improve the accuracy of these projections.

As a first approximation, the five functional forms for ADT, presented in Table 2, were used to project ADT for each highway segment with adequate historical ADT before the SDHPT projections were made. The lack of historical ADT data eliminated all new location construction projects and some improvement projections, but left 19 highway segments in this sample which could be used to project ADT.

In order to compare the accuracy of these projections to the SDHPT projections, the functional form which most closely fit the historical ADT
data was used to make projections to the same years as the comparable SDHPT projections. In addition, the projections used only the ADT data to the year before the SDHPT projections were made. The ADT data since that time were not used in any form to make the projections in order to compare the accuracy of these projections to the SDHPT projections. Projection errors were calculated in exactly the same manner as those previously presented for the SDHPT projections.

This simple regression model does not take into account the effect that a capacity change may have on ADT. Three different functional forms were used to measure the size of that effect.

The equations are given as:

\[
\begin{align*}
(1) \quad \ln ADT_t &= a_1 + a_2 t + a_3 C, \\
(2) \quad \ln ADT_t &= a_1 + a_2 t + a_3 C, \\
(3) \quad \ln ADT_t &= a_1 + a_2 e^{-t} + a_3 C;
\end{align*}
\]

where \( C = 1 \) if capacity has increased and \( = 0 \) otherwise.

These three were chosen because each one can be estimated using multiple regression and each one estimates the effect that a capacity change has as a constant percentage of ADT. The estimated percentage change (PC) in ADT is a function of the estimated coefficient \( a_3 \), and is given by:

\[
PC = e^{a_3}
\]

The particular functional form which most closely fit the historical ADT was used for each highway segment with adequate historical ADT. Table 21 provides an average of the estimated effects that capacity changes have, reflected by the sample ADT data.
Table 21  Capacity Change Effects on ADT

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<th>Average Percentage Change</th>
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<td>Developed Areas</td>
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<tr>
<td>Developing Areas</td>
<td>.1695</td>
</tr>
<tr>
<td>Total:</td>
<td>.1362</td>
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A much larger sample would be needed to determine, with greater precision, the effects of capacity changes on ADT. For example, the number of lanes added to capacity should affect the percentages presented in Table 21, but this sample is too small to measure those effects.

Multiple regression projections were then prepared for each highway segment used in the simple regression projections. When the capacity change occurred before the SDHPT projection, a projection was made using one of the three multiple regression equations listed above. When the SDHPT projection was made before the capacity change, the simple regression projections were adjusted by the average percentages presented in Table 21. In each case, percentage errors in the projections were again calculated in the same manner as the previously presented SDHPT projection errors.

The results of each projection method are presented in Table 22. The multiple regression method lowered the average percentage error from .2222 using SDHPT projections, to .1857 using this sample. Of course this multiple regression model cannot be relied upon to lower the projection error in every case, but it does offer an approach for further study and testing to improve the accuracy of ADT projections at a lower time and data gathering cost.
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<th>Multiple Regression</th>
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<tr>
<td>Average</td>
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A larger sample would be required to construct a reliable multiple regression model to project ADT. The present model could be expanded to account for the effects of different types of improvements, along with the size of the capacity change. In addition, the type, as well as the level of economic activity should be incorporated. Projections involving new location construction could be made potentially with a corridor approach to ADT projections, possibly as a supplement to current ADT projection methods.

If a reliable multiple regression model is developed, it is possible it could be adapted for use in the HEEM. The model itself could make its own corridor ADT projections and in the process determine the appropriate growth pattern for ADT up to the projected year. Instead of having an externally assumed projected ADT and trying to determine the appropriate growth pattern to conform to that projection, this alternative method would estimate the two together, improving both the consistency and potentially the accuracy of the model.

This, of course would not mean that current ADT projections and projection methods are unnecessary. Many times historical information provides poor or inaccurate guidance for future events. This could certainly be the case for ADT projections. The procedure described above could be incorporated into the HEEM as a supplemental analysis and the results compared as part of a sensitivity analysis for various values of the projected ADT.
CONCLUSION AND RECOMMENDATIONS

Conclusions

This study has revealed that there are a number of factors which seem to be influencing ADT growth patterns. The sample size is too small to measure the magnitude of those effects, but some conclusions can be made from this sample.

The aggregative analysis of the 18 case study areas has revealed that the stage of area development and the size of capacity change may have significant impacts on ADT growth rates, even though that influence may diminish over time. There also may be a significant impact on parallel and intersecting routes resulting from a capacity change on the primary route. A logical conclusion would be that it is not appropriate to use the same growth rates for all routes within a corridor without some additional study and justification.

The analysis of ADT growth rates on highway segments within Dallas County has provided additional information on the factors affecting ADT growth patterns and the accuracy of ADT, land use, and population projections. The analysis revealed that about one fourth of the variation in the size of the ADT projection errors could be explained by the year the projection was made, the percentage commercial/industrial land use, and a binary variable to measure the effects of a capacity change after the projection was made.

It might be further concluded that implementing improved formulations of the HEEM declining growth rate model, presented in this study, could
significantly reduce the time costs of running the model and could incorporate more that one ADT projection for a given highway corridor. Ultimately it seems that determination of the appropriate growth rate formula in the HEEM should be combined with an ADT projection model rather than trying to fit an appropriate growth rate pattern to a given ADT projection. For this reason, a simple multiple regression model to project ADT is presented that would also estimate the appropriate growth rate pattern. The model was tested against the SDHPT projections in this sample, reducing the average error by about 16%.

**Recommendations**

Based upon the findings presented in this report, the following recommendations are made:

1. A larger sample of highway improvement segments should be obtained to determine the proper ADT growth rate patterns to use and the factors which affect those growth rates.

2. The HEEM model should be adjusted so that it would take account of major improvements in developing areas. A simple method to accomplish this would be to shift the ADT curve upward when construction is completed, but retain the same growth rate pattern.

3. The HEEM should be adjusted to allow for different growth rate patterns for each route within the corridor. Alternative recommendations for growth rates in the HEEM are:

   a. Use the declining growth rate formula presented in this report which requires only one iteration, thereby reducing the running cost of the model,

   or

   b. Use one or both alternative growth rate formulas proposed in this study which incorporate an assumed terminal growth rate, requiring no iterations even
when multiple projections are made.

c. Incorporate into the HEEM the ability to choose the appropriate growth pattern which is not sensitive to an assumed terminal growth rate. A number of functional forms for varying traffic growth patterns could be programmed into the HEEM, including those suggested in this report, and the functional form most closely fitting the available historical ADT would be used.

d. Incorporate into the HEEM the ability to estimate the projected ADT, along with the growth rate pattern, from historical ADT, proposed capacity changes, and stage of development. Additional study will be required to determine the exact procedure and model which could significantly improve the accuracy of ADT projections.

4. Reduce errors in ADT projections by using formulas that account for capacity changes and stages of land use development, especially commercial land use.
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Table A1  ADT for Various Functional Forms

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a  assuming ADT goes from 10,000 to 20,000 in 20 years
b  Functional forms presented in Table 2
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Table A3

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* last year before construction

a estimated using linear interpolation
b estimated using growth rate calculated in Table A3
Table A5  Primary Route Estimated Growth Rates

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### Table A6
Primary Route Estimated Growth Rates for Capacity Changes

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<td>Overall</td>
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* a last year before construction
  
a estimated using linear interpolation
  
b estimated using growth rate in Table A7
### Table A9 Parallel Routes Estimated Growth Rates

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* last year before construction
a estimated using linear interpolation
b estimated using growth rate calculated in Table A10
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a ADT Counts which could not be verified using traffic count maps. Those counts are not used in calculating errors in ADT projections.
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### Table B3

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<td>(\ln ADT = -.14010 + 2.9798 \cdot \ln t - .02214 \cdot t)</td>
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<td>(\ln ADT = -87.058 + 28.455 \cdot \ln t - .33817 \cdot t)</td>
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<td>(\ln ADT = -68.907 + 22.168 \cdot \ln t - .22156 \cdot t)</td>
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<td>(\ln ADT = -83.954 + 26.526 \cdot \ln t - .27229 \cdot t)</td>
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<td>(\ln ADT = -66.325 + 21.340 \cdot \ln t - .22423 \cdot t)</td>
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<td>(ADT = -454.69 + 112073 \cdot \ln t)</td>
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Table B3 (continued)  
Equations for Estimating ADT  
Using SDHPT Projections

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Table B4. Proposed Program Change for Declining Growth Rate Calculation in HEEM
(Program lines 3620 through 3850)

674 \( X = \frac{\text{VOLUME}(I+1) - \text{VOLUME}(I)}{I}/\text{VOLUME}(I) \)

675 \( X_1 = \frac{\text{VOLUME}(I+1) - \text{VOLUME}(I)}{I}/\text{VOLUME}(I+1) \)

676 IF \( X_1 \lt \text{ASSUMP}(9) \) GOTO 681

680 A = 0.1

681 A = -0.1

682 F = 1 - \text{EXP}(A*1) + \frac{\text{VOLUME}(I+1) - \text{VOLUME}(I)}{(\text{ASSUMP}(9)*\text{VOLUME}(I+1))}*A)

683 FP = \frac{\text{VOLUME}(I+1) - \text{VOLUME}(I)}{(\text{ASSUMP}(9)*\text{VOLUME}(I+1))} - I*\text{EXP}(A*I)

684 FR = \text{ABS}(F/FP)

685 IF \( FR \lt 0.0001 \) GOTO 684

686 A = A - F/FP

687 K = \frac{\text{VOLUME}(I+1) - \text{VOLUME}(I)}{(1. - \text{EXP}(-A*I))}

688 DO 688 I2 = 1,40

689 VOLUME(I2) = VOLUME(I) + K*(1. - \text{EXP}(-A*(I2-1)))

688 CONTINUE

508 FORMAT (/82H *** PROJECTED VOLUME TOO HIGH - CHANGE PROJECTION OR USE CONSTANT GROWTH RATE ***)

509 FORMAT (/95H *** MAXIMUM DECLINING GROWTH RATE TOO HIGH - CHANGE ASSUMPTION OR USE CONSTANT GROWTH RATE ***)

510 FORMAT (24X,15HGROWTH RATE IN ,I4,3H = , F5.2,1H%)
Table B5  
Comparison of Declining Growth Rates

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Table B6

Equations for Estimating
Simple Regression Projections

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<td>ADT = -96,440 + 1943.8 t</td>
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<td>ln ADT = -19.588 + 7.2000 ln t</td>
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<td>ln ADT = 2.9288 + .10664 t</td>
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<td>ln ADT = 4.4108 + .08678 t</td>
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<td>ln ADT = 4.3458 + .07884 t</td>
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Table B7

Calculated Errors in Simple Regression Projections

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Table B8  Equations for Estimating Percentage Change
in ADT Resulting from a Capacity Change

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<tr>
<td>5999</td>
<td>$\ln \text{ADT} = 9.6066 + 37.547 \ e^{-\frac{t}{10}} + 0.02014 \ c$</td>
<td>.1151</td>
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<tr>
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<td>$\ln \text{ADT} = 6.4799 + 0.05864 \ t + 0.12730 \ c$</td>
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<tr>
<td>6387</td>
<td>$\ln \text{ADT} = 17.370 + 6.6559 \ \text{Int} - 0.09840 \ c$</td>
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<td>6393</td>
<td>$\ln \text{ADT} = -16.628 + 6.5219 \ \text{Int} - 1.17146 \ c$</td>
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<tr>
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<td>$\ln \text{ADT} = 11.599 - 746.65 \ e^{-\frac{t}{10}} - 0.45875 \ c$</td>
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<td>$\ln \text{ADT} = 3.7548 + 0.09807 \ t - 0.18274 \ c$</td>
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<tr>
<td>6574</td>
<td>$\ln \text{ADT} = 8.4661 + 0.01634 \ t + 0.36473 \ c$</td>
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<td>$\ln \text{ADT} = 10.362 - 238.85 \ e^{-\frac{t}{10}} + 0.03686 \ c$</td>
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<td>$\ln \text{ADT} = 0.24761 + 2.2423 \ \text{Int} + 0.23199 \ c$</td>
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<td>$\ln \text{ADT} = 5.6559 + 0.05850 \ t - 0.0022 \ c$</td>
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<td>$\ln \text{ADT} = 1.9952 + 0.09663 \ t - 0.00224 \ c$</td>
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<td>$\ln \text{ADT} = 4.4016 + 0.06309 \ t + 0.21616 \ c$</td>
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<td>$\ln \text{ADT} = 4.3943 + 0.05814 \ t + 0.15924 \ c$</td>
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<td>$\ln \text{ADT} = 10.467 - 67.906 \ e^{-\frac{t}{10}} + 0.03990 \ c$</td>
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<td>$\ln \text{ADT} = 4.5435 + 0.07383 \ t + 0.08463 \ c$</td>
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<td>$\ln \text{ADT} = 10.080 - 87.821 \ e^{-\frac{t}{10}} - 0.06810 \ c$</td>
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<td>$\ln \text{ADT} = 8.9638 - 141.21 \ e^{-\frac{t}{10}} + 0.49301 \ c$</td>
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<td>$\ln \text{ADT} = 5.6999 + 0.05806 \ t + 0.21999 \ c$</td>
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<td>$\ln \text{ADT} = -13.038 + 5.3980 \ \text{Int} + 0.07967 \ c$</td>
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<td>$\ln \text{ADT} = 4.2120 + 0.08111 \ t + 0.11499 \ c$</td>
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<td>$\ln \text{ADT} = 5.3071 + 0.06289 \ t + 0.58210 \ c$</td>
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### Table B9

#### Equations for Estimating Multiple Regression Projections

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<td>$\ln ADT = -9.1041 + 4.4788 \ln t + 0.22159 c$</td>
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<td>$\ln ADT = -9.7688 + 4.6414 \ln t - 0.15435 c$</td>
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<td>$\ln ADT = 10.1972 - 134.62 e^{\frac{t}{10}} - 0.06328 c$</td>
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