Factors that Affect Traffic Growth Rates and Projection of Traffic Volumes for Use in Highway Economic Models

JEFFERY L. MEMMOTT

The magnitude of potential highway user benefits and costs that results from proposed highway improvements must be estimated with a reasonable degree of accuracy for highway agencies to make rational decisions in the public interest. One of the important aspects of most highway economic analysis models is the assumed traffic growth-rate pattern, which is based on one or more projected traffic volumes. The effects of different growth-rate patterns on the estimate of future benefits from a proposed project, as well as the factors that affect traffic projection errors from data collected in Dallas County, Texas, are examined. These factors include the year the projection was made, the percentage of commercial and industrial land development, and changes in highway capacity. A simple model for projecting future traffic volume is also presented, which is based on a multiple regression analysis of historical traffic volume data and adjustments for capacity changes and land development. The model is tested against the traffic projections collected for the Dallas County study sites, with the model producing somewhat more accurate projections in this sample.

An important aspect of most highway economic analysis models is the use of one or more projected traffic volumes for some future year(s). These values are generally provided as part of the input data for a particular project evaluation. Some functional relation is assumed between the current traffic volumes and the given projected traffic volumes. Traffic volumes are then estimated for each year during the analysis period.

The assumed traffic growth pattern between the current traffic volumes and the projected traffic volumes varies between models. The Highway Investment Analysis Package (HIAP) (1), for example, uses linear approximations between each given traffic volume. The Highway Economic Evaluation Model (HEEM) (2) uses only one projected traffic volume but has two traffic growth patterns from which to choose. One assumes a constant traffic growth rate, and the instructions indicate that it should be used for rapidly developing areas. The other growth pattern assumes a declining growth rate, and it should be used when the constant growth-rate pattern is not appropriate. The terminal growth rate must be specified and the parameters iterated for the declining growth-rate formula.

EFFECT OF TRAFFIC GROWTH RATES ON BENEFIT-COST RATIOS

The assumed pattern of traffic growth can have a significant impact on the flow of future benefits from a proposed project and therefore can affect the desirability of undertaking the project. A simple example can illustrate those effects.

Suppose the average daily traffic (ADT) is projected to grow from 10 000 to 20 000 in 20 years if a particular highway improvement project is undertaken. Otherwise, the traffic volume will remain the same. Figure 1 shows the six possible traffic growth-rate patterns in this example if the project is completed. Assume the project will yield $10/vehicle in incremental benefits, and a discount rate of 10 percent is used.

Table 1 gives the results of this example. The benefit-cost ratio varies from 0.78 to 1.54, almost a 100 percent difference. Of course, a much wider range of values could be devised, but the example is sufficient to illustrate the significant effect of the assumed traffic growth pattern on project desirability and selection.

Therefore, it is worthwhile to examine the fac-

tors that affect traffic projections, the underlying traffic growth-rate patterns, and the errors associated with those projections.

ANALYSIS OF ADT PROJECTION ERRORS

A detailed examination of the factors that affect ADT growth rates was undertaken for Dallas County, Texas. Capacity changes on the federal and state highway system in Dallas County were identified in order to examine the effects that these changes had on the accuracy of ADT projections for these projects, which were prepared by the Texas State Department of Highways and Public Transportation (TSDHPT).

Limitations and deficiencies in the historical ADT data severely restricted the size of the sample used in this study, but it includes a total of 47 highway segments, with 34 different projects on 10 different highways within Dallas County. A total of 62 different traffic projections were collected, dating from 1957 to 1974. Traffic growth is projected to various years, ranging from 1975 to 1995, and includes some multiple projections (traffic projected for more than 1 future year). Details of the highway segments and projections are given elsewhere (3).

The wide variety of projections presents some difficulties in determining the accuracy of those projections. For some projections, the projected year has already past, so the projection error can be calculated directly by using the following formula:

$$E = |[(ADT_p - ADT_h)/ADT_p]| \cdot 100 \qquad (7)$$

where

E = percentage error,
ADT_p = projected ADT, and
ADT_h = historical ADT.

One of the uses of ADT projections is to determine the required future capacity; presumably it is more desirable to have some amount of excess capacity than the same amount or undercapacity. Therefore, the projected ADT is used in the denominator, which gives a smaller error for overprojections than for the same absolute amount of underprojection.

In most cases, the projected year(s) is still some time in the future. To handle these cases, the ADT trend that the projections imply is compared with the historical ADT because the projection was made to estimate the error in the projection. When multiple projections were made, that trend is calculated by using the following equation:

$$\ln ADT_t = a + b \ln t + ct \qquad (8)$$

where ADT_t is the ADT in year t.

By using the historical ADT for the year before the projection was made along with the multiple projections, the implicit ADT for each year is established by calculating or estimating the coefficients in Equation 8. The projection error is then calculated by taking an average of the errors for
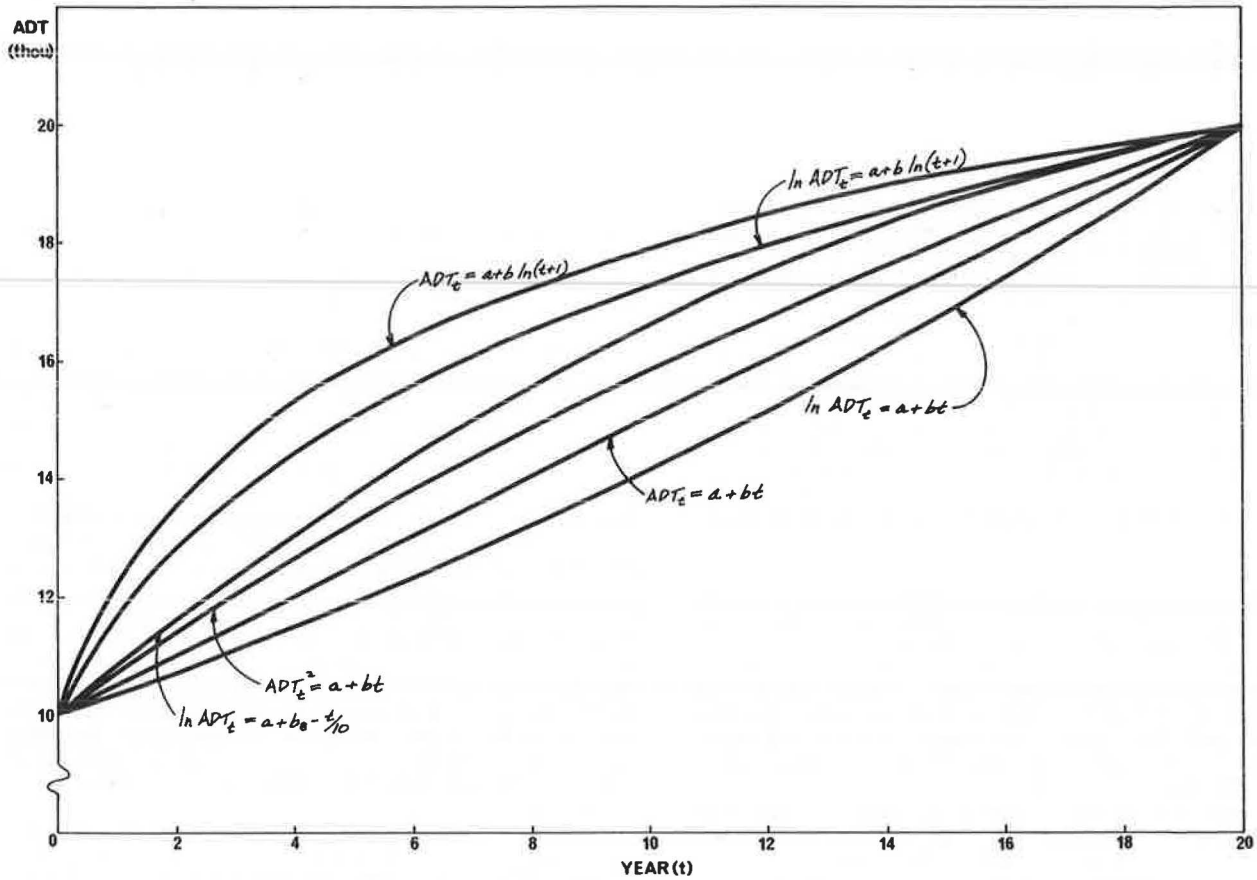
Figure 1. Examples of traffic growth patterns.

Table 1. Effect of traffic growth patterns on benefit-cost ratios.

Equation No.	Functional Form	Growth Rate[a]	Present Value Benefits[b] ($)	Construction Costs ($)	Benefit-Cost Ratio
1	$\ln ADT_t = a + bt$	b	272 400	350 000	0.78
2	$ADT_t = a + bt$	$b/(a + bt)$	319 600	350 000	0.91
3	$ADT_t^2 = a + bt$	$b/2(a + bt)$	369 300	350 000	1.06
4	$\ln ADT_t = a + b \exp(-t/10)$	$(-b/10)\exp(-t/10)$	408 400	350 000	1.17
5	$\ln ADT_t = a + b\ln(t + 1)$	$b/(t + 1)$	483 900	350 000	1.38
6	$ADT_t = a + b\ln(t + 1)$	$b/\{t[a + b\ln(t + 1)]\}$	537 800	350 000	1.54

[a]Traffic assumed to grow from 10 000 to 20 000 ADT in 20 years, where t is the year. Zero is used as the current year. Growth rate is defined as $(dADT/dt) \cdot (1/ADT)$.

[b]Benefits are calculated by using the following formula: $PV_B = \sum_{t=1}^{20} [\$10(ADT_t - 10\,000)/(1.1)^t]$. It is assumed that the net yearly incremental benefits is $10/vehicle The discount rate is 10 percent.

each year since the projection was made. The formula is given as follows:

$$E = (100/n) \sum_{t=1}^{n} |[(ADT_{pt} - ADT_{ht})/ADT_{pt}]| \qquad (9)$$

where

E = percentage error,
ADT_{pt} = projected ADT in year t,
ADT_{ht} = historical ADT in year t, and
n = number of years since the projection was made, up to 1980.

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 trend lines can pass between those two data points. Because 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 functional forms for ADT, except for Equation 4 (given in Table 1), are used to find the one that most closely fits the historical data. That particular functional form is then used to estimate the trend of projected ADT, and the projection error is calculated by using the same procedure and formula (Equation 9) described above for the multiple projection case.

FACTORS THAT AFFECT ERRORS IN ADT PROJECTIONS

When the variables that might affect the size of the projection errors are analyzed, the highway segments and projections are divided up into the following categories: (a) time of projection, (b) stage of development, (c) stage of commercial and industrial development, and (d) size of capacity change. The

Table 2. Average percentage errors in ADT projections.

Category	Projection Made Before Project Completed	Projection Made After Project Completed	Total
Time projection was made			
Before 1960	33.85	--	33.85
1960-1965	38.74	17.48	31.01
1966-1969	28.81	13.72	25.57
After 1969	19.83	10.38	16.29
Stage of development			
Developed	29.87	11.71	24.68
Developing	32.97	15.73	29.21
Stage of commercial and industrial development			
Developed	52.26	17.02	32.13
Developing	29.85	12.66	27.70
Size of capacity change			
2 lanes	36.71	17.12	32.14
4 lanes	28.56	--	28.56
6 lanes	25.65	17.20	22.58
8 lanes	31.28	7.82	26.25
Total	32.66	15.15	28.70

average error for each category is given in Table 2.

Overall, the ADT projections are good, with an average error of 28.7 percent. Considering the difficulties in making any long-range forecasts, and in particular projecting 20-year traffic volumes for a small highway segment in a growing metropolitan area, the errors are small.

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 32.66 percent for projections made before the project was completed to 15.15 percent for projections made after capacity had been added. This would tend to indicate that capacity change does have a significant impact on the accuracy of ADT projections, even though the size of the capacity change does not appear to exert a systematic effect in this sample.

The time period in which the projection was made also appears to have a significant impact on the average errors--from 33.85 percent in the late 1950s to 16.29 percent in the 1970s. 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 appears to exert an influence on the size of the errors. Developed commercial and industrial areas are defined as segments where 10 percent or more of the acreage abutting the highway segment is classified as commercial or industrial land use as of 1970. The average error of 32.12 percent is larger for developed areas than the average error of 27.70 percent for areas that have not yet developed significant commercial or industrial activity. The difference is especially pronounced among projections made before completion of the highway project, where the average error for developing areas is 29.85 percent compared with 52.26 percent in developed areas.

The stage of overall development in the area also appears to exert some influence on the size of the average projection errors, where developing areas have a higher average error (29.21 percent) compared with developed areas (24.68 percent).

It would appear that the level of economic activity in the area affects the accuracy of ADT projections and is something that may not be adequately accounted for in current ADT forecasting procedures.

MODEL FOR EXAMINING ADT PROJECTION ERRORS

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

$$E = 0.780\ 34* - 0.010\ 91*T + 0.136\ 94*F + 1.483\ 71*D + e \quad (10)$$
$$\quad\ (2.27) \quad\ (-2.14) \quad\ (2.33) \quad\ (2.37)$$
$$R^2 = 0.2450$$

where

- E = percentage error, divided by 100;
- T = year projection was made;
- F = 1 if projection was made before end of project, 0 otherwise; and
- D = percentage of commercial and industrial land in 1970, divided by 100.

(Note that the * indicates that the coefficient is significant at the 5 percent level, and the t-statistic is listed below each coefficient.)

This model explains almost a fourth of the variation in ADT projection errors, and each of the coefficients are statistically significant. This would indicate there are some factors that appear to affect the size of the errors that, if taken into account, could potentially increase the accuracy of those projections. The next section presents a simple model to project ADT by incorporating some of these factors.

SIMPLE MODEL FOR PROJECTING ADT

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

As a first approximation, the functional forms for ADT in Table 1 (excluding Equation 4) are used to project ADT for each highway segment with adequate historical ADT before the TSDHPT projections were made. The lack of historical data eliminated all new location construction projects and some improvement projects but left 19 highway segments in this sample that could be used to project ADT.

In order to compare the accuracy of these projections with the TSDHPT projections, the functional form that most closely fits the historical ADT data is used to make projections to the same years as the comparable TSDHPT projections. In addition, the projections use only the ADT data up to the year before the TSDHPT projections were made. Projection errors are calculated in exactly the same manner as those previously presented for the TSDHPT projections.

The table below presents the average percentage error by using the simple regression technique described above:

Estimation Method	Avg Percentage Error
TSDHPT	22.22
Simple regression	30.83
Multiple regression	18.57

The average error is higher when compared with the TSDHPT projections in this sample, but the simple regression technique does provide a basis for a

slightly more sophisticated and accurate model.

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

$$\ln ADT_t = a_1 + a_2 t + a_3 C \tag{11}$$

$$\ln ADT_t = a_1 + a_2 \ln t + a_3 C \tag{12}$$

$$\ln ADT_t = a_1 + a_2 \exp(-t/10) + a_3 C \tag{13}$$

where C equals 1 if capacity has increased, 0 otherwise. These three equations were chosen because each one can be estimated by using multiple regression and each one estimates the effect of a capacity change as a constant percentage of ADT. The estimated percentage change (PC) in ADT is a function of the estimated coefficient a and is given by

$$PC = e^{a_3} \tag{14}$$

The particular functional form that most closely fits the historical ADT is used for each highway segment with adequate historical ADT. The table below gives an average of the estimated effects of the capacity changes in this sample of ADT data:

Area	Avg Percentage Change
Developed	6.13
Developing	16.95
All	13.62

Multiple regression projections are then prepared for each highway segment used in the simple regression projections. When the capacity change occurs before the TSDHPT projection, a projection is made by using one of the three multiple regression equations listed above (Equations 11-13). When the TSDHPT projection is made before the capacity change, the simple regression projections are adjusted by the average percentages presented in the table above. In each case, percentage errors in the projections are again calculated in the same manner as the previously presented TSDHPT projection errors.

The results of the multiple regression model are also presented in the previous in-text table of percentage errors in ADT projections. The multiple regression method lowered the average percentage error from 22.22 percent (using TSDHPT projections) to 18.57 percent in this sample. The multiple regression model does not lower the error for every projection, 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.

A larger sample would be required to construct a more reliable multiple regression model to project ADT. The current model could be expanded to account for effects of different types of improvements, size of the capacity change, and improvements along alternate routes. In addition, the type as well as the level of economic activity should be incorporated. Projections that involve new location construction potentially could be made with a corridor approach to ADT projections, possibly as a supplement to current ADT projection methods.

TRAFFIC GROWTH RATES IN ECONOMIC MODELS

If a reliable multiple regression model is developed, it is possible that it could be adapted for highway economic models. The model itself could make its own ADT projections and in the process determine the appropriate growth pattern for that projection. This alternate method would estimate the two together, thereby improving both the consistency and 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, which could certainly be the case for ADT projections, especially taking into account the rapid change in the real price of gasoline over the past few years. A simple way by which the reasonableness of internally generated projected ADTs could be controlled would be to set a minimum and maximum value that the projected ADT value could take. In addition, a sensitivity analysis could be performed for various values of the projected ADT.

CONCLUSIONS

The pattern of traffic volume growth and the projected traffic volume itself have been relatively neglected aspects of most analyses of highway projects. However, the assumed traffic growth pattern can have a significant effect on the accuracy of the estimated benefits, even if all the other calculations are correct. It is important that more emphasis be placed on these neglected areas of economic analysis models.

Some factors have been identified that appear to affect the accuracy of traffic projections in this sample. These factors include the year the projection was made, the percentage of commercial and industrial land use, and the capacity changes along the highway segment. The accuracy of ADT projections could potentially be improved by more fully incorporating these factors into the projection process.

Ultimately, rather than attempting to fit a traffic growth-rate pattern to a given traffic projection, the two should be combined into one process. A possible method that could accomplish that purpose has been presented in this paper. The multiple regression model is designed to project ADT, and an important part of that process is to estimate the appropriate traffic growth pattern. The accuracy of the ADT projections were somewhat better in this sample for the multiple regression model compared with the TSDHPT projections.

Undoubtedly, more work must be done in this area to improve the accuracy and reliability of a traffic projection model that will also yield the traffic growth pattern. The model presented in this paper, however, appears to demonstrate that such a model is possible without sacrificing the accuracy of current projection methods.

REFERENCES

1. Multisystems, Inc.; Wilbur Smith and Associates. Highway Investment Analysis Package (HIAP)-- Volume 2: Technical Manual. FHWA, June 1979.
2. Guide to the Highway Economic Evaluation Model.

Texas Department of Highways and Public Transportation, Austin, Feb. 1976.

3. J.L. Memmott and J.L. Buffington. Predicting Traffic Volume Growth Rates Resulting from Changes in Highway Capacity and Land Development. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 225-23, Jan. 1981.

Vehicle Life-Cycle Costing with Probabilistic Part Replacement and Repair Options

GEORGE C. JACKSON AND T. H. MAZE

The purchase of transportation parts and equipment is a complex task that requires more than just the simple comparison of prices submitted by potential vendors. Ideally, the financial implications of a purchase should be analyzed over the entire life cycle of the item. The theory of how Markov chains were used by a purchasing analyst to solve the problem of whether to equip a new fleet of semitrailers with radial or conventional tires is described. Markov chains are used to develop total tire costs over the life cycle of the semitrailer for both types of tires. Although the methodology is demonstrated by using a truck tire example, the methodology is equally applicable to analyze the life-cycle costs of other transportation equipment.

The use of a life-cycle costing methodology to determine the most cost-efficient type of tire to purchase with new truck trailers is described in this paper. Although the methodology is applied to a truck trailer costing problem, it is equally applicable to the purchase of bus tires, maintenance truck tires, garbage truck tires, school bus tires, and so on, or to other cases where vehicle parts have probabilistic replacement or repair options or both.

Choosing the right tire for a new fleet of trailers is an important problem for many fleet managers. Tires will normally account for 10 to 15 percent of the purchase price of the trailer and can contribute significantly to maintenance costs over the life of the trailer. Trailer tires also play an important role in customer service by influencing the incidence of late deliveries caused by tire problems. Thus, the choice of tires to be specified on new trailer fleets is an important decision, i.e., one that requires careful analysis.

The choice is generally between steel-belted radials and conventional belted tires. The initial cost of radial tires is substantially greater than the cost of conventional tires. However, radials have been found to wear longer and to be able to be recapped more times, thus reducing the total tire cost over the life of the trailer. The question that remains is which type of tire to buy: radial or conventional.

The methodology developed to answer the question of which type of tire to purchase uses a Markov chain. The Markov chain is employed to develop estimates of total tire costs over the expected life of a truck trailer. By using these cost estimates, the present worths are calculated for both steel-belted radial tires and conventional belted tires and the minimum cost tire type is selected.

ANALYTICAL APPROACH

Markov chains are used as a mathematical means of forecasting the probability of a particular item transcending from one state to another during a time period. For example, after a period of wear, a new tire can either be recapped or, if no longer recappable, scrapped. Thus, there is a probability that a new tire will either transcend to a state where it is recapped or to a state where it is scrapped. If the tire is recapped, after another period of wear it again faces the possibilities of being recapped or scrapped. Every time wear causes the tire to reach the end of its safe tread, the tire can transcend into one of two states (scrap or recap). Markov chains are used to quantify the probability of an item transcending from one state to the next. The probability of transcending from one state to any other state is defined in a Markov chain by a transition matrix ($\underline{1}$).

To demonstrate a transition matrix, suppose that there are m states. For example, the states could be new, scrap, first recap, second recap, and so on. Let the probability of transcending from one state to another be represented by p, where p_{12} represents the probability of transcending from state 1 to state 2. For example, p_{12} could represent the probability of transcending from the first recapping to the second recapping. Of course, the probability of impossible transitions would be zero. For example, if p_{32} represented the probability of transcending from the third recapping to the second, then p_{32} would equal zero. An example of a transition matrix with m states is shown below:

States	0	1	2	3 ...	m
0	p_{00}	p_{01}	p_{02}	p_{03}	p_{0m}
1	p_{10}	p_{11}	p_{12}	p_{13}	p_{1m}
$\underline{P}$ = 2	p_{20}	p_{21}	p_{22}	p_{23}	p_{2m}
3	p_{30}	p_{31}	p_{32}	p_{33}	p_{3m}
.					
.					
.					
m	p_{m0}	p_{m1}	p_{m2}	p_{m3}	p_{mm}

To demonstrate the use of the transition matrix for forecasting tire states, suppose that a new tire has a probability of 0.6 of being able to be recapped successfully. The transition from the state new to the state first recap is defined by the transition probability whose value is 0.6. At some point, the tire must be discarded and replaced by a new tire. Returning to the example cited above, the probability of an unsuccessful recap would be 0.4, in which case a new tire would be purchased. This would mean that the probability of remaining in the state new would be 0.4. Once a tire is scrapped, it