Highway Needs for the Year 2005

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Results of a study aimed at estimating the highway needs for 2005 are presented. The study approach is based on forecasting the travel demand using socioeconomic variables and translating the growth into lane-miles of required highway facilities. The Highway Performance Monitoring System (HPMS) data set is used to obtain information on current conditions and recent trends in usage and supply (lane-miles) of urban highway systems. The lane-miles of highway facilities, stratified by highway functional class and urban location, required to meet the expected growth in travel in urban areas of different sizes are presented. Urban travel is expected to increase at an average annual rate of between 2.36 and 2.72 percent. To accommodate this travel growth, it is estimated that, depending on the level of service desired, between 75,211 and 220,284 lane-mi of additional capacity will be required by 2005. The primary highway system (freeways, expressways, and principal arterials) accounts for over 70 percent of these needs. Freeway and expressway needs are estimated to be between 40,000 and 50,000 lane-mi. The analysis performed suggests that the suburbs of large urban areas will require the most additions in capacity, particularly of primary highway types, in future years.

The continuing suburbanization of society is overburdening the urban highway system. In 1985, for example, in metropolitan areas with more than 1 million in population, nearly 50 percent of travel on freeways and expressways occurred at volume/capacity ratios of 0.85 or greater (*1*). Many suburban or newly urbanizing areas are doing even worse as this travel continues to shift from the dominant journey of suburb to central business district (CBD) to both intra- and intersuburb trips. The highway systems in suburban areas, consisting primarily of minor arterials and local roads, are in many cases not well suited for suburb-to-suburb commuting. As the nation moves into the 1990s, urban and suburban mobility will continue to be challenged by the growth in travel demand and the shift in travel patterns. To formulate a framework of policy and program options for future highway system design, questions such as the following must be answered:

- What will be the growth rate of travel in the urban areas? How will this growth vary by urban areas of different sizes and by different regions of the country?
- What will it cost to maintain an acceptable quality of travel service in urban areas in the 1990s and beyond?
- What is the most cost-effective mix of highway facilities by functional class and by location within urbanized areas?
- What level of service (LOS) would be more economically efficient?
- Given estimates of available capital, what LOS can be expected in the future?
- How much new construction is required?

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A study was undertaken as part of an ongoing research effort aimed at identifying optimal highway network configurations to accommodate future highway needs (*2*). The objective of this study was to develop a procedure for forecasting future highway travel demand in urban areas, with particular emphasis on suburban areas, and then to use that procedure to estimate suburban highway needs for 2005. The approach used to achieve this objective is based on forecasting travel demand [daily vehicle miles of travel (DVMT)] through the use of socioeconomic variables and translating the travel growth into lane-miles of required highway facilities. The Highway Performance Monitoring System (HPMS) data set is used to obtain information on current conditions and recent trends in usage and supply of urban highways.

An overview of the study methodology and its data sources is provided in the following paragraphs, along with estimates of the highway needs derived from the analysis. The future highway needs are a function of present conditions, future travel growth and its pattern, future investment (supply), and a desired LOS, among other things. The needs forecasts are presented in terms of lane-miles of highway facilities, stratified by facility type (i.e., highway functional class) and location within urban areas, required to meet the expected growth in travel in urban areas of different sizes. To account for the dynamics of urban system growth, and to illustrate the sensitivity of supply needs to LOS, a scenario analysis has been performed to estimate a range of needs resulting from different LOS and over a range of future travel growth. For example, one of the scenarios is the highway needs required to maintain the 1987 LOS in all highway functional classes.

RELATED RESEARCH

The Federal-Aid Highway Act of 1987 continues the federal-aid highway program through September 30, 1991. In advance of congressional debates in 1990 and 1991 on new highway legislation, future highway needs and the federal role in the nation's highway program have been carefully examined by FHWA. Several studies have been performed or are currently under way to identify the issues, needs, trends, technologies, and program options that will affect the nation's future highway systems. This effort is titled the Future National Highway Program (FNHP). Mid-range (2005) and long-range (2020) forecasts are being prepared to develop a transportation program and to define the federal role in meeting future needs. To assist the federal policy makers, a series of 19 working papers was commissioned by FHWA (*3*). Most of these papers have been completed and are being reviewed within and outside FHWA. On the basis of the findings of these papers, FHWA has prepared two reports: an interim report on the nation's future highway needs (*4*) and a report to the U.S. Congress from the Secretary of Transportation (*5*).

This research complements Working Papers 1, 2, 13, and 14 in that series. Working Papers 1 and 2 provide information on the current status of the nation's highway system and attempt to quantify the magnitude of problems expected in the future (*6,7*). In Working Paper 13 (*3*), an economic analysis was done to compare benefit-cost ratios of investment by highway functional class within urban areas. The analysis indicated that additional expenditures could be justified on all functional systems. It was suggested that, depending on the functional class, each dollar invested in capacity improvements would return $5 to $12 in benefits. However, the study did not differentiate the higher costs (including right-of-way costs) in the urban core versus the lower costs of development at the urban fringe. Working Paper 14 (*8*) attempted to address the shift in travel between highway functional classes. The economic analyses presented in that study relied on the current trends in share of travel to estimate the potential for shift between functional classes as the population of the urban area grows. As in the previous study, it was suggested that investments in higher functional classes (freeways and expressways) would be more economically efficient than in lower-order facilities. However, this assessment is not necessarily appropriate because the incremental utility of adding a new facility is a function of level of usage, which itself is a function of the current supply.

Other studies by Fleet and DeCorla-Souza (*1*) and by the FHWA planning Support Branch (*9,10*) looked further into current urban travel-supply relationships and the changing trends in these relationships. These studies noted a general upward trend in travel share on freeways and expressways as urban areas increase in size and concluded that LOS C was generally more economically efficient than LOS D on these facilities. The studies identified past trends in shares of travel and supply between highway functional classes and urban locations. Fleet and DeCorla-Souza developed future suburban needs assessments on the basis of aggregate population forecasts translated into square miles of density-specific land development and, thus, needed lane-miles of highway facilities. This methodology was the first such effort to estimate highway infrastructure needs from surrogate measures of land development. It included disaggregation of future travel by population ranges, and its estimate of needs by facility type was an extrapolation of the existing network found in suburban areas.

The research documented in the following paragraph is also an attempt to assess the trends in urban travel-supply relationships and to use that information in estimating future urban needs disaggregated by facility type (i.e., highway functional class), urban area size, and location within urban areas. However, a somewhat different approach is used than in the previous FHWA studies. The approach is based on working with disaggregate data (i.e., at individual urban area level) and relying more on mathematical relationships to depict the trends in future urban travel and its distribution across categories of interest.

The estimation of future highway needs requires an estimation of future travel demand. A comprehensive review of forecasting models for vehicle miles of travel (VMT) is provided by Southworth (*11*). This review covers post-1974 studies of national VMT forecasting. Traditionally, econometric forecasting approaches are used to forecast travel demand. However, these approaches do not recognize the constrained nature of travel, especially the availability of time for travel. Greene (*12*) suggests a demographic approach to long-run forecasting of highway vehicle travel. Chan (*13*) developed national urban and rural forecasting models using time-series data on VMT. An interesting three-tier approach was adapted by COMSIS (*14*). Their intent was to alleviate the difficulties associated with capturing both micro-level (individual and household) behavioral factors and macro-level (demographic and economic) trends within a single equation framework. Recently, models for short- and long-range forecasting of VMT and vehicle stocks were developed by Jack Faucett Associates (*15*). These models are capable of forecasting national VMT through 2020 and of disaggregating it by state, regions, or highway functional classes.

A final relevant research area is the modeling of urban system dynamics, particularly the evolution of urban systems over time. There is extensive literature, both theoretical and empirical, on the nature of urban growth (*16–18*). Theories cover the expansion over time of residential, industrial, and commercial development, seen as a result of population growth and demands for greater living space and in response to increasing commuting times. Griffith (*16*), for example, modeled the urban population distribution pattern using population density and activity center locations. For the purposes of this study, however, approaches based on urban system dynamics were not considered because of the unavailability of the data sources required to model the urban growth patterns, at least within the time constraints and resources available. Also, such studies have not yet seen such an application in practice.

METHODOLOGY

Typically, national highway needs estimation and investment and performance analysis studies are performed using HPMS data and analytical procedures (*19,20*). The HPMS analytical process simulates future capacity needs as needed lane-miles of improvement on the existing facilities. Thus, this procedure assumes that the growth in traffic will occur in a static network. Due to this static network configuration, the HPMS analytical process suboptimally determines the urban highway needs in three ways. First, the procedure does not include new highway facilities, that is, the new construction that may be planned in an expanding urban area. Second, the procedure does not provide the investment levels required to meet the specified needs because it only reflects the unit costs for improvements on facilities for which right-of-way is deemed to be readily available. Third, the HPMS forecasting approach does not consider the expansion of urban area boundaries, erroneously attributing much of the suburban growth to rural areas.

Despite these limitations, only HPMS contains the necessary information about the condition and use of the national highway system and about the capital investments on these highways. Because future highway travel and system requirements are a function of current conditions, such information will be necessary regardless of the forecasting procedure employed. With these considerations in mind, an approach based on supplementing the HPMS data with socioeconomic data from other sources is established.

Figure 1 is an abbreviated flow chart of the study procedure. The approach to forecasting future urban highway needs is based on estimating the growth in VMT and translating this growth into the required lane-miles of highway facilities. The methodology consists of three major analysis components: (a) forecasting growth in the levels of daily travel (DVMT) for urban areas, (b) distributing the forecast DVMT across various highway functional classes and locations within urban areas, and (c) estimating the lane-miles of highway facilities by functional class required to accommodate the growth in DVMT at specified levels of service. The detailed analysis procedure is outlined in the following paragraphs.

Step 1

Using HPMS areawide and sample data, DVMT and lane-mile data are obtained for each individual urbanized area in the United States for 1982–1988. The data are cross-tabulated by highway functional class, by location within urban areas, and by urban area size. The urban highways are categorized into four classes: freeways and expressways (HPMS Codes 11 and 12), other principal arterials (Code 14), minor arterials (Code 16), and collectors (Code 17). Three urban location categories are used: core (Codes 1 and 2), suburb (codes 2 and 3), and fringe (Codes 4 and 5). Urban areas are divided into three population groups: greater than 0.5 million (large), between 0.1 and 0.5 million (medium), and less than 0.1 million (small).

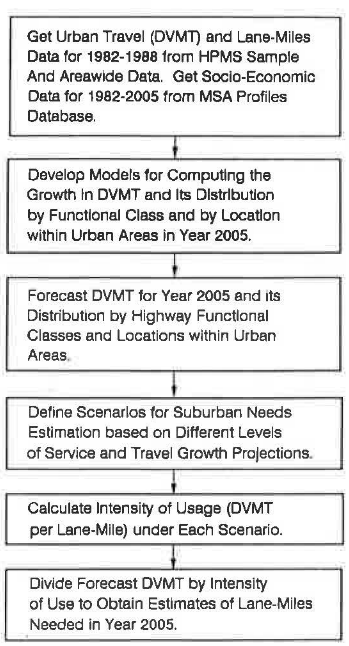

FIGURE 1 Study procedure.

Step 2

The socioeconomic data and forecasts for every metropolitan statistical area (MSA) in the United States through 2005 are obtained from MSA profiles published by Woods and Poole Economics, Inc. (*21*). The MSA data are used as a proxy for the urban areas contained by the MSA.

Step 3

Using 1982–1988 data for 339 urban areas, a pooled time-series, cross-sectional regression model is developed for forecasting total DVMT for the urban areas. In this model, DVMT per capita is used as the dependent variable, and the socioeconomic variables (number of driver licenses per 1,000 persons, household size, real income, and employment) and a measure of highway supply deficiency are used as independent variables. The supply deficiency of the primary highway system is included as an independent variable to account for the impact of constrained supply on demand for travel.

Step 4

On the basis of forecasts of socioeconomic variables for 2005, the future DVMT for each urban area is estimated. Depending on the scenario analyzed, DVMT is estimated for constrained or unconstrained conditions (by highway supply) and by high or low rates of travel growth.

Step 5

The dynamics of shift in urban travel between highway functional classes and locations within urban areas as the urban area increases in size is modeled through conditional logit models in which population is used as an explanatory variable. These logit models, together with the forecast population of the urban areas, are then used to predict the shares of travel by functional classes and by locations within urban areas in 2005. Initially, the current supply (lane-miles) was also included as an independent variable in these models. However, it was found to be highly correlated to population and had little impact on the distribution of DVMT by itself.

Step 6

The estimate of suburban needs (lane-miles) is then obtained by dividing the forecast DVMT in each category by a service index (DVMT per lane-mile) corresponding to desired LOS in five different scenarios:

1. 1987 service index, constrained demand, and low rate of travel growth;

2. 1987 service index, constrained demand, and high rate of travel growth;
3. Desired service index (DSI), constrained demand, and low travel growth;
4. DSI, constrained demand, and high travel growth; and
5. DSI, unconstrained demand, and high travel growth.

The term "service index" has the same meaning as average intensity of use in other studies. Here, the service index represents the level of service desired by the policy makers or planners. DSI is a service level comparable to LOS C on highway segments in small and medium-size urban areas and LOS D in large urban areas.

MODELS

Three models were developed in this study. The first is a regression model for forecasting DVMT for urban areas in 2005. The second and third models are conditional logit models that forecast the future shares of travel across highway functional classes and locations within urban areas, respectively. A brief description of these models is given in this section. The major findings derived from these models are presented in the following section. A companion paper (*22*) describes these models in detail.

DVMT Forecasting Model

The choice of DVMT forecasting model is based on several factors: (a) forecast horizon (midrange), (b) available time-series and cross-sectional data, (c) differences in travel demand among urban areas, and (d) future forecasts as more time-series data become available. The final model of choice is one in which a varying intercept term is assumed to capture the differences in travel behavior over individual urban areas and the slope coefficients are assumed to be constant within a group of urban areas with similar populations. The model has the following form:

$$Y_{it} = \beta_{0i} + \sum_{j=1}^{6} \sum_{g=1}^{G_j} \beta_j^g \cdot X_{jit}^g + e_{it} \quad (1)$$

where

i = urban area index (1, 2, . . . , 339);
t = yearly time index taking on a value from 1 to 8 (1 for 1981);
g = population group index from 1 to G_j (within each group the regression coefficient β_j can be considered constant);
j = index for independent variable X (all variables in natural log form):
1 = real income per capita (1982 dollars);
2 = number of persons employed per 1,000 population;
3 = number of persons per household;
4 = number of driver licenses per 1,000 population;
5 = time variable, i.e., in (t); and
6 = supply deficiency of primary highway system;
Y = natural log of DVMT per capita for population between ages 15 and 65 years;
X = independent variable (if urban area i belongs to group g, $X_{jit}^g = X_{jit}$, otherwise $X_{jit}^g = 0$);
e = model residual; and
β_j = regression coefficients.

The first four independent variables (j = 1, 2, 3, and 4) represent the influence of socioeconomic variables on DVMT that could be readily quantified. Some less readily quantified influences that could be significant include the percentage of people traveling to and from work by public transit, the amount of car- and vanpooling, the land area of an urban area, and the population distribution within an urban area. Although these influences are implicitly reflected in the varying intercept term of the model, changes in any of these variables over time could influence travel behavior and could result in a time trend in DVMT that would not be picked up by the first four explanatory variables and by the intercept term. The yearly time index (j = 5) is used as a proxy to represent the combined time trend as a result of the changes in these less readily quantified variables over time. The supply deficiency variable captures the impact of constrained supply on demand, which applies primarily to large and medium-size urban areas. This restrained travel is referred to as latent demand because it may surface given adequate supply.

The model is quite flexible in structure. For example, by setting the number of population groups (G_j) to the number of urban areas for all explanatory variables, a regression model results that allows the slope coefficients to vary over each individual urban area. If it is further assumed that model errors are uncorrelated between urban areas, the process is then equivalent to building a time-series regression model for each individual urban area. This feature is attractive because, as more time-series data become available for each urban area, more weight can be placed on each area's time-series data to forecast its future travel and less weight can be placed on the data from other urban areas.

Logit Model of Travel Shares by Functional Class

The model is intended to forecast the total shares (summed over urban locations) of travel on different highway functional classes in the future. A logit model based on 1981–1988 data of shares of highway use by function classes in 339 urbanized areas was developed. Logit models have been widely used in travel choice and behavioral analysis. With urban area population as a dependent variable, this model captures the variation in shares of travel on highway functional classes as the size of the urban area grows. The model is of the following form:

$$S_{it}^f = \frac{\exp[\beta_{0i}^f + \beta_1^f \ln(P_{it})]}{\sum_{m=1}^{4} \exp[\beta_{0i}^m + \beta_1^m \ln(P_{it})]} \quad (2)$$

where

f = highway functional class index, (1 = freeways and expressways, 2 = other principal arterials, 3 = minor arterials, and 4 = collectors);

S = share of DVMT; and
P = urban area population (in thousands).

Logit Model of Travel Shares by Urban Location

This model is similar in form to the functional class shares model. It estimates the total shares of travel (summed over functional classes) for different locations within an urban area for 2005. Unlike the functional class shares model, however, this model is based on 1982, 1984, and 1987 data on shares of DVMT by location for 169 urban areas only. (The urban location data are contained in the HPMS sample data. Within the short time frame in which this study was performed, only these 3 years of HPMS data were available. Useful data on shares of urban travel by location were available for only 169 urban areas for the 3 years. However, these 169 urban areas contained a fairly representative sample of all urban area sizes.) The travel shares model is of the following form:

$$S_{it}^{l} = \frac{\exp[\beta_{0i}^{l} + \beta_{1}^{l} \ln(P_{it})]}{\sum_{n=1}^{3} \exp[\beta_{0i}^{n} + \beta_{1}^{n} \ln(P_{it})]} \quad (3)$$

where

i = urban area index (1, 2, . . . , 169);
t = yearly time index (2 = 1982, 4 = 1984, and 7 = 1987); and
l = urban area location index (1 = core, 2 = suburbs, and 3 = fringe).

FUTURE URBAN TRAVEL DEMAND

This section presents the notable findings from the estimation of future DVMT and its distribution across highway functional classes and locations within urban areas, derived on the basis of the models previously described. Before proceeding, however, some words of caution are necessary. The estimates for future level (DVMT) and the resulting suburban highway needs estimates are based primarily on the forecasts of socioeconomic variables. However, there is always considerable uncertainty associated with the future economic variables on which the estimation of future travel is based. In addition, the travel demand data (DVMT), highway usage, and supply data are derived from the HPMS. The information derived from the HPMS is based on sample data, and all the cautions that are normally applied to estimations from samples apply. Also, since the data has been stratified across categories (i.e., urban location) not initially incorporated within the HPMS sampling scheme, the application of HMPS expansion factors to these cells is questionable. Also, the urban locational indexes "core," "suburb," and "fringe" are strictly as defined in HPMS urban location codes for sample sections. For individual urban areas, these definitions may be different from the common meaning of the terms. Because it is difficult to establish absolute locations of the sample sections from the HPMS, the location codes submitted by the states must be used. Rathi et al. (*23*) provide further discussion on locational data, including suggestions for HPMS improvement.

Growth in Urban DVMT Through 2005

Urban DVMT is expected to increase at an average annual rate of 2.72 percent between 1985 and 2005. Of that increase, population growth will contribute approximately 1.12 percent, the increase in the number of driver licenses 0.65 percent, better income 0.45 percent, and employment another 0.10 percent. In addition, 0.4 percent will come from those less readily quantified factors represented by the time variable. This annual growth amounts to a total travel growth of 56 percent by 2005 over 1987 DVMT, in which population alone accounts for about 22 percent of the growth.

For the 339 urban areas examined, DVMT in 1987 was 15.9 mi/capita and is expected to increase to 20.8 mi/capita by 2005.

The Pacific West, Mountain, and South Atlantic regions will experience relatively higher growth rates than the rest of the nation.

The analysis of the impact of highway supply on DVMT suggests some latent demand for large and medium-size urban areas. It was estimated that travel demand may be constrained below a supply level of approximately 2.15 lane-mi of primary highways (freeways and expressways and other principal arterials) per 1,000 population.

The number of driver licenses is forecast by FHWA (*15*) to increase at an average annual growth rate of 0.57 percent from 1985 to 2005. However, recent trends indicate a slight decline (*15*), suggesting that past increases may be slowing down and that the forecast based on Model 1 (which includes this variable) may be high. Another estimate of growth in DVMT is obtained without this variable. This model indicates a smaller average annual growth rate of 2.36 percent, an estimated latent demand of approximately 13 percent, and an estimated DVMT per capita of 19.4 in 2005.

During 1982–1988, the intensity of highway use (DVMT per lane-mile) for urban areas increased annually by 3.0 percent on freeways and expressways, 2.4 percent on other principal arterials, 2.12 percent on minor arterials, and 1.3 percent on collectors.

These are based on an assumption that the current levels of highway supply will be maintained in the future. A lower growth in travel should be expected if highway supply falls below current levels. On the other hand, if the future highway system can be improved to accommodate all latent demand by 2005, the urban DVMT could increase by an average annual growth rate as high as 3.48 percent. Although this constraint-free highway travel scenario is unrealistic in practice, it provides an upper bound of expected travel growth.

DVMT Shares by Functional Class and Urban Location

Table 1 presents the shares of DVMT of an average urban area in each population group by highway functional class and by urban location for 1987 and 2005. The 1987 shares are based on HPMS data, whereas the 2005 shares are estimations based on the logit models described previously.

Table 1 indicates that nearly two-thirds of DVMT in urban areas is carried by the primary highway system. For urban areas greater than 0.5 million in population, this share is expected to increase to nearly 70 percent by 2005. This es-

TABLE 1 AVERAGE DVMT SHARES

Urban Area Size (Population)	Year	Average Urban Population	Functional Class				Location		
			F&E	OPA	MA	COL	Core	Suburb	Fringe
Large (≥0.5M)	1987 2005	1.928M 2.314M	0.412 0.430	0.264 0.267	0.225 0.216	0.099 0.087	0.186 0.180	0.634 0.599	0.180 0.221
Medium (0.1-0.5M)	1987 2005	0.224M 0.261M	0.299 0.309	0.338 0.333	0.251 0.249	0.112 0.108	0.185 0.151	0.589 0.578	0.226 0.271
Small (0.05-0.1M)	1987 2005	0.076M 0.088M	0.196 0.211	0.414 0.409	0.270 0.262	0.120 0.118	0.172 0.177	0.621 0.612	0.207 0.210

F&E: Freeways and Expressways; OPA: Other Principal Arterials; MA: Minor Arterials; COL: Collectors.

timate assumes, of course, that the highway supply level in 2005 will remain the same as in 1987 and that any change is due to the increase in urban area size only.

Freeways and expressways carry a significantly larger portion of travel in large urban areas than in small and medium-size urban areas and will continue to do so in the future. On the basis of 1982–1988 data used in this analysis, nearly 40 percent of DVMT occurs on freeways and expressways in urban areas greater than 0.5 million in population, compared with only 30 percent in medium-size urban areas and 20 percent in small urban areas. This trend is similar to that observed by Fleet and DeCorla-Souza (*1*).

Between 1987 and 2005, the DVMT shares of freeways and expressways for all urban sizes are estimated to increase. All other functional classes will decrease except the other principal arterial in the large population group.

In 1987 nearly 80 percent of all urban travel occurred outside the core area (i.e., in the suburbs and fringe). This share will increase somewhat in 2005. For large and medium-size urban areas, the DVMT shares will decrease in the urban core and suburbs but increase considerably in the fringe for all population groups.

By computing the direct elasticities of DVMT shares to a change in the log-population, it is estimated that, for an average urban area with a population greater than 0.5 million in 1987, a 10 percent increase in population will result in a 1 percent increase (above 1987) shares) in DVMT share in freeways and expressways; a 2 percent increase in travel share in the fringe; and a commensurate decrease in travel share in the suburbs, core, and on lower order facilities.

For an average urban area in each population group, the DVMT shares of freeways and expressways will increase between 1987 and 2005 by 1.8 percent and 1.0 percent for large and medium-size urban areas, respectively, as a result of population growth. The increase in urban fringe DVMT shares in the same category is estimated to be 4.1 percent and 4.5 percent, respectively.

SUBURBAN HIGHWAY NEEDS FOR 2005

The suburban highway needs estimates for 2005, categorized by urban area size and highway functional class, are presented. Because the objective is to determine the needs for both the existing suburban areas and the newly suburbanizing areas, HPMS urban location codes 3 (outlying business district), 4 (residential), and 5 (rural in character) have been combined into a single category—suburb and fringe. For simplicity of presentation, the highway functional classes have been coalesced into three groups: freeways and expressways, other principal arterials, and minor arterials/collectors. Urban areas are divided into three population groups: greater than 0.5 million (large), between 0.1 and 0.5 million (medium), and less than 0.1 million (small).

Service Indexes

Highway needs are expressed as lane-miles of additional highway facilities required to meet the anticipated future travel demand. The procedure that translates the forecast DVMT into needs estimates is described in this subsection. The translation is based on the concept of service index (SI), a measure that can also be tied to the LOS concept. LOS is a qualitative measure used commonly by transportation professionals to indicate the quality of traffic flow. Associated with each LOS is a service flow rate, which is the maximum hourly rate of flow that can be accommodated by various highway facilities. An SI is a daily equivalent of the hourly service flow rate. For a given highway functional class, urban area size, and location within urban area, the SI is computed as follows.

Step 1

For the base year (1987) service level, the average DVMT per lane-mile is obtained from the HPMS data and used as the base year service index (BSI).

Step 2

The DSI is computed, reflecting a desired LOS that is equivalent to a systemwide LOS C for small and medium-size urban areas and LOS D for large urban areas. These levels are arbitrarily selected for the purposes of estimation and scenario analysis. For a specified service level (LOS C or D), the maximum service flow rate per hour per lane is obtained for the given highway facility type and design speed from the *Highway Capacity Manual* (HCM) (*24*). For example, Table 3-1 of the HCM is used to calculate the hourly flow rate on freeways and expressways. This flow rate is then adjusted for the presence of heavy vehicles, restricted lane widths, and other factors as applicable. The average DVMT per lane-mile for the target LOS is then obtained by dividing the hourly maximum flow rates by the peak-hour travel shares derived from the time-of-day travel percentages and directional split (*3*). The peak-hour travel shares were assumed to be the same for all locations within urban areas. The average DVMT per lane-mile for various highway functional classes, stratified by urban area size and LOS, is presented in Table 2.

Step 3

The future lane-miles are estimated by dividing the forecast DVMT by the corresponding SI (BSI or DSI). The highway needs are then estimated as the difference between the future lane-miles and the base year lane-miles. It is possible to have no highway needs for an urban area despite growth in travel demand if its forecast SI (future DVMT per current mileage) is lower than the DSI in Scenarios 3, 4, and 5 (described in the following paragraphs).

Scenarios

The suburban highway needs are estimated for five different scenarios comprising different service levels and rates of future travel growth:

Scenario 1

Scenario 1 is based on BSI, a service index based on 1987 quality of traffic flow, under a projected 2.36 percent average annual travel growth rate (AATGR) in future travel. This scenario represents a condition in which the LOS in large urban areas does not deteriorate as in the recent past, and in which the small urban areas continue to enjoy the good LOS they do today. The average 1987 DVMT per lane-mile for various highway functional classes stratified by urban area size is also presented in Table 2.

Scenario 2

Scenario 2 is the same as Scenario 1 except that it is based on a 2.72% AATGR, representing a high travel growth projection. Thus, this scenario represents an upper bound of needs estimates when maintaining the same level of performance as in 1987.

Scenario 3

Scenario 3 is based on DSI, a service index associated with maintaining LOS D in large urban areas and LOS C in small and medium-size urban areas across all functional classes and locations. As in Scenario 1, an AATGR of 2.36 percent is used to estimate future DVMT. In terms of the quality of service, this scenario represents a condition for which the LOS of small urban areas will deteriorate considerably. The LOS will remain the same for most of the medium-size and large urban areas but will be improved for those large urban areas that are currently experiencing severe congestion.

Scenario 4

Scenario 4 is the same as Scenario 3 except that it is based on a 2.72 percent AATGR, representing a high travel growth projection. This scenario represents an upper bound of needs estimates when maintaining DSI.

Scenario 5

Scenario 5 is the same as Scenario 3 and 4 except that it is based on an even higher growth rate projection. A 3.48 percent AATGR is used in estimating future DVMT. This high travel growth is obtained when the supply deficiency is excluded from the DVMT forecasting model. Scenario 5 represents a condition in which demand is not constrained due to supply and thus the current latent demand in large urban areas will materialize in the future.

Needs Estimates

Before presenting the needs estimates derived from the analysis, some remarks about the interpretation of these results

TABLE 2 AVERAGE DVMT PER LANE-MILE FOR DIFFERENT LEVELS OF SERVICE

Urban Population	LOS	F&E	OPA	MA/COL
Large (≥0.5M)	C	12,000	7,500	5,000
	D	14,500	9,500	6,500
	1987	13,000	6,100	3,100
Medium (0.1-0.5M)	C	11,000	7,000	5,000
	D	13,000	8.500	6,000
	1987	8,300	4,800	2,500
Small (0.05-0.1M)	C	9,000	6,500	4,500
	D	11,000	7,500	5,000
	1987	5,300	4,100	2,000

Notes: (1) LOS: Level of Service; F&E: Freeways and Expressways; OPA: Other Principal Arterials; MA: Minor Arterials; COL: Collectors.
(2) DVMT/Lane-Mile for LOS C and D are derived from 1985 Highway Capacity Manual [24] assuming the following:
F&E: 5% trucks, 60 mph design speed, 11-ft wide lanes;
OPA: no trucks, 0.7 adjustment factor for development environment, 11-ft wide lanes, 45 mph design speed;
MA/COL: intermediate design category, no trucks, saturation flow for LOS D = 1500 vphpl, saturation flow for LOS C = 1200 vphpl, g/c ratio =0.5.
(3) DVMT/Lane-Mile numbers are rounded to nearest 100.

are in order. The estimates of lane-miles for 2005 are simply an indication of the extent of the urban highway system in the forecast year. These estimates are constrained neither by a static network configuration as in the HPMS analytical procedure nor by any fiscal or geopolitical constraints that may affect the growth of individual urban areas. An urban growth dynamic is inherent in the needs forecast because it is assumed that not only will the DVMT grow but also its distribution by highway functional class and urban location will change as a result of the population growth. For example, the share of travel on freeways and expressways would increase from 19.6 percent to nearly 30 percent if an urban area is forecast to increase in size from small to medium by 2005 (see Table 1). Furthermore, the future travel demand itself is forecast by factors exogenous to urban boundaries or location of sample sections, allowing these estimates to be free from any fiscal or geopolitical constraints. Figure 2 shows a schematic representation of the needs estimates.

Also, the difference between current lane-miles and forecast lane-miles represents an estimate of the additional capacity that will be required to accommodate the anticipated travel growth. This additional capacity will be provided in practice through new construction, upgrades along existing right-of-way, and in some cases reclassification of a road from rural to urban. Within the scope of current research, the capacity realized through each of these sources has not been distinguished. Consequently, the work does not address the investments required to meet these future highway needs. Rather, the objective is to generate an important and improved set of mileage inputs to such a forecast.

The results of the analysis are summarized in Tables 3–10. Table 3 presents a distribution of 1987 lane-miles by urban area size, location, and highway facility type. Tables 4–8 present the estimate of additional lane-miles (over 1987 conditions) needed to accommodate travel growth through 2005 under Scenarios 1 through 5. Table 9 presents the additional lane-miles (over the 1987 condition) by highway functional class along with an earlier FHWA estimate (*8*) for comparison purposes. Table 10 presents the 1987 and estimated 2005 lane-miles by highway functional class and by urban location compared with the FHWA estimate. Examination of these tables suggests the following:

1. The suburban highway needs estimates range from 75,211 lane-mi (Scenario 3) to 220,284 lane-mi (Scenario 2). The low estimation—75,211 mi, or 18 percent over 1987 conditions—is based on a level of performance that would allow the LOS in small urban areas to deteriorate to the levels currently experienced in medium-size and large urban areas. On the other hand, it would mean significant improvement in LOS in urban areas that are experiencing acute congestion today. Essentially, this scenario represents a desire to address the needs of urban areas greater than 0.5 million in population at the expense of letting the quality of service in small urban areas deteriorate. The estimate of 220,284 lane-mi (54 percent over 1987 conditions) is based on maintaining the 1987 LOS in 2005 in all urban areas and highway functional classes. This estimate may be unrealistic, because maintaining today's quality of service in small urban areas is neither necessary nor possible given current trends in highway financing.
2. Suburban needs account for 75 to 88 percent of all urban needs. In Scenarios 1 and 2, the suburban needs are 88 percent of all urban needs compared with nearly 75 percent in Scenarios 3 through 5. This difference can be attributed mainly to the higher estimates of needs for nonfreeway facilities when maintaining the 1987 level of performance.
3. For large urban areas and for the same level of future travel growth, the suburban needs to maintain 1987 LOS (Scenario 1) are nearly twice the needs when maintaining DSI (Scenario 3). This finding indicates that, on average, over all functional classes the BSI in the suburbs and fringe of large urban areas is still better than the DSI (equivalent to LOS D in large urban areas). However, more lane-miles of freeways and expressways are required to maintain DSI than to maintain the 1987 LOS. On the other hand, to maintain 1987 LOS in highway functional classes, other principal arterials would

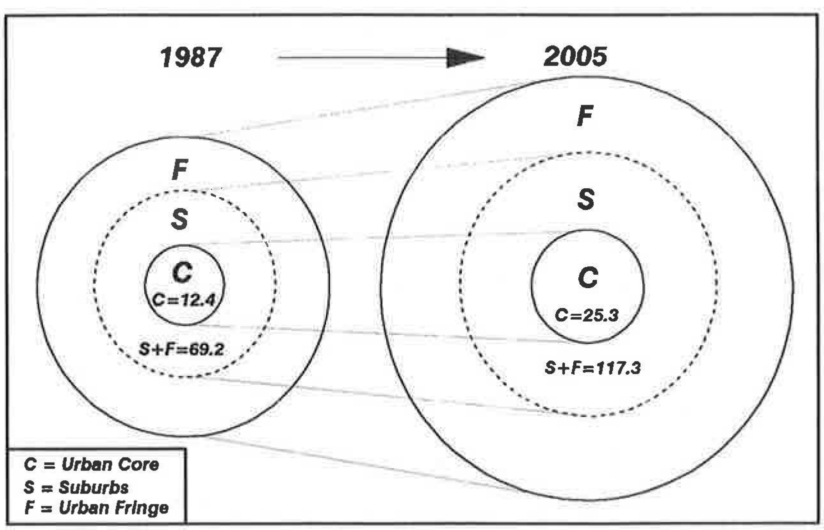

FIGURE 2 Current and future freeway and expressway lane-miles for Scenario 4 (in thousands).

TABLE 3 1987 HIGHWAY LANE-MILES

Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	7,990	10,875	23,704	42,569
		Suburb+Fringe	47,137	64,504	142,711	254,352
Medium (0.1-0.5M)	149	Core	3,481	6,294	12,819	22,594
		Suburb+Fringe	17,158	30,678	63,530	111,366
Small (0.05-0.1M)	136	Core	892	2,077	4,091	7,060
		Suburb+Fringe	4,887	12,311	24,641	41,839
All	339	Core	12,363	19,246	40,614	72,223
		Suburb+Fringe	69,182	107,493	230,882	407,557

TABLE 4 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 1

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	3,826 (48%)	4,633 (43%)	7,258 (31%)	15,717 (37%)
		Suburb+Fringe	26,466 (56%)	32,000 (50%)	53,349 (37%)	111,815 (44%)
Medium (0.1-0.5M)	149	Core	807 (23%)	1,159 (18%)	2,242 (17%)	4,208 (19%)
		Suburb+Fringe	8,584 (50%)	12,401 (40%)	26,771 (42%)	47,756 (43%)
Small (0.05-0.1M)	136	Core	496 (56%)	1,013 (49%)	1,919 (47%)	3,428 (49%)
		Suburb+Fringe	2,661 (54%)	5,054 (41%)	10,342 (42%)	18,057 (43%)
All	339	Core	5,129 (41%)	6,805 (35%)	11,419 (28%)	23,353 (32%)
		Suburb+Fringe	37,711 (55%)	49,455 (46%)	90,462 (39%)	177,628 (44%)

Needs with BSI (1987 level of service for all urban areas) under a projected 2.36% average annual growth rate in highway travel.

TABLE 5 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 2

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	4,700 (59%)	5,781 (53%)	9,481 (40%)	19,962 (47%)
		Suburb+Fringe	31,925 (68%)	39,178 (61%)	67,804 (48%)	138,907 (55%)
Medium (0.1-0.5M)	149	Core	1055 (30%)	1,560 (25%)	3,049 (24%)	5,664 (25%)
		Suburb+Fringe	10,448 (61%)	15,489 (50%)	33,166 (52%)	59,103 (53%)
Small (0.05-0.1M)	136	Core	595 (67%)	1,236 (59%)	2,342 (57%)	4,173 (59%)
		Suburb+Fringe	3,193 (65%)	6,307 (51%)	12,774 (52%)	22,274 (53%)
All	339	Core	6,350 (51%)	8,577 (45%)	14,872 (37%)	29,799 (41%)
		Suburb+Fringe	45,566 (66%)	60,974 (57%)	113,744 (49%)	220,284 (54%)

Needs with BSI (1987 level of service for all urban areas) under a projected 2.72% average annual growth rate in highway travel.

TABLE 6 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 3

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	10,435 (131%)	6,575 (60%)	5,360 (23%)	22,370 (53%)
		Suburb+Fringe	35,686 (76%)	15,949 (25%)	10,141 (7%)	61,776 (24%)
Medium (0.1-0.5M)	149	Core	605 (17%)	481 (8%)	376 (3%)	1,462 (6%)
		Suburb+Fringe	4,459 (26%)	3,214 (10%)	3,143 (5%)	10,816 (10%)
Small (0.05-0.1M)	136	Core	284 (32%)	442 (21%)	299 (7%)	1,025 (15%)
		Suburb+Fringe	835 (17%)	1,110 (9%)	674 (3%)	2,619 (6%)
All	339	Core	11,324 (92%)	7,498 (39%)	6,035 (15%)	24,857 (34%)
		Suburb+Fringe	40,980 (59%)	20,273 (19%)	13,958 (6%)	75,211 (18%)

Needs with DSI (LOS D for large urban areas and LOS C for medium and small urban areas) under a projected 2.36% average annual growth rate in highway travel.

TABLE 7 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 4

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	11,794 (148%)	7,841 (72%)	6,744 (28%)	26,379 (62%)
		Suburb+Fringe	41,631 (88%)	21,081 (33%)	13,965 (10%)	76,677 (30%)
Medium (0.1-0.5M)	149	Core	765 (22%)	647 (10%)	535 (4%)	1,947 (9%)
		Suburb+Fringe	5,457 (32%)	4,325 (14%)	4,334 (7%)	14,116 (8%)
Small (0.05-0.1M)	136	Core	331 (37%)	550 (26%)	382 (9%)	1,263 (18%)
		Suburb+Fringe	1009 (21%)	1,423 (12%)	870 (4%)	3,302 (8%)
All	339	Core	12,890 (104%)	9,038 (47%)	7,661 (19%)	29,589 (41%)
		Suburb+Fringe	48,097 (70%)	26,829 (25%)	19,169 (8%)	94,095 (23%)

Needs with DSI (LOS D for large urban areas and LOS C for medium and small urban areas) under a projected 2.72% average annual growth rate in highway travel.

require twice as many lane-miles and minor arterials and collectors nearly four times the lane-miles required under comparable DSI scenarios.

4. Large urban areas account for nearly 85 percent of urban needs in Scenarios 3 through 5, compared with only 64 percent under Scenarios 1 and 2. Similarly, the freeway and expressway needs are only 20 percent of all urban needs in Scenarios 1 and 2, compared with over 50 percent in Scenarios 3 through 5. For both 1987 LOS (Scenarios 1 and 2) and DSI scenarios (3, 4, and 5) at the same level of future travel growth, the highway needs for freeways and expressways are not as radically different as they are for other functional classes. These numbers illustrate the extent of primary highway system needs in large urban areas in the future.

5. Freeway and expressway needs in suburban areas are estimated to be from a low of 37,711 lane-mi in Scenario 1 to a high of 66,856 lane-mi in Scenario 5, with most needs being in large urban areas. In Scenarios 1 and 2, nearly 70 percent of the freeway and expressway needs are in large urban areas. For Scenarios 3, 4, and 5, this proportion is nearly 85 percent. The methodology employed did not include the cost-effectiveness aspects of various highway functional classes. Instead, the analysis relied on the shift in highway usage as a function of population.

6. The urban highway needs estimates range from 100,068 lane-mi (Scenario 3) to 250,000 lane-mi (Scenario 2). An estimate of 171,392 unconstrained lane-mi for the period between 1985 and 2005 is indicated in FHWA Working Paper 14 (*9*). The term "unconstrained" implies that additional lane-miles can be provided regardless of feasibility of capacity expansion on the HPMS segments. However, the procedure as well as the assumptions made in deriving these needs es-

TABLE 8 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 5

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	15,533 (194%)	11,357 (104%)	10,863 (46%)	37,753 (89%)
		Suburb+Fringe	58,190 (123%)	36,244 (56%)	28,728 (20%)	123,162 (48%)
Medium (0.1-0.5M)	149	Core	1105 (32%)	1054 (17%)	955 (7%)	3,114 (14%)
		Suburb+Fringe	7,657 (45%)	7,106 (23%)	7,474 (12%)	22,237 (20%)
Small (0.05-0.1M)	136	Core	331 (37%)	550 (26%)	382 (9%)	1,263 (18%)
		Suburb+Fringe	1009 (21%)	1,423 (12%)	870 (4%)	3,302 (8%)
All	339	Core	16,969 (137%)	12,961 (67%)	12,200 (30%)	42,130 (58%)
		Suburb+Fringe	66,856 (97%)	44,773 (42%)	37,072 (16%)	148,701 (36%)

Needs with DSI (LOS D for large urban areas and LOS C for medium and small urban areas) under a projected 3.48% average annual growth rate of highway travel (free from supply constraints).

TABLE 9 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005—ALL SCENARIOS AND FHWA ESTIMATE (*9*)

Highway Functional Class	Additional Requirements over 1987 Lane-Miles by Scenario					FHWA* Estimate (1985-2005)
	1	2	3	4	5	
Freeways & Expressways	42,840 (53%)	51,916 (64%)	52,304 (64%)	60,987 (75%)	83,825 (103%)	60,406
Other Principal Arterials	56,260 (44%)	69,551 (55%)	27,771 (22%)	35,867 (28%)	57,735 (46%)	52,685
Minor Arterials & Collectors	101,881 (38%)	128,616 (47%)	19,993 (7%)	26,830 (10%)	49,272 (18%)	58,301

TABLE 10 SUMMARY OF 1987 AND 2005 LANE-MILES FOR 339 URBAN AREAS

Highway Functional Class	Location	1987	Future Lane-Miles by Scenario					FHWA* Estimate
			1	2	3	4	5	
Freeways & Expressways	Core	12,363	17,492	18,713	23,687	25,253	29,332	
	Suburb+Fringe	69,182	106,893	114,748	110,162	117,279	136,038	
	Total	81,545	124,385	133,461	133,849	142,532	165,370	139,057
Other Principal Arterials	Core	19,246	26,051	27,823	26,744	28,284	32,207	
	Suburb+Fringe	107,493	156,948	168,467	127,766	134,322	152,266	
	Total	126,739	182,999	196,290	154,510	162,606	184,473	177,078
Minor Arterials & Collectors	Core	40,614	52,033	55,486	46,649	48,275	52,814	
	Suburb+Fringe	230,882	321,344	344,626	244,840	250,051	267,954	
	Total	271,496	373,377	400,112	291,489	298,326	320,768	321,779

Notes: (1) Scenario 1: BSI (1987 service level), constrained demand, annual travel growth = 2.36%.
(2) Scenario 2: Same as above, but with annual travel growth = 2.72%.
(3) Scenario 3: DSI (LOS D for large and LOS C for medium/small urban areas), constrained demand, annual travel growth = 2.36%.
(4) Scenario 4: Same as (3) but with annual travel growth = 2.72%.
(5) Scenario 5: Same as (4) but with unconstrained demand and annual travel growth = 3.48%.
(6) * The numbers are obtained by adding the 1985 lane-miles from the 339 urban areas to the highway needs estimate in "The Future National Highway Program 1991 and Beyond," Working Paper No. 14 [9].

timates are not clear from the working paper. In any case, the freeway and expressway needs estimates given in the working paper are nearly the same as the Scenario 3 and 4 estimates, which are perhaps more realistic than the other scenarios. For the same scenarios, however, the estimates for nonfreeway facilities are considerably higher. Without a good understanding of the study methodology, such differences or similarities cannot be explained.

SUMMARY AND CONCLUSIONS

The results of this study suggest that urban travel will increase at an average annual rate of between 2.36 and 2.72 percent by 2005. The annual growth in urban travel could be as much as 3.48 percent if sufficient supply of the primary highway system can be provided in urban areas with a population greater than 0.5 million (i.e., the latent demand could be accommodated). A forecast of 2.72 percent annual travel growth, which is equivalent to a total growth of nearly 56 percent between 1987 and 2005, is used as the basis for the discussion.

To accommodate this travel growth while maintaining the 1987 level of performance, it is estimated that 220,284 lane-mi of additional highway capacity will be needed in suburban areas. Over 70 percent (138,907 lane-mi) of this additional capacity will be needed in urban areas with a population greater than 0.5 million. The primary highway system accounts for nearly 50 percent (106,540 lane-mi) of these needs. Suburban needs are nearly 90 percent of all urban needs under this scenario. For the scenario based on the DSI, suburban highway needs are estimated to be 94,095 lane-mi with over 80 percent needed in large urban areas. The findings suggest that, without further addition of highway capacity, the average LOS in small and medium-size urban areas can be expected to be slightly worse than those reflected by the DSI (LOS C) by 2005. The primary highway system accounts for nearly 80 percent of needs in this DSI scenario. Regardless of the LOS desired, the total freeway and expressway needs estimates are nearly the same.

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REFERENCES

1. C. Fleet and P. DeCorla-Souza. *Supply and Use of the Nation's Urban Highways.* Highway Planning Technical Report, FHWA-ED-89-051. FHWA, U.S. Department of Transportation, 1989.
2. B. E. Peterson. *National Highway Network Analysis.* Oak Ridge National Laboratory, Oak Ridge, Tenn., 1989.
3. *The Future National Highway Program 1991 and Beyond: Highway Performance and Investment Analysis.* Working Paper 13. FHWA, U.S. Department of Transportation, 1987.
4. *America's Challenge for Highway Transportation in the 21st Century.* Interim Report of the National Highway Program Task Force. FHWA, U.S. Department of Transportation, 1987.
5. U.S. Department of Transportation (Office of the Secretary of Transportation.) *The Status of the Nation's Highways: Conditions and Performance.* Report to the U.S. Congress. U.S. Government Printing Office, Washington, D.C., 1987.
6. *The Future National Highway Program 1991 and Beyond: Changing Demographics and Economic Base.* Working Paper 1. FHWA, U.S. Department of Transportation, 1988.
7. *The Future National Highway Program 1991 and Beyond: Trends and Forecasts of Highway Passenger Travel.* Working Paper 2. FHWA, U.S. Department of Transportation, 1988.
8. *The Future National Highway Program 1991 and Beyond: Overall Highway System Requirements and Investment Levels.* Working Paper 14. FHWA, U.S. Department of Transportation, 1987.
9. *The Future National Highway Program 1991 and Beyond: An Evaluation of the Economic Efficiency of New Highway Capacity on Alternative Facility Classes.* Working Paper 3. FHWA, U.S. Department of Transportation, 1988.
10. *Analysis of Future Urban Needs: Capital Investment Requirements for New Highway Capacity.* Working Paper 2. FHWA, U.S. Department of Transportation, 1990.
11. F. Southworth, *VMT Forecasting for National Highway Planning: A Review of Existing Approaches.* Oak Ridge National Laboratory; Office of Policy Planning, FHWA, U.S. Department of Transportation, 1986.
12. D. L. Greene. Long-Run Vehicle Travel Prediction from Demographic Trends. In *Transportation Research Record 1135*, TRB, National Research Council, Washington, D.C., 1987, pp. 1–9.
13. Y. Chan. Highway Travel and Fuel Consumption from 1970 to 1980. *Transportation Quarterly*, Vol. 39, 1985, pp. 39–57.
14. COMSIS Corporation. *Development of VMT Forecasting Model: Phase I and II Reports.* U.S. Department of Transportation, 1981.
15. Jack Faucett Associates. *The FHWA/Faucett VMT Forecasting Model.* FHWA, U.S. Department of Transportation, 1988.
16. D. Griffith. Evaluating the Transformation from a Monocentric to a Polycentric City. *Professional Geographer,* Vol. 33.2, 1981, pp. 189–198.
17. D. L. Greene. Urban Subcenters: Recent Trends in Urban Spatial Structure. *Growth and Change*, Vol. 11, 1980, pp. 29–40.
18. Y. Zahavi, M. Beckmann, and T. Golob. *The UMOT/Urban Interactions.* Mobility Systems Inc.; Research and Special Programs Administration, U.S. Department of Transportation, 1981.
19. *Highway Performance Monitoring System Analytic Process, Vol. II—Version 2.1.* FHWA, U.S. Department of Transportation, 1987.
20. *Highway Performance Monitoring System Field Manual.* FHWA, U.S. Department of Transportation, 1987.
21. *MSA Profile: Metropolitan Area Forecasts to 2010.* Woods and Poole Economics, Inc., Washington, D.C., 1989.
22. S. P. Miaou, A. K. Rathi, F. Southworth, and D. L. Greene. *Forecasting Urban Highway Travel for Year 2005.* Oak Ridge National Laboratory; Office of Policy Development, FHWA, U.S. Department of Transportation, 1990.
23. A. K. Rathi, S. P. Miaou, F. Southworth, and B. P. Peterson. *National Highway Network Analysis: Suburban Needs Estimates.* Oak Ridge National Laboratory; Office of Policy Development, FHWA, U.S. Department of Transportation, 1990.
24. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.

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