PROJECTING COSTS FOR ROADS UNDER VARIOUS GROWTH SCENARIOS

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Abstract

The State of New Jersey Office of State Planning (OSP) has developed a spreadsheet based computer model which allocates growth projections, estimates future incomes and housing needs by municipalities, and then evaluates the impacts of this future growth on several infrastructure systems. This paper describes the road impact model.

The road model is based on detailed information, provided by the New Jersey Department of Transportation, which describes the supply of roads (lane-miles of roadway), by type of road, in each of the State's 567 municipalities. Rather than attempting to simulate future travel demands, the model is based on the assumption that the supply of roadway has been adjusted over time to meet the travel needs of the population. In fact, a very high correlation was discovered between municipal population density and the supply of roadways. Further analysis of this relationship led to the identification of adjustments for urban, suburban, and rural areas. Once future road needs were estimated, the model produces capital costs to build, but not acquire, the roadways. Because the model is sensitive to changes in municipal density it is useful for regional analysis, but can not be used to address sub municipal highway costs.

Use of the model to analyze various regional planning scenarios has been encouraging. A test of a scenario in which future growth was redistributed to the more urbanized portions of a county generated capital cost savings of almost $100 million (13.5%) by the year 2010.

Introduction

Since 1988 the New Jersey Office of State Planning (OSP) has been developing computer models to simulate both future demographic and economic conditions and various trend and regional planning scenarios. This paper describes that portion of the Office of State Planning (OSP) computer model, referred to as the Roads model, which estimates capital costs for new roadways under future growth scenarios.

User inputs required to run the model include municipal-level population projections for the target year, (which can be entered by the model user or generated by other OSP models) and construction cost per lane-mile for both State and local roads. The model runs at a municipal scale and is sensitive to alternative distributions of municipal population. However, the user may also select a factor that calculates the effect of sub-municipal compact development, a major policy recommendation of the New Jersey's State Development and Redevelopment Plan. Results are calculated and reported by municipality, and can be aggregated to any region comprising municipalities.

The methodology used in this model is unconventional but not unknown in the transportation literature. Because of the quantity of data required at the state level, we have bypassed traditional origin/destination approaches in favor of a simple statistical correlation between municipal population and road densities. Transportation planners have recognized that

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the analysis of this relationship can replicate results that would be obtained using information on traffic generated by more conventional methods.[1]

The strong relationship identified between population and road densities suggests that roads have been built to accommodate population in a predictable way. Since our main goal is to compare the effects of different distributions of growth, we feel justified in assuming that the existing relationship between local population density and road building will continue.

This is not to say that this relationship will not change in the future as a result of other government policies (such as transportation demand management or changes in fuel taxes). The roads model is designed to be more of a comparative than a predictive tool: it focuses on the impact of land use patterns, other things being equal.

Thus the model incorporates assumptions about such variables as service levels, vehicle ownership, modal splits and commuting behavior. The analysis of these additional variables, though important, is beyond the scope of this study.

Cost Projection Methodology

The basic algorithm for calculating future road costs in any municipality is as follows.

$$\text{Cost} = (\text{future lane miles required} - \text{existing lane miles}) \times \$/\text{lane mile} \qquad (1)$$

This simple equation is sufficient to handle a variety of situations, including those in which an existing road network or compact development reduce future road requirements. Costs for State and local road systems are calculated separately. The following sections explain each component of equation #1 in greater detail.

Existing Lane Miles

An inventory of existing land miles by municipality for both State and local roads was obtained from the New Jersey Department of Transportation (NJ DOT). The Department of Transportation provided two datasets which together constitute a comprehensive inventory of roads in the State.

The first dataset, dated December 31, 1987, lists total center-line miles by municipality for state highway system. The second dataset, entitled "mileage from inventory" lists center-line miles by municipality for county and municipal roads. NJ DOT has verified that the municipal and county inventory is the latest data available, representing surveys conducted from 1980 to 1987.

These inventory files contain information on center-line (linear) miles, while equation #1 requires information on existing lane-miles. Existing center-line miles were therefore converted to lane-miles using the following assumptions:

- All roads in the municipal and county inventory are 2-lane roads[2].
- Roads in the State inventory are adjusted to lane-miles using a county-wide ratio of lane-miles to center-line miles. These ratios were calculated from an NJ DOT dataset entitled "mileage statistics data from PSM files -- mileage by municipality by functional class for State, Authority, and other Primary Routes in FAP Sub-File." The methodology for calculating these ratios is described later in this paper.

Construction Costs per Lane-Mile

Construction costs per lane-mile are selected from a dialog list box by the user. (The model user may also elect to enter a number of their own invention if they choose). The model is currently running with a default costs of $1,000,000/lane-mile for both State and local roads. This is an OSP estimate based on interviews with NJ DOT personnel. Although State roads are normally more expensive to construct than local roads, we have standardized costs on the assumption that State roads will only be widened, which is less expensive than road extension.

NJ DOT reviewers suggested that it would be useful to program regional cost differentials into the model. To this end, NJ DOT provided OSP researchers with construction cost information for a sample of recent State highway widening projects. NJ DOT classified the projects into three groups: "dense urban," "urban/suburban" and "rural". NJ DOT calculated average lane-mile costs for each group. A map was also provided which delineated the Department's opinion on boundaries between the three cost areas.

After generalizing this mapped information so that the boundaries corresponded to municipalities, it became possible to program regional cost differentials into the OSP computer model. In effect, the user-selected lane-mile cost ($1,000,000 default) is considered the "urban/suburban" cost. This figure is adjusted upward for DOT "dense urban "municipalities and downward for DOT "rural" municipalities. The factor used to adjust the cost is the ratio of averages from the NJ DOT sample described above. The result is a model that permits the user to select a general cost level (driven, perhaps, by the user's definition of what ought to be included in construction costs); this cost level is then adjusted using real-world data on regional cost differentials.

Projection of Lane-Miles Required

The calculation of future lane-mile requirements makes this model unique. This portion of the model utilizes the existing relationship between population and road densities. This is also where assumptions about existing capacity or PLAN design features are incorporated.

Different techniques are used to project State and local road needs under PLAN and TREND. A description of the methodologies follows.

Calculation of Local Road Needs

Local road needs are calculated by carrying forward the current relationship between road and population densities at the municipal scale. Linear regression analysis is used to model this relationship.

Trend Scenario

Figure 1 depicts the relationship used to project local road needs under TREND. All 567 municipalities are plotted. The vertical axis depicts the 1987 density of local roads in 1987 in center-line miles per square mile. The horizontal axis depicts municipal residents per square mile in 1985.

Regression analysis reveals a strong correlation between the two variables when the data are transformed by taking natural logs (see figure 2). The test statistics from this regression are shown in Table 1 below; parameters from the regression are graphed in figure 3.

figure 1
Local Road Mileage per Square Mile as a Function of Population Density

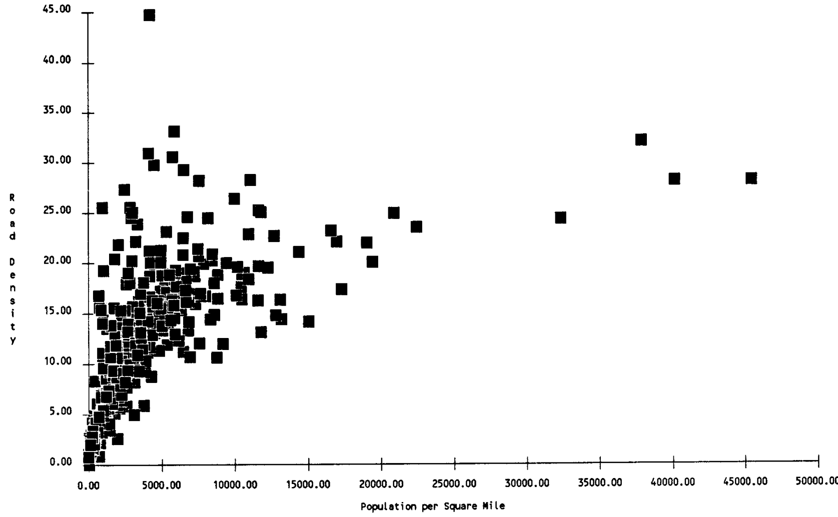


figure 2
Local Road Mileage per Square Mile as a function of Population Density

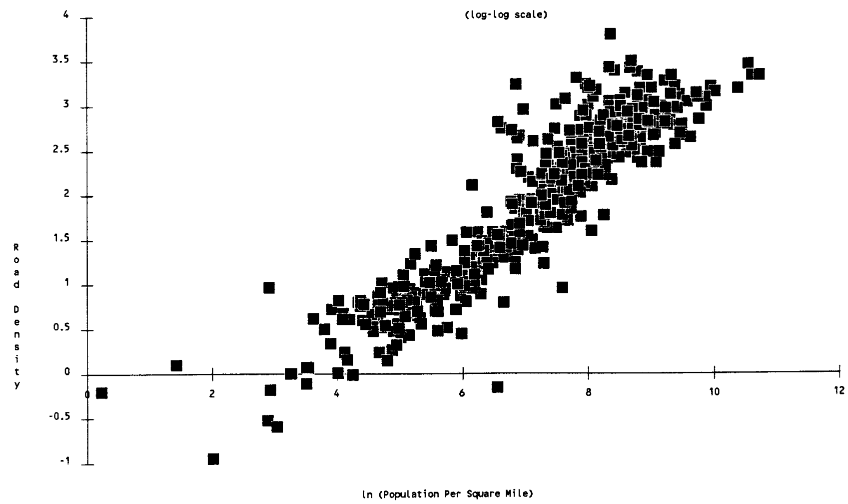


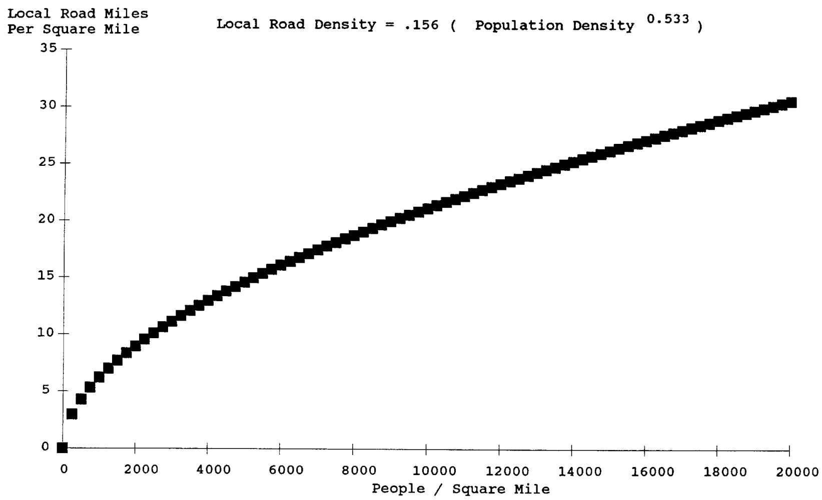
table 1
Regression Results: Local Road Density as a Function of Population Density(Log-Log form)

Dependent variable: LNG (local road miles/municipal area)
Independent variables:

VARIABLES	PARAMETER EST.	S.E.	PROB > T
Intercept	-1.86597	.06764	.0001
LOGPOP	.53302	.00924	.0001
HUD	-0.49475	.10128	.0001

F-value: 1696.41 (.0001)
Degrees of Freedom: 562
Adjusted R-Squared: .8574

figure 3



Figures 1 and 3 suggest that the relationship between local road density and population density in the 1980's followed a curve that is concave to the horizontal axis. Actually, common sense suggests that the curve should approach an asymptote parallel to the horizontal axis (corresponding to a town that is mostly paved over). Using the log-linear form for the regression analysis is a simplification, but it is suitable for simulation purposes. The simulation of a road density "ceiling" is handled elsewhere in the model.

The line depicted in Figure 3 represents an average for the mid-1980's. Municipalities that lie above or below this line vary in predictable ways from the average. They may be older or less residential, or they may have a different pattern of urban design. Indeed, if two municipalities have the same population density (i.e., position on the horizontal axis), then their relative positions on the vertical axis may be a good measure of the amount of sprawl found within their borders.

Assuming that this cross-sectional relationship can be used to describe longitudinal changes in New Jersey municipalities, an additional conclusion can be drawn. The decreasing slope of the curve suggests that sparsely populated municipalities need to build more miles of local road per new resident than do densely populated municipalities.

In other words, the slope of the relationship depicted in Figure 3 may be a good proxy for a deficient road net (high marginal costs to growth) in rural areas[3]. An analysis of the intercept (perhaps through dummy variables) may provide insight into issues of design and compactness.

Projecting Local Road Needs under TREND. We have assumed for purposes of projecting local road requirements under TREND that future road-building in any municipality will start at the 1980's legacy (the point depicted for that municipality in Figure 1) and proceed according to the historical pattern that has been identified (along the slope shown in Figure 3). Thus, the coefficient for LOGPOP calculated in Table 1 is the only parameter required; the simulation equation takes the following form:

Local Road Density under TREND =

$$e^{[\ln(popden85) + .533(\ln(newpopden) - \ln(popden85))]} \qquad (2)$$

Once future municipal road density is projected, linear and lane-miles of local road can easily be calculated. The following equation is used:

Lane-miles of road required in each municipality (3)
= 2 x projected center-line miles
= 2 x [(projected center-line road density) x area in sq. miles]

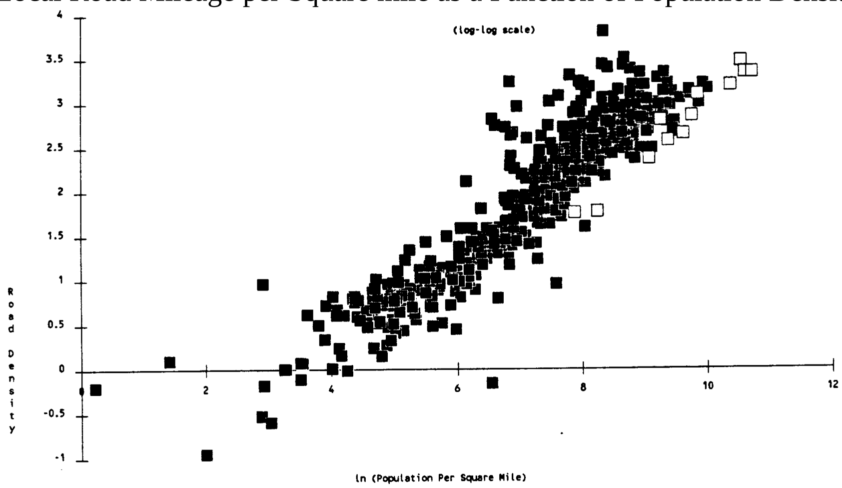
In addition to these equations, the model incorporates two additional rules for projecting local road needs under TREND:

- A municipality that declines in population does not lose any roads.
- No municipality may have a local road density greater than 45 center-line miles/sq. mile, which is the highest density identified in the State.

Plan Scenario

In addition to the coefficient on population density, Table 1 contains a coefficient for a variable called "HUD." HUD is a dummy variable that attempts to measure design as a factor affecting road density independently of population density.

Figure 4
Local Road Mileage per Square mile as a Function of Population Density



Hudson County Municipalities are represented in white blocks, All other municipalities are black blocks.

The derivation of the HUD variable is shown in Figure 4. Figure 4 is identical to Figure 2 except that a portion of the municipalities is shown in white. These are the municipalities of Hudson County, which is the county with the highest population density in the State.

We hypothesize that Hudson municipalities represent an older form of urban design -- one that is not so oriented to the automobile. At a given population density, Hudson municipalities appear to have fewer miles of road per square mile than other municipalities in the sample.

The coefficient on HUD on Table 1 was calculated by adding a dummy variable that was coded 1 for Hudson municipalities and 0 for other municipalities in the State. This is equivalent to hypothesizing that Hudson municipalities lie along a line that has the same slope but different intercept than other municipalities in New Jersey (the difference being a design factor). The coefficient on this dummy variable is significant and does not lessen the significance of the other (slope) coefficient.

Projecting Local Road Needs under PLAN. Under our simulation of TREND, all municipalities start from the mid-80's status quo and proceed along the slope calculated in Table 1. Under PLAN, we would like to project future road requirements using a reasonable estimate of the extent to which PLAN will reduce sprawl in growing communities.

The model currently uses the HUDSON intercept shift to help simulate the effect of compactness on future road-building. It is neither likely (nor, perhaps, desirable) that exurban areas will suddenly resemble Hudson's streetcar suburbs as a result of PLAN. Therefore we permit the user to determine how much of a shift will occur. When the user chooses to simulate a PLAN scenario, future local road requirements are projected by the following equation (see Table 1):

Local Road Density under PLAN =

$$e^{[\ln(\text{popden } 85) + \text{SHIFT} + .533(\ln(\text{newpopden}) - \ln(\text{popden85}))]} \quad (4)$$

where SHIFT is a constant between 0 and -.495, depending on user choice.

As in the TREND case, we must incorporate additional programming rules to keep road-building estimates within reasonable bounds. In addition to the two rules described above for TREND (i.e., no road decline and a fixed ceiling of 45 miles/sq. mile) we have incorporated the following:

- o Municipalities that start out at a point below the state average road-density line behave as they would under TREND>
- o Municipalities that start at a point above the state average road-density line will never fall below the average road-density corresponding to their new population density.

These two rules represent conservative assumptions about the extent to which better planning can influence road-building in municipalities with various initial characteristics.

Taken together, these rules lead to a reasonable model of future road densities under PLAN. The shape of the average density curve shown in Figure 3, for example, combined with the assumption that road density does not decline, means that as modeled here, PLAN has less effect on road-building in the more densely populated municipalities of the State than in the less dense municipalities. This outcome makes sense, since the road net is largely fixed in these places.

To the extent that the PLAN model alternative reduces road requirements in moderately dense areas, an appropriate interpretation would be that more redevelopment and infill are occurring than under TREND. This seems to be a reasonable simulation of PLAN intent.

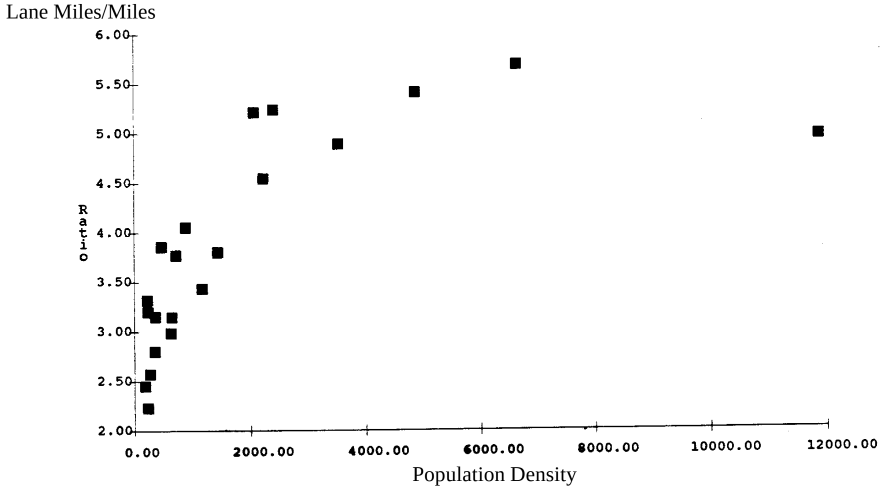
Calculation of State Road Needs

The calculation of future State road needs is somewhat different from the calculation of local road needs. Instead of assuming that all roads are 2-lane roads and estimating center-line road density as a function of population density, we assume that State roads will only be widened in the future[4]. Thus we need to estimate and incorporate the relationship between municipal population density and the average width of State roads.

Our basic road inventory files do not contain information on road width (i.e., lane-miles, as opposed to center-line miles). Another NJ DOT data source, however, provides a way of estimating road width for State roads. This source is entitled "mileage statistics data from PSM files -- mileage by municipality by functional class for State, Authority, and other Primary

Routes in FAP Sub-File," and was submitted to the Office of State Planning along with the inventory files described above.

figure 5
Ratio of Lane Miles to Miles as a Function of Population Density



Because it lists lane-miles and center-line miles for State and Authority roads in each municipality, this datafile provides a method for estimating average State road width by jurisdiction. Figure 5 displays the relationship between population density and the ratio of lane-miles to center-line miles for "State, Authority, and other Primary Routes." The data are shown for each of New Jersey's 21 counties.

Figure 5 reveals the asymptotic relationship identified earlier in our comparisons of local road building and population density. The ratio of lane-miles to center-line miles increases most sharply in the less densely populated counties and levels off in the denser counties. As before, a logarithmic transformation of the data yields a significant relationship. The result of this regression analysis is shown in Table 2.

table 2
Regression Results: Ratio of State Lane-miles to Center-Line-miles as a Function of Population Density
(Log-Log form)

Dependent variable: Ln(ratio)
Independent Variables:

VARIABLE	PARAMETER EST.	S.E.	PROB > T
Intercept	-0.07991	.16784	.6394
LOGDEN	.20283	.02414	.0001

F-value: 70.577 (.0001)
Degrees of Freedom: 19
Adjusted R-Squared: .7767

Projecting State Road Needs under PLAN and TREND

Use of these parameters to project future State road requirements is the same under PLAN or TREND[5]. Given center-line miles from our existing inventory, an assumption that State roads will only be widened, and an assumption that the relationship between State lane-miles and center-line miles shown in Figure 5 continues to hold, one can easily calculate the number of new State lane-miles that must be built to accommodate growth in each municipality. The equation for this calculation follows:

State lane-miles required =

$$\text{(existing lane-miles)} * e^{[.203(\ln(\text{newpopden})]} \quad (5)$$

As before, no decline in lane-miles is permitted an any municipality. The calculated value of future lane-miles of State road required in each municipality is used directly in equation #1 to calculate the increment in lane-miles, and, ultimately, the total capital cost for State roads.

Conclusion

This paper has described a methodology for projecting future road costs for the State and local road systems. The model assumes existing service levels, modal splits and commuting patterns. Its municipal-level analysis of the relationship between population and road density permits the user to measure the costs of any future growth scenario that can be characterized by municipal population projections.

The model however is not perfect. It does not estimate right-of-way acquisition costs. It does not evaluate the very high cost of maintaining the existing roadway system. The model produces more satisfying results in estimating local road costs than state road costs. The relatively small size of New Jersey, its very high cost of housing and the recent development (last 20 years) of service industries in the center and north center of the State have resulted in substantially increased highway travel by out-of-state residents traveling to jobs in New Jersey. The impact of these work commuters is not represented in the model.

Despite these shortcomings, use of the model to analyze various growth scenarios has been encouraging. A test of a scenario in which future growth was redistributed to the more urbanized portions of a particular county generated capital cost savings of almost $100 million (13.5%) by the year 2010. The simulation of compact design (using 50% of the HUD constant) generated additional savings of almost $150 million. The model also has been used by the Rutgers University Center for Urban Policy Research to perform a legally mandated evaluation of the New Jersey State Development and Redevelopment Plan. Using 1990 population data, as opposed to the use of 1985 estimated populations used in this paper, Rutgers found higher correlations than those reported in this paper. Rutgers also found significant capital cost savings associated with the implementation of the State Plan.

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[1] For a published model that uses this approach, see U.S. Department of Transportation, Federal Highway Administration, Urban Planning Division, Land Use and Arterial Spacing in Suburban Areas (Washington, DC: US Department of Transportation, August 1982).

[2] this assumption is supported by interviews with NJ DOT personnel, and by data contained in an overlapping NJ DOT dataset entitled "mileage by municipality by functional class for county and municipal routes in FAS and FAU sub-files".

[3] In effect, a case of deficient capacity.

[4] This is virtually NJ DOT policy at the present time.

[5] This does not mean that Plan is modeled as having no effect on State road requirements. Since we only allow for the widening of State roads, however, the issue of linear design does not apply.