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Density, Design and Infrastructure Costs:
Physical Survey of New Jersey Development

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Prepared by:
The New Jersey Office of State Planning
33 West State Street, CN 204
Trenton, New Jersey 08625-0204

Density, Design and Infrastructure Costs:
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This report was written, and statistical analyses conducted by Paul Gottlieb of the Office of State Planning's research unit. The study design was developed by Mr. Gottlieb, James Reilly and William Bauer, who also collected the data analyzed here.

I. INTRODUCTION

A major recommendation in the State Development and Redevelopment Plan is that growth in the State's more rural areas be concentrated into mixed use developments, called Communities of Place.

The objectives of this strategy are threefold:

1. To reduce the horizon year (2010) demand for land by increasing densities. This allows for a more orderly and phased program of public and private acquisition of land or land easements, to insure the future supply of open space. It also provides for an undeveloped land reserve adequate to accommodate growth beyond the horizon year.

2. To preserve the quality of the State's natural resources, especially its water quality. The higher densities recommended for Communities of Place will require that such places be served with both sewers and water supply infrastructure systems. The plan presumes that beneficial effects will accrue from the use of these systems, as opposed to a less dense development pattern utilizing on-site septic systems and wells.

3. To insure that cost-efficiencies will be achieved through the provision of infrastructure serving higher density development. Intuitively it appears that provision of services to more compact development requires fewer linear feet of roads, water mains, storm sewers and sewer pipes.

Planners have often assumed, quite logically, that increased density yields cost-efficiencies in the provision of infrastructure. Yet this proposition has generated considerable academic controversy. The first famous investigation of this assumption occurred in 1974, when the Federal Government (HUD, EPA, CEQ) published the Costs of Sprawl study prepared by the Real Estate Research Corporation. Since the release of this study there has been severe criticism of its methodology, such that today the study is not perceived as credible.

The purpose of the New Jersey Office of State Planning's series of papers on Density, Design and Infrastructure is not to settle an argument that an entire generation of scholars has failed to resolve. Our much more limited goals are defined by the three papers in this series:

In Part I, "Literature Review," we weigh the evidence on both sides and make reasoned arguments about the likely impact of the Plan's regional design system on infrastructure costs.

In Part II, "Physical Survey of New Jersey Development," we attempt to quantify the relationship between density, design, and linear infrastructure systems using a sample of actual New Jersey developments.

In Part III, "Recommendations for the Regional Design System," we attempt to translate the research of parts I and II into the language of planners. Here we prepare recommendations for the design of Communities of Place that can reasonably be expected to meet the Plan's goal of providing "adequate public services at reasonable cost."

It should be noted that all of the papers in this series deal with only one of the rationales for compact development: cost efficiencies in the provision of infrastructure systems. Even if all the arguments made in parts I, II and III of this series were to be regarded as unpersuasive, the natural resources/open space justification for Communities of Place would remain.

Part II: Physical Survey of New Jersey Development

The present paper, part II of the series, attempts to quantify the relationship between density, design and linear infrastructure systems using data on actual developments in New Jersey. The general approach was to generate a large and diverse sample of residential development patterns using 1986 aerial photoquads at the 1:24,000 scale. For each development pattern, measures were made of density, design (degree of cluster), and length of the linear road net. Descriptive statistics were reported in order to give a picture of these variables for New Jersey development, circa 1986.

In the second part of the study, a statistical analysis was conducted in order to identify the relationship between density/design on the one hand, and per-unit road requirements on the other. To the extent that other linear infrastructure systems -- particularly sewer collectors -- are built beneath or parallel to local roads, these results can be extended to several infrastructure systems.

Since no fieldwork was conducted, it was necessary to restrict the sample to single-family residential development, which is easily identifiable from the air. One must therefore exercise caution before extending the results of this analysis to developments containing mixed-use or multi-family structures (even though intuitively, multi-family development could be expected to increase infrastructure cost-efficiencies far beyond those identified here.)

II. SAMPLING METHODOLOGY

[The Cost of Sprawl study was designed to examine the savings effect associated with cluster development. Theoretically, given two tracts of land with identical acreage and identical dwelling unit density, a cluster development pattern would be associated with less road length and presumably less sewer length than a typical grid pattern of development. Hence, the design of the cluster pattern would represent a cost savings in addition to open space preservation. In order to test this hypothesis, the Research Division of the Office of State Planning needed to examine numerous samples of housing development in the State of New Jersey and associated road lengths.]

[In order to determine "cluster" some measure of undeveloped land within a larger tract was necessary. The larger tract needed to be uniform in size so that overall acreage would be constant. Cluster and large tract total density would be determined through a count of housing units at a sub grid level. Road length would be calculated and later compared with large tract total density and "cluster".]

To conduct the study on New Jersey physical development, the following materials were used: a New Jersey photoquad set from the March 1986 flight showing December 1988 preliminary tier delineations, an electronic digital curvimeter, and clear plastic sheets with 20-acre grids (divided into 16 squares of 1.25 acres each) drawn at the 1:24,000 scale.

The tier delineation photoquad set covered that part of the State not under jurisdiction of the Hackensack Meadowlands Commission, the Pinelands Protection Act, or the Coastal Area Facilities Review Act. Therefore substantial parts of the State of New Jersey are not included in the study. (See Figure 1 for a map showing photoquads used.)

The twenty-acre grids were placed on the photoquads. Center-line road lengths within each grid were calculated using an electronic digital curvimeter (naturally, driveways were excluded). The number of housing units in each subsquare was counted and recorded, along with photoquad number, sample number, tier delineation and road length. From this information, measures of density and cluster can be calculated, and each development sample traced back to the original photoquad for review. (Appendix A contains photocopies of several of the 20-acre samples used in the study.)

Samples were chosen based on clarity and recognition as single-family housing development patterns. The intent of this exercise was to count housing units, not industrial, commercial or office use. In consideraiton of this, major roadways and non-residential land uses were avoided.

Approximately three samples were taken from each photoquad. Exceptions to this occurred in cases where the photoquad only showed a small amount of New Jersey land covered under the State Planning Act. Eventually, 368 samples of residential development were taken from a total of xxx photoquads. For purposes of descriptive analysis, photoquads 1 through 53 were designated "northern" New Jersey; photoquads 54 through 92 "central" New Jersey; and photoquads 93 through 177 "southern" New Jersey (See Figure 1.)

The frequency distribution of observations in the sample across 1988 PSDRP tier and region is shown in Table 1 below:

Table 1

Distribution of 368 Observations of New Jersey Development Patterns

TIER	FREQUENCY	PERCENT
1	20	5.4
2	96	26.1
3	42	11.4
4	62	16.8
5	45	12.2
6A	36	9.8
6B	27	7.3
7	40	10.9

REGION	FREQUENCY	PERCENT
C	98	26.6
N	161	43.8
S	109	29.6

III. DESCRIPTION OF TREND DEVELOPMENT

A. Development of Variables

- Density

Density was calculated as the total number of units in each development sample divided by 20 acres. Since roads are not netted out, the result is a gross density in d.u.'s per acre.

- Road Length

Measured within each 20-acre grid, excluding driveways, and expressed in linear feet.

- Cluster/Design

Two variables were used. The first variable, labelled COVER, is the percentage of subsquares in each sample that contain any development. Holding density constant, the COVER variable clearly serves as a measure of cluster. The second variable, STDEV, is calculated as the standard deviation of the number of units in each subsquare, excluding subsquares that are empty. Other things equal, the STDEV variable may serve as a measure of cluster (or an inverse measure of sprawl) at a scale smaller than the full 20 acres.

Descriptive statistics for these variables in the entire sample are shown in Table 2 below:

Table 2

Descriptive statistics for Entire Sample

VARIABLE	UNITS	N*	MEAN	STD DEV	MINIMUM	MAXIMUM
ROAD	FEET	368	2405.49	1149.31	236.20	6141.73
DENSITY	GROSS DU/ACRE	368	1.58	1.29	0.05	6.30
COVER	PCT/100	368	0.71	0.29	0.06	1.00
STDEV	# OF DU'S	345	0.95	0.57	0.00	2.72

* STDEV could not be calculated for samples that contained only one dwelling unit. Thus the STDEV variable exists for only 345 observations.

B. Density by Location

Given the distribution of the sample by tier and region of the State, it ought to be possible to make statistical inferences about existing single-family density by location. This exercise is subject to two very important caveats:

1. The sample excludes all portions of the State under the jurisdiction of Pinelands, CAFRA and HMDC -- almost a third of the State's land area.

2. The sample is not random, since the researcher collecting the data selected areas of contiguous development for analysis. This might have led to bias, although it is not clear in which direction the bias would occur.

Keeping these cautions in mind, we can tentatively draw conclusions about trend densities from Table 3 below:

Table 3

Single Family Development Densities by Location
(Units/gross acre)

Tier	Sample Size	Average Density	Min	Max	Std. Dev.
1	20	4.02	1.70	6.30	1.43
2	96	2.45	.65	5.25	1.08
3	42	2.05	.15	4.00	.86
4	62	1.42	.15	3.50	.79
5	45	.77	.05	4.05	.80
6A	36	.46	.05	1.65	.33
6B	27	.30	.05	1.15	.29
7	40	.84	.05	2.65	.61

Region	Sample Size	Average Density	Min	Max	Std. Dev.
North	161	1.56	.05	6.30	1.37
Central	98	1.65	.05	5.25	1.28
South	109	1.55	.05	5.40	1.19

Several conclusions can be drawn from Table 3. First, single-family development densities appear to vary predictably by State Plan tier. Densities in our sample declined smoothly from tiers 1 to 6B before rising again in tier 7 (See Figure 2). Statistical tests suggest that these differences in average densities do, in fact, represent real differences in the residential densities underlying the sample. There are two exceptions: densities in tiers 6A and 6B, as well as 5 and 7, cannot reliably be said to differ from each other.

Second, after controlling for tier (using an ANOVA procedure), there does not seem to be any significant difference in single-family density in the north, central and southern regions of the state. This finding runs counter to widely-held beliefs about residential development in different parts of the state.[1]

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[1] See, for example, South Jersey Land Plan Coalition, "Land Availability Under the Preliminary State Development and Redevelopment Plan," May 1990, p. 4.

C. Design by Location

It was recognized early in the analysis that our measures of gross density and cluster were likely to be highly collinear: over a certain range, a dense sample of single-family development of 20 acres must cover more subsquares than a less dense sample of development. In part because of the difficulty of separating measures of design and density, we have omitted a discussion of design by location. We will return to design in our analysis of its impact on linear road lengths.

IV. IMPACT OF DENSITY ON INFRASTRUCTURE

A. Relationship between Density, Cluster and Roads

Linear regression was used to analyze per-unit length of road (dependent variable) and the various measures of density and cluster (independent variables). The coefficient on DENSITY is hypothesized to be negative; COVER, positive; and STDEV, negative.

At the outset, it was recognized that density and cluster are likely to be highly collinear.[1] In some sense, whether a land use pattern is dense or highly clustered is simply a matter of scale. This problem has not been satisfactorily resolved in the analysis.

Plots of data suggested using a log-log form for the regression equation. If one had to choose among the collinear independent variables, it appears that DENSITY provides the strongest confirmation of the hypothesis. Some of the regression results are shown below:

Model 1

DEPENDENT VARIABLE: LOG OF PER-UNIT ROAD LENGTH

PARAMETER	ESTIMATE	T-STAT	PROB>|T|
INTERCEPT	4.66	259.48	0.0
LOG DENSITY	-0.64	-39.40	0.0

N = 367

F-VALUE	PR>F
1552.39	0.0

R-SQUARE
.809

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[1] Pearson correlation coefficient of .759 between DENSITY and COVER in this sample, .844 between DENSITY and STDEV, .617 between STDEV and COVER.

Model 2

DEPENDENT VARIABLE: LOG OF PER-UNIT ROAD LENGTH

PARAMETER	ESTIMATE	T-STAT	PROB>|T|
INTERCEPT	4.61	113.77	0.0
LOG DENSITY	-0.58	-12.92	0.0001
LOG COVER	-0.10	-1.45	0.1469

N = 367

F-VALUE	PR>F
1557.11	0.0

R-SQUARE
.810

These results correspond to a decrease of approximately 3 feet of frontage for an increase in density from 6.3 to 7.3 units per acre; 67 feet decrease in frontage for an increase in density from 1 to 2 d.u.'s per acre (to describe cases in the suburban 'tails'.)

Some regressions were also run with "farm" observations (density = .05) omitted, on the grounds that the case of a single arterial road stretching across the grid was uninteresting, and that it might bias the results. Coefficient were not appreciably different, but the R-square dropped because of the leverage provided by these observations on the high-road, low-density end of the spectrum.

An attempt was made to control for collinearlity by dividing the sample into several density classes. Regression analysis of COVER within each class should yield information on the relationship between cluster and roads, holding density more or less constant.

The table on the following page shows the results of this procedure. Within each class, per-unit road length is regressed on COVER. Logarithms were not used. While the few significant results have the expected sign and magnitude, the effect of COVER on road length is largely insignificant.

This is the extent of the work done to date on this sample. The variable STDEV has not yet been analyzed.

Relationship Between Cluster and Per-Unit Road Lengths
(OSP sample adjusted for density using classes)

Density Class	Number in Sample	Significant at 5% Level?	Coefficient on COVER
3.25-6.30	49	NO	*
3.00-3.24	5	YES	121.61
2.75-2.99	14	NO	*
2.50-2.74	13	NO	*
2.25-2.49	11	NO	*
2.00-2.24	23	NO	*
1.75-1.99	25	YES	102.15
1.50-1.74	31	NO	*
1.25-1.49	18	NO	*
1.00-1.24	27	NO	*
.75-.99	31	NO	*
.50-.74	40	YES	280.72
.25-.49	43	NO	*
.200-.249	4	NO	*
.150-.199	9	NO	*
.100-.149	2	NO	*
.050-.099	23	NO	*

This table presents the results of a number of regression analyses, in which the dependent variable was per-unit road length and the independent variable was percentage of sub-grids developed (an inverse measure of cluster). Density, expressed as units per gross acre, was controlled by dividing the sample into several narrow density classes and analyzing each class separately. Where coefficients are significant, they have the hypothesized sign. They should be interpreted as follows: an increase of 1% in sub-grids covered yields X/100 additional feet of road per dwelling unit, other things equal. For example, a coefficient of 280 yields 2.8 additional feet of road per unit for each 1% increase in cover.