Limited-Access Highway Construction Costs In the Tri-State Region

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Region-wide expressway installation cost criteria have been developed for the Tri-State metropolitan area. Data were drawn from the "1965 Estimates of the Cost of Completing the National System of Interstate and Defense Highways." Expressway installation expenditure estimates were analyzed for overall road-mile and lane-mile costs and for separate cost elements, such as right-of-way, grading and surfacing, structures, interchanges, engineering, and others. All of these costs were related to gross population density. The resulting regression equations provide four different cost estimation approaches: for overall road-miles, overall lane-miles, lane-mile and separate interchange estimates, and estimation by separate road elements. All four criteria were tested by estimating construction costs for road segments, the costs of which were known but not included in the study sample. All four estimation approaches were found to give satisfactory results.

•IN planning transportation systems for metropolitan regions, at some point in the planning process it becomes necessary to estimate the costs of proposed facilities. Since such planning considers facility networks on a region-wide basis, the costs estimation criteria must reflect the regional range of development intensities. Land utilization intensities predicate the facility installation costs, especially for expressways, which require extensive land takings. These considerations influenced the choice of data, variables, and the framework of this study.

DATA USED

The study utilized data contained in the "1965 Estimates of the Cost of Completing the National System of Interstate and Defense Highways." Such estimates were prepared by each state highway department as a revision of earlier plans to complete the Interstate Highway System. As required by the U. S. Bureau of Public Roads, the estimates were to conform with the set of rules outlined in the instruction manual.

The manual emphasized that ". . . there must be substantiating calculations and records in the files of the State for every estimate submitted and accuracy in all respects is of great importance." The highway departments were instructed that the estimates ". . . be made from preliminary or final plans, specifications and estimates . . . . As a minimum for all other work there should be preliminary layouts of line and of all major structures and interchanges in order that reasonably accurate quantity estimates can be made." Right-of-way (ROW) costs were to be assessed by experienced personnel on the basis of 1963 costs.

Although not actual expenditures, the estimates provided a reasonable source of data for this study. The data representing costs that were computed following a con-

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sistent set of rules at one point in time possess homogeneity not readily attainable from actual expenditures.

The cost variations were studied in two approaches. The first dealt with the overall highway and ROW costs, and the second attempted to show costs of separate highway elements.

The overall construction costs first were correlated to population density, disregarding widths and other facility differences. Another set of equations represents a similar correlation of costs by lane-mile, thus giving consideration to the facility size.

In order to learn about the cost variation of different highway elements and the relative influence of such variations upon the total construction cost, statistics were developed for the costs of separate road elements. These statistics can also be employed to estimate the anticipated construction expenditures for extraordinary highway designs and for roadways with a varying number of lanes.

Variables

Unless indicated otherwise, the following symbols and units of variables apply to all equations:

Y = dependent variable: cost in thousands of dollars per specified unit; facility spacing (in miles);
D = gross population density (persons per square mile); and
N = number of lanes.

Cost data and population densities for the observed highway segments were established following the criteria outlined below

Criteria for Establishing Population Density

Population densities were determined from the 1960 U. S. Census tract data. In high-density areas such as Manhattan, extensive nonresidential land uses tend to reduce the average population density if the latter is considered on a small area basis. To eliminate this deficiency in the density variable, the census tract gross population densities were evaluated as follows:

- The average population density of census tracts traversed by the highway segment under consideration was compared with the average density of the adjoining tracts.

- If the traversed track density was lower than the average density of the adjoining tracts, the average of the adjoining tracts was taken to be the corresponding density of the analysis segment.

- If the traversed tract density was higher than the average density of the adjoining tracts that include industry and commerce, the highest of the traversed tract densities was recorded with the highway segment.

- Where the proposed road passed through open areas such as cemeteries or parks, the average population density of the adjoining tracts was taken.

In the outer area of the region, sparsely settled towns comprise a single census tract. In such cases, the average density of the town was recorded.

The determination of densities was guided by the assumption that the ROW cost is influenced not only by the actual development of a given land tract, but also by the development density of adjacent areas. Hence, density figures employed for the estimation of highway costs were made to represent not only the land taken by the road, but also that of the surrounding tracts.

Length of Analysis Segments

There is considerable land cost variation from parcel to parcel in the same vicinity, and a certain minimum land area must be covered by a single highway segment to obtain a reasonably representative average cost.

Within a 10-mile radius of Manhattan, the segments recorded in the data entries averaged 0.8 miles. Some of the segments were as short as 0.2 miles, while others exceeded 1 mile—especially those which were routed through open areas. In densely populated areas, one segment traversed up to six census tracts, but about one-half of the segments in such areas were within the confines of one tract.

In areas located between 10- and 20-mile radii of Manhattan, the average analysis unit was just over 2 miles long. The segments ranged from 1.2 to 3.5 miles. At an average, the segments stretched over five census tracts. In more dense areas, the units traversed six to eight tracts.

Beyond 20 miles, the segments ranged from 2.5 to 7 miles in length. The average unit was 4.4 miles and stretched through two census tracts.

It is not always possible to set the analysis segment length at will. The source of data and a variety of other conditions fix the limits. Nonetheless, to obtain reasonable cost estimates from the given equations, the segment lengths should fall within the ranges similar to these from which the cost equations were developed.

Data Characteristics

The equations were derived from a sample consisting of 44 observations. The availability rather than the requisite of randomness predetermined the choice of data. However, an attempt was made to have the distribution of road segments reasonably representative of the locational pattern of highways in the Region. Consequently, the data should be looked upon not as a random sample, but as a regression sample depicting a road network as shown in Figure 1.

For this kind of data the random sample correlation measures, such as the coefficient of correlation, have little or no meaning. To provide for confidence judgment, however, the data were plotted for each linear regression. The plots present the correlations for visual judgment and for convenience in using the curves.

Population densities in the sample ranged from 100 to 80,000 persons per square mile; the number of lanes were from four to ten. Consequently, any inference made from the following statistics has validity only within these variable limits.

All 44 links represent roads nearly at grade. Continuous elevated roads on structure or depressed segments within retaining walls were excluded. Cost variations in densities beyond the upper limits of this sample and for roads other than at grade are discussed separately.

OVERALL CONSTRUCTION COSTS

The scattergrams, regression lines, and equations for the overall Interstate-type facility costs are shown in Figures 2 to 5. Figure 2 shows the total cost per mile, Figure 3 the ROW part of this cost, Figure 4 the total cost per lane-mile, and Figure 5 the total cost per lane-mile less interchanges. In Figure 3, the ROW costs include land acquisition, clear and grub, demolition, and utility adjustment. The total cost in Figures 2, 4, and 5, represents ROW and construction expenditures.

Figures 2 and 3 reflect neither facility size nor design characteristics. The general segment costs are correlated to population density. Consequently, the resulting statistics represent not only the relation between the development densities and the costs, but also the facility size that corresponds to such densities.

There is a considerable difference in the slope of total cost and ROW cost regression lines, indicating that the ROW cost in high-density areas constitutes a larger percentage of the total cost than in low densities. In fringe areas, on the other hand, construction expenditures mainly determine the cost of highways. Construction costs alone, however, showed an insignificant correlation to population density. This could be the explanation for a rather wide data scatter in low-density regions in Figure 2 and in Figure 4, where the ROW cost is low.

Figure 4 represents the total cost per lane-mile. In reducing data to cost per lane, account is given to the facility size. The regression statistics derived on this basis, therefore, provide a cost estimation criterion when facility needs are considered in lane-mile units.

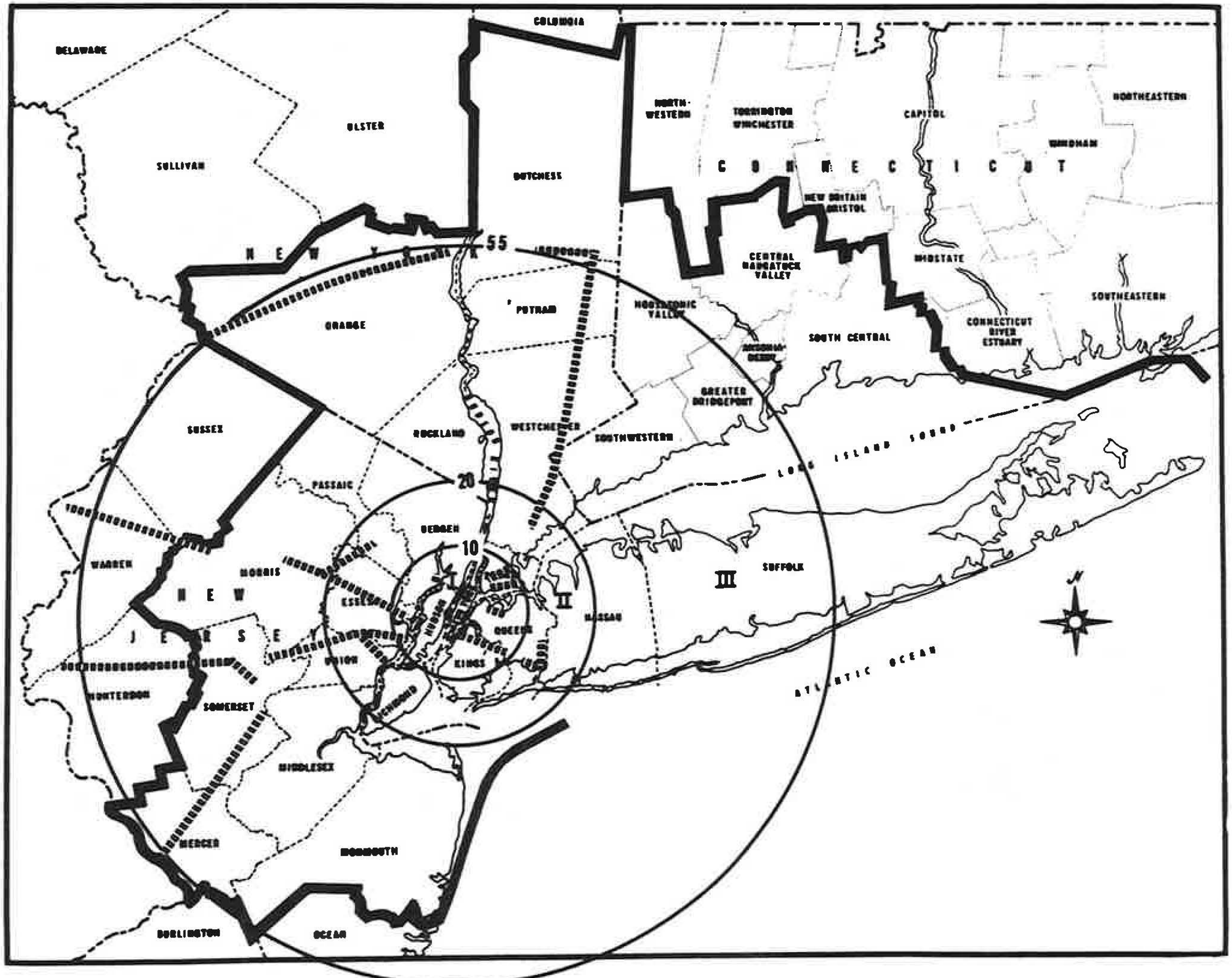


Figure 1. Interstate highways included in the cost analysis study.

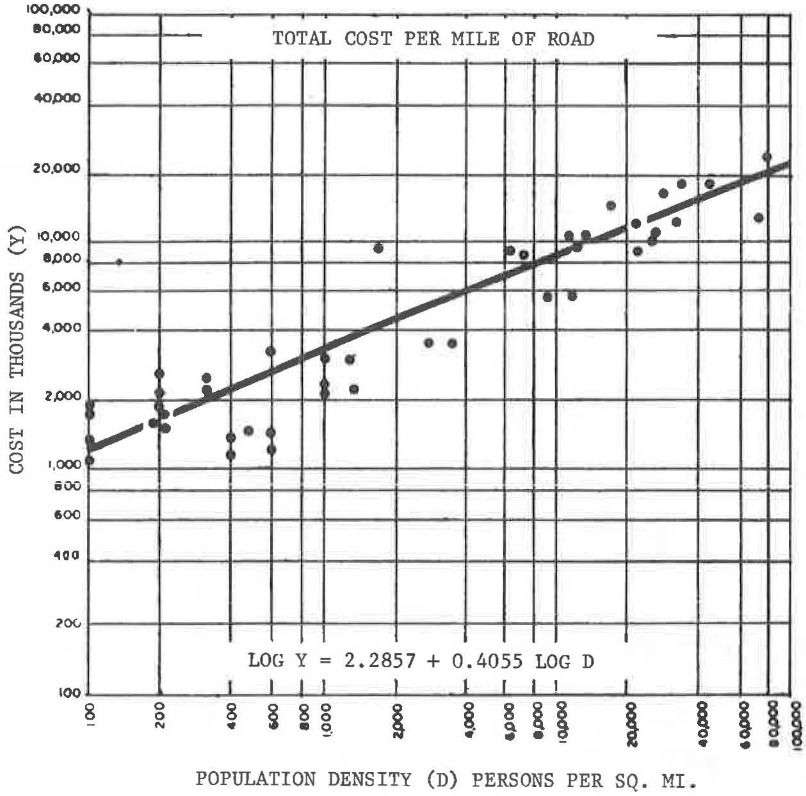
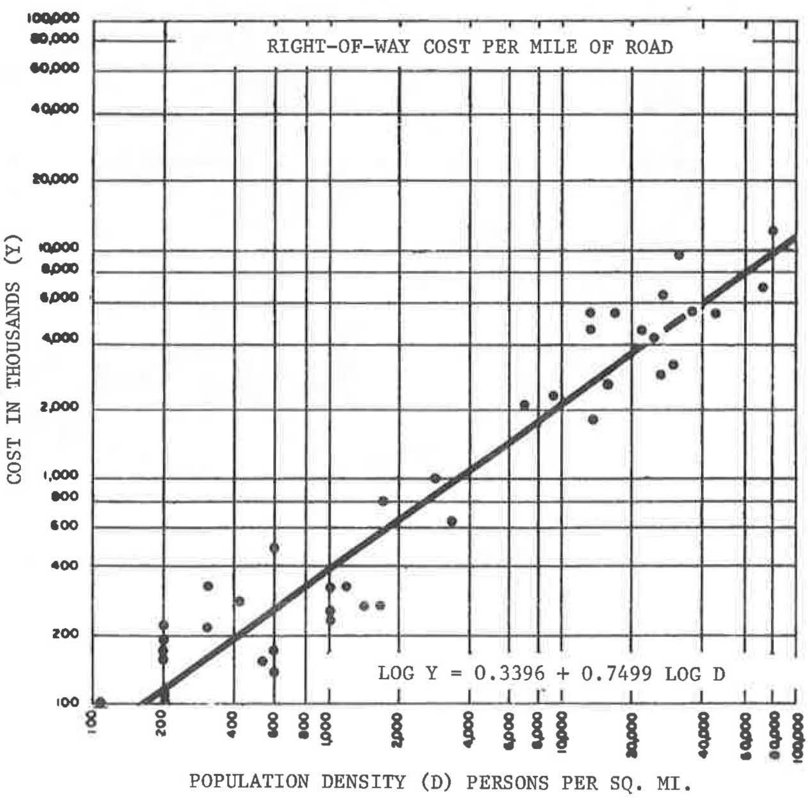

TOTAL COST PER MILE OF ROAD
COST IN THOUSANDS (Y)
100,000
80,000
60,000
40,000
20,000
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
LOG Y = 2.2857 + 0.4055 LOG D
100
200
400
600
800
1,000
2,000
4,000
6,000
8,000
10,000
20,000
40,000
60,000
80,000
100,000
POPULATION DENSITY (D) PERSONS PER SQ. MI.

Figure 2.


RIGHT-OF-WAY COST PER MILE OF ROAD
COST IN THOUSANDS (Y)
100,000
80,000
60,000
40,000
20,000
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
LOG Y = 0.3396 + 0.7499 LOG D
100
200
400
600
800
1,000
2,000
4,000
6,000
8,000
10,000
20,000
40,000
60,000
80,000
100,000
POPULATION DENSITY (D) PERSONS PER SQ. MI.

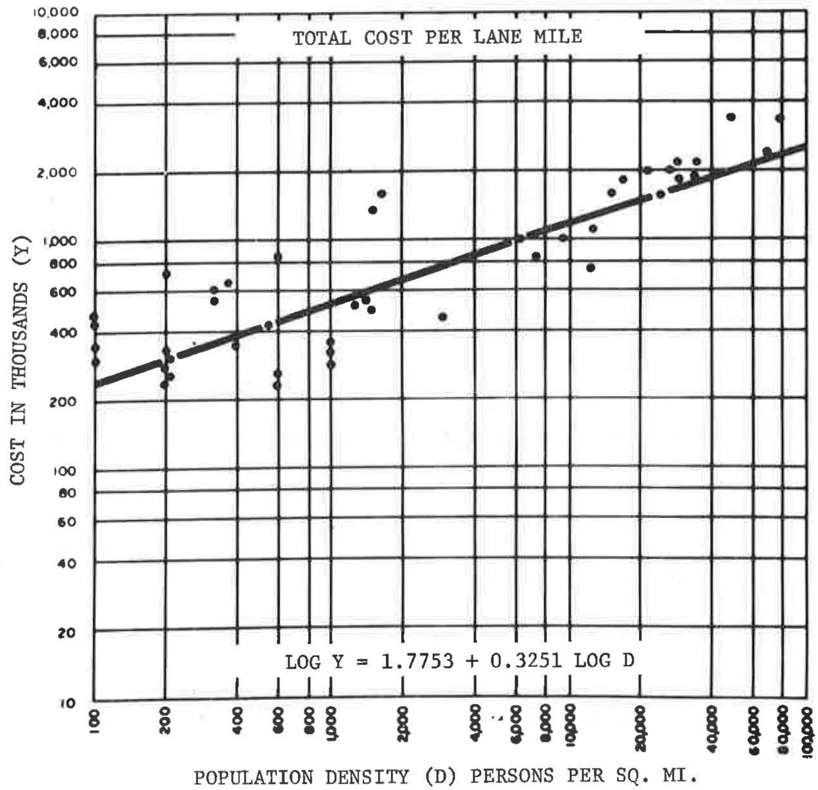


Figure 4.

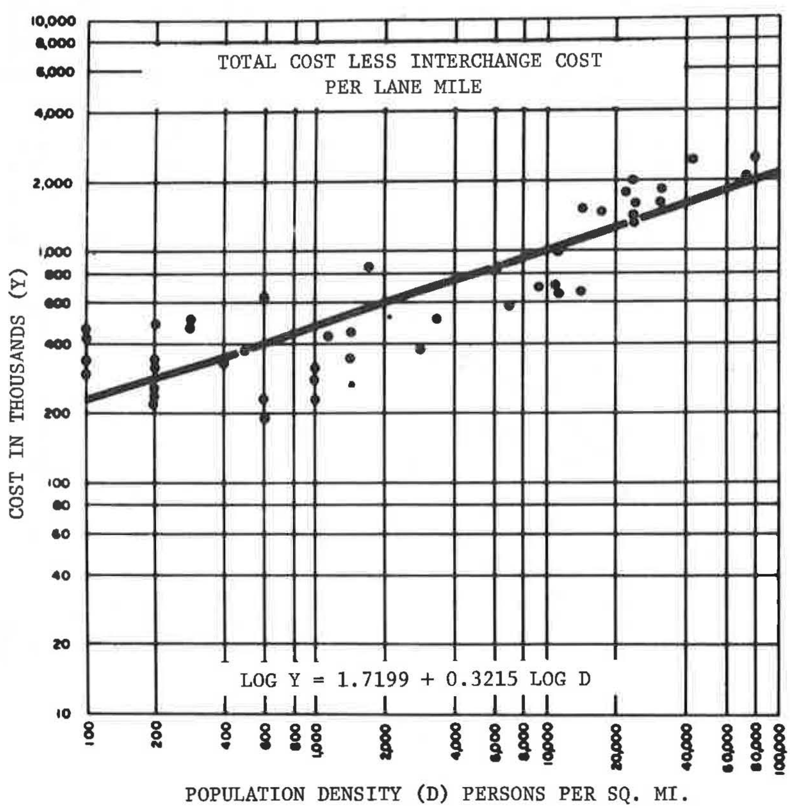


Figure 5.

Figure 5 was constructed on a similar basis as Figure 4, except that the cost of interchanges was deducted from the total segment cost before dividing it over the number of lanes.

The spacing of facilities and, consequently, the spacing of interchanges is one of the several answers sought for in transportation planning. Separation of interchange costs from the cost of the through lanes, therefore, provides flexibility in assessing the economic aspects of different facility spacing alternatives.

COSTS BY ROAD ELEMENTS

This part of the highway construction cost analysis shows the variation in the ROW acquisition and in the highway installation costs by elements, such as grading and surfacing, structures, interchanges, other costs, and engineering. The findings that follow can be employed for the cost estimation of highways that are not typical for their locations. Alternate design considerations of planned facilities can also be evaluated by this method.

1. ROW cost (for land strip 100 ft wide and 1 mile long) includes land acquisition, clear and grub, demolition, and utility adjustment or relocation. Figure 6 shows the correlation of the ROW costs to population density, the corresponding regression line, and equation.

2. Grading and surfacing cost scattergram and the regression equation are shown in Figure 7. Although the cost variation trend is in evidence, the correlation between these two series is not high, and the dispersion of data is considerable for this slope of regression. The correlation is somewhat improved by the introduction of the "num-

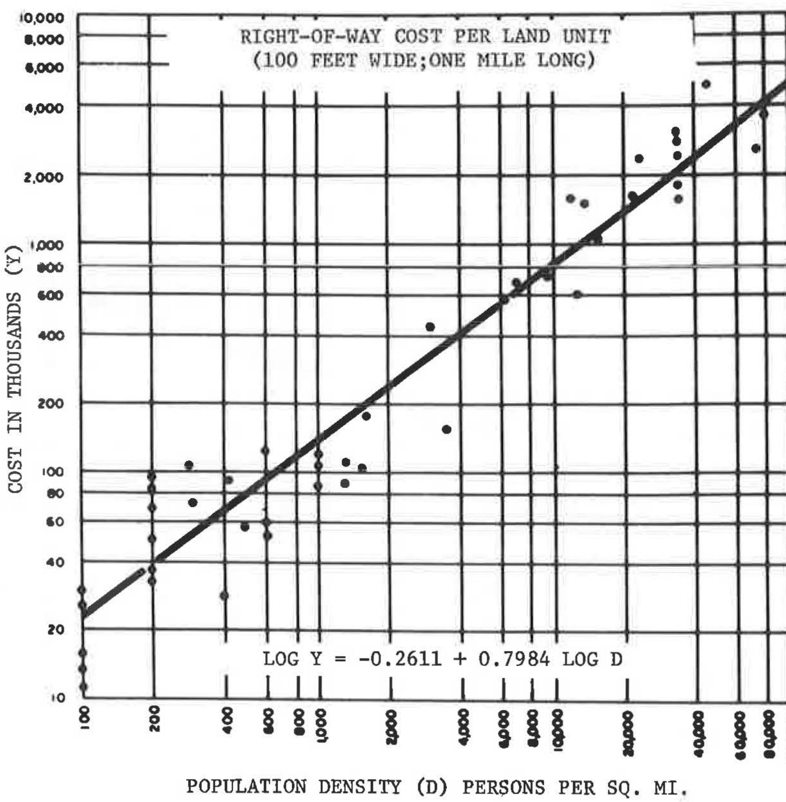


Figure 6.

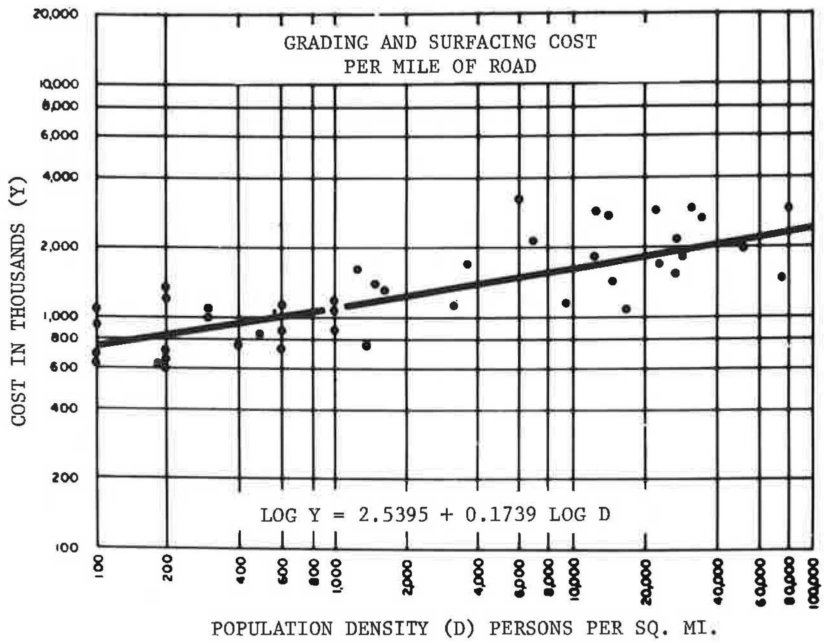


Figure 7.

ber of lanes" variable. Thus, the following equation can be used as an alternate to that given in Figure 7:

$$\text{Log } Y = 2.4985 + 0.1565 \log D + 0.0158 N$$

In addition to grading and surfacing, this cost category includes minor drainage structures, subbase, and shoulders.

3. Structure cost, representing highway grade separations without ramps, railroad grade separations, and bridges, did not significantly correlate to the tested variables. Clustering the data in three density ranges, the structure cost for these densities averaged as shown in Table 1. Structure spacing is represented by Figure 8. This correlation is also indicative of the spacing of streets, such as secondary arterials, which cannot be terminated at expressways. This statement presupposes that most of the railroad grade separations and stream crossings also span some kind of arterial or occur infrequently. The spacing ranges from 0.12 miles in high densities to just over 1 mile in fringe areas.

4. Interchange costs depend on the importance of interconnecting facilities and on the complexity of structures. Three classes of commonly occurring interchanges indicated distinct cost characteristics: interchanges between two limited-access facilities, between limited-access and U. S. or state highways, and between limited-access and arterial streets. Table 2 shows the mean cost and the range of costs.

Interchanges of more than two facilities and those requiring elevated ramps or other structures in densely populated areas considerably exceed the above estimates, and no generalization could be drawn from the sample data. Sketch layouts should be prepared to help estimate the cost of these complexes.

To check the representativeness of the mean values for the three interchange types

TABLE 1

COST OF STRUCTURES

Density Range (Persons/sq mile)	Mean Cost ($000)	Cost Range ($000)
100–10, 000	297	180–510
11, 000–30, 000	383	210–560
31, 000–80, 000	489	305–877

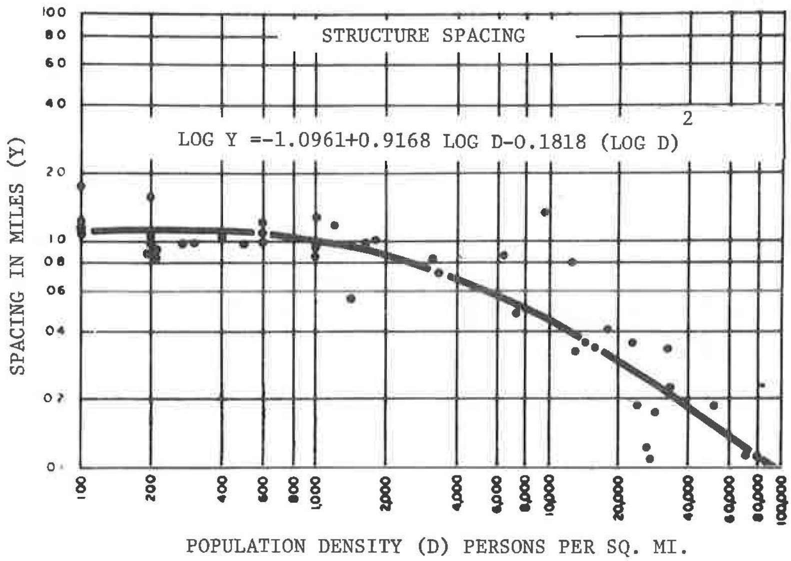


Figure 8.

in Table 2, costs for all interchanges that appeared in the "1965 Estimates" of the three states within the Tri-State Region were extracted and grouped into similar classes. Out of 120 such interchanges, 26 were with Interstate roads or other divided high-volume facilities, 32 with federal or state highways, and 62 with other arterials. The range of costs and the mean values for these groupings are shown in Table 3.

All costs that pertain to the Interstate through-traffic lanes were excluded from the above interchange figures. Included in the interchange costs are those that are part of the interchange development: structure, excavation, walls, grading, drainage and surfacing of all ramps, curbs, slope treatment, roadside improvements, lighting, and traffic control devices. Also included are the costs for the entire improvement of the crossroad, unless it is another Interstate route.

Estimates of actual interchange costs that appear in technical reports and publications do not always correspond to the above definition. Therefore, a comparison between the findings of this report and similar costs from other sources must be made with care and caution.

Interchange spacing was found to correlate to population density as shown in Figure 9. The spacing ranges from 0.6 miles in densely developed areas to 7 miles in the outer region.

5. Other costs include walls, guardrails, fencing, lighting, traffic control devices, roadside improvements, miscellaneous items, and contingencies. Figure 10 shows the correlation of these costs to population density.

TABLE 2

INTERCHANGE COSTS FROM SAMPLE DATA
(Excluding Cost of Interstate Through Lanes)

Connecting Roads	Mean Cost ($000)	Range ($000)
Limited-access facilities		
Predominantly designs at grade	2, 157	2, 010–2, 521
Nonlimited access		
U. S. or state highways	1, 264	943–1, 964
Other arterials	635	497–801

TABLE 3

INTERCHANGE COSTS FROM REGION-WIDE DATA
(Excluding Cost of Interstate Through Lanes)

Connecting Road	Mean Cost ($000)	Range for 90% of Data ($000)
Limited-access facilities		
All interchanges	3, 920	2, 010–7, 338
Complex designs	4, 979	3, 273–7, 338
Predominantly designs at grade	2, 386	2, 010–2, 897
Nonlimited access		
U. S. or state highways	1, 337	727–1, 929
Other arterials	620	330–894

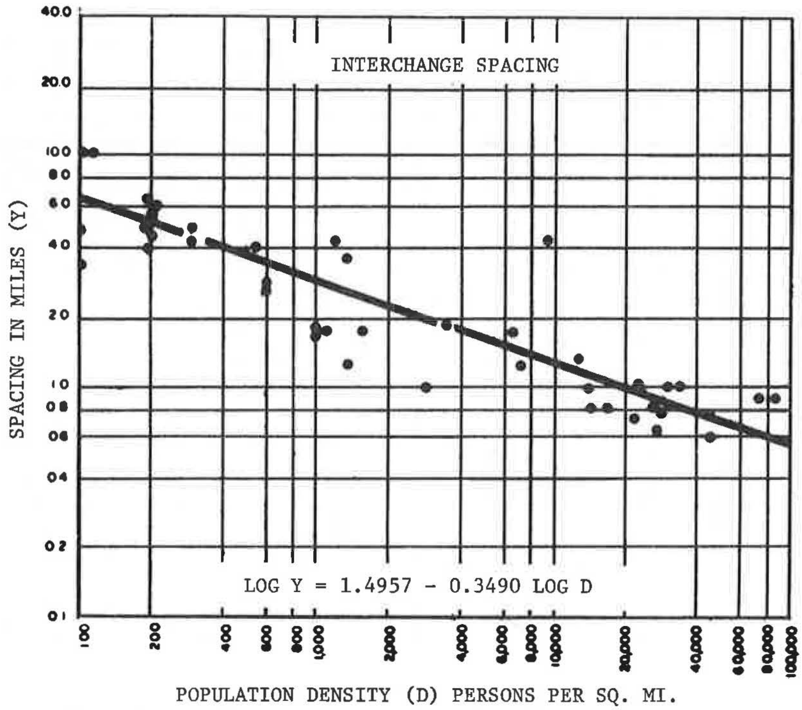


Figure 9.

6. Engineering costs amount to approximately 15 percent of the total construction cost (excluding ROW) in New York City and to 10 percent in the rest of the Region.

To obtain highway construction costs from the above equations and tables, it is necessary to estimate and add up items 2, 3, 4, and 5, and add to this sum the corresponding percent for engineering expenses as described in item 6. This total, plus the ROW cost, would represent the total cost of a given highway segment.

HIGHWAY CONSTRUCTION COST IN HIGH-DENSITY AREAS

ROW and construction costs in areas where the population density exceeds 80,000 persons per square mile could not be incorporated in the preceding study because of the irregularity and paucity of data. The ROW width in such areas is decreased to a minimum, and roads become a chain of elevated structures, tunnels, and depressed roadways. Among the available data there were too few observations for a firm generalization on the cost of these elements. However, approximations, were made to provide an idea about the range of cost for such structures.

1. Right-of-way—ROW in densely developed areas within a 10-mile radius of Manhattan can be estimated by the following equation:

$$\text{Log}\ (Y - 1.68) = -\ 0.3563 + 0.125X$$

where Y = cost in millions for a land strip 100 ft wide by 1 mile long, and X = population density in 1,000 persons per square mile.

2. Tunnels—Estimates prepared for the Mid-Manhattan Expressway indicate a $25 million-per-mile construction cost for a four-lane tunnel, excluding the ROW cost at the entrances and auxiliary structures.

3. Elevated Highways—The construction cost of eight elevated highway links totaling 4.7 miles in length averaged to $16.25 million per mile; individual segment costs range from $12.8 to $20.8 million per mile for six- and eight-lane facilities.

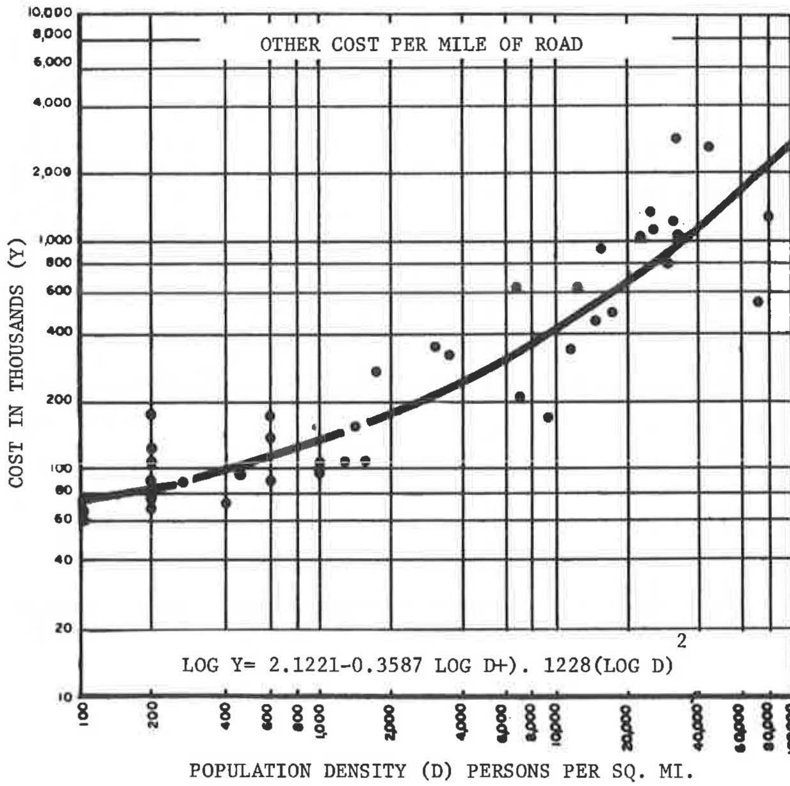


Figure 10.

4. Depressed Highways—Two links, 1.6 miles long, of depressed highways averaged to $20.6 million per mile, excluding ROW cost.

All of the above roads were located in Manhattan and Brooklyn.

Items 2 to 4 represent the total construction cost, which includes structures, interchanges, improvements, and engineering.

TESTING THE EQUATIONS

Parts of I-278 and I-287 not included in the sample data were utilized for testing the equations. The location of these routes is shown in Figure 11.

Following the prescribed procedures for determining the segment length and population density, the test routes were divided into 18 analysis segments and each segment was accorded its density value. The cost of each segment was then estimated on the basis of the four estimation criteria.

The differences between the test and the statistics sample were considerable. The test data consist of 18 segments as opposed to 42 in the statistics sample. Population density in the test data ranges from 200 to 12,400 persons per square mile. The sample covered densities up to 80,000 persons per square mile. While the sample consisted of radial and circumferential roads with respect to the core of the region, both I-278 and I-287 are circumferential.

Because of the disparity between the two samples, chances were that the aggregate estimation error would be larger than that for a system of segments more evenly distributed with respect to population density and road orientation. The resulting errors, however, proved to be low, and the test outcome demonstrates the relative validity of these estimation criteria.

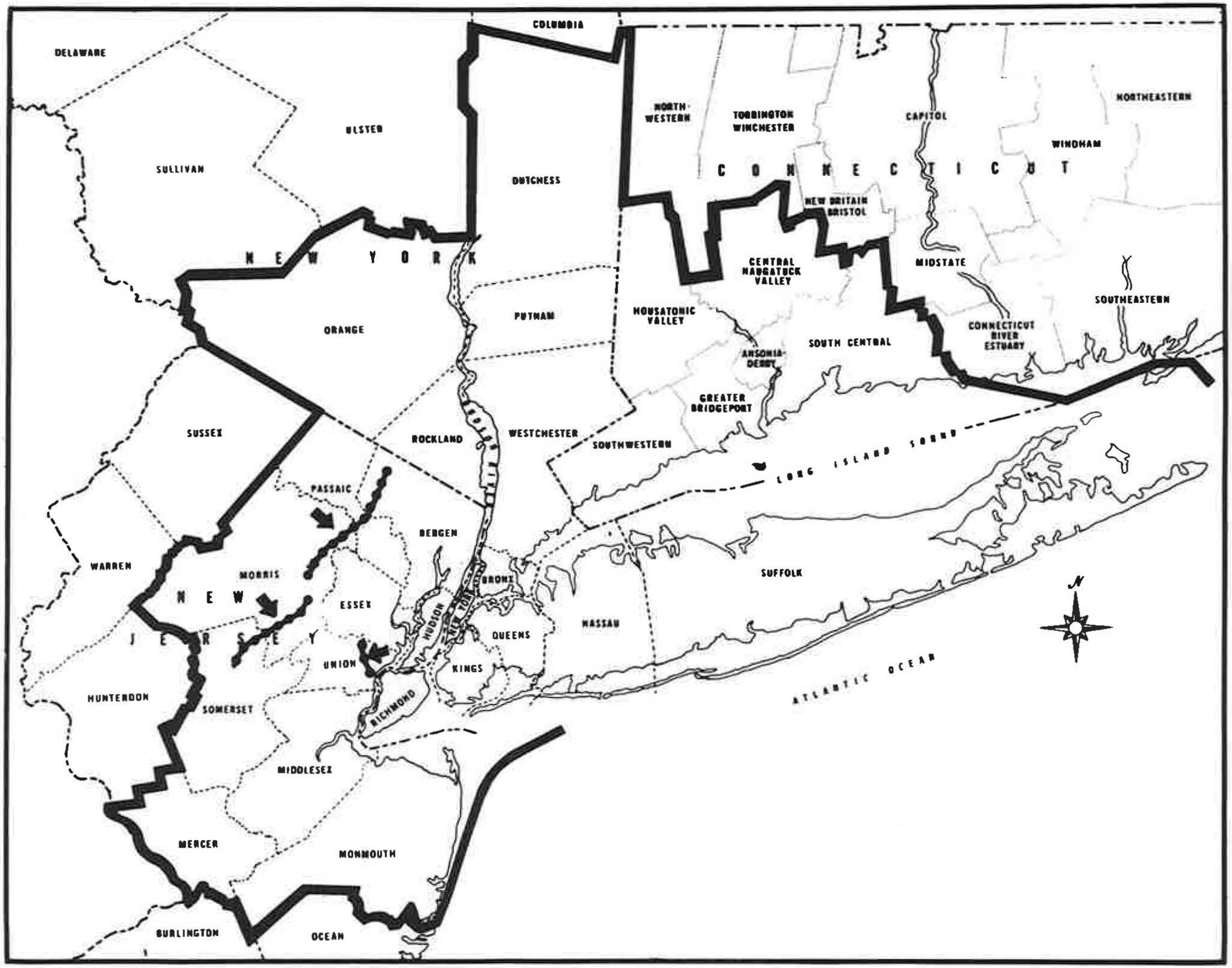


Figure 11. Test segments of I-278 and I-287.

TABLE 4

ESTIMATED COSTS OF ROAD ELEMENTS

Road Element	Actual Cost ($000)	Estimated Cost ($000)	Error (%)
Right-of-way (100 ft by 1 mile)	48,524	39,929	-17.7
Grading and surfacing Y = f (DN)	45,619	52,911	+17.2
Structures	21,255	16,758	-21.2
Interchanges	23,861	21,530	-9.8
Other, includes engineering	22,324	19,114	-14.4
Total	161,583	150,242	-7.0

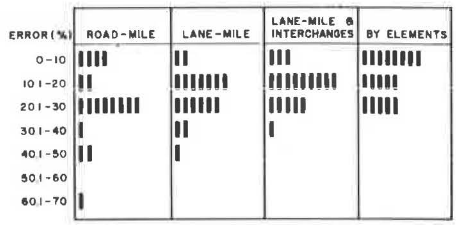


Figure 12. Frequency distribution of errors for cost estimates by link and by four criteria of estimation (in absolute values).

The aggregate errors for estimates by the different criteria are as follows:

Criteria of Estimation	Error (%)
Road-mile	+15.0
Lane-mile	- 1.7
Lane-mile and interchanges	- 2.4
Road elements	- 7.0

The range and the frequency of errors for the cost estimates by segments are illustrated in Figure 12. The estimation approach by road elements shows the lowest range of errors; eight out of 18 segments were estimated with a 10 percent error. The second best in the distribution of errors is the lane-mile and interchanges criterion; lane-mile is third, and road-mile fourth.

Judging from the range and distribution of errors shown in Figure 12, estimates on the basis of road elements yielded the best results. From the point of view of the total error, however, it ranks only third. The estimation method by road elements consists of several steps, each of which showed a resultant error larger than that of the aggregate. The aggregate error is a chance error of the five estimation stages, as may be seen in Table 4.

It cannot be said that the test provided adequate evidence for singling out one estimation method as better than the others. Nonetheless, since the test data in several respects differ from the statistics sample and since, in spite of these differences, the estimates obtained by the four different methods indicate relatively low level of errors, the test suggests that all four cost estimation approaches are suitable for the intended purposes.

CONCLUSIONS

A reasonably good correlation was established between the cost of various expressway installation elements and gross population density. Regression equations derived from this correlation may be employed for expressway cost estimation criteria in transportation planning. The test of four estimation approaches yielded reasonably good results—the aggregate error ranged between +15.0 and -7.0 percent. This test indicates that all four approaches are suitable for the intended purpose. The criteria, however, have been developed for a regional distribution of facilities, and estimates of facilities having similar distribution characteristics would yield better results than isolated segments of roads.