ALLOCATION OF RESOURCES FOR CONSTRUCTION OF TRI-STATE REGIONAL HIGHWAYS

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The purpose of this analysis is to develop alternative proposals for the geographic allocation of freeway construction funds. These allocations can be used as guidelines for the development of alternative regional highway networks. The development of such networks is, however, not considered in this paper. The objective is to emphasize the policy level allocation decision. Furthermore, the development of such a network should not be construed as being a final solution to the network planning problem but rather as a step in the problem solving process. The analysis indicates that the reallocation proposals will provide significant benefit to highway users in terms of reduced per-mile travel costs and increased service. The changes would also lead to a reduction in community impacts because of the reduction in highway construction in the most densely developed portions of the region. Further study must be undertaken to consider the redistributive and equity effects of each of the possible alternatives as well as the original plan.

•A MAJOR policy issue of regional planning is the geographical and functional allocation of limited funds to obtain the greatest benefit for the community. This report describes an approach to the area-wide allocation of capital funds required for construction of the 1985 interim plan for limited-access highways in the Tri-State region (7). The report has 4 sections covering regional objectives for highway travel, highway travel description model, allocation of highway resources, and a comparison of alternative resource allocations.

REGIONAL OBJECTIVES FOR HIGHWAY TRAVEL

The objectives of the regional transportation system must be considered within the framework of overall regional objectives wherein transportation is viewed as a service system. For the purposes of this study, the objectives of the highway investment program have been narrowly construed to be the minimization of per-mile highway user costs subject to the available level of capital investment funds. Prior work has indicated that, although the inclusion of representative community impact costs is important to the selection of an appropriate total investment level, they do not significantly affect the allocation of a predetermined budget.

The overall objective of this study is to determine the allocation of capital resources that will minimize daily time and accident costs, subject to the availability of a fixed capital investment budget. This can be expressed mathematically as follows:

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Sponsored by Committee on Transportation Systems Design.

Minimize

$$\sum_{i=1}^{N} \{[\$6.00\ TC_i + \$2.50\ TP_i + \$1{,}470\ EXPA_i + (\$930 + \$320)\ ARTA_i]/VMT_i\} \quad (1)$$

Subject to

$$\sum_{i=1}^{N} CCOST_i \leq \text{available budget} \quad (2)$$

where

TC = commercial vehicle time,
TP = passenger vehicle time,
EXPA = expressway accidents,
ARTA = arterial and local street accidents,
VMT = vehicle-miles of travel,
CCOST = expressway construction cost,
N = number of subregional areas, and
i = the individual areas.

Highway user costs have been interpreted to include only time and accident costs. At the general level of analysis being considered, vehicle operating costs are not significantly affected by changes in the allocation of highway capital investment funds and can therefore be ignored.

Time costs are particularly significant in highway travel. Every day more then 10 million man-hours are spent in motor vehicles in the Tri-State region. This travel time is a major element in the total transportation costs incurred in the process of accomplishing other objectives. For the purpose of this study, the value of commerc time—based on driver salaries, fringe benefits, and depreciation—is estimated to be \$6.00/vehicle-hour. The value of passenger car travel time is estimated to be \$2.50/vehicle-hour based on regional per capita income and average vehicle occupancy rates (3).

Accidents also cause a major portion of the costs of motor vehicle travel. Approximately 1,600 reportable accidents (those resulting in personal injury or damage exceeding \$100) take place every day in the Tri-State region. Per accident costs in the region have been estimated as averaging \$1,470 on expressways and \$930 on other roads. An additional cost of \$320 is assignable to reported accidents on arterials and local streets to account for the frequent occurrence of low-cost unreported accidents on these facilities.

The capital cost of new expressways varies among the subregional areas. These costs have been found to be related to the density of activity and development in each area (1). The estimating equation used in this study is based on population density, spacing between interchanges, and average number of driving lanes (2).

The following analysis and conclusions are based on this formulation of objectives. Separate analyses have indicated that the allocation results are not highly sensitive to minor variations in the values used.

HIGHWAY TRAVEL DESCRIPTION MODEL

To determine the allocation of funds available for highway construction that will minimize highway user costs (Eq. 1) requires that highway travel, system performance, and user costs be described under various assumptions of capital resource allocation. A model capable of providing such a description has been developed for use in the Tri-State region (3). The model is based on demand theory supported by observations of regular and repetitive travel behavior in the region. Specific equations were obtained through use of multiple regression statistical techniques. The model has the following general characteristics:

1. Vehicle-miles of travel can be predicted as a function of vehicle trip ends—origins or destinations—and the available roadway supply,

2. Distribution of vehicle-miles of travel among different classes of facilities can be predicted as a function of the relative supply of different facility types, and

3. Quantitative measures of average performance for each facility type can be estimated from the expected loading of each class of facility.

Projections are made independently for 83 analysis areas (Fig. 1) ranging in size from about 10 square miles in the high-density core of the region to more than 200 square miles in low-density areas on the outer edge of the region.

The expected number of motor vehicle trips in each subregional area is estimated from projections of population, household size, household income, and automobile ownership. [For the purpose of this discussion, the number of expected vehicle trips is considered to be fixed; that is, motor vehicle trip generation is independent of the quality of highway or public transportation service. Additional work must be done to develop a travel demand index that is responsive to changes in the level of service provided. At present this is accomplished by incorporating the accessibility characteristics provided by the proposed highway system into the development of land use projections (5) and therefore also into vehicle trip projections.]

The model provides information on the performance of the highway system in each analysis area in the region and also summarizes the data at the county, state, and regional level. The output has been designed to provide the information required to evaluate the objective function specified in Eq. 1. (Output also includes a variety of system performance measures and estimates of household relocations and land area used.) The operation of the model is shown in Figure 2. The effect of changes in expressway supply on travel parameters is shown in Figure 3. An increase in the supply of expressways in any area leads to an increase in the proportion of total travel that takes place on the faster, safer expressways (Fig. 3a) and thereby results in overall reductions in both travel time (Fig. 3c) and accidents (Fig. 3d). Another effect of an increase in overall highway supply in any area is to reduce average volume per lane on all route types (Fig. 3b), resulting in additional reductions in travel time and accidents. These benefits are subject to diminishing returns; that is, each additional increment of expressway supply yields a smaller reduction in travel time and accidents.

These savings can be reduced to a common index of benefit expressed in dollar terms on an annual basis through the objective function specified earlier (Eq. 1). A comparison between savings and investment may be standardized by computing the estimated savings per year for each thousand dollars of additional investment as shown in Figure 4. The annual savings for each additional unit of investment in a given area depend on the density of development and the level of expressway supply in that area. The negative slope of each curve indicates the diminishing benefits that can be expected from each additional investment as service levels increase in the zone. The upward shift in the curves in areas of higher density (left to right in Fig. 4) indicates that the increased benefits due to relief of higher levels of congestion outweigh the effect of increased construction costs in areas of higher density. However, as one might expect, in extremely high-density areas the construction, right-of-way, and relocation costs increase so rapidly as to outweigh the increase in travel benefits. This occurs in the Tri-State region at densities between 30,000 and 40,000 vehicle trip ends per square mile. It is our expectation that the density at which this transition point occurs will vary from region to region.

ALLOCATION OF HIGHWAY RESOURCES

The distribution of construction funds among subregional areas will influence the overall level of travel time and accident costs. The greatest savings will accrue to the region as a whole when funds are distributed such that the marginal annual savings per $1,000 additional investment is equalized among all areas as shown in Figure 5.

The resulting expressway supply will vary from very low in the rural and exurban areas, increase in suburban areas, reach a maximum at the fringe of the urban core, and drop rapidly in the center where the costs of highways are too great to justify their construction and where transportation service must be provided by alternative means. The authors believe this "doughnut effect" exists in other large urban areas.

Figure 1. Analysis areas of Tri-State region.

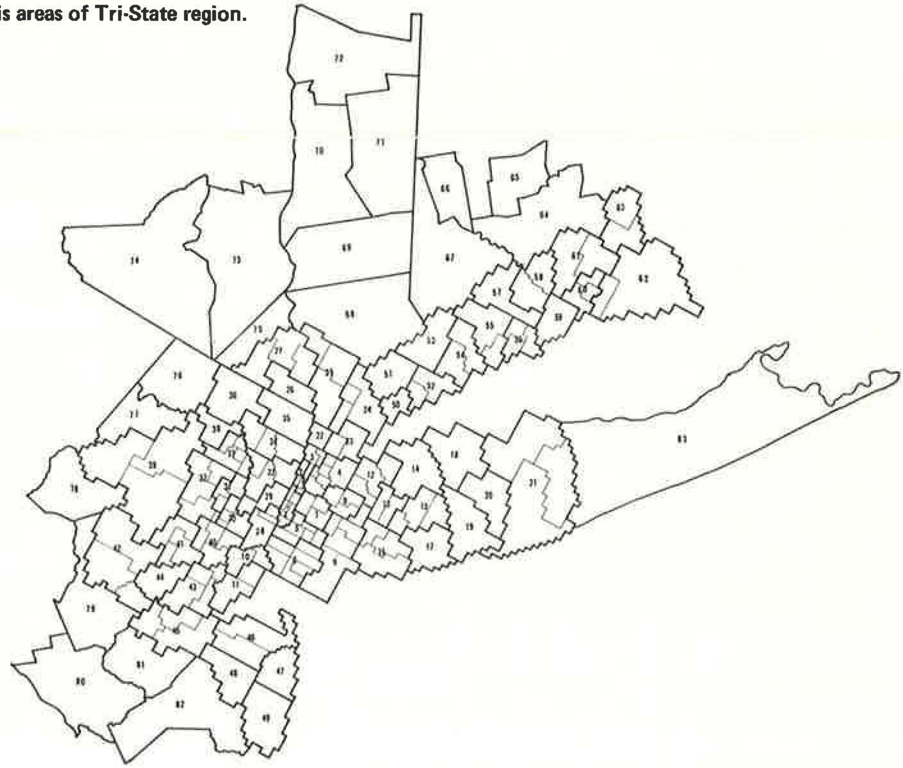


Figure 2. Highway travel description model.

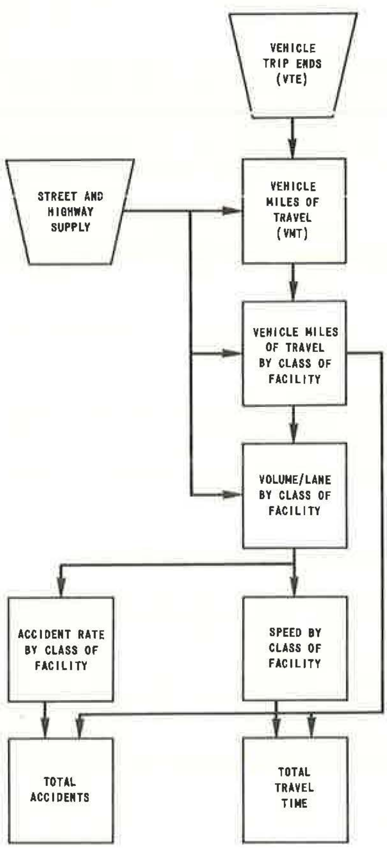
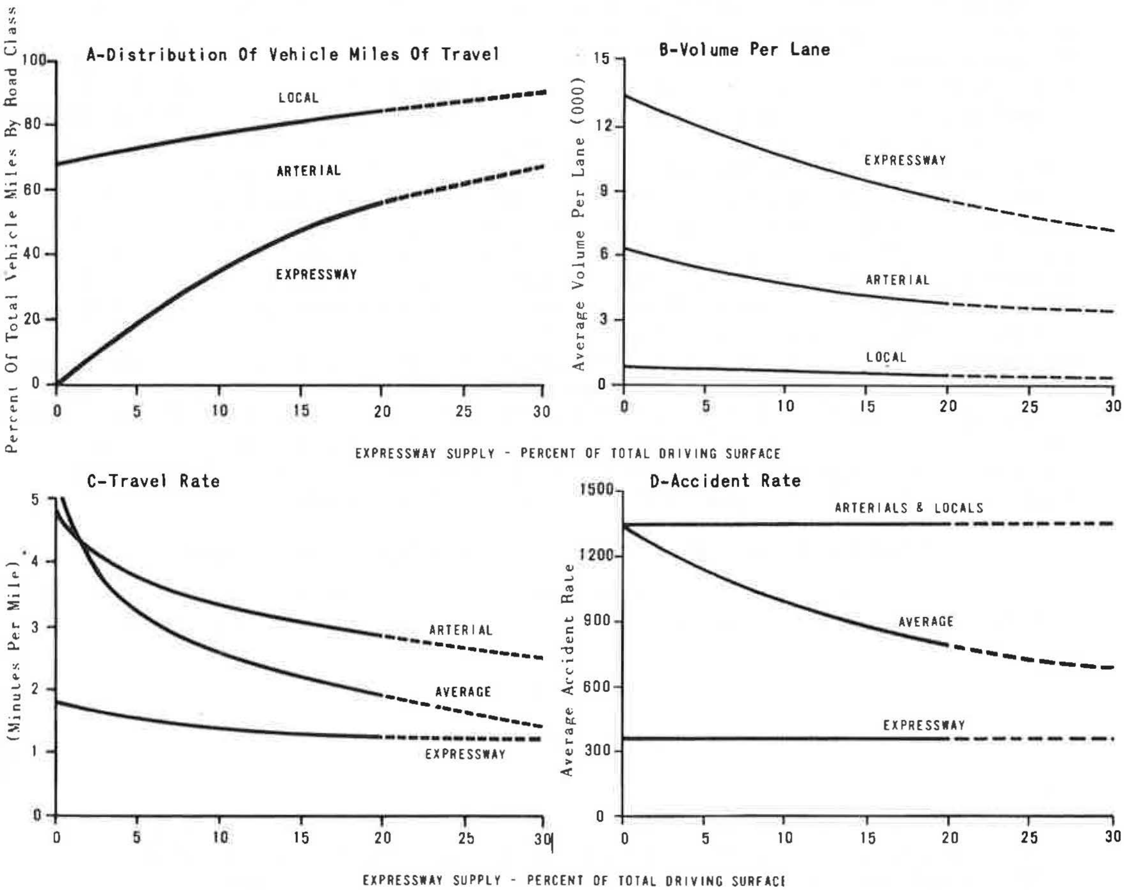
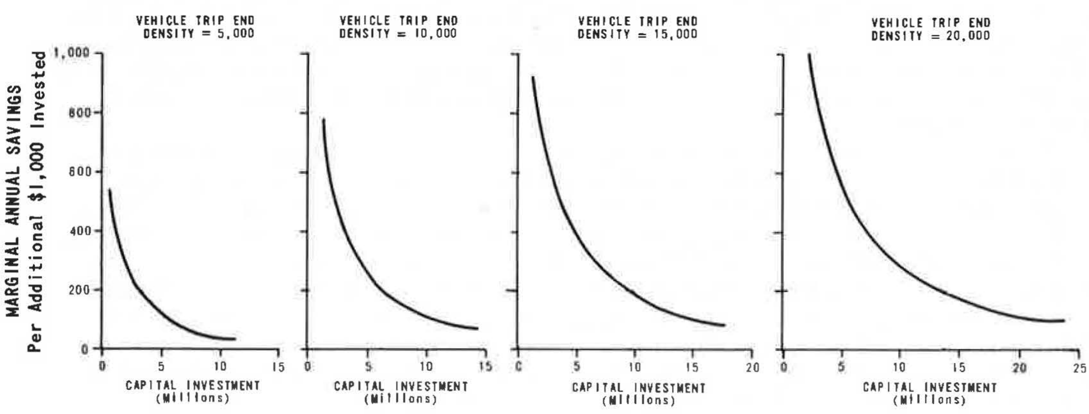


Figure 3. Effect of change in expressway supply on travel parameters.



NOTE: Solid lines indicate range of data (0-20% of road surface being expressways) ; dashed lines are extrapolated

Figure 4. Marginal savings in user costs at different levels of investment in areas of differing density.



The savings per year per $1,000 invested may be converted to a measure of return on investment based on the assumption of a uniform growth in benefits over a fixed project life (although oversimplified, the assumption does not affect the method of the interpretation of the results). It is then possible to view the cutoff point (the point at which all funds are allocated) in terms of the marginal return on investment, thus providing an index for comparability to returns on investment in other functional areas. An extremely high or low cutoff return on investment will indicate that consideration should be given to increasing or decreasing respectively the assigned budget.

In accordance with the Commission's program to evaluate and adjust the interim highway plan as data collection and analysis were completed, this approach has been applied to the Tri-State region for the year 1985. First, an analysis was undertaken to determine the objective-maximizing allocation of funds based on a single region-wide budget limitation of $8.2 billion, the present estimated cost of the interim highway plan adopted by the Commission in 1966 (7). [All costs are estimated in 1970 current dollars by using the method described by Huvane (2) and therefore differ from earlier published cost estimates. Shelkowitz (6) gives a description of interim plan cost and performance.] This plan (called alternate 1) will be compared with the interim plan in terms of (a) the resulting distribution of expressway supply in 1985, (b) performance of the highway system, and (c) resource allocation. A second alternative based on adoption of subregional budget limits is introduced later.

COMPARISON OF ALTERNATIVE RESOURCE ALLOCATIONS

Expressway supply may be measured either by the average number of route-miles per square mile or by the average spacing between expressways determined by the following:

$$R_{ei} = M_{ei}/A_i$$

$$S_{ei} = 2A_i/M_{ei} = 2/R_{ei}$$

where

R_{ei} = average route-miles of expressway per square mile in the i th analysis area,
S_{ei} = average spacing in miles between expressways in the i th analysis area,
M_{ei} = total route-miles of expressway in the i th analysis area, and
A_i = size of the i th analysis area in square miles.

In general, it is expected that the objectives of equity and efficiency will be best served by an allocation of similar levels of expressway supply to areas with similar levels of travel demand.

The subregional distributions of expressway supply that would result from implementation of the interim plan or alternate plan 1 are shown in Figures 6 and 7. Construction of the interim plan (Fig. 6) will result in large disparities in the spacing assigned to areas of similar density. (The range of spacing variation is bounded by the shaded area.) Figure 7 shows the greater consistency that will prevail if alternate plan 1 is adopted.

An alternative view of expressway supply variation is shown in Figures 8 and 9, which indicate the geographic distribution of different levels of expressway supply (route-miles per square mile) for the interim plan and for alternate plan 1. The expected distribution of express highways is to have high supply in the high-density core areas with decreasing supply in the more remote areas (with the exception of those coastal and corridor areas identified in the Regional Development Guide). Figure 8 shows an erratic picture with gaps existing in density ranges (i.e., areas with 0.21 to 0.40 miles/square mile are adjacent to areas of over 0.80 miles/square mile) or isolated areas (i.e., those that are completely surrounded by areas of either higher or lower levels of supply). Figure 9 shows much greater consistency throughout.

System Performance

The second comparison is with respect to the performance of the different plans, where performance is evaluated with respect to total vehicle-miles of travel served,

Figure 5. Optimal allocation of resources to subregional areas.

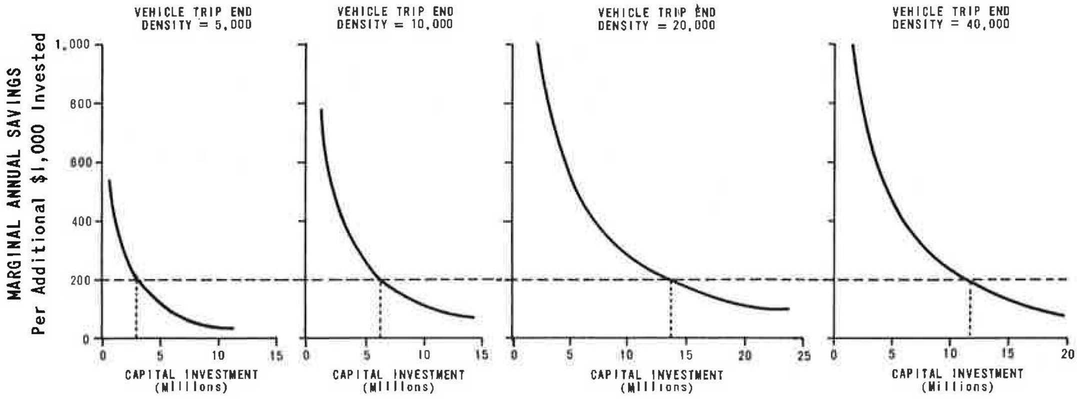


Figure 6. Expressway spacing versus vehicle trip end density with interim plan.

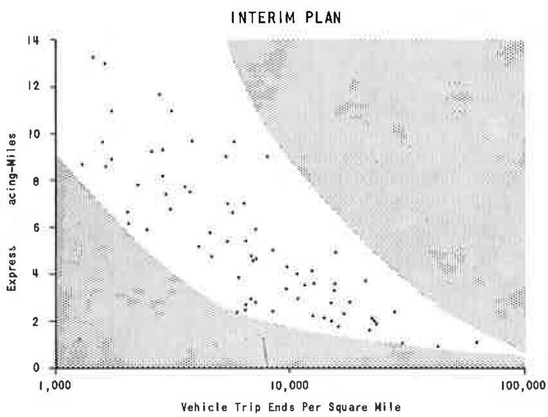


Figure 7. Expressway spacing versus vehicle trip end density with alternate plan 1.

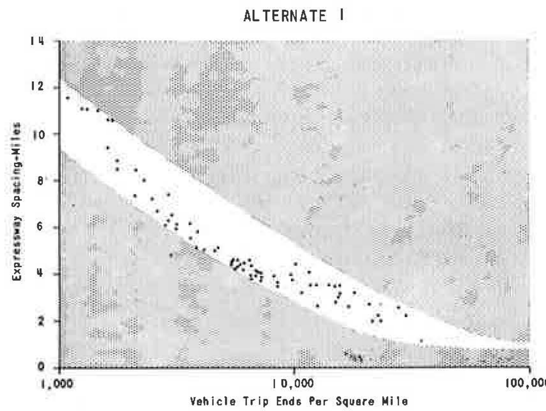


Figure 8. Expressway supply with interim plan.

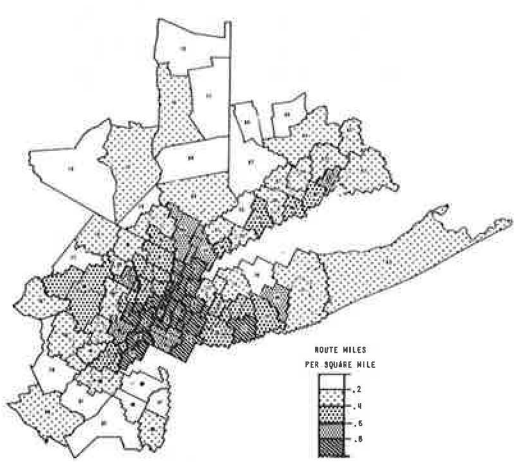
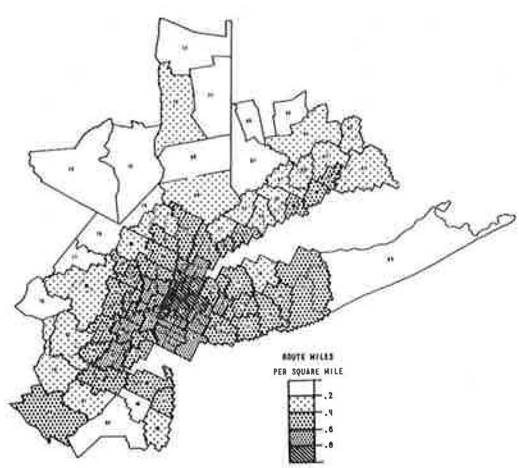


Figure 9. Expressway supply with alternate plan 1.



portion of total travel served by expressways, total travel time and accidents throughout the region, and overall user costs.

Table 1 gives a summary of this information for each of the 4 major subareas in the region—New York City, New York suburbs, New Jersey, and Connecticut. On a region-wide basis, alternate plan 1 out-performs the interim plan with respect to each of these measures. It provides savings of 90,000 vehicle-hours and 60 accidents/day. These savings, worth about $320,000/day, are obtained, but total vehicle-miles of travel is increased by about 4 million vehicle-miles per day. This improved performance derives from the increase in the proportion of total travel on expressways from 34.4 to 37.2 percent. A more detailed review indicates that savings are achieved in every major subarea except New York City where time and accidents increase while vehicle-miles of travel decline. This is a direct result of reallocation of a large portion of funds from New York City to use in other areas. The implication of this shift is that the costs of locating additional expressways in portions of New York City are too great to be justified by the highway user benefits that would be generated. Separate analysis should be aimed at determining the extent to which other highway or nonhighway improvements can provide required travel service. Account must be taken of the equity implications of concentrating express highway investment in low- and moderate-density areas and the corresponding need for alternative transportation service in the central portions of the region.

In view of the practical limitations of reallocating funds across major political boundaries, a second analysis was undertaken to determine the optimal allocation of funds based on budget limitations for the subareas. Each budget limitation was based on the estimated cost of the construction specified in the interim plan for that subregional area. This reallocation of capital is referred to as alternate plan 2. The results of this analysis are also given in Table 1. In terms of the region-wide estimates of vehicle-miles of travel served, average travel speed, average accident rate, and overall average cost, alternate plan 2 falls between the interim plan and alternate plan 1. The overall savings that would be achieved by substituting this plan for the interim plan are approximately two-thirds as great as those that would be obtained by adoption of alternate plan 1. This plan has the advantage of providing improved performance over the interim plan in each major political area including New York City.

Resource Allocation

An indication of the differences among alternatives may be seen by comparison of the allocation of resources to subregional areas. Table 2 gives this allocation for each major subregional area for all 3 plans in terms of capital investment, route-miles of new expressways, and resulting total route-miles of expressways. The differences for alternate plan 1 are a large reduction in the allocation to New York City, a significant increase in New Jersey, and modest increases in the New York suburbs and Connecticut. Because of the a priori restrictions on alternate plan 2, it has a similar fund allocation to the interim plan at this scale of analysis. However, relocation of some investment among the counties within each major area results in greater route-miles of new expressways. The total addition to the expressway system increases in both alternatives as a result of this redistribution.

The overall result is to shift funds from those areas with relatively low marginal benefits to areas of higher marginal benefit. Figure 10 shows the marginal rate of return that would prevail in each county based on the interim plan. The wide variation—from less than 10 percent to more than 16 percent—demonstrates the degree of imbalance in the plan. The diversion of funds is largest from the low return areas such as New York City, to the high return areas of New Jersey.

The region-wide marginal rate of return that will prevail for alternate plan 1 will be 12.8 percent. For alternate plan 2 the marginal rates of return would vary by major areas as follows:

Area	Percent	Area	Percent
New York City	9.0	New Jersey	14.4
New York suburbs	12.9	Connecticut	13.7

Table 1. Performance comparison of interim plan and alternate plans 1 and 2.

	Daily VMT (millions)			VMT on Expressway (percent)			Expected Daily Accidents			Daily Travel Time (millions of hours)			Average User Cost/VMT (cents)		
Subarea	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2
New York City	39.2	37.6	39.9	46.0	41.2	48.3	465	481	457	2.04	2.07	2.03	18.2	19.3	17.8
New York suburbs	91.1	91.6	91.4	33.2	34.7	34.1	673	660	663	3.87	3.85	3.85	13.3	13.2	13.2
New Jersey	99.4	103.5	100.4	32.0	38.9	34.2	877	825	859	4.75	4.67	4.72	15.1	14.2	14.9
Connecticut	41.3	42.0	41.6	32.0	35.2	33.5	303	295	299	1.76	1.76	1.76	13.4	13.1	13.3
Region	271.0	274.8	273.3	34.4	37.2	36.1	2,319	2,260	2,278	12.43	12.34	12.37	14.7	14.4	14.5

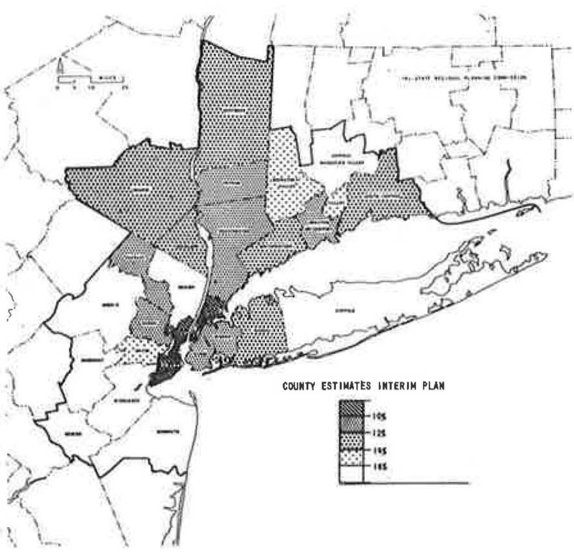
Note: Changes in route-miles of expressway are given in Table 2. Totals may not add because of rounding.

Table 2. Allocation of resources under different alternatives.

	Capital Investment (millions)			Expressway Route-Miles Added			Total Expressway Route-Miles		
Subarea	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2
New York City	2,100	800	2,100	119	68	144	311	259	335
New York suburbs	1,900	1,950	1,900	404	433	411	916	946	924
New Jersey	3,300	4,400	3,300	535	750	595	751	966	811
Connecticut	900	1,050	900	190	241	217	379	430	406
Region	8,200	8,200	8,200	1,248	1,493	1,367	2,357	2,601	2,476

Note: Totals may not add because of rounding.

Figure 10. Marginal rate of return from increased highway construction.



For alternate plan 2 the marginal rate of return remains constant within each subarea. The high rate of return indicated for New Jersey and Connecticut illustrates that there are additional investment opportunities that would achieve greater savings than the region-wide average rate. The reverse condition exists in New York City indicating that some of the accepted investments should be reconsidered as they are earning benefits at less than the region-wide average rate. (No benefits are included for the value of connecting regional facilities through the core of the region in this analysis, but neither has there been an estimation of community disruption costs due to new construction in high-density areas. Explicit inclusion of such costs and benefits would improve the completeness of the analysis.) These remaining variations in return on investments are indicative of the imbalance that will remain in the system if political boundaries act to restrict investment alternatives. In all 4 subareas, there are numerous changes among the individual counties (planning regions in Connecticut) that can be traced to the analysis areas shown in Figure 1. No general conclusion as to the overall funding level may be made based on this analysis as certain costs (household relocation, community disruption, and traffic disruption during construction) have not been included in the analysis. The inclusion of these costs might lead to a significant reduction in the region-wide rate of return, although it is our contention that such reduction would preserve the general pattern of differences among alternatives.

SUMMARY AND CONCLUSIONS

This paper describes an approach to evaluating the allocation of funds for highway capital investment based on a quantitative objective function and a highly aggregate model describing highway system performance. The evaluation indicates a significant imbalance in the existing interim plan for 1985.

The analysis has resulted in the development of alternative plans for resource allocation that will provide improved travel service and lower user costs within the same capital budget required for completion of the interim plan. The more efficient of these alternatives offers travel cost reductions valued at more than $320,000 daily while supporting additional travel of 4 million vehicle-miles per day. These gains are achieved by elimination of imbalances in the existing plans through the reallocation of funds from areas of low to high return on investment. The other alternative obtains approximately three-quarters of these benefits while taking account of the difficulty of redistributing funds across major political boundaries.

The analysis provides a guideline for the development of alternative regional networks; the guideline can be more exhaustively evaluated in terms of user benefits, community impact, and financial feasibility.

Although not included in the analysis, the effect of shifting expressway construction to less developed portions of the region would reduce the amount of household relocation and community disruption, in general. Because of the rightfully increasing emphasis on community and environmental factors in transportation planning, these issues will have to be treated more directly in the future.

ACKNOWLEDGMENTS

The authors wish to thank the following Tri-State Regional Planning Commission staff members: Edward F. Sullivan for his advice and support, and Dennis Price and Rose Weber for their technical assistance.

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