Analytical Problems	Studies
Nonrandom samples	Daytime telephone surveys
Surveys with missing data	Small area surveys
Limited budget or small samples	Transit on-board studies
Need for quick turnaround	Disaggregate data for mode choice
Limited population data	Community attitude studies
	Travel update studies
	Corridor studies

NYSDOT has applied these techniques in many contexts, including a 1000-household survey, a 300-household survey on community attitudes toward transit, a survey of 1200 transit riders in Albany, and 200- to 300-household surveys of community attitudes in six towns. In all cases, the method has proved to be useful and time saving and to provide reasonable results. The procedure develops reasonable weights with manageable effort for real-world data even if those data are highly skewed with many empty cells. Examples may exist that cause the method to fail, but they must be concocted for the purpose, would probably not occur in practice, and would probably cause other methods of marginal weighting to fail also. We feel that both methods are valuable additions to the repertoire of survey analysis techniques used by transportation analysts, and we particularly recommend the Johnson procedure because of its ease of understanding and programming.

ACKNOWLEDGMENTS

We wish to recognize the important contribution of Richard Johnson of Market Facts in constructing and describing his procedure. The assistance of Wilma C. Marhafer in preparing this manuscript is gratefully appreciated.

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**Messrs. Ollmann, Howe, and Kloeber were with the New York State Department of Transportation when this research was performed.*

Demonstration of a Simplified Traffic Model for Small Urban Areas

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A simple and straightforward method for forecasting highway traffic that was applied in Plaistow, New Hampshire, is described. The method requires an external origin-destination survey, demographic forecasts, and good ground counts. No home interview survey or demand model calibration is required. The approach combines a Fratar expansion of external trip tables with a factoring of internal travel on a link-by-link basis to produce a forecast of total automobile travel by link. A unique feature is that the link-by-link factoring of internal travel is directly related to the growth of population and employment in internal zones. This is done by means of an artificial trip-generation and gravity model that requires no calibration. The method produced logical results for Plaistow and appears to have promise for other applications.

There is widespread recognition today that traditional transportation planning techniques are somewhat more complex and costly than warranted by the types of problems to be addressed in smaller urban areas. This recognition and the desire to direct more of limited planning resources toward the solution of short-range problems have led to a search for simplified approaches to long-range travel forecasting that are tailored to the needs of smaller urban areas.

Planners for smaller urban areas are urged to perform an analysis of problems, growth, and related factors and to design study techniques that best suit these problems. Yet, lacking proven step-by-step alternatives to current forecasting methods, planners for these areas are justifiably reluctant to risk new approaches. The profession badly needs demonstrations of new methods, or new ways of using old methods, that are relatively straightforward and are suited to typical problems of small urban areas. Both the method and the outcome of these demonstrations as well as the types of situations to which they are adaptable need to be well documented. This paper attempts such a documentation of an approach taken by the New Hampshire Department of Public Works and Highways to forecasting automobile traffic for the town of Plaistow, New Hampshire.

PLAISTOW

Plaistow is a 27-km^2 (10.5-$mile^2$) community with an estimated 1975 population of 5330 persons. Located on the Massachusetts border north of Boston and Haverhill, Plaistow is defined by the U.S. Bureau of the Census as part of the Lawrence-Haverhill (Massachusetts) urbanized area.

Plaistow is part of rapidly growing Rockingham County, New Hampshire, the population of which increased by 40 percent between 1960 and 1970. Plaistow itself grew by 60 percent during that decade. The county population is projected to increase by over 70 percent between 1975 and 1995. During the same period, Plaistow's growth is expected to be more moderate because of restraints on land use. The high rate of development in surrounding communities will contribute to the increase of commercial activities in Plaistow.

Approximately 50 percent of the land area in Plaistow is developed; of that, about 66 percent is residential, 21 percent is commercial, and the remainder is industrial and governmental. Nearly 90 percent of the undeveloped land is currently zoned for residential use.

As part of an urbanized area, Plaistow is subject to the requirements of the Federal-Aid Highway Act of 1962 for continuous, comprehensive, and cooperative transportation planning within urbanized areas. The Plaistow Highway Transportation Study is an element of the comprehensive transportation plan for the New Hampshire portion of the Lawrence-Haverhill urbanized area.

METHODOLOGY

The traffic forecasting approach in Plaistow may briefly be described in the following steps:

1. Data preparation—(a) Functionally classify the road system and code the network; (b) conduct an external-cordon roadside origin-destination (O-D) survey and build trip tables (no O-D home interview is needed); (c) expand the highway counting program to cover all main facilities; and (d) assemble zonal population and employment estimates (retail and other) for the base year and make zonal forecasts of these to the future year.
2. External travel—(a) Assign the external-cordon trip tables to the highway network; (b) subtract the resulting assigned volumes from counted volumes on links where counts are available (the difference represents the internal volume on each link); (c) factor the external trip tables to the future year by using the Fratar method; and (d) assign the future external trip table to the highway network.
3. Internal travel—(a) By using base-year zonal population as a proxy for "productions" and employment similarly for "attractions," apply a pseudogravity model and, for F-factors, either use all equal to 1 or borrow factors from other sources (the gravity model output is in the form of a trip table but does not contain trips because the productions and attractions were not calibrated to equal trips); (b) by using future-year zonal population and employment, again solve the pseudogravity model by using the same method as in step 1 above; (c) assign both base-year and future-year internal tables to the highway network; and (d) compute a growth factor for internal travel as the link-by-link ratio of future load divided by base load.
4. Forecasts of link traffic—Factor base-year internal volume on the link (the difference between assigned external trip table and full link count as in 2b above) by the internal growth factor (3d above) and add to this the future external trips (2d above).

The approach described is basically a link count-factoring approach to travel forecasting that includes the following advantages:

1. External travel is forecasted separately and is actually assigned to the network. Thus, when diversion of such long trips to other routes (e.g., a new bypass) is a future possibility, this is accounted for in the process.
2. Internal travel is a link count-factoring process, but the factor itself is based on land-use changes (population and employment) and thus is more logical and policy sensitive than many other count-factoring approaches.

The approach requires no model calibration, but it does require a coded highway network and the ability to apply a Fratar expansion and a simple gravity model. Its disadvantages include the following:

1. Estimating internal travel on entirely new links is not straightforward and was not attempted in Plaistow, but it probably could be done.
2. The procedure of assigning external travel and subtracting this on a link-by-link basis from total link counts (to impute internal link counts) is very sensitive to errors in the assignment process. In Plaistow, the all-or-nothing assignment with some manual adjustment worked satisfactorily.

Generally, the method has the appealing feature of being nonsynthetic, i.e., tied directly into an external O-D trip table so that link counts and radical errors are unlikely and would probably be quite apparent if they did occur. The approach is somewhat more rigorous than that usually taken for an area the size of Plaistow; however, the small size of the prototype area helped make this demonstration feasible.

The outstanding weakness of the approach is in its inability to handle diversion of internal travel to entirely new links in the future year since there are no existing counts on such links to factor up. A method by which the new link is added to the base-year network first, a count is then inputted for the link based on reassignment of the base-year internal (pseudo) trip table, and then future factoring is done seems plausible but was not attempted. Overall, one might conclude that the method is best suited where the following conditions exist:

1. A small urban area of rather slow or moderate growth;
2. An external O-D survey, land-use data, and computer processes are available or feasible given staff and resources; and
3. Future alternative highways do not include major new facilities on entirely new alignments except when these are to serve predominately external travel (e.g., a bypass).

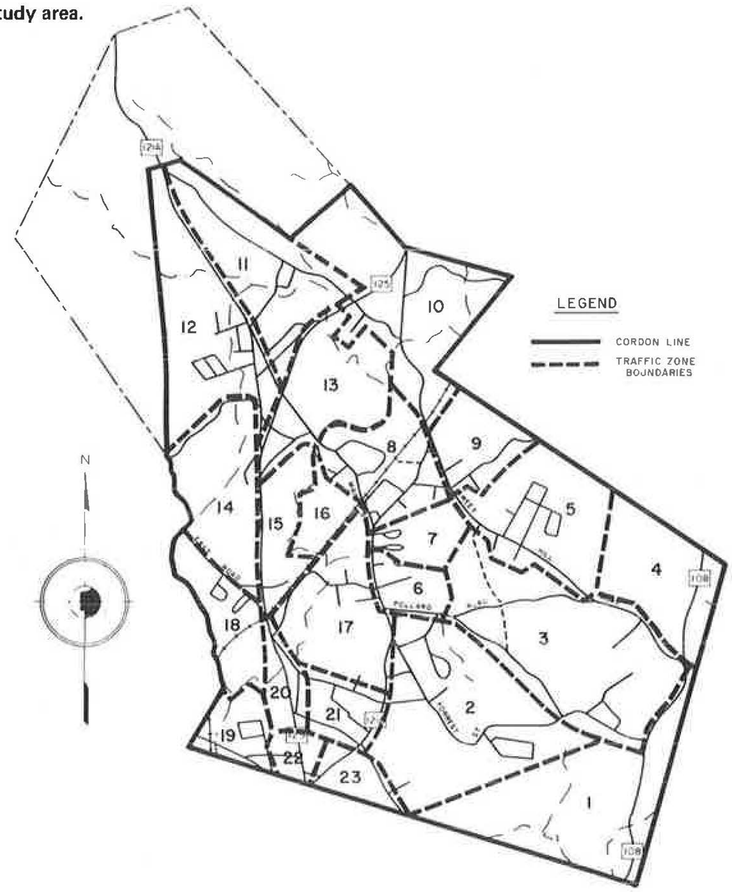
In regard to the third condition, it would be most difficult, for example, to estimate future internal travel on a new downtown river bridge if such a bridge were 3.2 km (2 miles) upriver from the existing bridge. The factoring of internal counts on the existing bridge would not produce relevant data for such a new bridge if it were located at such a distance from the existing bridge that it would attract trips between new internal O-D zones.

APPLICATION OF METHOD TO PLAISTOW

Data Preparation

The area included in the Plaistow Highway Transportation Study (Figure 1) includes the entire town of Plaistow except the lightly populated northwest portion along NH-

Figure 1. Plaistow, New Hampshire, study area.



121A. The study area was divided into 23 traffic zones. To the extent possible, the zones were partitioned so that the land use in each would be homogeneous. The land use in Plaistow, except along the NH-125 corridor, is predominately residential with a scattering of small businesses. It would have been impractical to establish a separate zone for each business; therefore, businesses were included in the residential zones. The transportation network was composed of all roads in Plaistow that are part of the federal-aid system. These are the streets and highways comprising the arterial and collector systems.

An external O-D study was conducted in Plaistow during August 1975 to survey travel patterns in the town. Twelve interview stations were established and were located wherever a collector or an arterial street or highway crossed the cordon line. From 6:00 a.m. until 8:00 p.m., as many vehicles as possible from each direction were stopped, and the drivers were interviewed. The sample rate varied from 32 to 70 percent depending on the traffic volume, the number of personnel doing the interviewing at a particular station, and the frequency of illegible and illogical interviews.

All interviews were coded and keyed for computer processing. All records were edited, and illogical trips were eliminated. The trip origins and destinations were coded in six-digit notation that conformed to the external zoning system of the New Hampshire Department of Public Works and Highways.

Tables developed for each station, by direction, summarized the trips between each O-D pair. These O-D tables were factored upward so that the total number of trips would equal the average summer weekday traffic (ASWT) at the station. The O-D tables were reduced to zone-to-zone tables by replacing the origin or destination or both (if outside the study area) by the station through which the trip entered or exited the study area.

During August 1975 and concurrent with the collection of driver interviews, short-term automatic traffic recorder counts were taken at selected locations in Plaistow. The traffic volumes were expressed in terms of ASWT. The ASWT was used rather than annual average daily traffic (AADT) because it is more representative of the traffic during the busiest period of the year—June through August. Eight-hour manual turning movement counts were made at all significant intersections in Plaistow during August 1975. These were factored to ASWT volumes by using traffic recorder data.

The population forecasts in this study are based on a cohort survival projection of the New Hampshire population by the New Hampshire Office of Comprehensive Planning. Planning region forecasts were made by using the same technique; the regional totals were controlled to the state totals. The regional projections were disaggregated to the community level on the basis of (a) the potential saturation population of the town, (b) its accessibility to nearby urban centers, and (c) its competitive advantage for attracting growth as compared with other towns of the region.

A dwelling unit count by traffic zone has been done for Plaistow. The current population was distributed among the zones proportionately to the zonal dwelling units. The forecast town population was allocated to traffic zones on the basis of the number of existing and anticipated housing units in each zone.

Existing employment was obtained from New Hampshire Department of Employment Security data. The employers' addresses were given so that the determination of employment by zone was straightforward. Future employment was forecast by analyzing the area available for commercial and industrial development and estimating the number of employees resulting from that development.

External Travel

The next step in the process is to assign the base-year external trip table to the coded highway network. The PLANPAC program for doing this is LOADVN, which assigns the trips between a pair of zones to the minimum time path between the zones. This assignment is on an "all or nothing" basis; in other words, although two paths between a pair of zones may differ in time by only a fraction of a minute, all the trips are assigned to the shortest path. Travel times or speeds may be adjusted slightly to achieve an optimal assignment. However, unrealistic assignments still occur where there are two or more equally efficient paths between pairs of zones. In a large network, such "lumpiness" is often masked. However, the problem is more obvious when it occurs in a small network such as that of Plaistow.

In an attempt to model traffic assignments more accurately, a different procedure was tried. The UROAD program from the Urban Transportation Planning System (UTPS) has the capability for doing a probabilistic multipath assignment in which trips between each pair of zones are assigned to more than one path. Each "efficient" path receives a fraction of the trips that is proportional to exp ($-\theta$*DI), where θ is the user-specified diversion parameter and DI is the difference between the total impedance of the given path and the minimum path's impedance. As θ approaches zero, all efficient paths become equally likely and, as θ becomes larger (approaches 10.0), only the minimum path has a significant likelihood.

Although stochastic assignment programs have been available for many years, they have been used only infrequently because of their relative complexity, the user's lack of control over program operation, and the difficulty in determining how a change in the network (an increase or decrease of speed on a particular link) will affect the assignment. Furthermore, the user must specify the value of θ. Trial and error—running the program and comparing the output to actual ground counts—constitutes the only method of reasonably estimating that parameter.

The suggested value of θ—0.002—assigns traffic too evenly to alternative paths and results in obvious overassignment on numerous links and improved loadings on only a few links. Higher θs were tried until 0.200 gave results very close to the "all-or-nothing" assignment. The very high overassignment on several key links when the lower values of θ are used seems especially perplexing and is a good example of the unpredictable nature of stochastic assignments.

The volumes from the various assignments were compared with the actual ASWT values. The assigned volumes should be less than or equal to the actual traffic since only external trips are being assigned. The difference between the assigned traffic and the actual ASWT volumes provides an estimate of the internal trips on each link.

None of the several assignments proved to be optimal for all links. When the all-or-nothing assignment was used, certain links were overassigned whereas others appeared to have too little traffic. Further refinement of the network improved the assignments to certain links, but there were generally compensating disadvantages to other links. Similar problems arose with the probabilistic assignment. Certain links would be improved by the use of that method, but other links would have poorer assignments. As smaller values of θ were used, some links become severely overassigned.

After analysis of the results of the different assignments, it was apparent that the all-or-nothing and θ = 0.20 assignments were the most realistic. For this study, the conventional all-or-nothing procedure was finally selected. It provides the best assignment and has the added advantage of being more convenient to use.

The projection of the base-year external trip table was done by using the Fratar trip-distribution model, which is based on the assumption that the change in trips in an interchange is directly proportional to the change in trips in the O-D zones that contribute to the interchange. The required input data are a base-year trip table and growth factors for each origin zone. Actually, two separate, but merged, tables are input—the external-external trips and the external-internal trips.

The model for zonal growth factors was developed by means of regression analysis. The number of external-internal trips originating in and destined for each zone was obtained from the trip table. These trips were the dependent variable. The independent variables—population and trade and nontrade employment by traffic zone—were provided as discussed above. The initial run of program BPR02R—the PLANPAC regression program—included all 23 of the zones in the study area. The regression analysis can be summarized as follows:

$$\text{Trips} = 128.22 + 21.44\,(\text{trade employment}) + 0.89\,(\text{population}) + 1.72\,(\text{other employment}) \quad (1)$$

$$\text{Trips} = 259.49 + 12.42\,(\text{trade employment}) + 0.89\,(\text{population}) + 1.14\,(\text{other employment}) \quad (2)$$

$$\text{Trips} = 8.43\,(\text{trade employment}) + 1.61\,(\text{population}) + 1.99\,(\text{other employment}) \quad (3)$$

The F and R^2 statistics and standard errors of estimate for the three equations are given below:

Equation	F	R^2	Standard Error of Estimate
1	41.91	0.869	593.54
2	14.62	0.745	171.32
3	60.95	0.920	208.97

The F and R^2 statistics of Equation 1 are very good, but the standard error of estimate of 593 is very high. The residuals were examined, and four cases that had the most extreme residuals (zones 6, 13, 15, and 22) were removed from the subsequent regression analysis. These zones have employment or population characteristics that result in atypical trip-generation characteristics. The second run of the BPR02R program produced Equation 2, which has lower F and R^2 values than the previous equation; both values remain high enough, however, to ensure a high level of statistical reliability. More favorably, the standard error has been reduced by 71 percent.

At this point, projected employment and population data were substituted into the model, and future trip ends by zone were computed. Future trips divided by computed existing trips produced growth factors for each zone. Trips to the four zones deleted from the regression analysis were estimated individually. Future trips from all zones were summed and divided by the total existing trips. The overall growth factor of 1.34 seemed unreasonably low since both population and employment are projected to increase at rates greater than 1.40. The reason for the relatively low growth rate is the constant term of 259.49 in the equation, which causes the model to be less sensitive than it would be if the constant was much smaller. To alleviate this problem, a third run of BPR02R was made in which the Y-intercept (the constant term) was forced to zero. This resulted in Equation 3, which is statistically valid and has a standard error of estimate of 209. Future-year trips for each zone were computed, and the zonal growth factors were obtained. The overall increase of external-internal trips is projected to be approximately 55 percent.

The growth factors at the external stations cannot be estimated by the preceding methodology. Where possible, analysis of the trend in traffic growth is an accepted procedure for developing growth factors at cordon-line stations. However, very few historical traffic data are available in the area of Plaistow. On NH-125 and NH-108, short-term counts have been taken fairly consistently over the past 6 or 7 years. The projections of these trends were used to temper the growth estimates on these two routes. The primary method of developing these growth factors was to determine in which town or towns the trips through particular stations were originating. The population projections made by the New Hampshire Office of Comprehensive Planning were examined, and growth rates from 1975 to 1995 were computed. These growth rates formed the basis for the external-station growth factors. For example, at station 30, 62 percent of the traffic originates in Atkinson and about 26 percent originates in Hampstead. The population of Atkinson is projected to increase by a factor of 3.30 and that of Hampstead by 2.31 between 1975 and 1995. A growth factor of 2.6, which moderates the traffic growth somewhat, was selected.

After inputting the growth factors and trip table, the FRAT program was run with three iterations. The ratio between the attracted trips computed by multiplying base-year attractions by the growth factors and the iterated trip attractions balanced within 11 percent for all zones and stations. The TRIPSO data set from FRAT was input to program TRPTAB, and the zone-to-zone trip table was output.

Future external trips were assigned to the highway network by using the same methodology as that used for base-year trips.

Internal Travel

The forecasting of internal trip volumes is a more complex task than is the projection of internal-external and external-external trips. Traditionally, in larger studies, internal-trip-making data are gathered through home interview surveys. However, in smaller study areas and recently in many larger areas, home interviews have not been conducted because of the excessive time and costs involved. One cannot calibrate a mathematical model for forecasting internal trips when no home interview survey has been done. The Fratar model requires the base-year trip table, which is not available for internal trips. The gravity model input includes trip productions (Ps) and trip attractions (As) by zone and friction factors (F) for each impedance increment. Although the F-factors may be estimated from similar studies, Ps and As depend on socioeconomic characteristics of the study area, which must be surveyed.

The procedure adopted for estimating future internal trip volumes by link was a novel part of this study. A single-purpose pseudogravity model was the basis of this methodology. Two runs of PLANPAC program GM were made. In the first, zonal productions were set equal to base-year population, and zonal attractions were estimated as follows:

1. For zones whose trade employment is predominately retail shopping, A = 1.0 (nontrade employment) + 9.0 (trade employment); and
2. For zones whose trade employment is in other categories, such as sit-down restaurants, automobile sales, and other lower generating categories, A = 1.0 (nontrade employment) + 5.0 (trade employment).

These relations do not estimate the number of trips attracted. Rather, as in the case of productions, they estimate only a rough relative attractiveness of one zone versus another. These relative rates were based on trip-generation models calibrated elsewhere in New Hampshire.

In the second GM run, the same procedure was followed for the forecast year, and projected population and employment were substituted for the base-year values. The other two data sets input to program GM are friction factors and impedances, which were the same for both runs. The friction factors were all assumed to be equal to 1, which means that trips of all lengths are equally likely. This is not an unreasonable assumption given a small network and a study area with only a few travel-time increments. The impedances are output from the PLANPAC program BUILDVN and reflect characteristics of the network.

The resulting trip table from each GM run was loaded onto the network. These are artificial volumes that should be approximately proportional to actual internal traffic. The growth rates for internal trips by link were computed by dividing base-year assigned volumes into the assignment for the forecast year. These growth factors by link were multiplied by the counted base-year internal trip volumes to produce forecast-year internal volumes.

To test the effect of using F-factors all equal to 1, the gravity model program was run twice more by using the same 1975 and 1995 Ps and As but normalized friction factors that ranged from 60 to 2 for 10 time increments. The F-factors were estimated from Federal Highway Administration charts (1). The assigned 1975 and 1995 internal trips varied by as much as 30 percent when the revised F-factors were used. However, the growth factors for nearly all links changed by less than 10 percent when the more refined factors were applied.

Forecasts of Link Traffic

The 1995 ASWT volumes are the sum of the assigned external trips plus the product of the 1975 internal counts times the link growth factor. Unadjusted computed values are not used indiscriminately because some individual links are unrealistic. Where two or more alternate routes exist, projected external and internal traffic on all links is summed and then divided between the alternate paths. If the base-year external trips had been severely overassigned or underassigned or if the artificial gravity model trips appeared very unrealistic, more reasonable estimates of link traffic volumes were developed.

It must be reemphasized that, when a small study area and network are being considered and the all-or-nothing assignment is being used, the resulting assignment is lumpy and many links have unrealistic traffic volumes. It is therefore inadvisable always to use the numbers directly as output from the assignment program.

Projected increases in traffic volume over the 20-

year forecast period on Plaistow's streets and highways vary from less than 50 percent on roadways that serve primarily local traffic to more than 150 percent on highways that carry traffic to and from more rapidly growing neighboring towns. The major through highway in Plaistow, NH-125, is the exception since it has a projected growth of 40 percent. Since these forecasts are based on certain anticipated growth trends, substantial changes in patterns of development will affect the projected traffic volumes.

Obviously, the anticipated traffic volumes on many of the links of the Plaistow network will result in congestion and less than ideal travel conditions. The next phase of the Plaistow Highway Transportation Study will compute the hourly capacity of the streets and highways in Plaistow and compare these with the forecast volumes. In this way, deficiencies in the existing network may be identified so that remedial measures can be planned.

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Evaluation of the Impact of Restricted Interchanges on Travel Demand

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A study was conducted to develop and apply a low-cost process for assessing the effect on travel demand of a less-than-optimal design for proposed freeway interchanges on I-476 in Delaware County, Pennsylvania. The principal strength of the procedure developed lies in its computational simplicity. It is primarily manual and, although it does not require the excessive computer costs associated with the usual set of transportation planning models, it produces the detailed information required for such an analysis. The process relies on travel demand, trip length, and service provided for each trip movement to isolate possible impacts. The diversions expected to result from the constrained interchange designs are then determined based on the conditions of the surrounding network. For the two interchanges considered in the study, the process provided detailed information not usually associated with typical planning models. Although little effect on demand was anticipated at either interchange, the information generated was used for incorporating design revisions at one of the locations analyzed to eliminate deficiencies in capacity.

Provisions contained in the National Environmental Policy Act of 1969 allow for the transportation-related use of parkland or historical sites if and only if no feasible and prudent alternative can be found. In response to testimony delivered at public hearings on the draft environmental impact statement (EIS) for I-476, the Pennsylvania Department of Transportation (PennDOT) modified two interchange designs to avoid the taking of such lands. Inherent in these modifications was a lessening in the quality of service provided at each interchange, where traffic signals replaced previously free-flow ramp movements at specified locations.

Concerned over the possible diversion of travel from these locations and its effect on the surrounding communities, PennDOT requested the Delaware Valley Regional Planning Commission (DVRPC) to evaluate the impacts of the design changes on future travel. In reviewing the request, it was deemed impractical to perform the analysis by using conventional simulation techniques because of both scope and cost. Such an approach would likely conceal the interaction between the system and the users and consequently hinder proper evaluation. To avoid these shortcomings, it was decided to accomplish the analysis by relying on a primarily manual process and using accepted techniques wherever possible.

The procedure developed is divided into two principal phases. Phase 1 focuses on traffic demand and operating characteristics for the original design of the freeway and each interchange. Phase 2 assesses the constraints created by the redesigned interchange and determines the movements affected.

This report details the procedure developed by DVRPC and presents an evaluation of the modifications proposed for the Mid-County Expressway. Figure 1 shows an outline of the process developed for this analysis and a description of each of the phases discussed.

PHASE 1—ORIGINAL DESIGN

Define Immediate Area of Impact

Trips that use the subject interchange will not be equally affected by the proposed modifications. Long-distance travel by the freeway will likely not divert to an alternative path regardless of the localized conditions at the interchange. The premise is that the time these trips save once they are on the freeway outweighs the time lost at the interchange.

This reasoning does not prevail for short-distance travel. Time saved on the freeway can readily be offset by time lost at the restricted movements and by the more circuitous routing caused by the freeway.

Trips that use the redesigned interchange and a short segment of the freeway should therefore be most severely affected, and the overall impact should be inversely related to distance traveled by way of the freeway. In conjunction with this hypothesis, trip movements by the modified interchange and a single segment of the freeway were first isolated for analysis as the most critical movements.

Since the facility under study is proposed, a "select link analysis" was performed to define trip movements that used the modified and adjacent interchanges. Ser-